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INVESTIGATIONS USING DATA IN ALABAMA FROM ERTS-A

Principal Investigator

DR. HAROLD R. HENRY

Submitted to

Goddard Space Flight Center
National Aeronautics and Space Administration
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GEOLOGICAL SURVEY OF ALABAMA STUDIES

James A. Drahovzal

SECTION TWELVE

of

VOLUME THREE

INVESTIGATIONS USING DATA IN ALABAMA FROM ERTS-A

CONTENTS

SECTION TWELVE

SECTION THIRTEEN

ERTS-1 RESEARCH AND THE GEOLOGICAL SURVEY OF ALABAMA

James A. Drahovzal

INTRODUCTION

This report describes the analysis and use of ERTS-1 data by the Geological Survey of Alabama (GSA) from August 1972 to July 13, 1974. It includes a discussion of the history of the research and the data problems encountered, the organizational aspects of the project, the personnel, the data handling system, and the publications and oral presentations resulting from the research. In addition, it discusses the user-oriented activities resulting largely from the project. Finally, the technical papers presented in this volume are introduced.

RESEARCH AND OPERATIONAL APPROACHES AND DATA PROBLEMS

Project History and Data Problems

Prior to the launch of ERTS-1, the GSA had been active in remote sensing investigations. With the exception of the use of low-altitude black and white photographs for base maps and in standard photogeologic interpretation, GSA first became active in the field of remote sensing in the latter half of 1969. It was at this time that GSA undertook a geologic and hydrologic study of Apollo 9 photographs (Powell, Copeland, and Drahovzal, 1970). Follow-up studies were done by Powell and LaMoreaux, 1971; Drahovzal and Neathery, 1972; Smith and Drahovzal, 1972;

and Smith, Drahovzal, and Lloyd, 1973. The initial work stimulated remote sensing research at GSA. As a direct result of some of the early Apollo 9 research, SLAR and other types of data were gathered in the vicinity of Logan-Martin Dam on the Coosa River where a fracture system was found to be contributing to leakage under the structure (Alverson, 1969; 1970; Spigner, 1969; Bailey, 1970; Drahovzal, Neathery, and Wielchowsky, 1974). In addition, low-altitude data was utilized in the selection of sites for construction in carbonate terranes (Newton and Hyde, 1971; Newton, Copeland, and Scarbrough, 1973) and in the location of lineaments and fracture traces to investigate their relationship to limestone hydrology (Sonderegger, 1970).

The members of GSA's ERTS group remained in the pre-launch phase until the first data was received. The formal activities of GSA in the NASA-supported ERTS-1 research began August 14, 1972. Much of the activity early in the project, before imagery was received, consisted of familiarizing the participating workers with the Apollo 9 photography of east-central Alabama and the remote-sensing literature. The Apollo 9 research had progressed about as far as it could and on August 22, 1972 the Survey's final paper dealing with the subject was delivered at the 24th International Geological Congress in Montreal (Drahovzal and Neathery, 1972). It was at the Congress that T. L. Neathery and J. A. Drahovzal of the Survey's ERTS team saw their first ERTS imagery. On September 28, 1972, J. A. Drahovzal saw the first ERTS-1 data for Alabama at Goddard but was not permitted to take it back to Alabama for study. The first ERTS-1 imagery to arrive in the State to our knowledge was on October 10, 1972, when the Geological Survey of Alabama received imagery through another ERTS-1 project (EROS 14-08-001-13377, User Acceptance and Implementation of ERTS-A Data in Alabama). In the later project, the Survey received limited ERTS-1 data for the state from the EROS Data Center through the EROS Evaluation and Experiments Office at Bay St. Louis, Mississippi. It was not until November 7, 1972, that the Geological Survey received the first ERTS-1 imagery through this project. The delay was most frustrating to all the investigators involved and served to delay the project considerably.

To add to frustrations, the quality of the first imagery received, and most of it throughout the project, was substantially inferior to that received through other projects and sources (see bi-monthly reports for specifics). A special report (Drahovzal, J. A., April 2, 1973, Special Report: Quality of NASA-Provided ERTS-1 Imagery) was written comparing the quality of 9 x 9 inch positive prints received from the EROS program and from Goddard. The former was greatly superior to the latter based on the same ERTS-1 frames. In response, Mr. Bernard Peavey of NDPF at Goddard supplied a few frames which were more useful to our research. At Mr. Peavey's suggestion, all near-cloud-free or cloudless data up to that time was placed on a retrospective order. To this date, the data, to our knowledge, has not been received.

Early attempts to secure two copies of the ERTS-1 imagery for the project failed. In light of the large number of workers at the Survey as well as in the other institutions and agencies involved and their wide separation (two in Tuscaloosa, one at Dauphin Island and one in Huntsville), access to the data supplied by Goddard was limited. To partially solve this problem, Marshall Space Flight Center agreed to copy 9 x 9 inch positive transparencies for Geological Survey use. Although this was helpful, the extended turn-around time and degradation of the imagery greatly limited the usefulness of the data.

To help mitigate the problem, the Geological Survey requested 70 mm negatives. It found that the Goddard-provided negatives were equivalent to or of higher quality than those provided by the EROS Program. The negatives enabled us to produce 1:1,000,000 scale positive prints that were much more suitable to our objectives. Some limited 1:250,000 and 1:500,000 scale imagery was also produced in this fashion at the Survey's photo laboratory, but most of this was limited to a 11 x 14-inch format. Some of the negatives were sent to a commercial firm, Plunkett Blueprint in Atlanta for enlarging to 1:250,000 scale (40 x 40 inch prints). At the same time 1:250,000 ERTS-1 coverage of the state was ordered from the EROS Data Center. The products received from Plunkett were comparable to 40 x 40-inch prints secured from the EROS Data Center. Turn-around time with Plunkett was less than 10 days, the cost was $10 and the product was within acceptable limits of being a true 1:250,000 reproduction. The EROS data on the other hand cost $9, was printed on a higher grade paper, but required as much as 3 months turn-around time and was not so nearly precise scale-wise. By September, 1973, GSA had most of the areas of the state covered by bands 5, 6 or 7, 1:250,000 scale imagery. It had been concluded earlier that most of our work would utilize the 1:250,000 scale both for reasons of convenience and interpretability; therefore at that time we were ready to begin our major effort in the project.

Nearly all of the data used in the project was derived either through the EROS project mentioned previously, purchased from EROS Data Center, reproduced at Plunkett Blueprint, or reproduced in our photo laboratory. Only a very small percentage of the data supplied by Goddard through this project was of acceptable quality for our purposes. The 70 mm negatives were a notable exception. The radiometric precision of the Goddard prints (Peavey, oral communication, 1973) from a photo interpreter's point of view is less important than the clear depiction of earth features.

Because of the cost of purchasing 1:250,000 scale data outside the project, only a few of the best scenes were obtained and some of the repetative advantage of ERTS was lost. In the case of the lineament studies, it would have been desirable to have had access to at least seasonal 1:250,000 scale coverage. In the case of the Mobile Bay study where large areas on a single image were not required for interpretation, the Survey's photo laboratory made periodic 1:250,000 enlargements.

Most of the research was completed during the final stages (beginning in September, 1973) of this project. Because of the lack of time, photo interpretation and other office work was done alternatively with field research. The results of some of the early research attempts are documented in the bi-monthly reports. Areas in which research attempts based on ERTS-1 data were begun but for various reasons were abandoned are as follows:

1) delineation and monitoring of strip mine activity
2) surface-water inventorying
3) topographic slope map
4) delineation of Coastal Plain faulting
5) delineation of Coastal Plain lineaments

The bi-monthly reports discuss these attempts in detail and indicate the reasons for abandonment. The completed research is reviewed in a later section of this paper and the papers of this volume record the details.

The final report writing phase was commensed on or about April 1, 1974.

Organization and Personnel

The NASA-supported project was run concurrently with another ERTS-1 project at the GSA which was designed to determine the usefulness of ERTS data to a group of selected users in the State who represented a variety of earth resources study disciplines (EROS 14-08-001-13377, User Acceptance and Implementation of ERTS-A Data in Alabama). In this research the Survey acted both as manager of the project as a selected user of ERTS information. In addition, GSA was and is currently involved in a Skylab Earth Resources Experimental Package (EREP) experiment with Marshall Space Flight Center (Irreversible Compression of EREP Data Flow) and cooperative research with the Prescott Research Group of the U. S. Geological Survey. This activity, in addition to the high interest in the application of remote-sensing technology at the GSA and the acquisition of large amounts of remotely sensed data made the formation of the Remote-Sensing Section and Laboratory essential to efficient operations. The section was created in October of 1972, soon after the first ERTS-1 imagery was acquired. In addition to managing the Survey's remote-sensing programs and projects, the section continually acquires, catalogues, stores and manages remotely sensed data. Section personnel, in addition to carrying out remote-sensing research, also assist the Survey staff and other Alabama users in the acquisition and interpretation of remotely sensed data. The section with its own facilities for the storage and viewing of ERTS data, served as a work area and library for ERTS investigators.

The ERTS team consisted of scientists from each major division of the Survey. The division and scientific subdisciplines of each investigator are listed below.

Geologic Division

1 Stratigrapher - paleontologist - structural geologist

1 Stratigrapher - paleontologist

2 Geomorphologist - geographer

1 Structural geologist

Mineral Resources Division

2 Metamorphic - structural geologists

3 Economic geologist - geochemists

Water Resources Division

2 Hydrologists

Energy Resources Division

1 Petroleum geologist

Environmental Geology Division

2 Environmental geologists

Each scientist attempted to use ERTS data in an operational sense (i.e., to more efficiently carry out his duties at GSA), as well as to undertake research in application of the data to specific problems. Weekly meetings allowed exchange and discussion of ideas between scientists.

Data Handling System

From the beginning of the project, the GSA established an in-house data filing system to facilitate access to the imagery. All ERTS data were given abbreviated in-house identifiers. These file numbers consist of an orbit identifier (letter), along-track identifier (number), date of acquisition, and band (e.g., NASA ERTS E-1050-155447 would be L1, 11 SEP 72, Band 7).

Though the ERTS data is easily filed and accessed through this system, GSA has acquired many other types of orbital and suborbital imagery. Thus IRIS (Imagery Retrieval and Information System), a computer based filing and retrieval system for the cataloguing, storing, and retrieving of remotely sensed data and information about the data (see Appendix 2), was designed by personnel of GSA. The system is in the latter design-early implementation phase, and when finally completed, should provide ready access to all remotely-sensed data acquired in Alabama. The necessity for this system becomes obvious when it is realized that much of the over 5,000 data products on file at the Survey are not available from any one source.

COMMUNICATIONS

During the project, a number of papers, abstracts and reports applying ERTS-1 data to geology were prepared by the investigators. A complete bibliography is as follows:

Drahovzal, J. A., 1972, ERTS-1 imagery of Mobile Bay _in_ Scarbrough, W. L. (ed.), Recent sedimentation along the Alabama coast: Alabama Geol. Soc. Guidebook 10th Ann. Field Trip, 1972, p. 89-92.

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*Drahovzal, J. A., Neathery, T. L., Wielchowsky, C. C., 1974, Significance of selected lineaments in Alabama, in Third ERTS Symposium: Natl. Aeronautics Space Adm., in press.

Drahovzal, J. A., Wielchowsky, C. C., and LaMoreaux, P. E., 1973, Geologic factors and hazards in land-use planning, prepared for Geology Panel, Committee Remote Sensing Programs Earth Resources Survey, Division Earth Sciences: Alabama Geol. Survey, open-file report, 44 p.

*Drahovzal, J. A., Wielchowsky, C. C., and Emplaincourt, J. L. G., 1973, Remote sensing of earth resources in Alabama: A new environmental perspective: Alabama Geol. Survey, in review for publication.

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Joiner, T. J., Walters, J. V., Miller, E. T., and Wielchowsky, C. C., 1974, Identification of user categories and users of ERTS acquired data in Alabama: Alabama Geol. Survey, Information Series 43, 128 p.

Simpson, T. A., and Wielchowsky, C. C., 1974, Use of satellite imagery in the study of geologic structure and roof stability relationships: Am. Institute Mining Engineers, submitted for approval.

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*Svehlak, H. T., and Wielchowsky, C. C., 1973, ERTS-1 mosaic of Alabama: Alabama Geol. Survey, Image Series 1.

Warren, W. M., and Wielchowsky, C. C., 1973, Aerial remote sensing of carbonate terranes in Shelby County, Alabama: Ground Water, v. 11, no. 6, p. 14-26.

*Wielchowsky, C. C., 1973, A small-scale information system for remotely sensed data: Geol. Soc. America, Abstracts with Programs, v. 5, no. 5, p. 451.

Wielchowsky, C. C., 1974, Evaluation and use of ERTS-1 data by the Geological Survey of Alabama -- EROS-ERTS project final report: Alabama Geol. Survey, open-file report, 52 p.

Wielchowsky, C. C., and Drahovzal, J. A., 1974, A comparison of lineaments and fracture traces to jointing in the Appalachian Plateau of Alabama -- Dora-Sylvan Springs area: Geol. Soc. America, Ann. Mtg., Miami, submitted for approval.

Wielchowsky, C. C., Emplaincourt, J. L. G., Warren, W. M., and

LaMoreaux, P. E., in press, Potential applications of remotely sensed data to sinkhole development problems in Shelby County, Alabama, U. S. A.: Proc. Ann. Mtg. Association Internationale des Hydrogeologues (Commission de l'Hydrogeologie du Karst), 1973.

* included in the Appendixes; many of the others included in bi-monthly reports.

The speaking engagements in which ERTS data was emphasized is presented in table 1. Most of these talks were presented by members of the Remote-Sensing Section.

Table 1. Speaking engagements where ERTS was emphasized.

Date	Group and Subject	Speaker*
Nov. 11, 1972	Talk to Engineering Symposium, University of Mississippi, on ERTS	CCW
Dec. 21, 1972	Talk to Survey staff on remote sensing, ERTS, and GSA	JAD
Jan. 16, 1973	Talk to Atlantic Aerial Surveys Incorp. Symposium, on Remote Sensing at GSA	CCW
Feb. 21, 1973	Practical Applications of Remotely Sensed Data in Alabama-EROS; Tuscaloosa meeting; talks delivered on ERTS and Apollo 9	JAD JLGE CCW
Feb. 23, 1973	Practical Applications of Remotely Sensed Data in Alabama-EROS; Mobile meeting; talks delivered on ERTS and Apollo 9	JAD JLGE CCW
March 6, 1973	Talk to the Geology Club, University of Alabama on ERTS and Apollo 9 lineaments	JAD
March 22, 1973	Talk to Prof. C.H.T. Wilkins metallurgical and chemical engineering class, University of Alabama, on ERTS and Apollo 9	JAD
April 19, 1973	Talk to Earth Resources Data Committee, State of Alabama, on ERTS	CCW
June 20, 1973	Presentation to Bechtel Corp. representatives; talk on ERTS and lineaments	JAD
May 7, 1973	Talk to Prof. H. R. Henry's remote sensing seminar, University of Alabama, on ERTS and Apollo 9	JAD CCW JLGE

Table 1 (Cont'd)

Date	Group and Subject	Speaker*
July 12-13, 1973	Cost Benefit Conference at Mississippi Test Facility (EROS); talk on ERTS and Apollo 9	JAD CCW
July 17, 1973	Talk to Rotary Club, Anniston, Alabama, on ERTS and Apollo 9 lineaments	JAD
Sept. 23-24, 1973	Presentation to members of Geology Panel, Committee on Remote Sensing Programs for Earth Resources Surveys (CORSPERS) in Mobile, on ERTS and Apollo 9 lineaments	JAD
Oct. 30, 1973	ERTS presentation before Geology Panel, GSFC	JAD
Nov. 19-20, 1973	Taught short course to physics professors of Talladega College on remote sensing and environmental geology	JAD
Nov. 21, 1973	Talk to Exchange Club, Selma, Alabama, ERTS and remote sensing at GSA	CCW
Dec. 10-13, 1973	Third ERTS-1 Symposium; presentation on ERTS lineaments	CCW
Feb. 18, 1974	Talk to Tuscaloosa Explorer Post; ERTS	JAD
March 5, 1974	Talk to Holt High geography class on maps and ERTS	JAD
March 28, 1974	Talk to Prof. C. H. T. Wilkins metallurgical and chemical engineering class, University of Alabama, on ERTS and Apollo 9 lineaments	JAD

Table 1 (Cont'd)

Date	Group and Subject	Speaker*
April 1, 1974	Talk to geology staff and students, Dartmouth College, on ERTS lineaments	JAD
April 15-19, 1974	Presentation before the 9th International Symposium on Remote Sensing of the Environment on remote sensing program of GSA	CDS
June 3-7, 1974	Presentation before the 1st International Conference on the New Basement Tectonics on ERTS lineaments	JAD
June 13, 1974	Talk to Exchange Club, Tuscaloosa, Alabama, on remote sensing at GSA	CDS

* JAD J. A. Drahovzal
CCW C. C. Wielchowsky
JLGE J. L. G. Emplaincourt
CDS C. D. Sapp

USER-ORIENTED ACTIVITIES

In addition to basic and applied research, the Remote Sensing Section of GSA acts as a service oriented organization for users of remotely sensed data. Ever since the establishment of the Remote Sensing Section and laboratory in 1972, many users or interested people have visited the facilities at the Survey. Although a great majority of visitors are geologists, many of the others represent other disciplines (table 2). One of the greatest benefits derived from the ERTS-1 project at the Survey has been this interaction between the Remote Sensing Section and people of Alabama who have shown an interest in remote sensing. It is felt that ERTS has created a greater state of awareness in space acquired data than any other earth resources program. In response to this interest, members of the Remote Sensing Section have completed a manuscript entitled Remote Sensing of Earth Resources in Alabama: A New Environmental Perspective (Appendix 3). The volume, currently being finalized for publication, emphasizes the ERTS satellite and the application of ERTS satellite data to earth resources problems in Alabama. The report defines remote sensing and its role in earth resources studies, discusses sensors and platforms, and treats applications of remote sensing techniques to geology, geography, forestry, agriculture, and oceanography. Support for this manuscript was supplied both through this project and a project of the EROS Program.

TABLE 2

Selected users who visited the Remote Sensing Section

Name	Agency and City	Profession	Purpose of Visit
Roger Carter	Law Engineering Testing Co. Birmingham	----	To inquire about imagery regarding possible lineaments and other indications of structure.
Dr. John S. Crossman	Telledyne Brown Engineering Huntsville	Aquatic Ecologist	To obtain information on various types of imagery.
Mr. Curtis	Geological Survey of Mississippi	----	To determine uses of remote sensing technology as applied to geological and environmental problems.
Carl Doering	Geological Consultant Mobile	Consulting Geologist	To look at ERTS and other types of imagery.
Robert J. Floyd	Tennessee Valley Authority Knoxville, Tennessee	Geologic Editor	To examine ERTS imagery.
Hal Gamble	Alabama Development Office Montgomery	Planner	To determine if remotely sensed data could be used to map strip mined areas.
Dan C. Holliman	Birmingham-Southern College Birmingham	Biology Professor	To examine imagery of the Alabama coastal region.
Perry Hubbard, Jr.	MESC Dauphin Island	Geologist	To use remotely sensed data in a Mobile Bay maintenance dredging study.
C. Frederick Logrengel II	Snow College Ephraim, Utah	Geologist-Stratigrapher	Bibliographical information on remote sensing.
Jay Massingill	University of Alabama University	Geologist	Literature research on remote sensing.

TABLE 2 - Cont.

Name	Agency and City	Profession	Purpose of Visit
P. F. Napolitano	University of Alabama University	Geologist	To get acquainted with remote sensing and to review imagery.
Rex Price	University of Alabama University	Geologist	To look at Cottondale quadrangle on U-2 data.
Robin Richardson	West Alabama Planning and Development Council Tuscaloosa	Research Analyst in ARC	To look at remotely sensed data.
Dyer N. Ruggles	Tuscaloosa	Horticulturist-Biologist	To learn about ERTS satellite.
Randy Ruggles	Chester, Virginia	----	To find out details about the ERTS satellite.
W. H. Wallace, Jr.	Alabama Development Office Montgomery	State planner	Contract review and ERTS interest in land-use mapping.
Mark Walters	Bechtel, Inc. San Francisco, California	Engineering Geologist	Review ERTS, Apollo, Westinghouse, and RB-57 imagery of Crooked Creek Nuclear Site.
Steve Wampler	Law Engineering Testing Co. Atlanta, Georgia	Geological Engineer	Review SLR imagery of east-central Tennessee.
Peter V. Wiese	Vulcan Materials Co. Birmingham	Geologist	----

In addition, the Remote Sensing Section has generated an ERTS-1 band 5 mosaic of the state for distribution to the public (Appendix 6). As an example of one of its uses, engineers with Alabama Power Company noted that the light area extending east-west across central Alabama coincides with the region where they were having difficulties with insulator breakage. After inquiring at GSA about the nature of this phenomenon, it was determined that this area was roughly coincident with the brittle chalks of the Selma Group. The strength of the chalk is probably related to this breakage problem. Though this information was available on any state-wide geologic map, it was not found until noticed on the ERTS mosaic of the state.

Members of the Remote-Sensing Section also spent considerable time speaking before various, local, state, national and international groups. Most of these talks emphasized our application of ERTS-1 data to geology. A listing of these speaking engagements is presented in previous section (table 1).

INTRODUCTION TO PAPERS PRESENTED IN THIS VOLUME

The eleven papers presented in the following pages of this volume represent the results of all of the major research undertaken by the ERTS team at the GSA.

Most of the work centered around a study of the lineaments first detected on Apollo 9 photography in 1969. The first paper by J. A. Drahovzal reviews all of the work done with the ERTS-derived lineaments in the state and attempts to tie in the research carried out by various individuals and groups dealing with specific aspects of the lineaments. A discussion on the nature and origin of lineaments as well as their relationships to jointing is also presented. The second paper by C. C. Wielchowsky presents the results of a detailed study comparing ERTS, U-2, and topographic lineaments and fracture traces with jointing measured in two quadrangles in the Appalachian Plateaus. The third paper presents a special study of the lineaments of the Piedmont by T. L. Neathery. In the following paper, T. L. Neathery and J. W. Reynolds present some detailed results of a field study conducted in the Crooked Creek area of the Piedmont aimed at comparing the field data with ERTS-1 and SLAR-derived lineaments. In the fifth paper, a team of workers, A. F. Skrzyniecki, N. E. Nordstrom and W. E. Smith combined efforts to study certain aspects of the geochemistry of soils taken from traverses across lineaments in seven areas of the state. Correlations of lineaments and trace element distributions were made and conclusions drawn. G. E. Moravec and J. D. Moore in the sixth paper compared karstic development and data on ground-water distribution with ERTS-1 derived lineaments of north-central Alabama. In some similar work, P. H. Moser and David Ricci compared the orientations of sinkholes, caves, joints and ERTS-1-derived lineaments in northwestern Alabama. In the eighth paper of this volume, G. V. Wilson presents results and interpretations of a series of gravity traverses run across several lineaments and lineament complexes in northern Alabama.

The final contribution dealing with lineaments is that provided by C. C. Wielchowsky in a part of the eleventh paper that deals with a geologic investigation of the Lawson Gap lineament.

In addition to lineament studies, several other applications of ERTS data were made. Most of these are covered in the eleventh paper compiled by C. C. Wielchowsky. One section of the paper deals with some of the applications of ERTS-1 data to Coastal Plain mapping, including possible utilization for reconnaissance in oil and gas exploration. Shoreline configurational changes in the vicinity of Mobile Bay were monitored using ERTS-1 data and a review of this work is presented. Finally, a study examining the utility of ERTS data in mapping flooded and flood-prone areas in southern Alabama is presented.

In the tenth paper C. D. Sapp and J. L. G. Emplaincourt present a new physiographic map of Alabama derived from existing sources, but up-dated and reinterpreted largely from information derived from the ERTS-1 imagery. In the final paper, R. L. Lipp has interpreted tidal marsh areas of the entire Gulf Coast area from St. Joseph Bay, Florida, to the Mississippi-Louisiana state line.

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LINEAMENTS

James A. Drahovzal

INTRODUCTION

The part of the ERTS investigation that directly or indirectly received the most attention was that of lineaments and their relationships to various aspects of geology. As used herein, the term "lineament" is applied to naturally occurring linear features delineated from aerial or space images consisting of topographic, vegetative, or soil tonal alignments that are at least partially continuous for distances greater than 1 mile (Lattman, 1958, p. 569). Lineaments have been variously termed "linears," "lineations," or "linear features" by other authors, but these all refer to essentially the same phenomena. Because very few lineaments have been defined, located precisely on the ground, and studied in detail, it is difficult to precisely define the nature of the elements that make them up. It has been our experience, however, that they represent one or a combination of the following: aligned offsets along several adjacent streams, straight stream segments, alignment of gaps or saddles on several adjacent ridges, alignment of adjacent ridge terminations, soil tonal differences, vegetative tonal differences, and land-use patterns. The latter element may suggest that some lineaments are not naturally occurring. In some cases this is true, but in several others cultural development along lineament-related valleys accentuate the lineaments. In this study, such lineaments are relegated to man-made phenomena and not considered, except where the lineaments continue beyond the influence of culture. In some cases, cultural influences destroy or obscure the natural conditions which permit the detection of lineaments. This is particularly true in urban areas. In farmed areas, soil tonal variation is often not destroyed, even where heavily plowed, and lineaments may be delineated with little difficulty.

Lineaments in northern Alabama were first recognized in 1970 on Apollo 9 photographs (AS9-26-3790 and 3791) by John G. Newton, a U. S. Geological Survey geologist. Subsequent studies delineated the features and suggested relationships to structural hydrologic factors (Powell and others, 1970). Later work explored the relationships of the Apollo 9 lineaments to mineralization, environmental geology, stratigraphy, seismicity, and the tectonic framework of the Appalachians (Drahovzal and Copeland, 1970; Drahovzal and Neathery, 1972; Smith and Drahovzal, 1972; Smith and others, 1973). Recently Isphording and Riccio (1974) described lineaments in the vicinity of Mobile Bay, Alabama.

In this study, lineaments were interpreted from ERTS-1 imagery for northern Alabama, including all of the Alabama parts of the Piedmont, Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus provinces and a small part of the Alabama Coastal Plain province (pl. 1). The lineaments defined by previous studies utilizing Apollo 9 photography were generally confirmed and extended by the use of ERTS-1 imagery (Drahovzal and others, 1974; see Appendix 1). In addition, many additional lineaments previously missed in Apollo studies were delineated through the use of the ERTS data.

The lineaments of Alabama are divided into two broad categories - major and minor lineaments. The major lineaments are those that are relatively long and persistent across the state, prominantly displayed on space imagery (including Apollo 9, ERTS-1 and Skylab data), and those that have been shown to have regional geologic significance. These lineaments at scales of 1:500,000 or larger appear as a single feature. Careful study of ERTS imagery at a scale of 1:250,000, however, has shown that the major lineaments are actually lineament complexes (pl. 1). The complexes are linear zones composed of a series of shorter discontinuous, enchelon member lineaments. At the present time, only two major lineament complexes are known and both transect Appalachian strike at nearly right angles. One is the Harpersville lineament complex which extends some 240 kilometers. The other is the Anniston lineament complex extending for 270 kilometers across Alabama and probably into Georgia to the southeast and Tennessee on the northwest (fig. 1). Various aspects of these lineaments are discussed in later parts of this paper and in several other papers of this volume (Neathery and Reynolds, 1974; Moravec and Moore, 1974; Wilson, 1974; Skrzyniecki, Nordstrom, and Smith, 1974; Drahovzal and others, 1974; see Appendix 1).

In addition to the two major lineaments there are a myriad of other shorter less prominant lineaments for which very little or no field information is available. Generally, these appear to have only local geologic significance. Some have been studied to various degrees and this information has been discussed (Drahovzal and others, 1974; see Appendix 1).

This study will examine the relationships of the lineaments to:

1. jointing
2. Appalachian structural features
3. stratigraphic factors

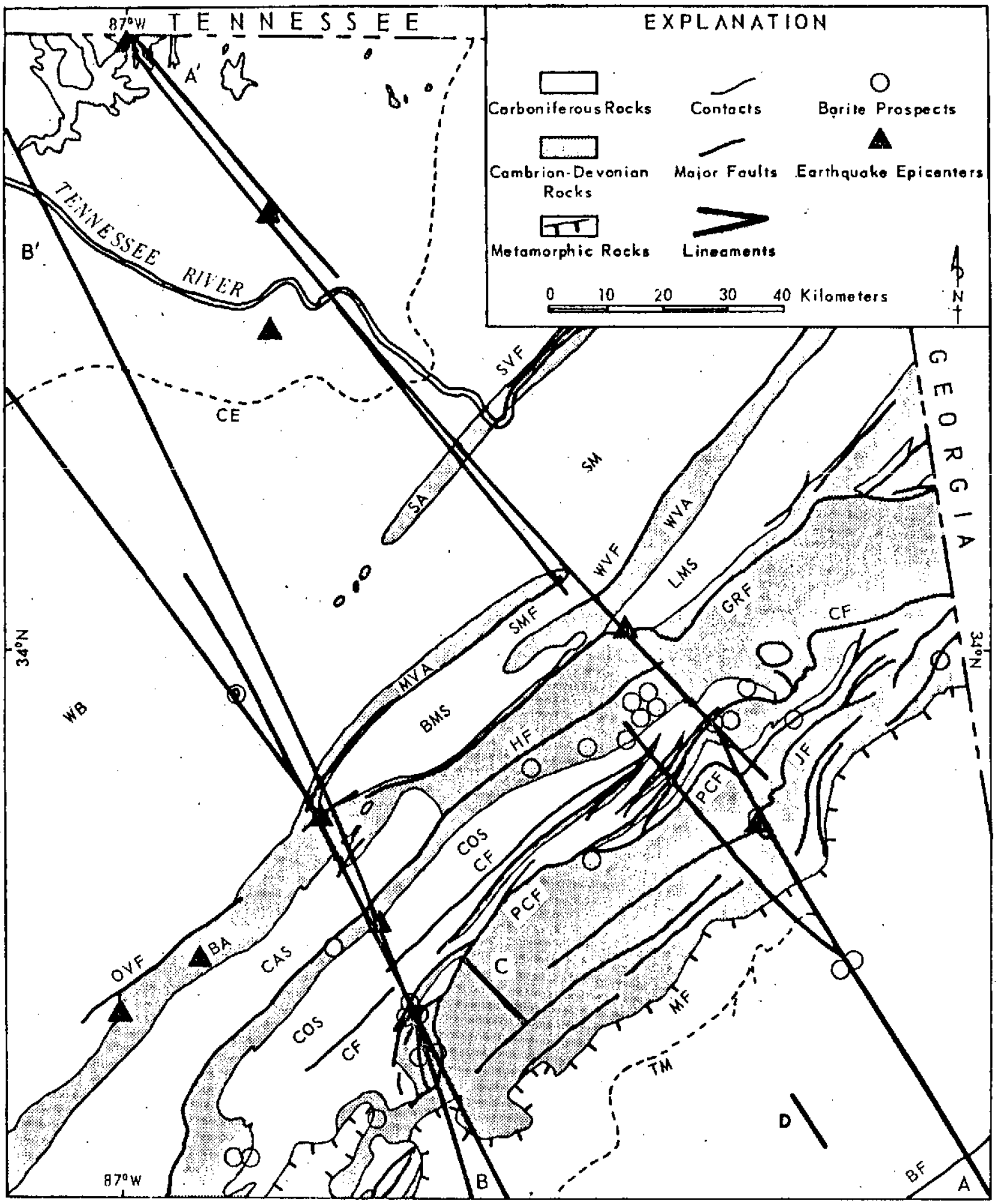

Figure 1.—Generalized geology of northeast Alabama, showing structural and physiographic features, barite prospects, earthquake epicenters and lineaments (A-A'—Anniston, B-B'—Harpersville, C—Wesobulga Creek and D—Kelly Creek). BA—Birmingham anticlinorium, BMS—Blount Mountain syncline, BF—Brevard fault, CAS—Cahaba syncline, CE—Cumberland escarpment, CF—Coosa fault, COS—Coosa synclinorium, GRF—Gadsden-Rome fault, HF—Helena fault, JF—Jacksonville fault, LMS—Lookout Mountain syncline, MF—metamorphic front, MVA—Murphrees Valley anticline, OVF—Opossum Valley fault, PCF—Pell City fault, SA—Sequatchie anticline, SM—Sand Mountain, SMF—Straight Mountain fault, SVF—Sequatchie Valley fault, TM—Talladega Mountain, WB—Warrior basin, WVA—Wills Valley anticline, WVF—Wills Valley fault. Geology modified from Adams and others, 1926.

4. mineralization and geochemical highs
5. high-yield wells and springs
6. karstic development
7. geophysical anomalies
8. earthquake eqicenters
9. tectonic sytle
10. plate tectonic considerations

PLOTTING PROCEDURES

Lineaments were plotted on both 1:1,000,000 and 1:250,000 scale images. The Anniston and Harpersville lineament complexes originally defined on Apollo 9 photography were extended into other parts of the state through the use of the 1:1,000,000 scale ERTS imagery. Most of the detailed lineament studies, however, were carried out on the 1:250,000 scale images. The plotting procedure described below for the 1:250,000 scale imagery was also followed in plotting lineaments on the 1:1,000,000 scale imagery.

From among the ERTS-1 data received as of June 1, 1973, the images possessing the least cloud cover and the finest detail were chosen to be purchased from the EROS Data Center as positive prints at scales of 1:250,000. Each image covering the northern Alabama area which showed lineaments was fitted with a clear, scale-stable overlay and registered with brass registration pins. The following images were used in the study:

1175-15492-5 (January 14, 1973)
1175-15495-5 and 6 (January 14, 1973)
1158-15552-5 and 6 (December 28, 1972)
1176-15553-5 (January 15, 1973)
1104-15555-5 (November 4, 1972)
1177-16005-7 (January 16, 1973)

It will be noted that winter imagery was found to be the most free of clouds and of the finest quality. The low sun angle also enhanced the definition of the Appalachian structural grain. It was found that only the strongest lineaments could be seen when viewing the image with the eye perpendicular to the photograph. Low-angle viewing with the line of sight parallel to the lineament was found to be the most satisfactory method of delineating lineaments. Each image was scanned in this fashion for an average of five hours, and all lineaments viewed in that time period were traced with India ink onto the overlay. The data was next transferred to a 1:250,000 base map of the northern part of Alabama. In some cases slight differences in scale and/or disagreements between the ERTS image and the base, prevented the accurate location of all lineaments on the base map. As a result, random error in location may be as much as $\pm$ 0.7 km. All man-made linear features were carefully excluded from the study by comparing lineament traces to known cultural features shown on 7½-minute quadrangle and 1:250,000 scale topographic maps and U-2 and other aerial photography.

When all the lineaments had been transferred to the base map, the orientations and lengths of each lineament were manually recorded on data sheets. Data were then compiled from all sheets on a second data sheet and grouped into 5° orientation categories for the entire area, sub-areas, and combinations of sub-areas. The percentages of lineaments falling into these 5° categories were then calculated. Percentages for 10° categories were also determined. Next, the information was transferred to rose diagrams utilizing 5° and 10° intervals for the entire area, sub-areas, and combinations of sub-areas. The information was also plotted on specially prepared cartesian diagrams in the fashion described by Gay (1973, p. 7, 8). The rose diagrams and the cartesian histograms were used in comparing and evaluating results. The lineament length data were transferred from the data sheets and categorized into 10-kilometer intervals for analysis. The data were then plotted on a percentage versus length category graph.

DESCRIPTIONS

Length, Density and Interrelationships

A total of 2,186 lineaments ranging in length from 3 to more than 160 km are present in the area based on interpretations from the 1:250,000 ERTS-1 images (pl. 1). Slightly more than 90 percent of the lineaments are of lengths between 3 and 40 km (fig. 2). Nearly 40 percent are between 10 and 19 km.

Most of the lineaments are straight, but some are slightly arcuate; some terminate at the intersection with other lineaments, but most cross each other with no apparent offset. Some splay into two or more branches and others exhibit an *en echelon* character. Because of their relatively straight character, regardless of land-surface topography, the lineaments, if possessing a third dimension, must represent vertical or near-vertical features.

Lineament spacing ranges from less than 1 km to nearly 20 km. The reasons for the range in spacing is not always readily apparent. The influences of culture often have the effect of decreasing lineament density as in the urban areas of Huntsville and Birmingham (Sapp and Emplaincourt, 1974). Just to the east of Huntsville, however, in the Jackson Mountains of

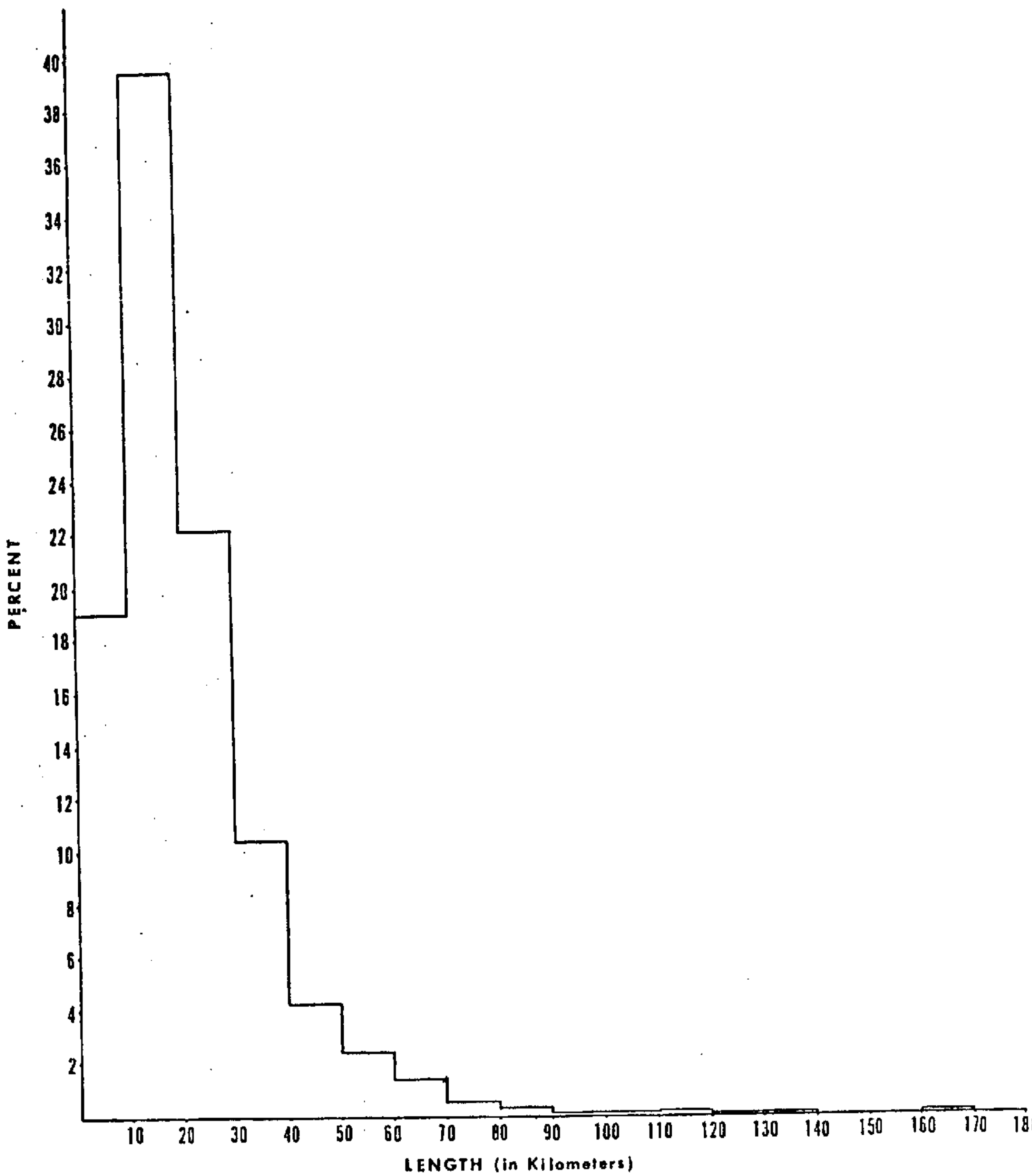

Figure 2.--Length versus percent for the lineaments in the entire northern Alabama area (based on a total of 2,186 lineaments).

eastern Madison and Jackson Counties and also in parts of the Warrior Basin where the influences of culture are few, lineaments are also sparse. It, therefore, appears that thick forest growth also inhibits lineament detection. In areas of dominant cleared land such as in the Tennessee Valley, the Sand Mountain area and the Coosa Valley, lineaments appear to be reasonably well displayed.

Orientation

Rose Diagram Analyses

Lineament orientation distributions are shown on 5° rose diagrams for the total area, the Piedmont, Valley and Ridge, Piedmont and Valley and Ridge combined, Appalachian Plateaus, Interior Low Plateaus, the Appalachian Plateaus and Interior Low Plateaus combined, and the Coastal Plain. Area and sub-area distribution patterns are compared to the total area pattern and differences discussed.

Total Area.--An orientation analysis for all 2,186 limeaments measured on plate 1 is shown in figure 3. Most of the lineaments lie in the northwest quadrant between N20°-70°W. The N40°-60°W lineament group is dominant with nearly one-quarter of the lineaments measured lying within this group. An accessory high lies between N30°-35°W. The dominant orientation in the eastern quadrant lies between N40° and 45°E. Less prominant highs lie between N0°-5°W and between N70°-80°E. The most prominant directions in each quadrant lie at approximately right angles to one another.

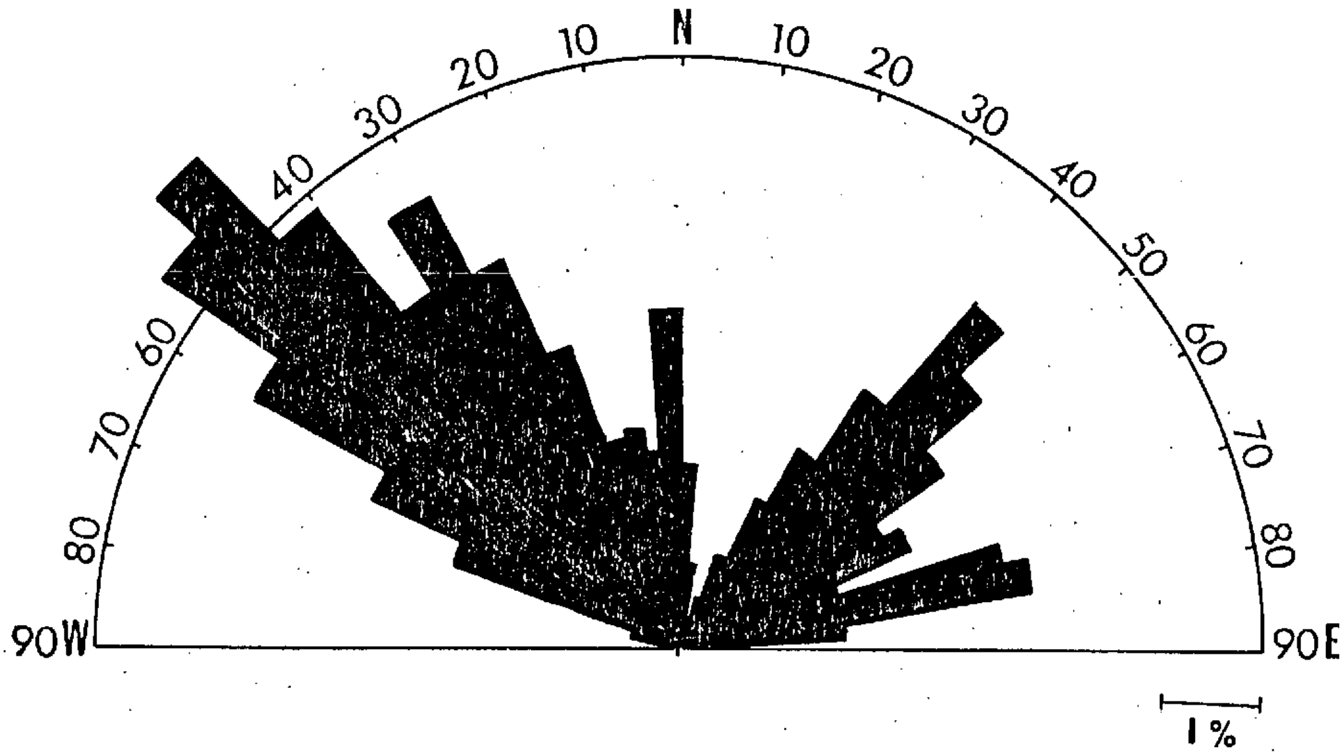

Figure 3.--Rose diagram of lineament orientations for the entire northern Alabama area shown in plate 1.

Piedmont.--As in the total lineament diagram (fig. 3), the most common Piedmont lineament orientations lie in the northwestern quadrant between N20°-60°W (fig. 4). The two nearly equally strong lineament groups lying between N25°-35°W and between N45°-60°W compare with those expressed in the total area diagram between N30°-35°W and N40°-60°W, respectively. The only other significant highs occur between N55°-65°E and between N5°W-N5°E. The latter correlates well with a comparable high on the total area diagram, but the other does not, lying 15° away from the nearest peak (N70°-80°W) on the total area diagram. The group lying N20°-45°E in the Piedmont does not show the strong development shown in the total area, but rather are composed of a series of weak highs in 5° groups that are separated from one another by 5°-10° lows.

Valley and Ridge.--Most of the lineaments in the Valley and Ridge show orientations between N20°-70°W (fig. 5). The accessory highs between N25°-30°W and between N45°-65°W agree well with comparable total diagram highs (fig. 3). Valley and Ridge lineament highs ranging from N0°-5°W, N40°-45°E and N65°-75°E combine to make the entire distribution strikingly similar to that for the total area.

Piedmont and Valley and Ridge.--A combination of lineaments delineated for the two provinces dominated by faulting and folding results in the lineament distribution shown in figure 6. Again the pattern shown is very similar to those expressed by the total area (fig. 3). Rather arbitrary averages taken for the most prominant orientations provide the following results:

Total	N48°W	N32°W	N2°W	N44°E	N75°E
Piedmont and Valley and Ridge	N58°W	N30°W	N2°W	N40°E	N68°E

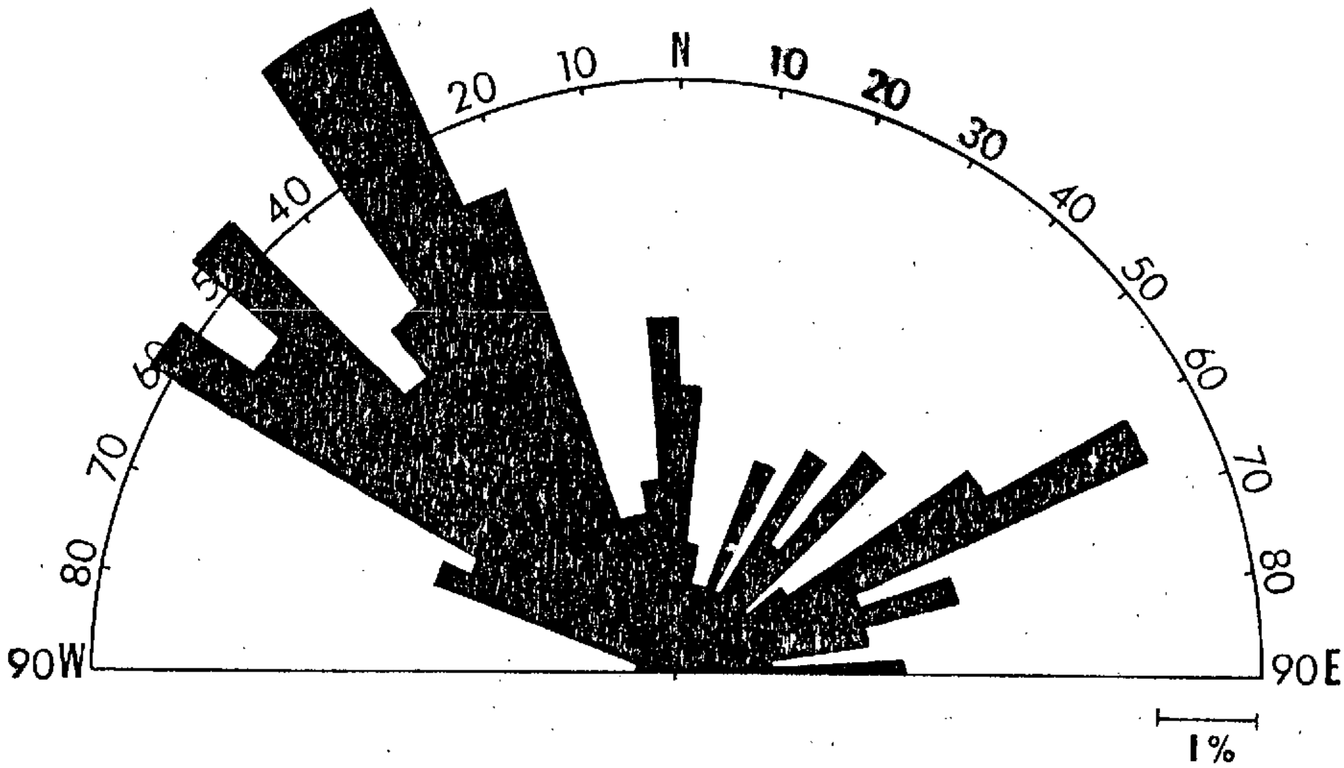

Figure 4.--Rose diagram of lineament orientations in the Piedmont province.

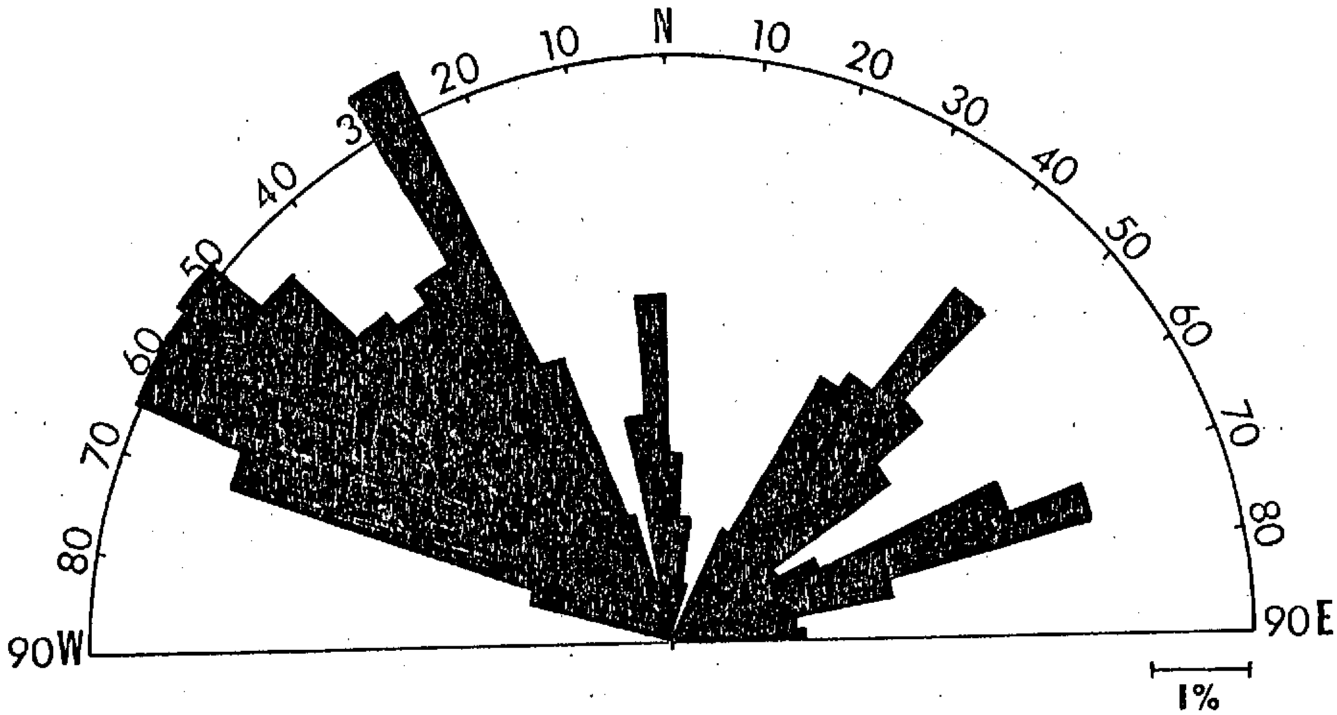

Figure 5.--Rose diagram of lineament orientations in the Valley and Ridge province.

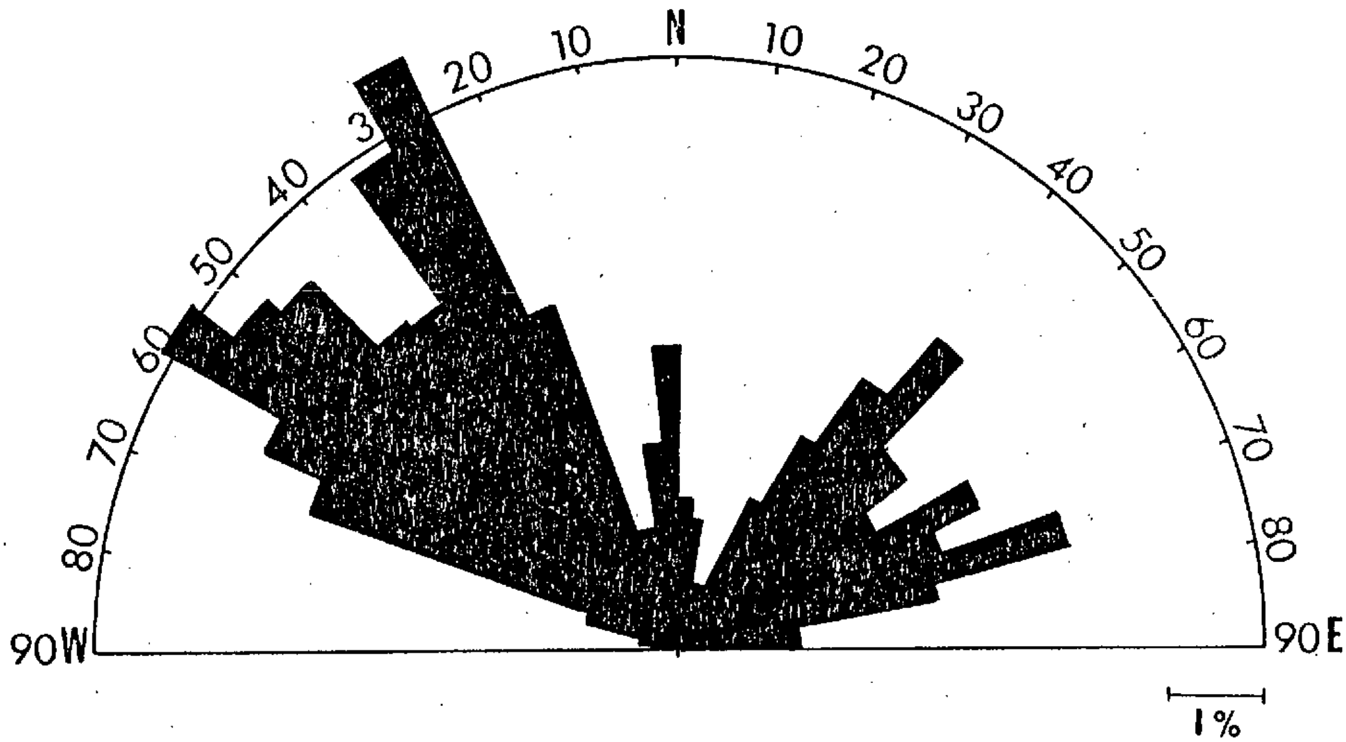

Figure 6.--Rose diagram of lineament orientations in the Piedmont and Valley and Ridge provinces.

Note that in the combined Valley and Ridge and Piedmont that 98° separates the N58°W group from the N40°E group as well as the N30°W group from the N68°E group.

Appalachian Plateaus.--As in the other provinces, the dominant trend in the Appalachian Plateaus, lies in the northwest quadrant between N30° and 55°W (fig. 7). The major peak lies in the range from N40°-55°W and an accessory peak occurs between N30° and 35°W. Both of these correspond closely to comparable highs in the total area (fig. 3). Relatively weakly expressed highs occur from N0°-5°W and from N10°-25°W. In the northeastern quadrant, a N40°-50°E high compares well with the comparable total area high as does a N70°-85°W peak. The latter is, however, relatively higher than the comparable group for the total area, consisting of more than 12 percent of the lineaments for the province. Examination of plate 1 reveals that this group is particularly well-displayed just north of Birmingham where they are the most densely spaced. The spacings range downward to less than a kilometer. Farther north, however, the spacing increases and may be as great as 20 kilometers. It will also be noted that this group does not commonly cross into the Valley and Ridge to the east. Some of the longer lineaments cross the boundary, but most are confined to the Appalachian Plateaus. Neither does the group persist north into the Interior Low Plateaus.

Interior Low Plateaus.--The lineament distribution in the northwest quadrant for the Interior Low Plateaus show an almost symmetrical high, rising from low values at N15°W to a peak between N40°-45°W and falling off to zero at N70°W (fig. 8). This broad peak is very similar to that expressed by the total area (fig. 3). A N0°-5°W peak is also present for the Interior Low

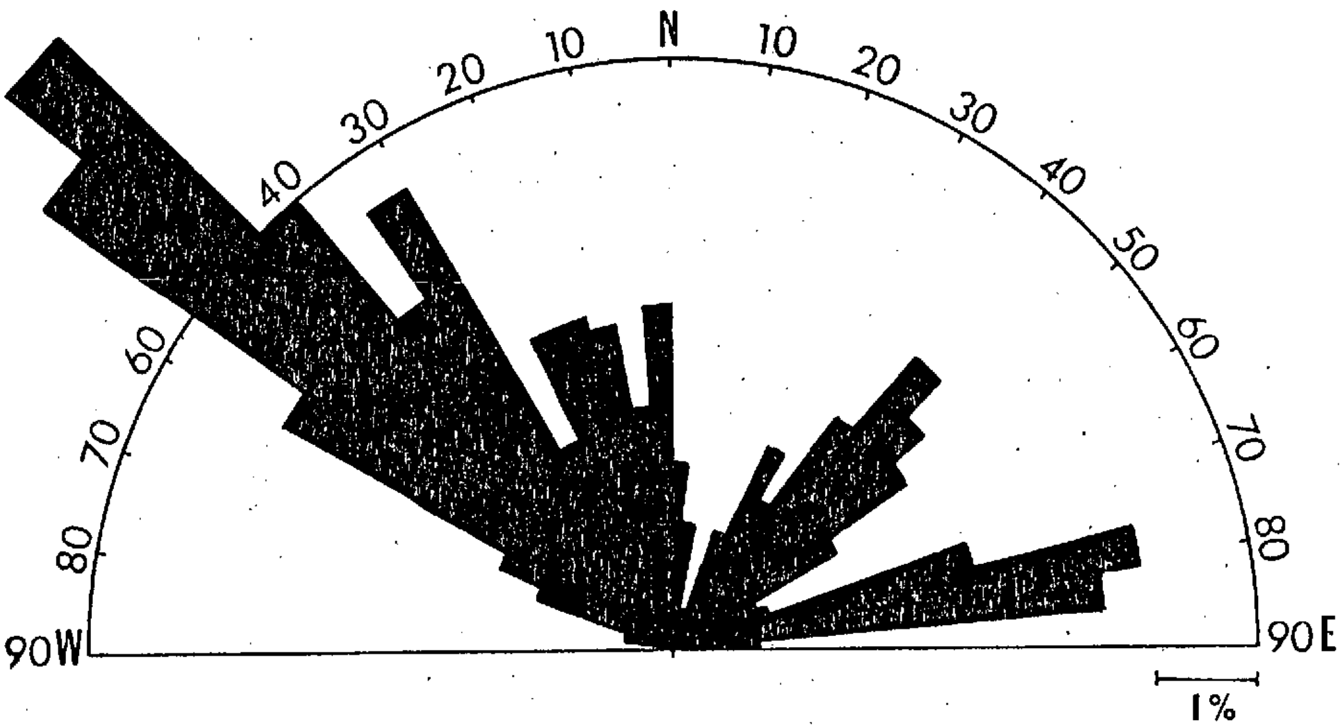

Figure 7.--Rose diagram of lineament orientations in the Appalachian Plateau province.

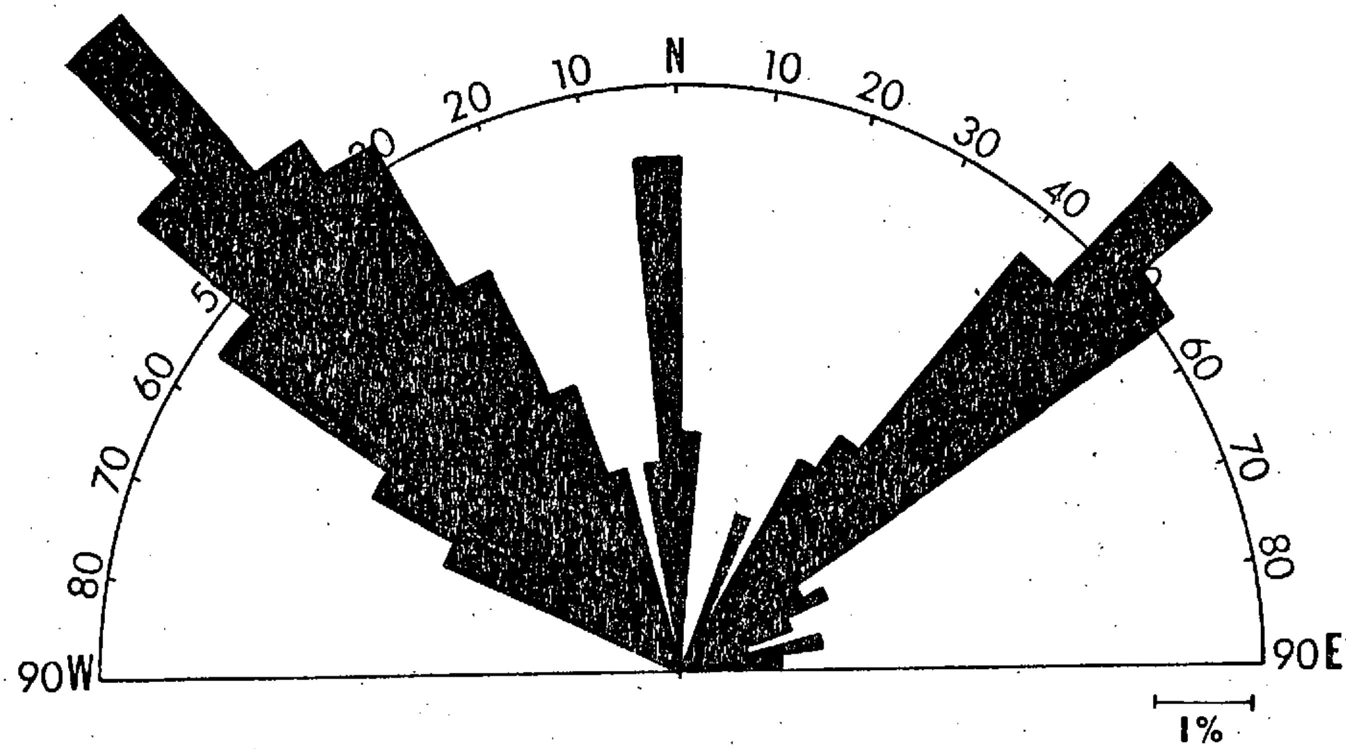

Figure 8.--Rose diagram of lineament orientations in the Interior Low Plateaus province.

Plateaus as is the case for the total area. In the northeast quadrant, the only peak lies between N40°-55°E. This peak is more prominant than northeast-oriented lineaments in other north Alabama provinces. The N70°-85°E peak present in the Appalachian Plateau (fig. 7), and expressed in the total area (fig. 3) is conspicuously absent. Nevertheless, the near 90° separation between mean orientations for the northeast and northwest quadrants is readily apparent both from the rose diagram (fig. 8) and from plate 1.

Appalachian Plateaus and Interior Low Plateaus.--The Appalachian Plateaus and the Interior Low Plateaus are similar in that most of their areas consist of nearly flat-lying sedimentary rocks. Only relatively gentle folds and a few thrust faults are present near the eastern edge of the Appalachian Plateaus. The most prominent lineament group lies between N40° and 55°W and an accessory high occurs in the N30°-35°W range (fig. 9). These compare favorably with comparable total area highs (fig. 3). The N0°-5°W lineament group is weakly expressed, but the N40°-50°E group is moderately well expressed as is the N70°-80°E group. The latter two are comparable to total area groups.

Coastal Plain.--Only a small part of the Coastal Plain is analyzed in this study, but it is significant that even this relatively small area generally shows the same trends as do the adjacent northern Alabama provinces (fig. 10). Examination of plate 1 reveals that many of the lineaments in the adjacent provinces cross the Coastal Plain boundary and continue without deflection or offset of any kind.

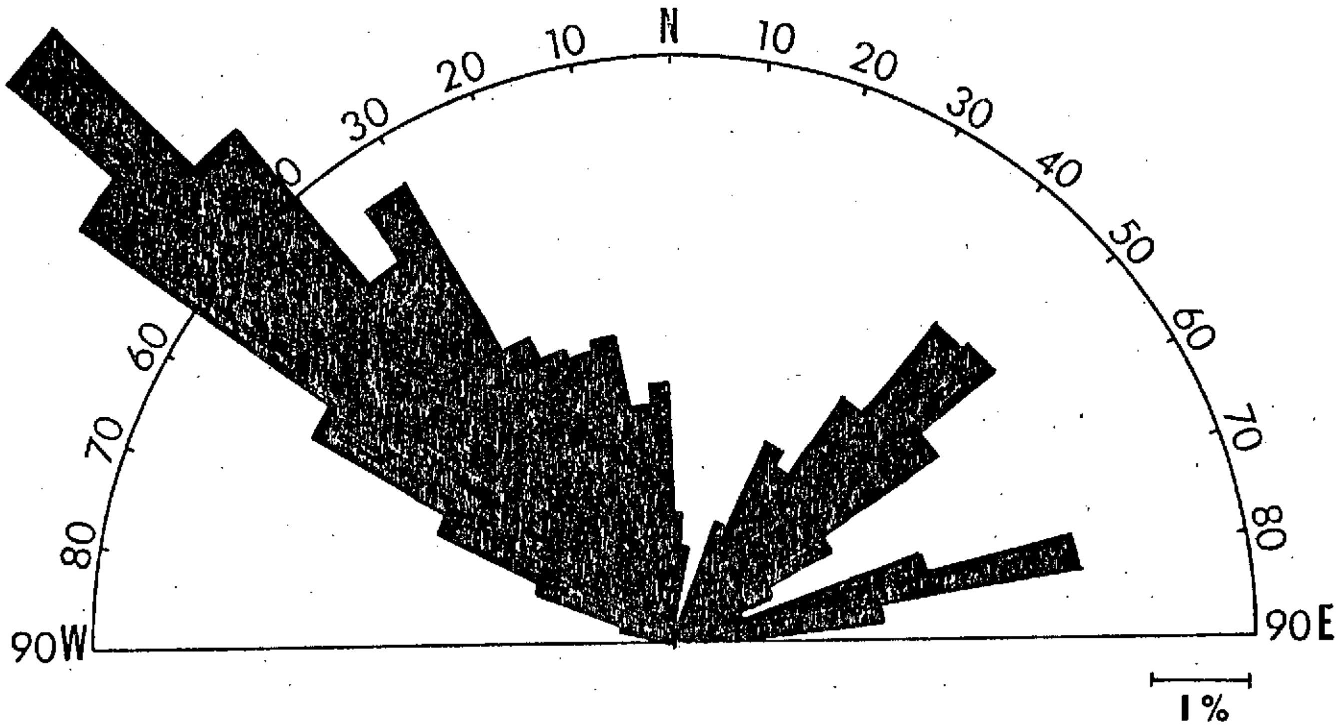

Figure 9.--Rose diagram of lineament orientations in the Appalachian Plateau and Interior Low Plateaus provinces.

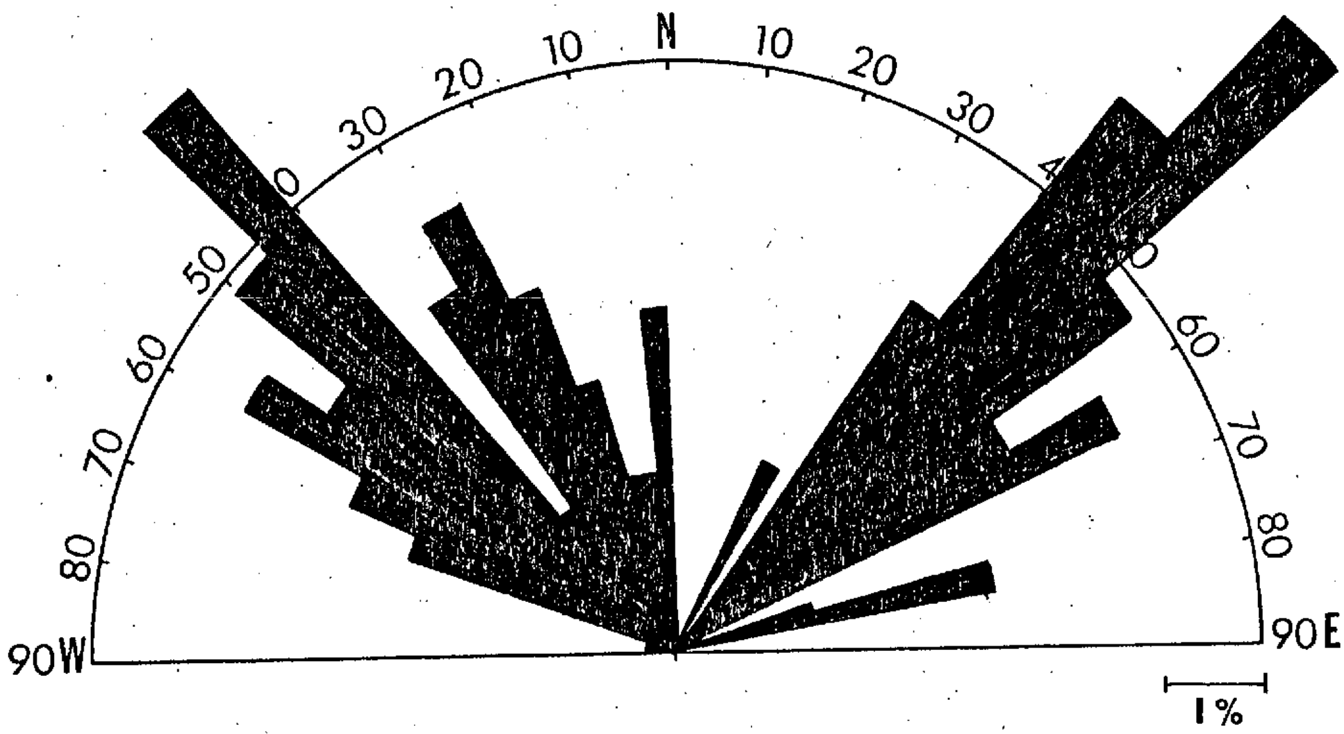

Figure 10.--Rose diagram of lineament orientations in the Coastal Plain province.

Cartesian Plot Analyses

A method of analyzing lineament data that is described by Gay (1973, p. 7-8) was attempted for the lineaments of north Alabama. The method allows rapid selection of characteristic or average strike directions for each lineament group and provides a basis of quick comparison with plots for other areas presented by Gay (1973). The characteristic direction is determined by positioning a vertical line in such a fashion that the areas to its right and left beneath prominant and possibly significant peaks are approximately equal. A polar planimeter was used in determining equal areas. Peaks for this analysis are defined as highs with greater than 1 percent relief above the 2 percent level and 10 or more degrees away from adjacent highs.

The primary reason for analyzing the data in this fashion was to test the basic hypothesis of Gay (1973), that continental lineaments and fractures occur in pervasive orthogonal (90°) sets rather than conforming to the more traditional stress-strain theory where lineaments and fractures develop at 60° and 120° angles (Billings, 1954, p. 103; Badgley, 1965, p. 100). In the following discussion, cartesian plots for the total area, individual provinces and combinations of provinces of north Alabama are analyzed and compared.

<u>Description of Total Area</u>.--The total area plot shows that the major lineament direction has a characteristic strike of 128° (N52°W) and is 87° (128°-41°) away from its possible counterpart with a characteristic strike of N41°E (fig. 11). The lineament group with a 178° (N2°W) characteristic strike is 102° (178°-76°) away from its possible counterpart at N76°E. Each of these

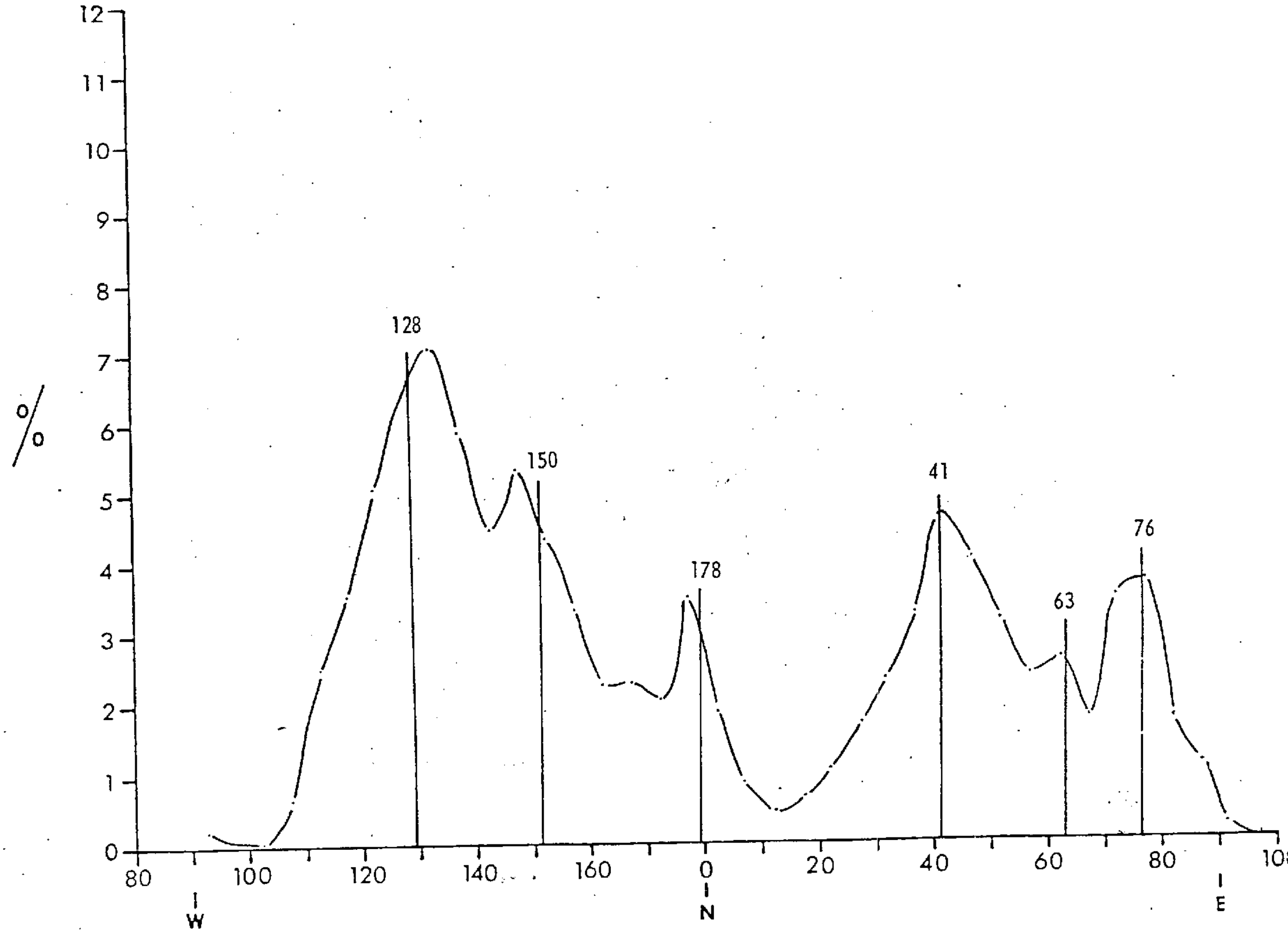

Figure 11.--Cartesian diagram of lineament orientations for the entire northern Alabama area shown in plate 1.

orthogonal groups is termed a "pairset" by Gay (1973, p. 5). Another possible, but much weaker pairset is made up of the 150° (N30°W) and the N63°E characteristic strikes and are separated by 87° (150°-63°). In terms of Gay (1973, p. 6), the area exhibits a "twin-orthogonal" or possibly even a "tri-orthogonal" lineament pattern.

Piedmont.--A cartesian plot of the Piedmont with the above assumptions shows a fairly well-expressed tri-orthogonal lineament pattern with 88° (150°-62°), 92° (125°-33°) and 91° (178°-87°) between pairsets (fig. 12). The N33°E characteristic strike is an average of three fairly low-magnitude peaks lying within 10° of one another and may represent an invalid characteristic strike.

Valley and Ridge.--The Valley and Ridge shows five strongly expressed characteristic strikes (fig. 13). The sixth strike (N86°E) is only very weakly expressed and may not be valid. A twin-orthogonal pattern is evident and possibly a tri-orthogonal, with 82° (152°-70°), 84° (125°-41°) and 91°? (177°-86°?) between pairsets.

Piedmont and Valley and Ridge.--The characteristic strikes of the Piedmont and Valley and Ridge considered together are almost a duplicate of that for the Valley and Ridge with 81° (151°-70°), 83° (125°-42°), and 91°? (179°-88°?) between pairsets (fig. 14). A twin-orthogonal pattern is definitely present and a tri-orthogonal possible.

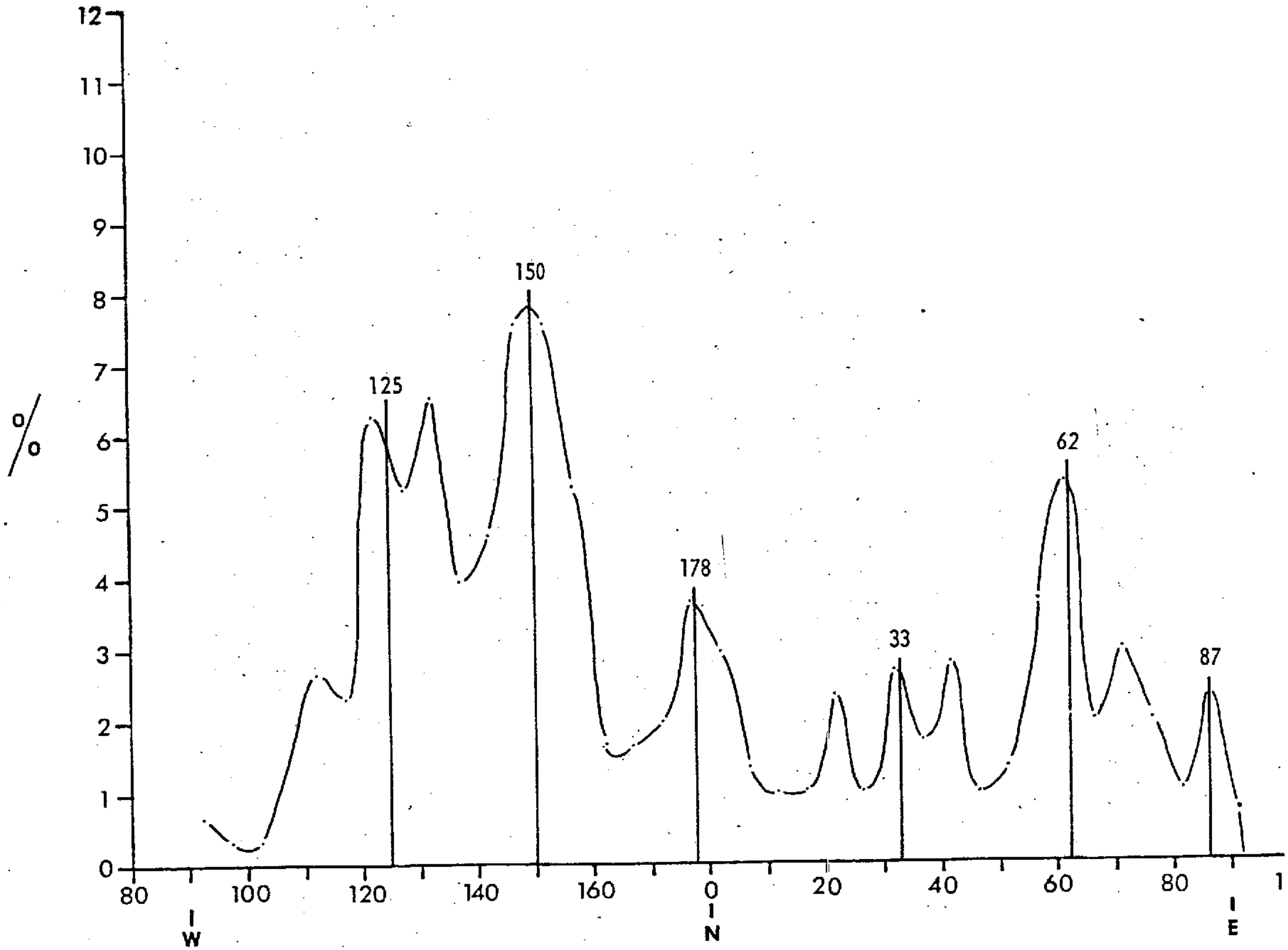

Figure 12.--Cartesian diagram of lineament orientations in the Piedmont province.

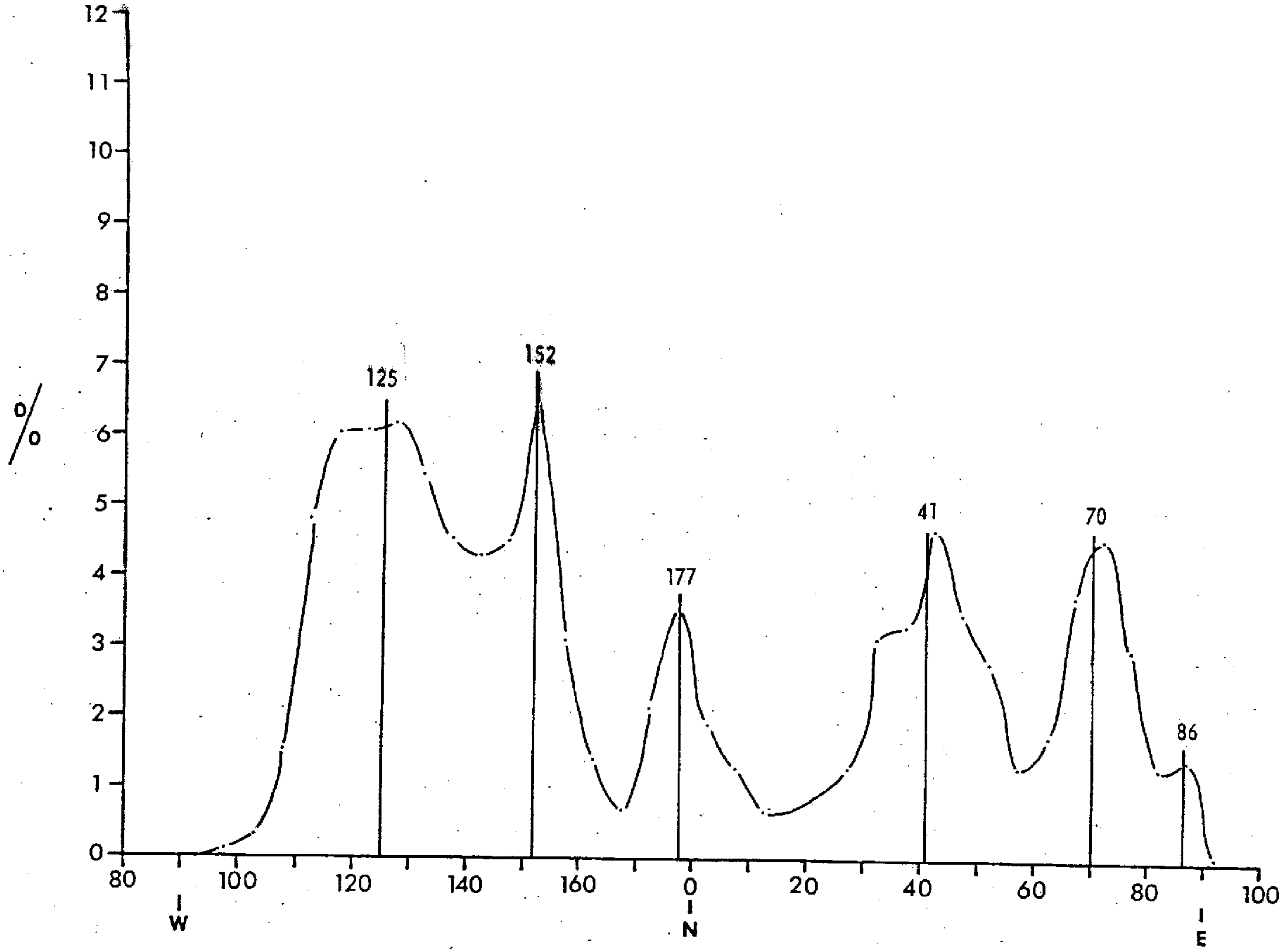

Figure 13.--Cartesian diagrams of lineament orientations in the Valley and Ridge province.

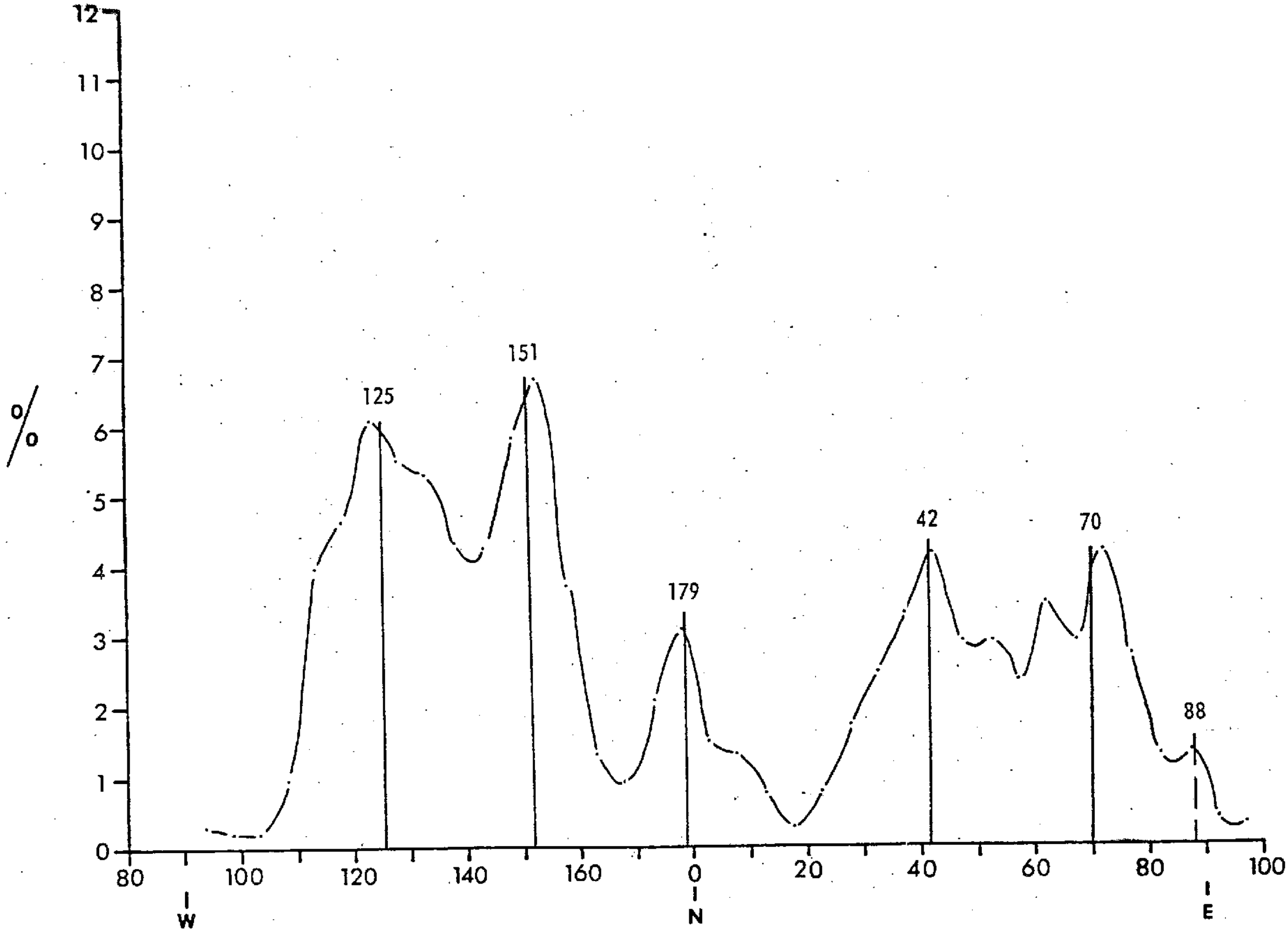

Figure 14.--Cartesian diagrams of lineament orientations in the Piedmont and Valley and Ridge provinces.

Appalachian Plateaus.--Lineament patterns in the Appalachian Plateaus are somewhat different, there being five fairly distinct characteristic strikes (fig. 15). These are arranged so that there are 88° (130°-42°) and 90° (167°-77°) between two pairsets and an unmatched set 147° (N33°W).

Interior Low Plateaus.--Only three lineament characteristic strike directions, according to the peak criteria previously stated, are present in the Interior Low Plateaux (fig. 16). One pairset is 93° (138°-45°) apart, while the 177° (N3°W) lineament group is unpaired.

Appalachian Plateaus and Interior Low Plateaus.--The character strike directions of the Appalachian Plateaus and Interior Low Plateaus provinces considered together consist of three strongly and two weakly expressed lineament groups (fig. 17). They are 93° (130°-43°) and 93°? (170°?-77°) apart. A possible fifth group is unmatched (147°?).

Coastal Plain.--The small part of the Coastal Plain analyzed yields a fairly distinctive tri-orthogonal lineament pattern with 83° (128°-45°), 92° (153°-61°) and 101° (176°-75°) between pairsets (fig. 18).

Discussion.--As can be readily seen from the foregoing, a case for orthogonal lineament patterns may be quite convincingly made for the lineaments of northern Alabama. The angular separation of pairsets ranges from 81°-102°, the deviation from 90° ranging from 0°-12°, but averaging only a little more than 4°.

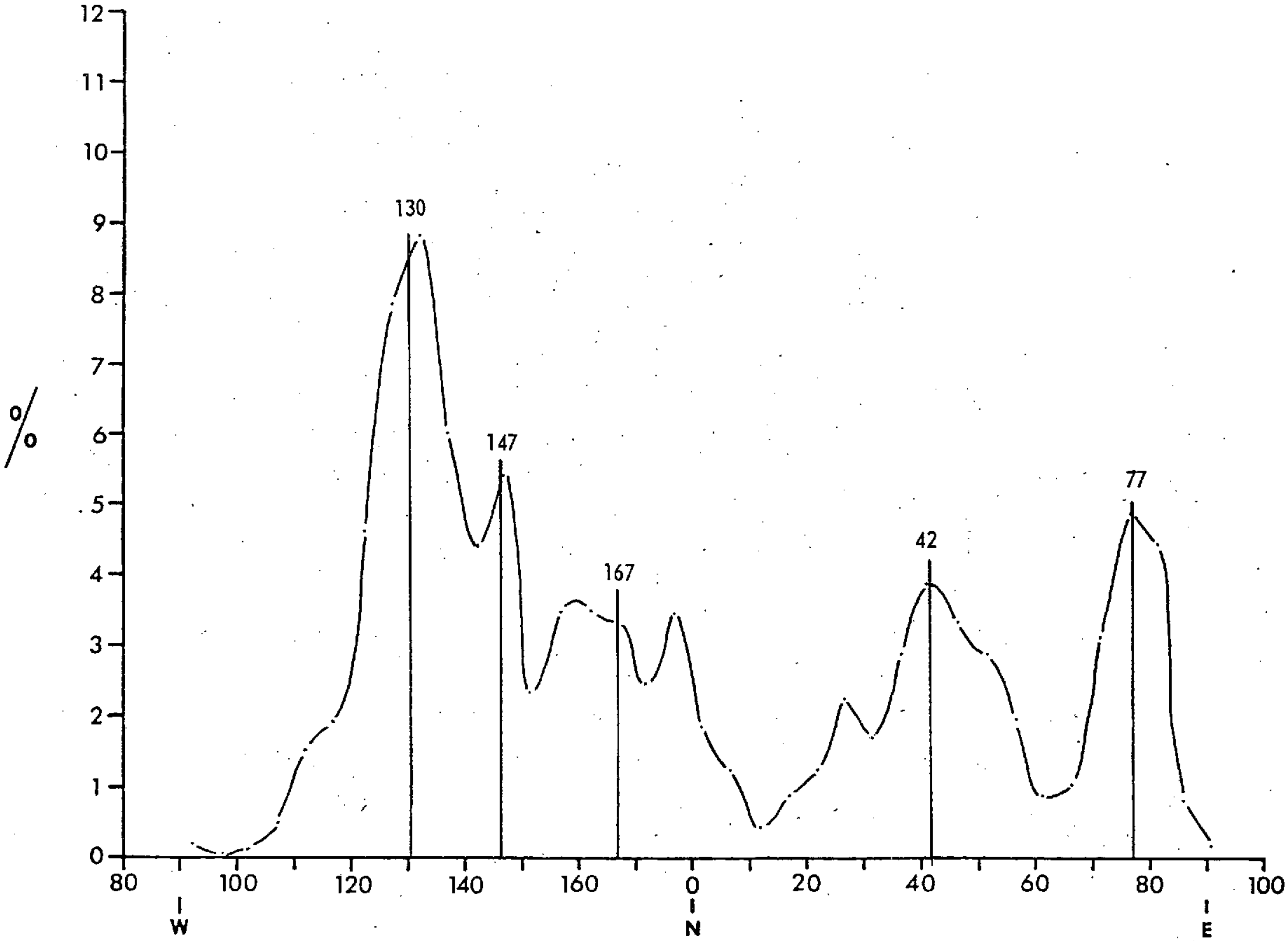

Figure 15.--Cartesian diagrams of lineament orientations in the Appalachian Plateau province.

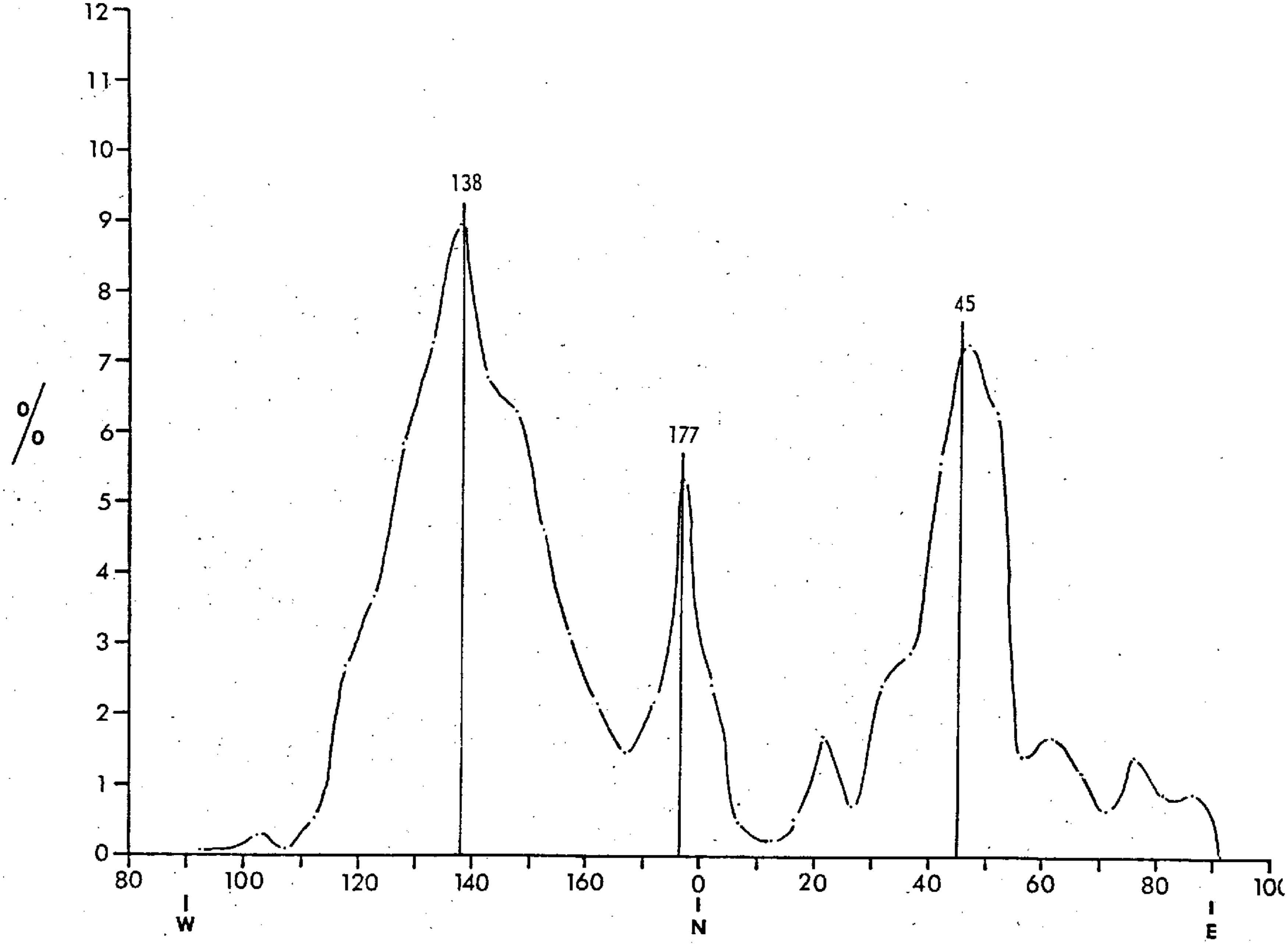

Figure 16.--Cartesian diagrams of lineament orientations in the Interior Low Plateaus province.

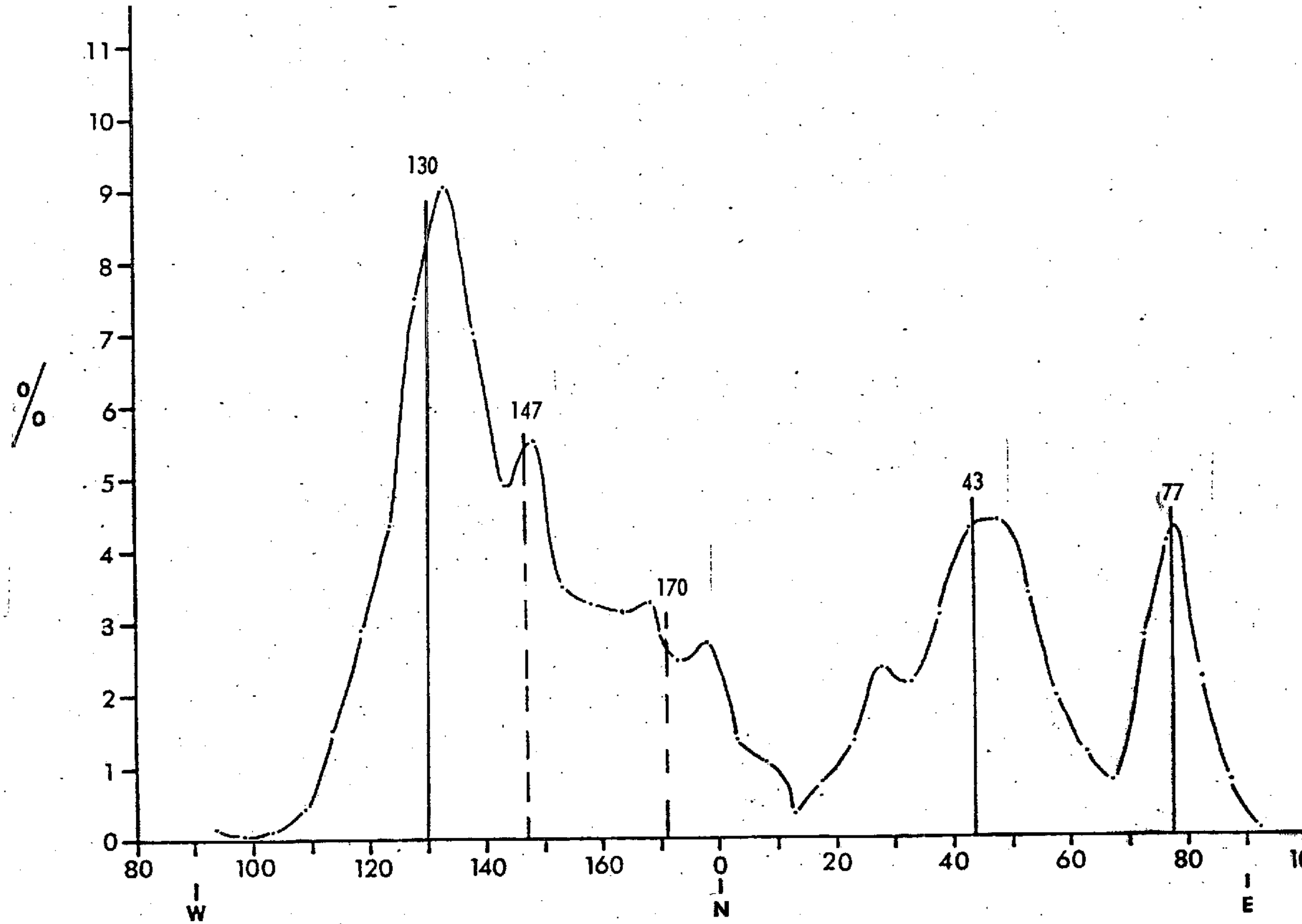

Figure 17.--Cartesian diagrams of lineament orientations in the Appalachian Plateau and Interior Low Plateaus provinces.

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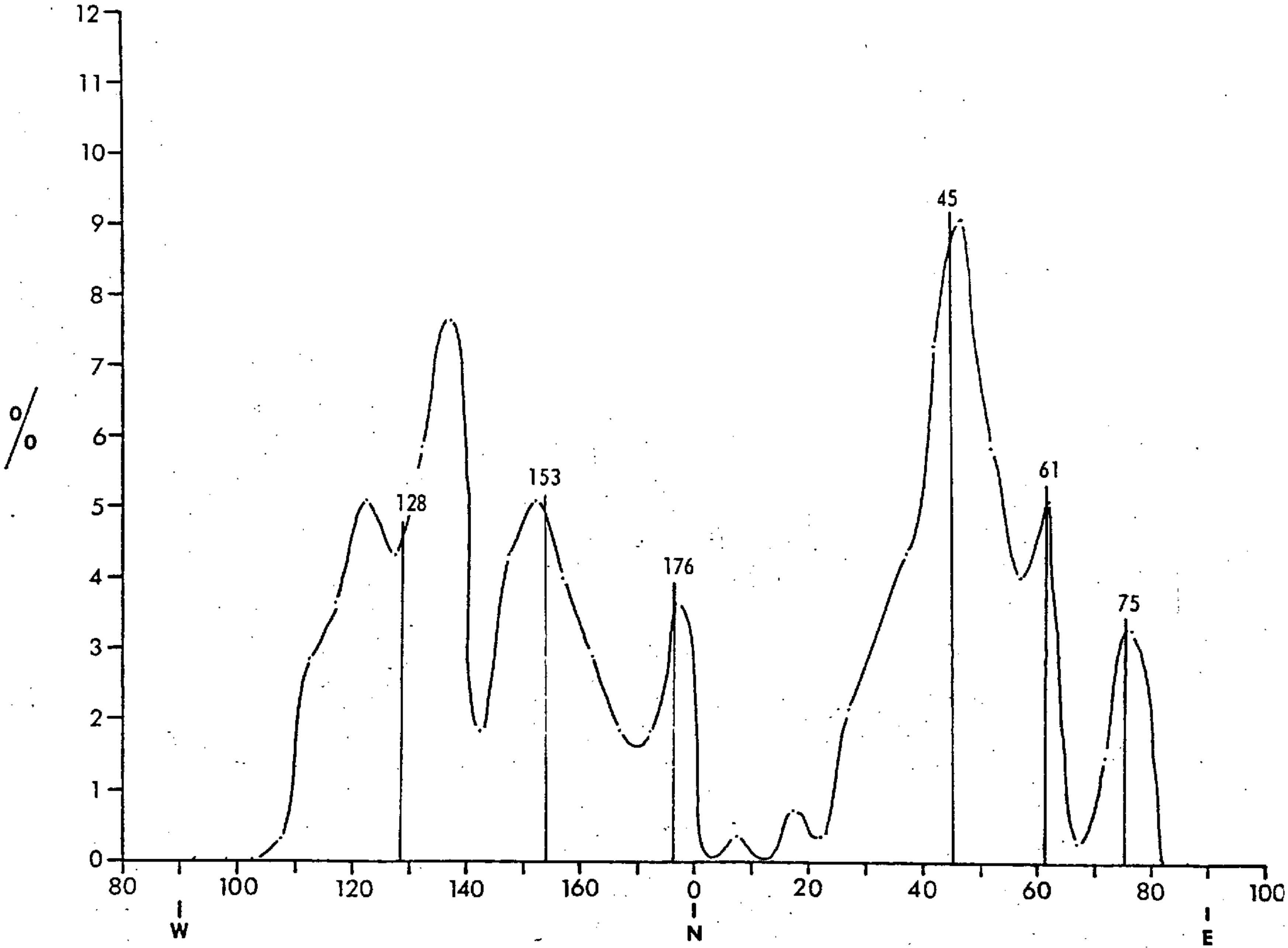


Figure 18.--Cartesian diagrams of lineament orientations in the Coastal Plain province.

The data plotted on cartesian diagrams may be quickly and easily compared to other areas of the Southeast as well as with other areas of the continent and world as compiled by Gay (1973).

The data collected in a previous study utilizing Apollo 9 photography in northern Alabama (Powell and others, 1970) exhibited three lineament groups as interpreted by Gay (1973, p. 17) (fig. 19). The dominant group with a characteristic strike of 146° (N34°W) is unpaired but lies approximately 100° (146°-46°) from the N46°E average strike for the structures of the Valley and Ridge. Lineaments parallel or subparallel to Appalachian strike were ignored in the Apollo 9 study, but have been plotted in this study where they do not conform in strike to known Appalachian structures. Two other lineament groups lie about 86° apart at 92° (N88°W) and 178° (N2°W). Another high that was not interpreted by Gay to be important lies in the vicinity of 124° (N56°W). Analyses prepared for the Piedmont and Valley and Ridge closely approximate, in area, the Apollo 9 study (figs. 6 and 14). Comparison of the two cartesian plots (figs. 14 and 19) shows good correlation in the northwest quadrant if the 124° (N56°W) lineament high in figure 19 is considered to be a significant peak. Due to the lack of lineaments interpreted subparallel to Appalachian strike in the Apollo 9 study, nothing can be said for the northeast quadrant. The major descrepency between the two plots is in the near-east-west region. The ERTS-derived lineament diagram shows a low at this point while the Apollo-derived lineament diagram shows a high. This descrepency may be accounted for by the interference of scan lines on the ERTS images which are within a few degrees of the Apollo lineament peak. Sampling error may also have an effect. The Apollo 9 analysis was based upon 103 lineaments while that for this study, involving approximately the same area, was based on 913 lineaments.

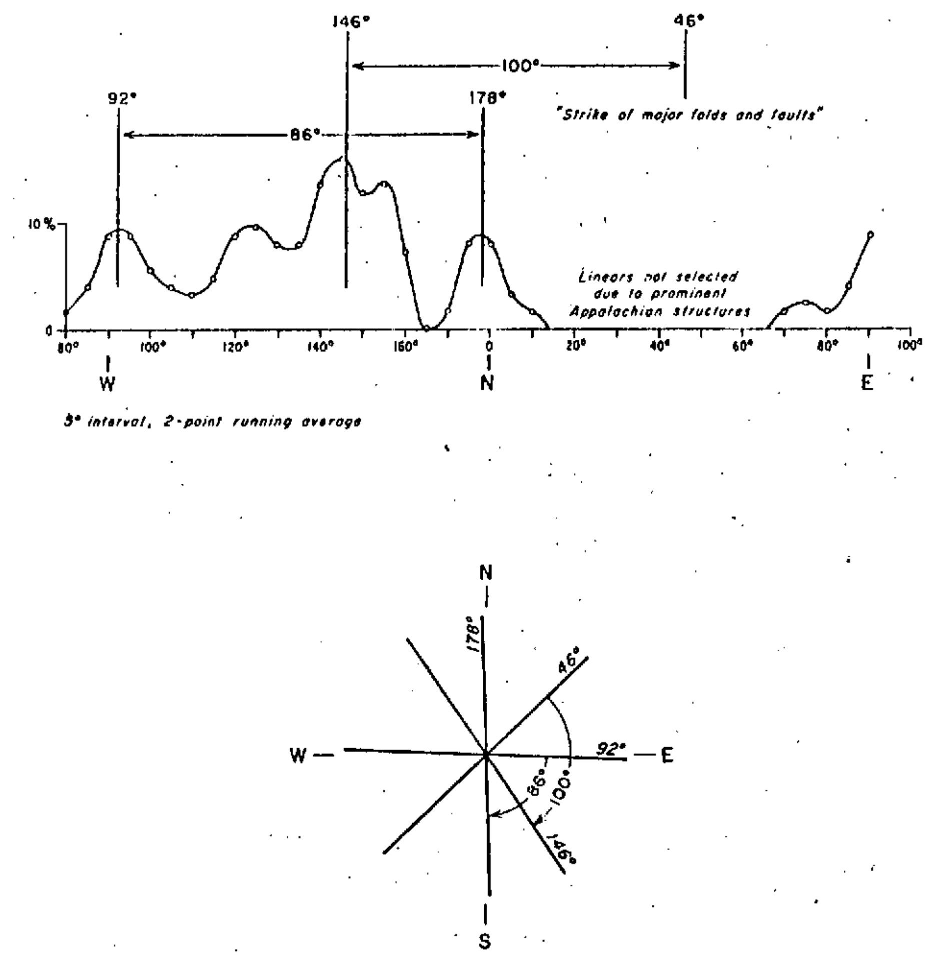


Figure 19.--Cartesian diagram of lineaments delineated from Apollo 9 photographs of central Alabama (Powell and others, 1970). From a diagram by Gay (1973, fig. 20).

A comparison of ERTS-1 lineament strikes for the Interior Low Plateaus (fig. 16) with airphoto fracture traces measured by Sonderegger (1970) in northern Limestone County, Alabama, and plotted by Gay (1973, fig. 19) on a cartesian plot (fig. 20) shows that characteristic directions are quite similar. Both exhibit a dominant characteristic strike in the northwest quadrant at 138° (N42°W) and 139° (N41°W) respectively. The ERTS lineaments show another characteristic strike at 45° (N45°E), 11° different from the 56° (N56°E) exhibited by the fracture traces. In addition, the ERTS lineaments show a 177° (N3°W) characteristic strike that is not represented in Sondegger's data. Because the ERTS lineaments represent a much larger area than that covered by the northern Limestone County study, they may be reflecting regional differences. A more detailed comparison of lineaments, fracture traces, and joints for this area is in a following section.

Lineaments delineated on aerial photographs in northern Florida in and around the Ocala uplift have been reported by Vernon (1951). A cartesian diagram for the 360 lineaments in Florida has been produced by Gay (1973, fig. 18) (fig. 21) and is grossly comparable to the northern Alabama lineament orientation (fig. 11). The dominant 132° (N48°W) orientation shown for Florida is very similar to the dominant 128° (N52°W) orientation shown for the north Alabama area. The 48° (N48°E) and the 41° (N41°E) orientations are both the dominant characteristic strikes for the respective northeast quadrants. The differences, including the lack of north-south striking lineaments and the 76° (N76°E) groups in Florida may be due to differences in sample size or more probably to regional variation.

Some 440 airphoto lineaments were delineated by Fisk (1947) for the lower Mississippi Valley region. The characteristic lineament strikes were

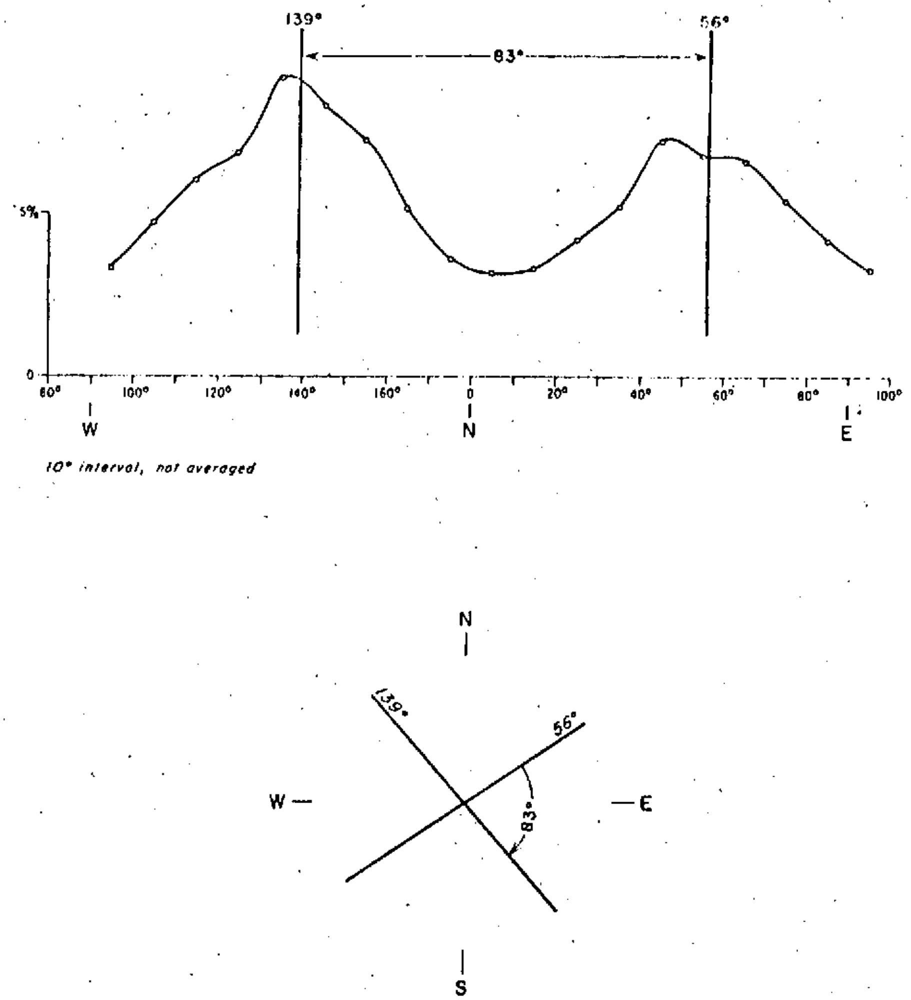


Figure 20.--Cartesian diagram of airphoto fracture traces delineated in the northern part of Limestone County, Alabama by Sonderegger (1970). From a diagram by Gay (1973, fig. 19).

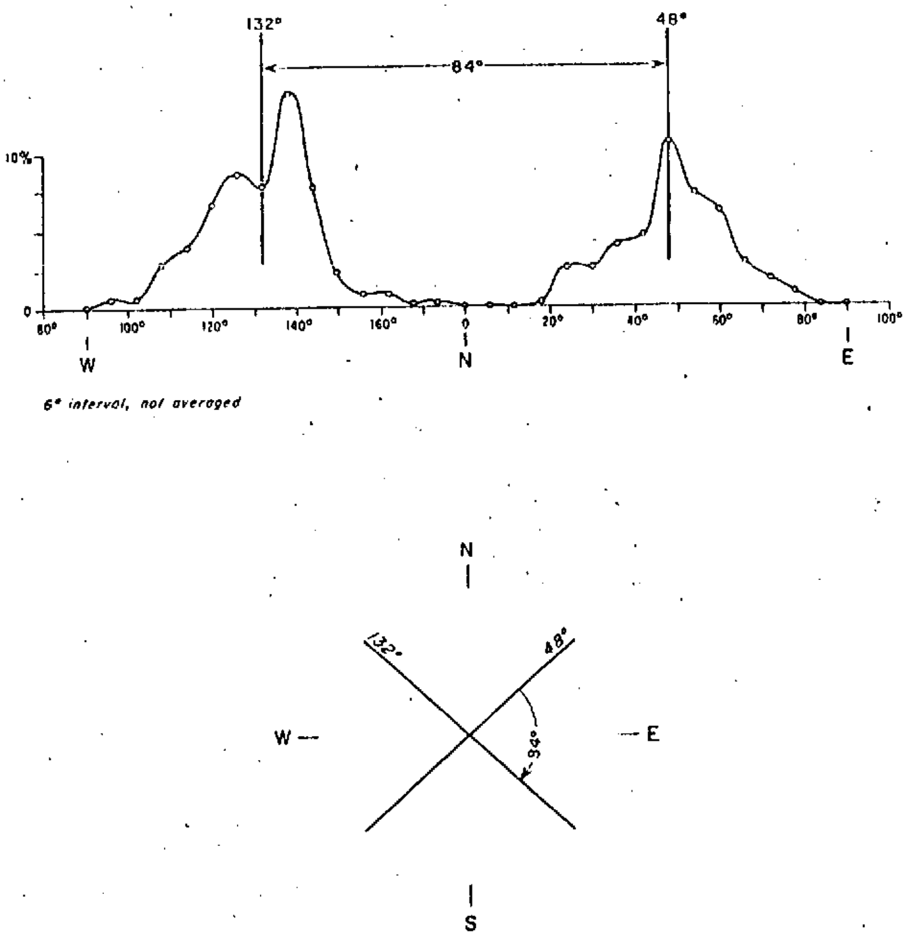


Figure 21.--Cartesian diagram of lineaments delineated in and around the Ocala uplift of northern Florida by Vernon (1951). From a diagram by Gay (1973, fig. 18).

analyzed by Gay (1973, fig. 17) in a cartesian diagram and are very closely similar to those for Florida (figs. 21 and 22). The same comments applied to the Florida study apply to the lower Mississippi **study**. The data analyzed for the Coastal Plain in this study was for only a relatively small area adjacent to the north Alabama provinces. A separate analysis of the Alabama Coastal Plain might indicate a pattern similar to those for Florida and the Mississippi Valley.

A comparison of ERTS lineament characteristic strikes in the Valley and Ridge of Alabama with fracture traces delineated by Trainer and Ellison (1967) for a small area in the Valley and Ridge of western Virginia shows rather poor correlation (figs. 13 and 23). The 175° (N5°W) and 89° (N89°E) peaks expressed for the Virginia data are similar to the peaks shown at 177° (N2°W) and 86° (N86°W) in Alabama. The 86° peak is, however, quite weak and may not be valid. The 125° (N55°W), 152° (N28°W), 41° (N41°E), and 70° (N70°E) peaks shown for the Alabama Valley and Ridge are not present in Virginia; however, the small area (8 km x 8 km) of the Virginia study may not be completely representative of the Valley and Ridge of Virginia.

Gay (1973, p. 87) has described gravity lineaments from a gravity map of the United States and the Gulf of Mexico and aeromagnetic lineaments from an aeromagnetic map of eastern Tennessee that fit the general northeast and northwest direction evident from most of the data discussed above. He has further pointed out that the dominant northwest and northeast trends of the Southeast are probably replaced by dominant cardinally (north-south) oriented lineament pairsets farther to the northeast, as is seen above in the case of fracture traces in the Valley and Ridge of western Virginia (Trainer and Ellison, 1967). Other studies to the northeast including those of Pincus (1951) in New Jersey and Wise (1964) from Dale (1923) in New England also

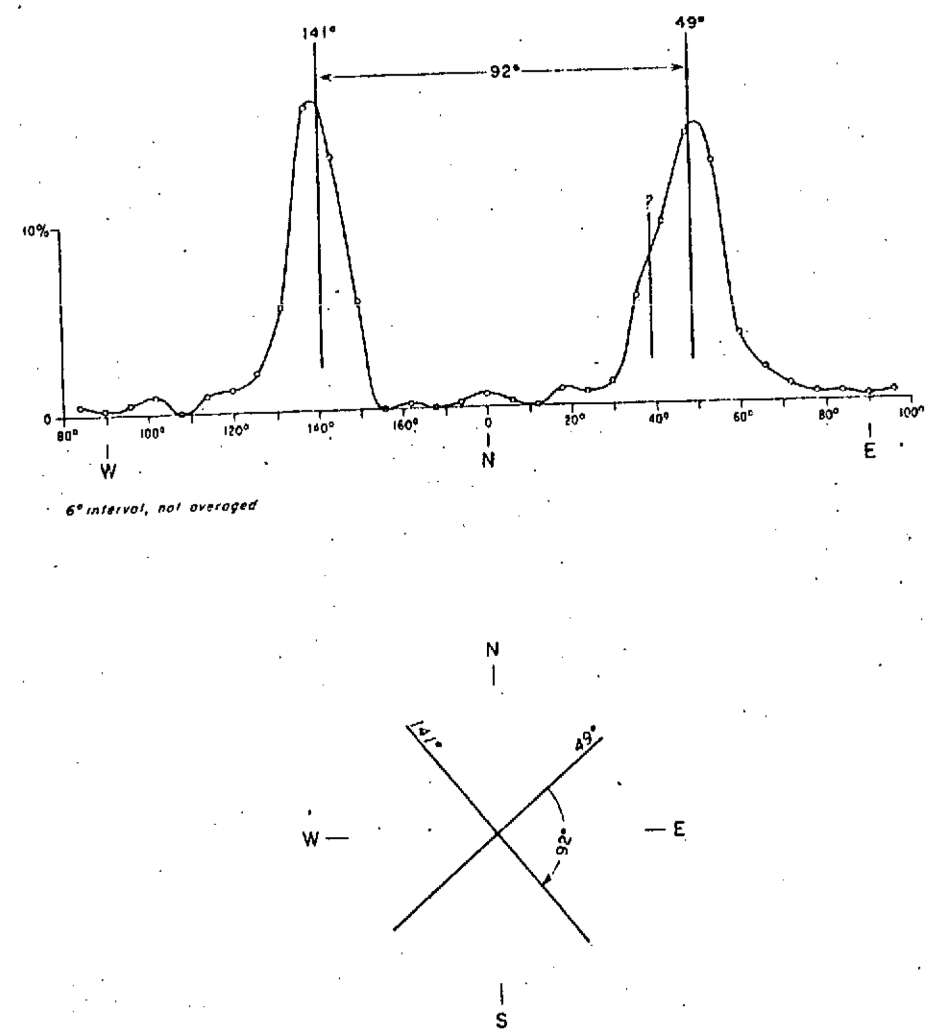
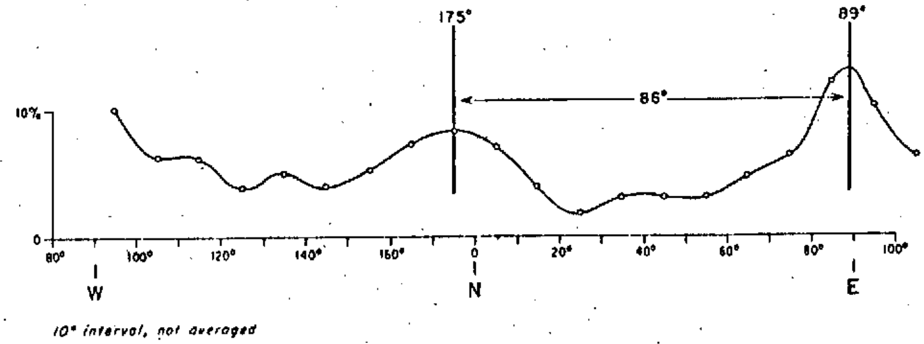


Figure 22.--Cartesian diagram of lineaments delineated for the lower Mississippi Valley region by Fisk (1947). From a diagram by Gay (1973, fig. 17).



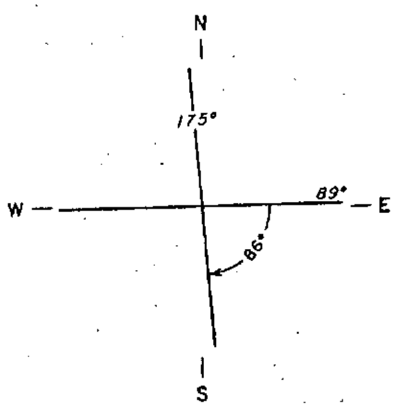


Figure 23.--Cartesian diagram of fracture traces delineated in the Valley and Ridge of Western Virginia by Trainer and Ellison (1967). From a diagram by Gay (1973, fig. 21).

show cardinally oriented joint, rift and grain directions. Shadowing methods utilizing plastic relief maps in New England, however, have shown fracture systems striking N20°E, N25°W, and N70°E (Wise, 1974).

The mechanism responsible for the development of orthogonal pairsets is yet unknown, but Gay (1973, p. 113) assumes that all were formed simultaneously by vertical movement because no offsets or terminations occur among various pairsets. Gay (1973, p. 97, 98) speculates that the occurrence of lineaments in sedimentary rocks may be a reflection of basement structure resulting from minor vertical movement along individual members of the basement pairsets by a "bridging" mechanism. Similar upward progagation of basement structure has also been described by others. Wise (1964, p. 302) suggests that orthogonality may result from the fact that fracturing in one direction would relieve the minimum stress in that direction, shifting the minimum stress direction 90° to form a second fracture set at right angles to the first.

In many cases, the characteristic strikes of lineaments may be interpreted in ways other than that of orthogonality as has been assumed above. For example, lineament distribution patterns in the Piedmont and Valley and Ridge may be equally easily explained employing textbook stress-strain principles (Billings, 1954, p. 103; Badgley, 1965, p. 100). Figure 24 is simply a model that explains all of the average lineament orientations (determined from fig. 14), assuming that they represent fractures. The lineament group at 151° (N29°W) may form one group of a shear set (Sh_1) that is 63° (151°-88°) away from the other set at 88° (N88°E). The fact that the 88° set is very weak would not be detrimental to this interpretation, because one element of a shear set is often weak or absent (Billings, 1954, p. 95). The major

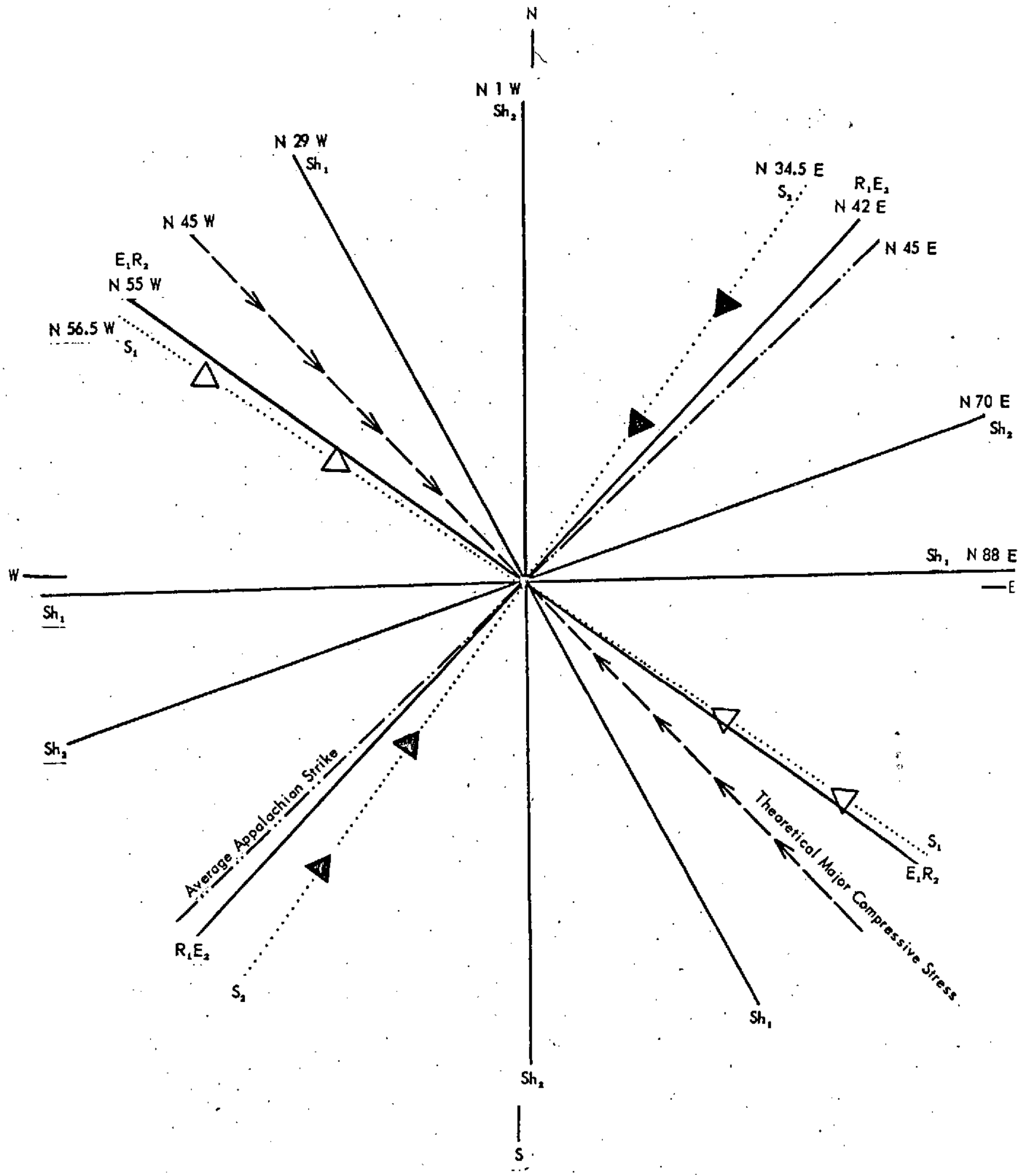


Figure 24.--Stress-fracture model for the Piedmont and Valley and Ridge lineaments, assuming that they represent fractures.

compressive stress (S_1) responsible for the shear sets (Sh_1) bisects the angle between the two sets and theoretically should be 30° away from each of them. In this case, the angle is 31.5°. The major compressive stress for this conjugate shear system is N56.5°W-S56.5°E which is within approximately 11° of the N45°W-S45°E theoretical major compressive stress direction thought responsible for folding and faulting of the Appalachians in Alabama. The 42° (N42°E) orientation may be interpreted in this model to represent release fractures (R_1) caused by the release of the major compressive stress and at near-right-angles to it. The 125° (N55°W) orientation may be interpreted as extension fractures (E_1) related to the major compressive stress and nearly parallel to it.

In this model, there are several other lineament groups to be accounted for. The 179° (N1°W) and the 70° (N70°E) characteristic lineament strikes may be a second conjugate shear system (S_2) with 71° between them and developed as the result of a major compressive stress (S_2) oriented N34.5°E-S34.5°W. Release fractures (R_2) would occur at about the same position as E_1 extension fractures. In like fashion extension fractures (E_2) related to S_2 would occur along the same approximate lines as R_1 release fractures.

From the data presently on hand, no suggestion as to the choronology of the two compressive events can be made, but the S_1 compression would be most logically related to the Alleghenian tectonic events. The S_2 compression could have occurred before or after this event. Simpson (1963) postulated a post-Alleghenian stress system with a north-south orientation based on joints and faults in the Birmingham area. Such a stress system could be interpreted as being related to horizontal compressive stresses associated with the north-south pull-apart of North and South America in the initial development of the Carribean and Gulf of Mexico Region during late Triassic (Freeland and Deitz, 1971).

If the concept of Walper and Rowett (1972) that the Carribean-Gulf of Mexico region developed from Early Mesozoic sea-floor spreading, the spreading action could also result in general north-south horizontal compressive stresses within the interior of North American plate similar in mechanism to the east-west stresses suggested for eastern North America by Voight (1969) and supported by Sbar and Sykes (1973).

One serious problem with the above explanation, is that the lineaments of the Coastal Plain (fig. 18) exhibit nearly the same pattern as those of the Piedmont and Valley and Ridge (fig. 14) and appear to be genetically related to them (pl. 1). Because the rocks in the Coastal Plain are younger than the Alleghenian tectonic events, they could not have been affected by it unless the Alleghenian brittle fracture features of the buried Paleozoics were propagated upward through the younger overlying sediments. The more simple explanation would be that all the lineaments form through upward propagation from basement structures. Upward propagation of older basement structural features seems to be unescapable in any explanation of lineament patterns. A more detailed discussion of the origin of lineaments is presented in a later section of this paper.

LINEAMENTS AND JOINTS

Introduction

Because the lineaments interpreted from ERTS-1 imagery fall into several distinct orientation groupings, it has been hypothesized that the lineaments reflect jointing that may be measured in the field. Indeed, previous workers have found this to be true in many differing geologic settings (Lattman and Nickelsen, 1958; Spencer, 1959; Boyer and McQueen, 1964). Others (Matzke, 1961; Lattman and Matzke, 1961; Meisler, 1963; Trainer and Ellison, 1967), however, have pointed out that the modes of joints differ from that of fracture traces in areas underlain by folded rocks. The ERTS-derived lineaments for several areas across the state were compared to joint data for the same areas. All of the lineament data was taken from 1:250,000 scale enlargements of ERTS imagery. Some of the joint data was taken from published information, other from existing field notes and in several cases, it was collected expressly for this project. The areas investigated include parts of the Alabama Piedmont, Valley and Ridge, Appalachian Plateaus, and the Interior Low Plateaus provinces (fig. 25).

Results

Piedmont

Crooked Creek Area.--The Crooked Creek area (fig. 25A) in Clay and Randolph Counties, Alabama (parts of the Lineville East, Mellow Valley, Wadley North, and Ofelia 7½-minute quadrangles) is underlain by sequence of metasedimentary and metavolcanic rocks that have been intruded by granites. A detailed report of this area is presented in this volume (Neathery and Reynolds, 1974).

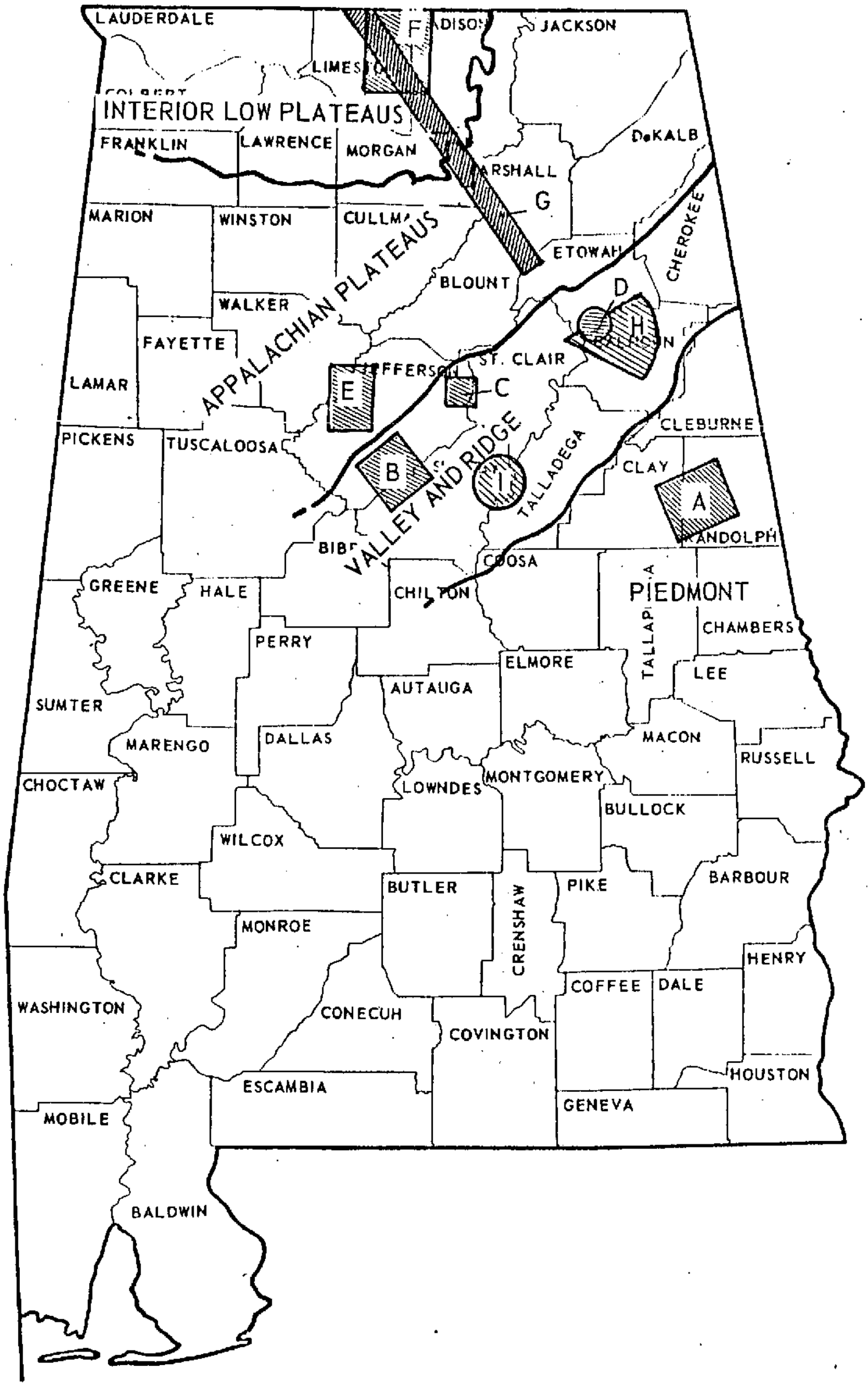


Figure 25.--Location map showing areas of detailed studies.

As part of this study, 669 joints were measured at 273 stations throughout the area. At each station, only the differing joint orientations were recorded; joint density information was not collected. Lineaments were also recorded for the area of study using ERTS imagery 1175-15495-5 and 6 (January 14, 1973). Rose diagrams constructed for the joints (fig. 26) and the lineaments (fig. 27) show a high degree of correlation. The dominant lineament trend of N50°-60°W matches the dominant joint set lying between N40°W and N70°W and averaging N55°W. At approximately right angles (N30°-60°E for the lineaments and N40°-70°E for the joints), are other moderately well-expressed orientations that correlate well with one another. North-south orientations are also represented in both the joint and lineament data. The moderately strong east-west orientations shown by the joints are not expressed on the ERTS image. This situation is the probable result of interference caused by the scan lines that are oriented N80°W.

Valley and Ridge

Birmingham area.--A study of the structural geology of the Birmingham area by Simpson (1963, 1965) included an evaluation of the jointing. The area of study lies near the west boundary of the Valley and Ridge province on parts of the Birmingham anticlinorium and Cahaba synclinorium and is underlain by faulted and folded Paleozoic sedimentary rocks (fig. 25B). Joints were measured at 24 stations throughout the area and their trends shown on a rose diagram (Simpson, 1963, fig. 7). Most of the joints dip at angles between 70° and 90°, but a few have dips as low as 10°.

The jointing measured in the field by Simpson (fig. 28) was compared to lineaments derived from ERTS-1 imagery (1176-15553-5, January 15, 1973,

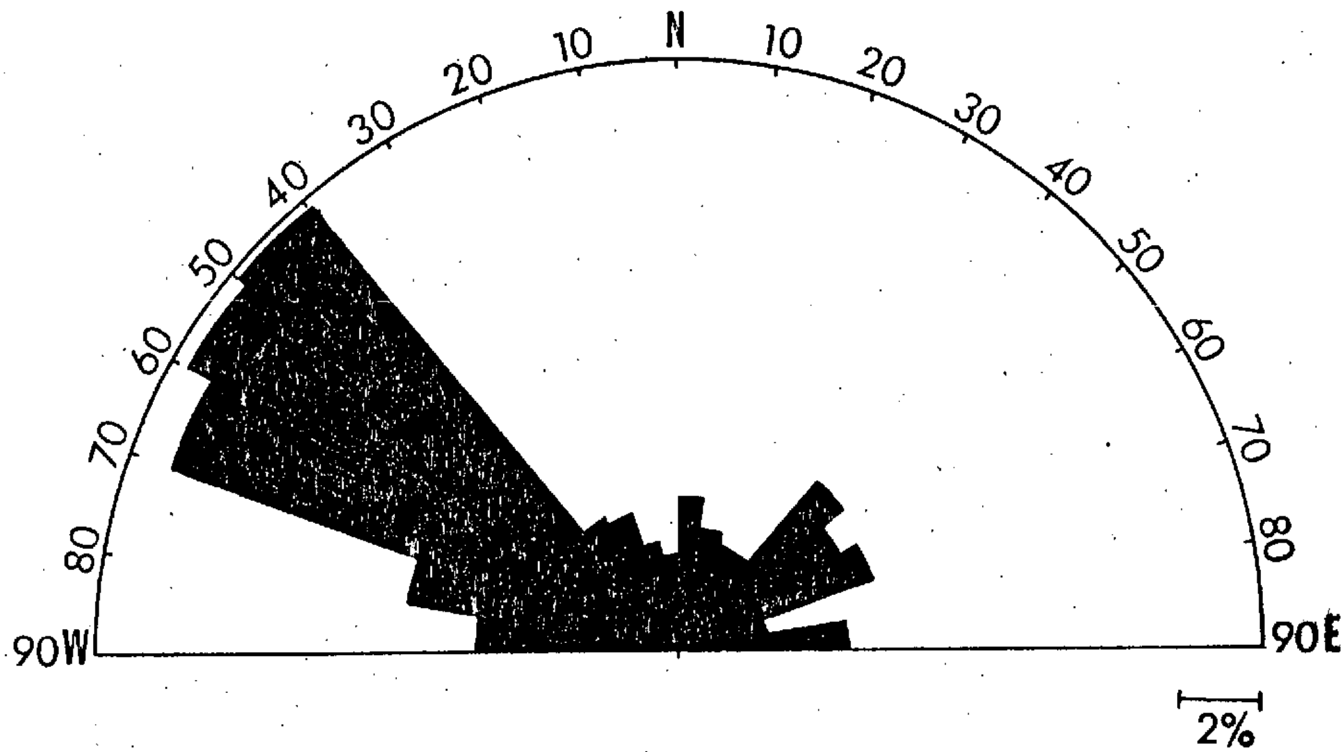


Figure 26.--Rose diagram of joint orientations for the Crooked Creek area.

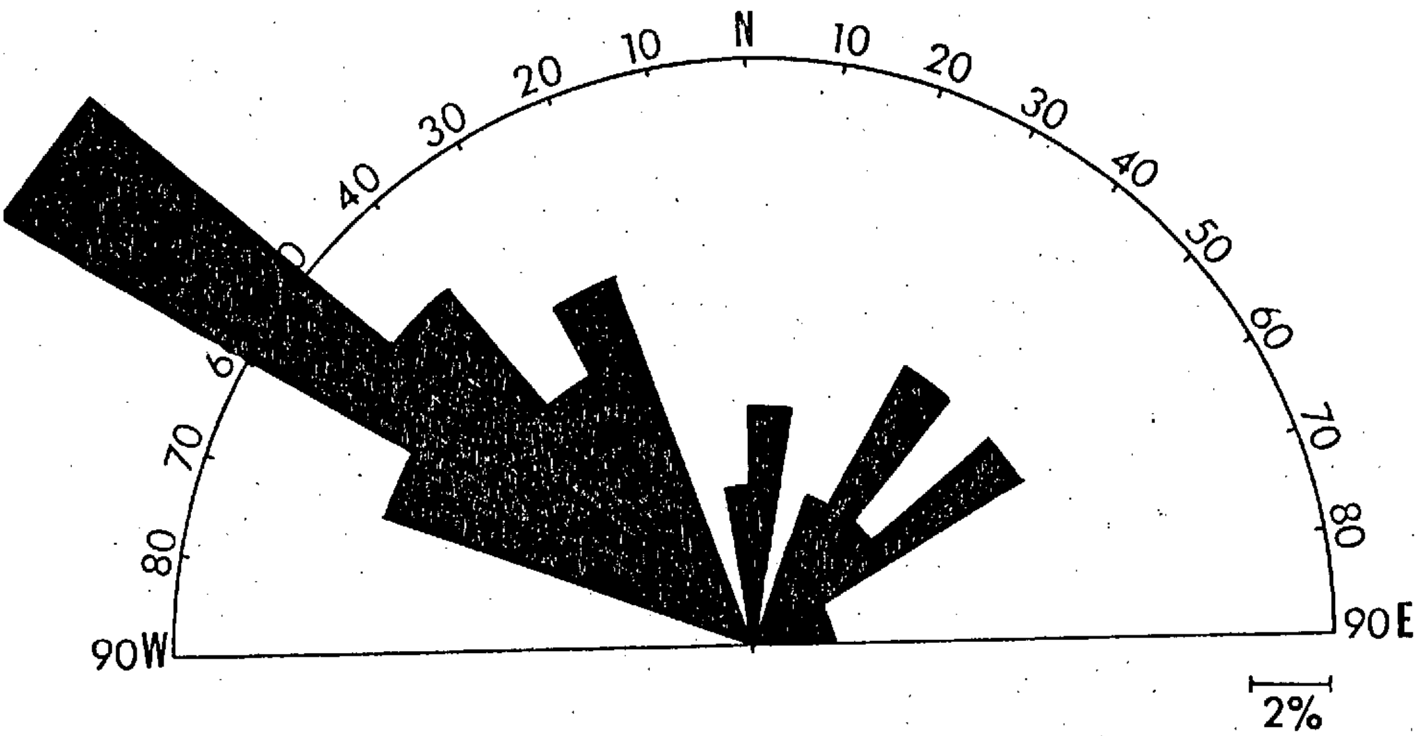


Figure 27.--Rose diagram of lineament orientations for the Crooked Creek area.

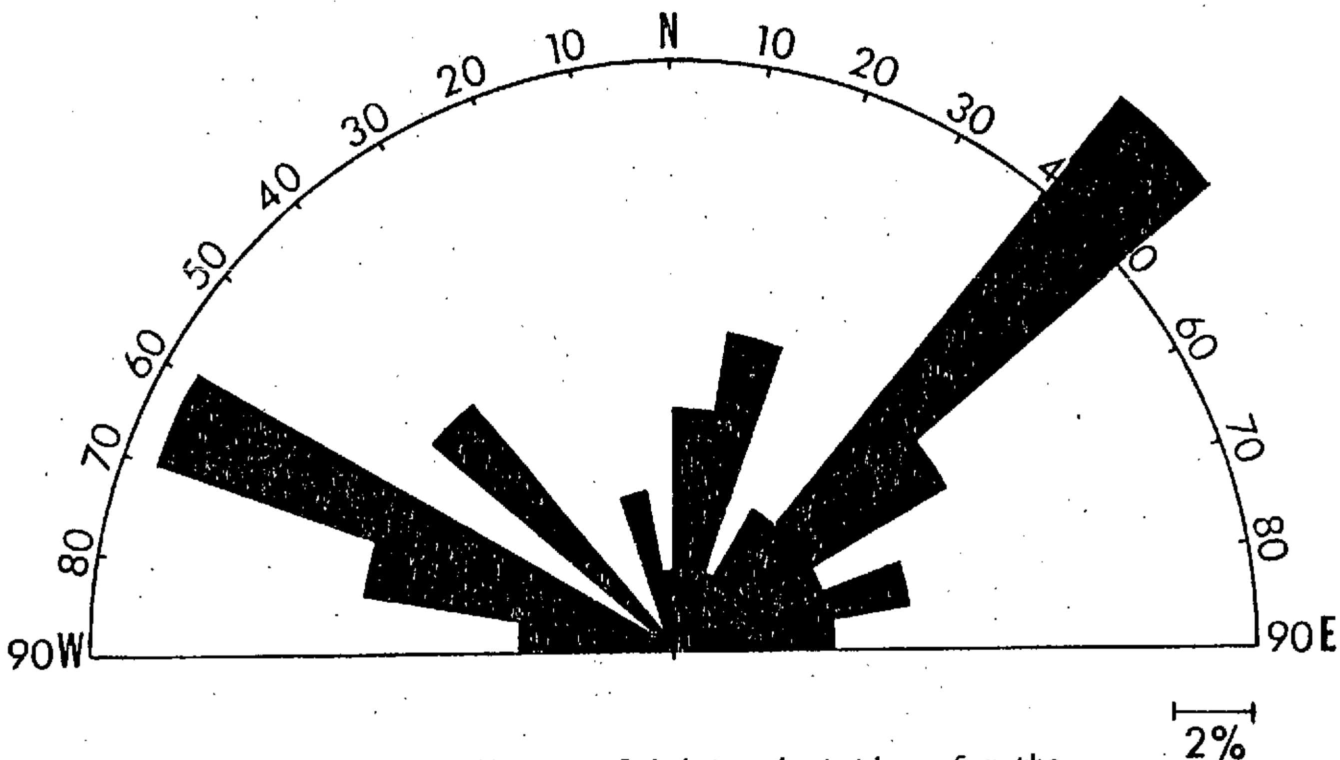


Figure 28.--Rose diagram of joint orientations for the Birmingham area. From Simpson, 1963, fig. 7.

and 1175-15495-5 and 6, January 14, 1973) for the same area (fig. 29). The dominant joint direction of N40°-50°E is very close to the average bedding strike for the area and Simpson shows that the dominant fault strike orientation falls within the same group (Simpson, 1963, fig. 6). No ERTS-derived lineaments are recorded in the N40°-50°E group, and masking by the dominant structural grain may be responsible for this. Lineaments coincident with known structural trends were not recorded on the lineament map (pl. 1) unless the lineament could be shown to cross known structures. Comparing the joint data to lineament data for the entire Alabama Valley and Ridge (fig. 5) and the Valley and Ridge and Piedmont (fig. 6), however, indicates that the N40°-50°E lineament trend is regionally moderately strong. The N60°-80°W joint set is quite well expressed in the Birmingham area and is nearly matched by the dominant lineament group lying between N50° and 60°W. Presumably, the N70°-80°W part of this lineament high is masked by the scan lines. The moderately strong N30°-40°W and N20°-40°E lineament trends have no joint counterparts and presumably are expressing some geologic phenomena that to date has not been recorded through conventional field techniques. These two lineament trends are also well expressed regionally (figs. 5 and 6), as is the north-south trend that does not appear on the lineament rose diagram for the Birmingham area but which is expressed by the jointing.

Taken together, the lineament data for the Birmingham area do not correlate well with the joint data. Somewhat better correlation occurs when comparing the joints to regional lineaments analyses, but certain lineament directions appear to express geologic structures that are currently unknown from field studies.

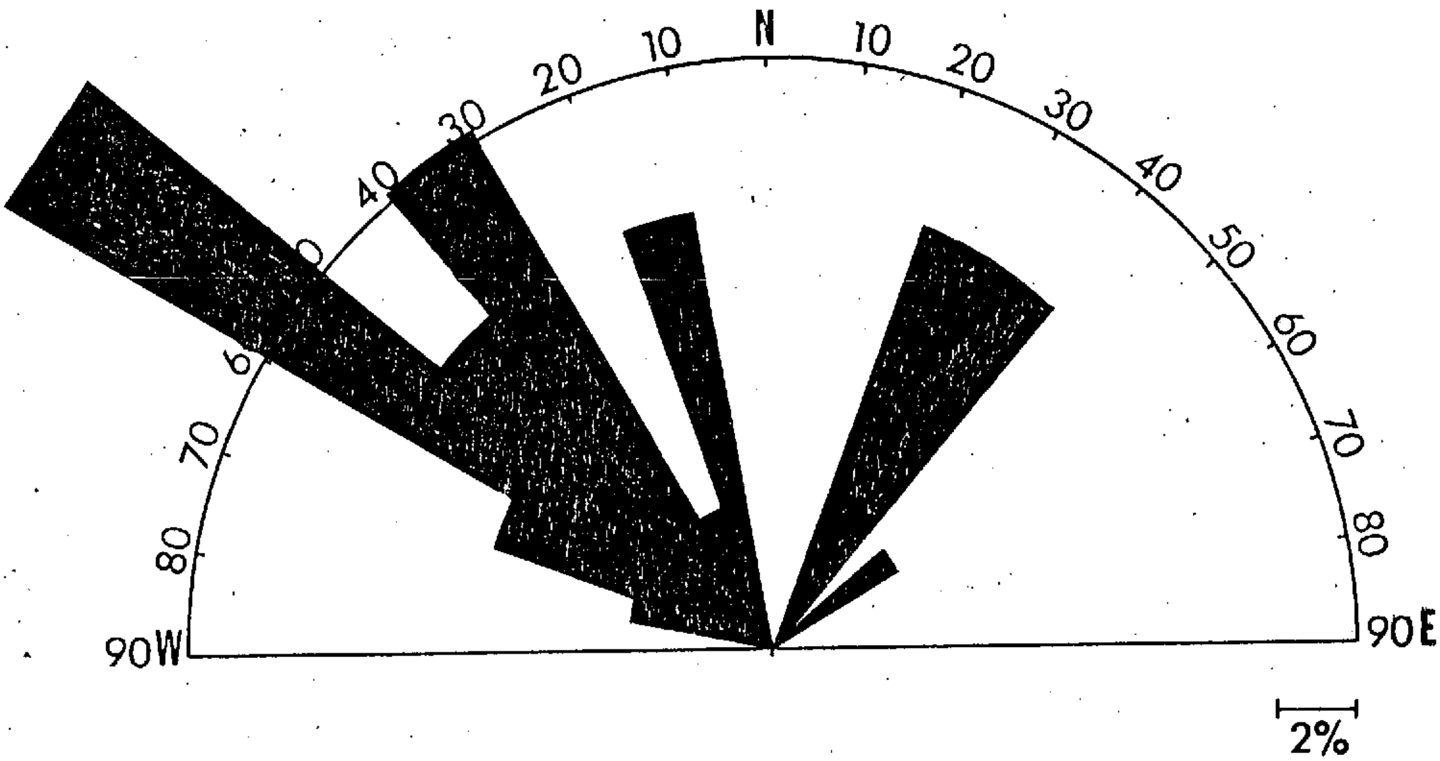


Figure 29.--Rose diagram of lineament orientations for the Birmingham area.

Trussville area.--The Trussville area lies approximately 35 kilometers north of the area previously discussed (fig. 25C). It too, lies near the western margin of the Valley and Ridge province and within a minor syncline on the Birmingham anticlinorium. The area is underlain by folded Paleozoic sedimentary rocks. Butts (1910) mapped the area in detail but did not record joint data. As part of this study, geologic data including joint data was collected for a part of the area. Twenty-two joint readings were made at 9 stations located in the southwestern two-thirds of the Argo 7½-minute quadrangle. The joint directions at each station were recorded but no attempt was made to determine joint densities. Joint distributions (fig. 30) were compared to lineaments derived for the area from ERTS-1 image 1176-15553-5 (January 15, 1973) (fig. 31). The dominant joint direction of N20°-30°W is also very strongly expressed by the lineaments. One of the major lineament complexes, the Harpersville lineament, crosses the area and is part of the dominant N20°-30°W lineament group. The moderately strong N40°-70°W and N50°-60°E joint sets are only moderately to weakly expressed by the local lineaments but appear much stronger when evaluated regionally (fig. 5). This difference is probably the result of random selection and does not reflect a major local variation. Again, as previously seen, the rather marked east-west joint set is well displayed but is almost nonexistent in either the local or regional lineament patterns. This lack may be attributable to the interference of the image scan lines.

Joints in the Trussville area correlate moderately well with the lineament patterns when the latter are considered together in both their local and regional contexts.

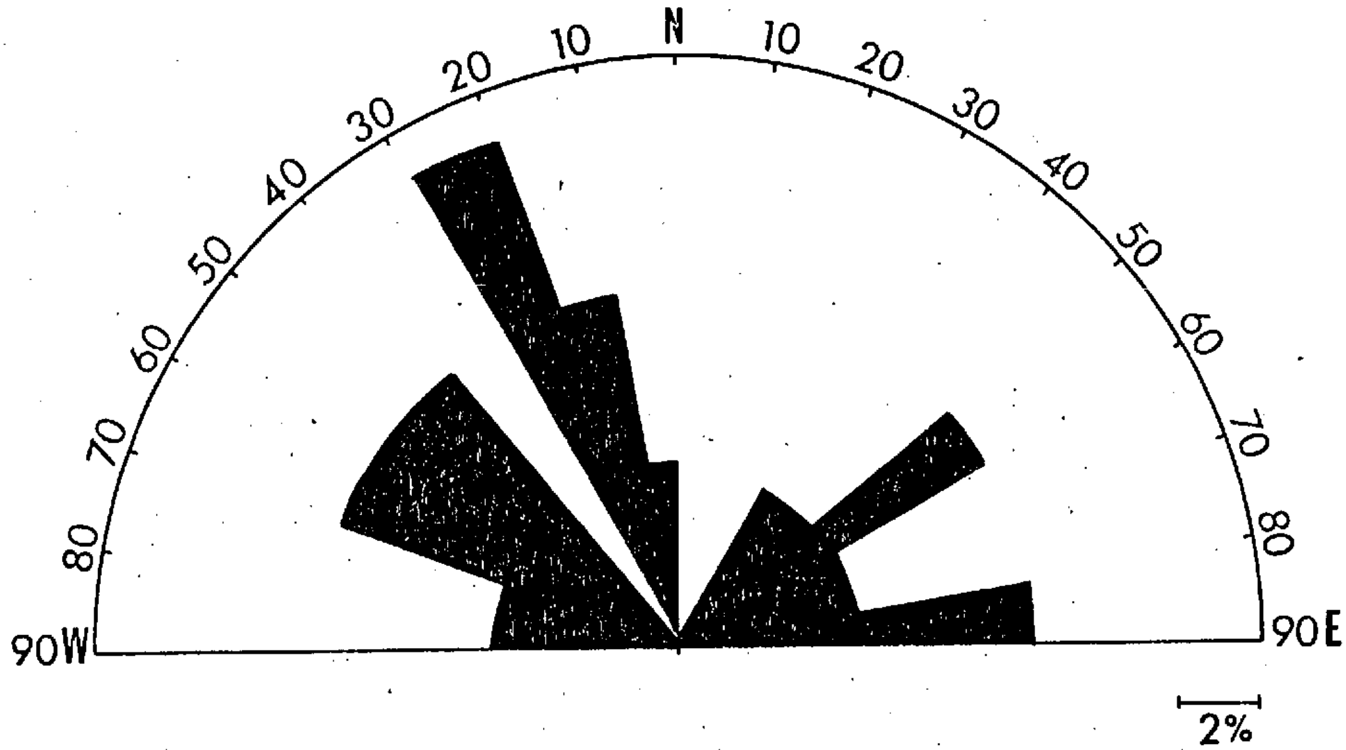


Figure 30.--Rose diagram of joint orientations for the
Trussville area.

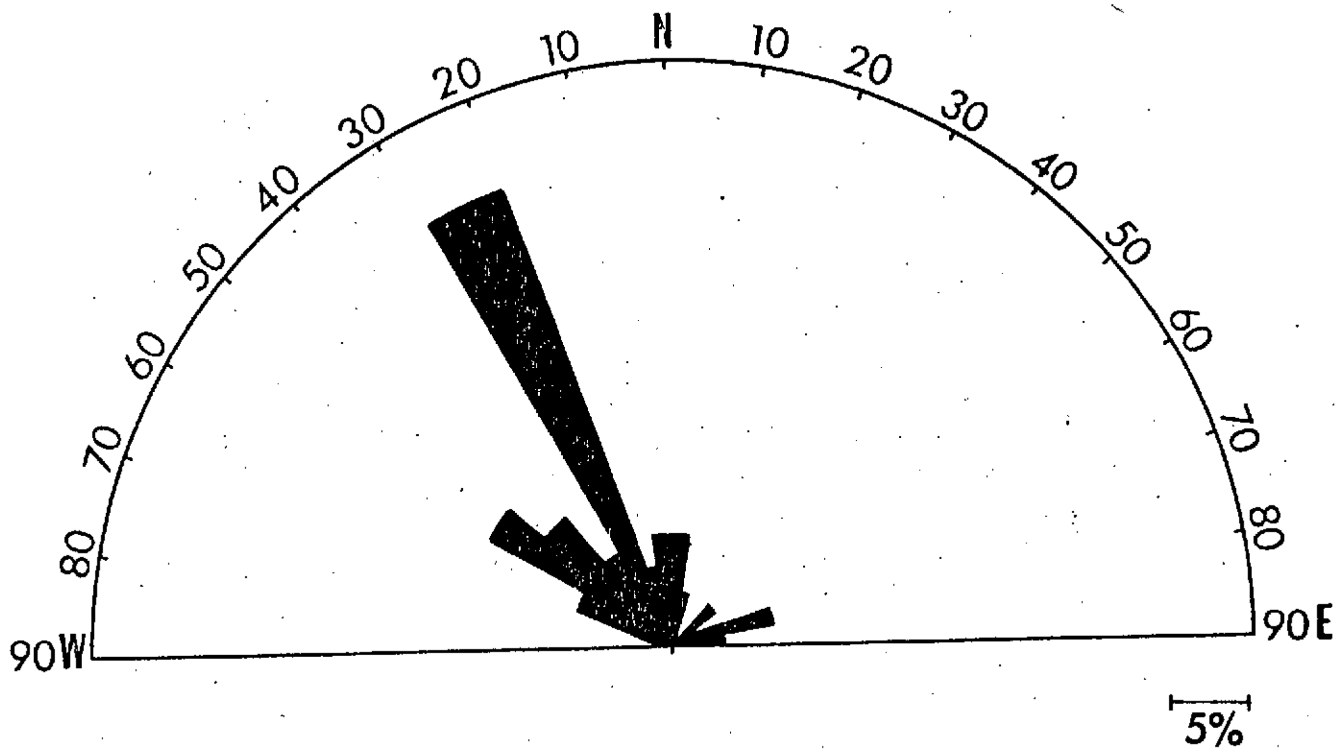


Figure 31.--Rose diagram of lineament orientations for the Trussville area.

Welikee Lake area.--The Welikee Lake area (fig. 25D) lies near the center of the Valley and Ridge province in the Coosa deformed belt, a narrow zone characterized by thin imbricate thrust slices (Drahovzal and Thomas, 1970; Thomas and Drahovzal, 1971). The study area lies in the northwest corner of Calhoun County (southeast corner of T. 13 S., R. 6 W. and the northeast corner of T. 14 S., R. 6 W., Wellington and Glencoe 7½-minute quadrangles) and is largely underlain by the Mississippian Floyd Shale, although local faulting immediately west of Welikee Lake brings older units up along a southeast dipping, northwest trending thrust fault. As part of this study, 60 joint and fracture cleavage planes were measured at 18 stations. At each station the orientation of each differing joint was measured, but information on joint density was not recorded. The dip of the joints and fracture cleavage ranges from vertical to 18°, but most dips are greater than 70°. The distribution of joints (fig. 32) was compared to that of the lineaments mapped for the area using ERTS-1 images 1175-15495-5 and 6 (January 14, 1973) (fig. 33). One of the dominant joint set lies between N70°W and N80°E, and averages N89°E. This group, throughout the area, represents the systematic joint set; all others appear to be non-systematic. ERTS imagery shows a moderately strong east-west lineament group that is comparable to the N70°W-80°E joint set, but the N70°-80°W part is absent on the lineament diagram. This is presumably because of interference caused by the ERTS image scan lines. Another strongly expressed joint set lies between N20° and 30°E. This group has no counterpart among the ERTS-derived lineaments for the area nor for the region (fig. 5). The reason for the lack of expression may be due to the fact that the average dip for this particular joint set is less than 60°. The moderately strong N30°-60°W

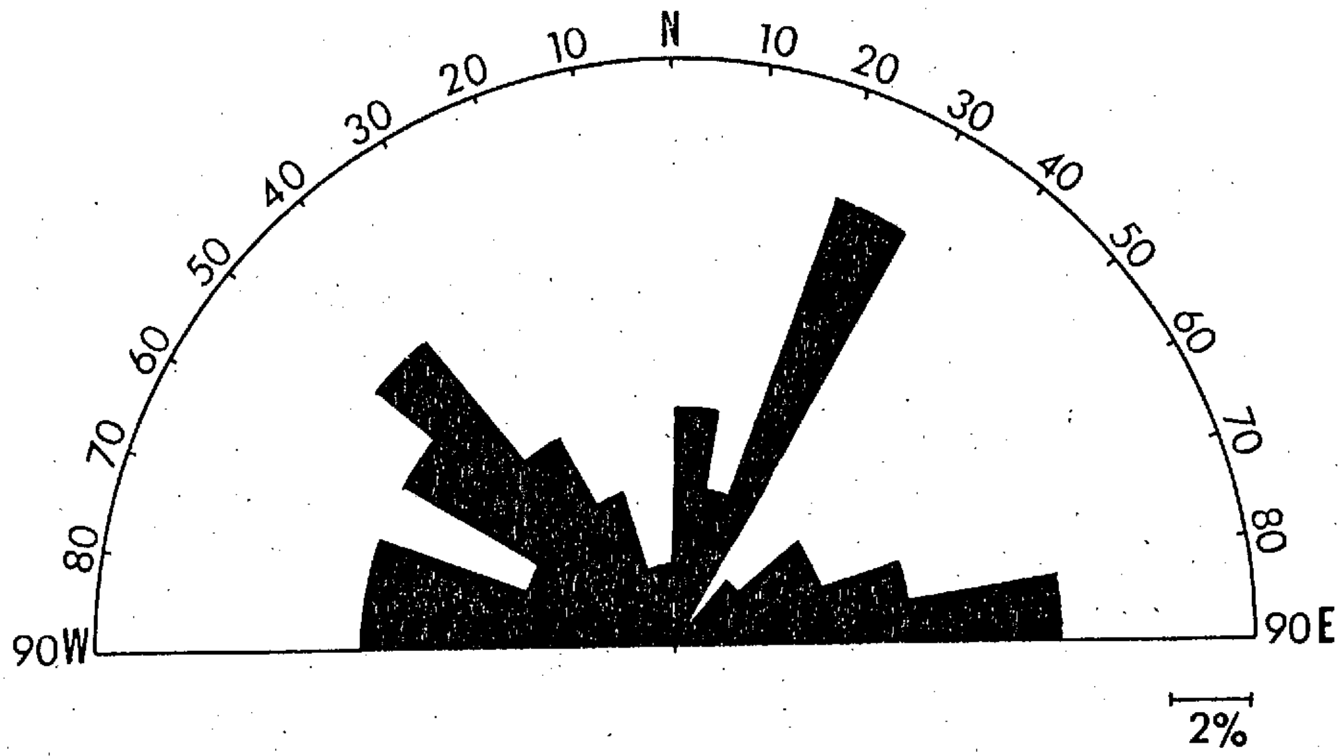


Figure 32.--Rose diagram of joint orientations for the
Welikee Lake area.

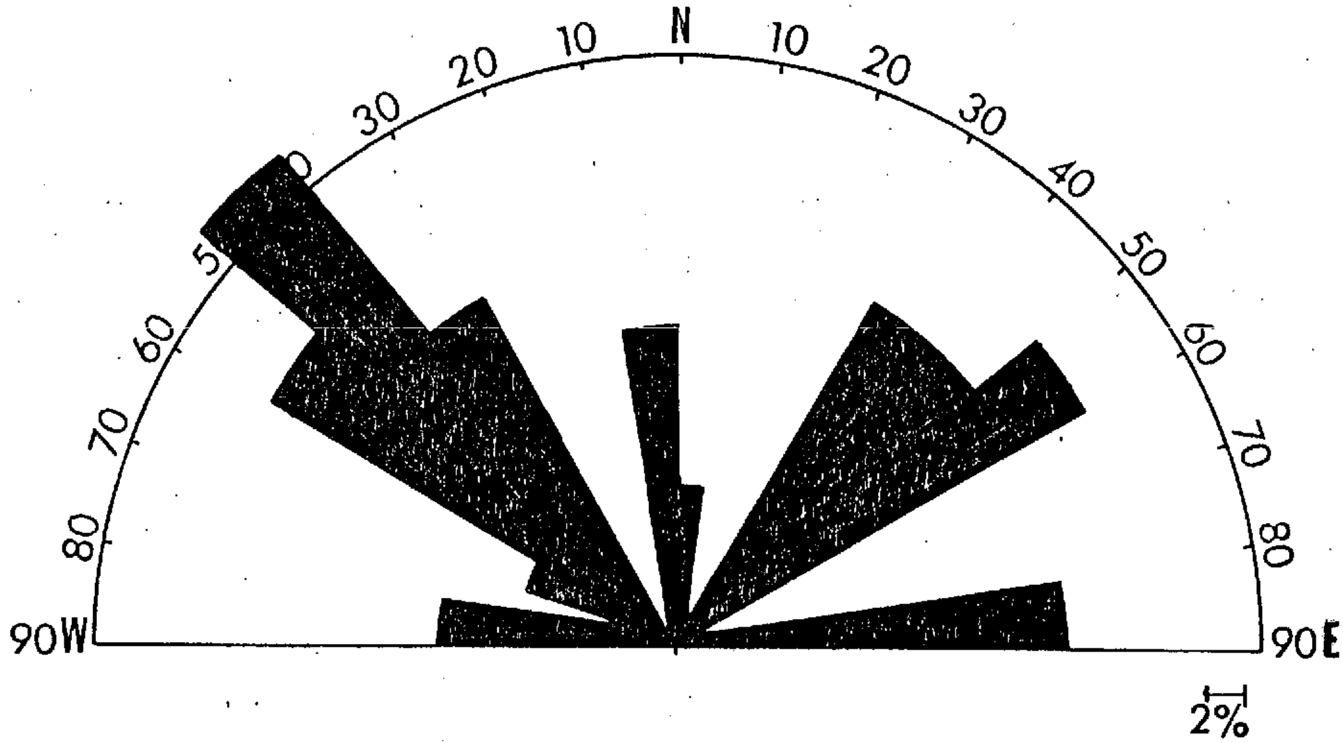


Figure 33.--Rose diagram of lineament orientations for the Welikee Lake area.

joint set for the area averages about N44°W and matches the very strong comparable group of ERTS-derived lineaments that exhibit an average strike of N46°W. The north-south joint set appears to be generally represented by a similar lineament group. The N30°-60°E lineament group interpreted from the ERTS imagery is not recorded among the joint sets. The lineament group may be reflecting local strike of bedding, however, many of these lineaments continue out of the area into adjacent regions where strike changes and acutely crosses the lineament traces.

In conclusion, the joints of the Welikee Lake area correlate reasonably well with the lineaments mapped for the local area and also with those mapped for the entire region, but some important differences are present.

Appalachian Plateaus Province

Flat Creek Area.--The Flat Creek area lies in the Dora and Sylvan Springs 7½-minute quadrangles near the Jefferson-Walker County line (fig. 25E). The entire area is underlain by the near-flat-lying Pennsylvanian Pottsville Formation although the influence Sequatchie anticline transects the area. A rather careful and detailed joint analysis was carried out in the area and is reported in another part of this volume (Wielchowsky, 1974). Eighteen rather evenly spaced stations were established on the two quadrangles. Information on joint attitudes, surface characteristics, persistence, spacing and fillings were recorded along a 12-meter traverse at each station. Data for coal cleats were collected separately.

The joint (fig. 34) and coal cleat (fig. 35) distribution patterns were compared to those for lineaments interpreted from the two topographic

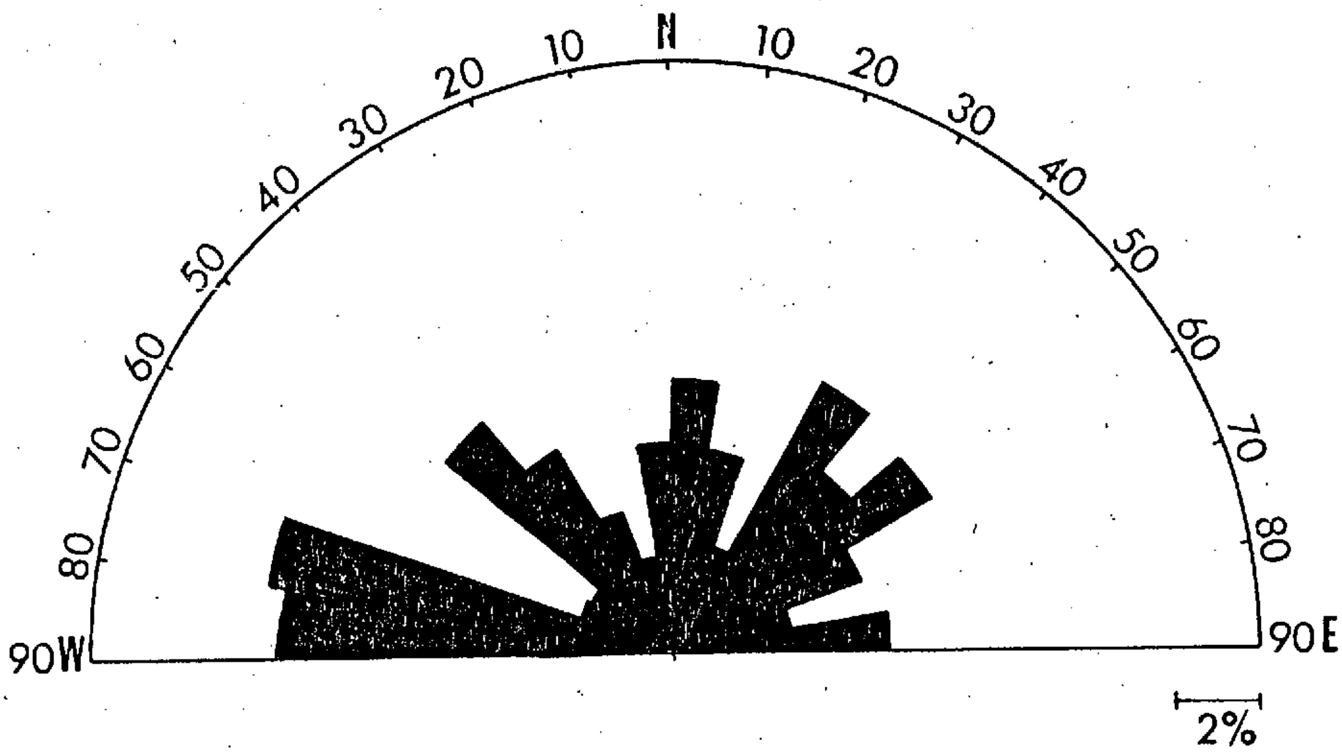


Figure 34.--Rose diagram of joint orientations exclusive of coal cleats for the Flat Creek area.

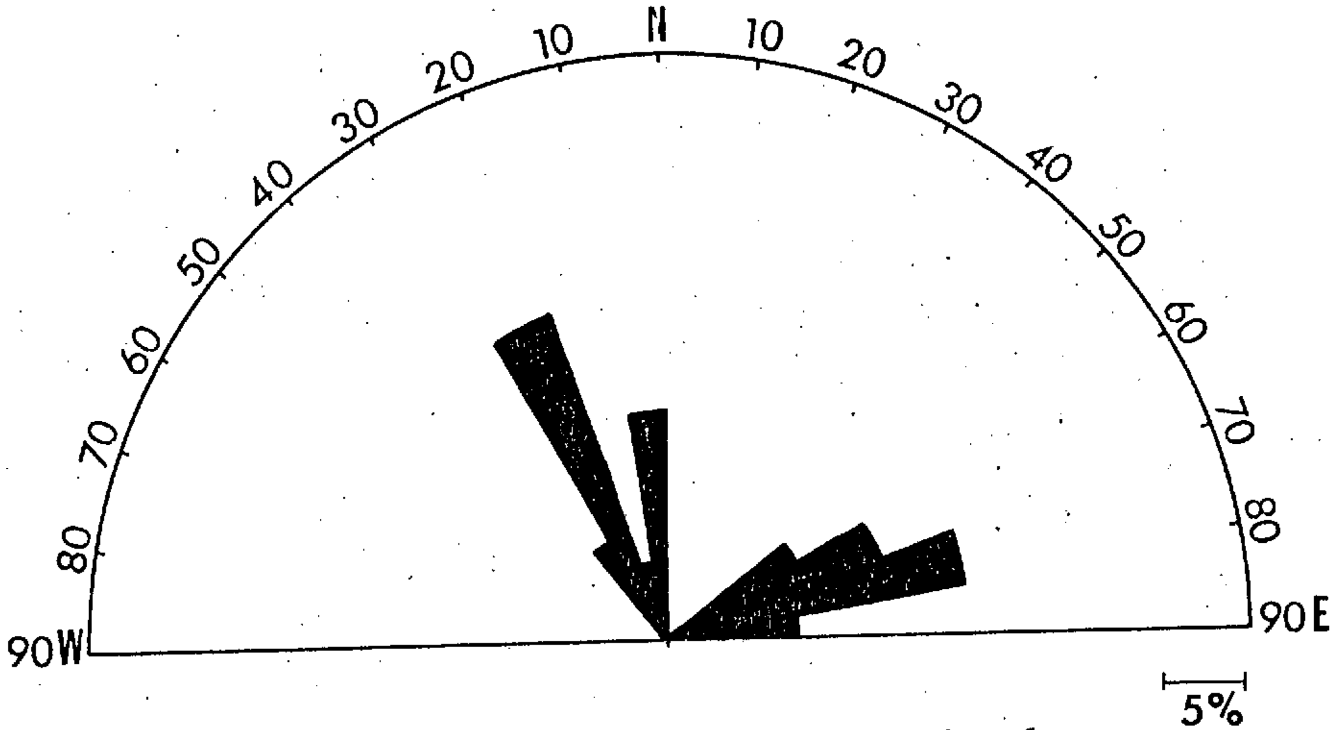


Figure 35.--Rose diagram of coal cleat orientations for the Flat Creek area.

quadrangles (fig. 36), U-2 photography (Flight number 73-023; FSR-237; February 22, 1973) (fig. 37) and ERTS-1 image 1176-15553-5 (January 15, 1973) (fig. 38). The strong joint trend of N30°-40°E is almost exactly matched by the dominant ERTS lineament trend. This joint set is made up of non-systematic, often open joints with generally limited persistence. The topographic and U-2-derived lineaments also show moderately strong groups with this orientation. The excellent relationship between this joint set, the ERTS-derived lineaments, and to a lesser degree, the topographic-and U-2-derived lineaments suggests that the closely spaced, open, nonsystematic joints are among those best delineated through remote means. In contrast, the open, highly persistent, but more widely spaced systematic joints in the N70°-90°W set are only poorly represented on the ERTS images, the U-2 photographs, and the topographic maps. Part of the reason that they are weakly displayed on ERTS-1 imagery may be related to the interference caused by the N80°W scan lines, but this does not explain why they are so poorly represented on the U-2 photography and the topographic maps. The coal cleats exhibit two main joint sets for the area. One ranges from N0°-30°W averaging N20°W and the other from N60°-90°E, averaging N70°E (fig. 35). These two average cleat orientations are matched very closely by relatively strongly expressed ERTS-derived lineament groups, ranging from N10°-30°W and N70°-80°E respectively. The two cleat directions do not appear to be very well represented by the conventional joints in the area and the reason for correlation with ERTS lineaments is presently unknown. The joints also show a moderate north-south trend that is weakly expressed by the ERTS lineaments but slightly better displayed by the topographic trends, the U-2 lineaments, and the regional ERTS lineaments (fig. 7). The moderately strong

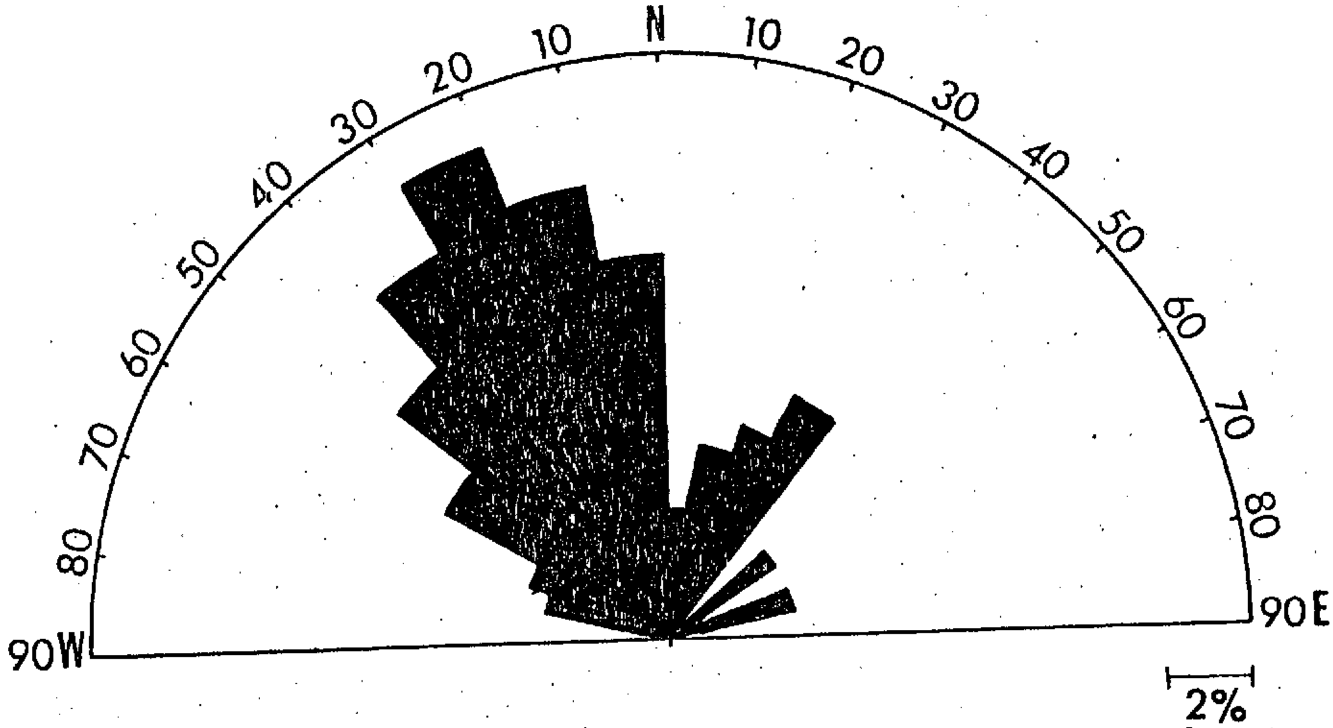


Figure 36.--Rose diagram of topographic lineament interpreted from topographic maps of the Flat Creek area.

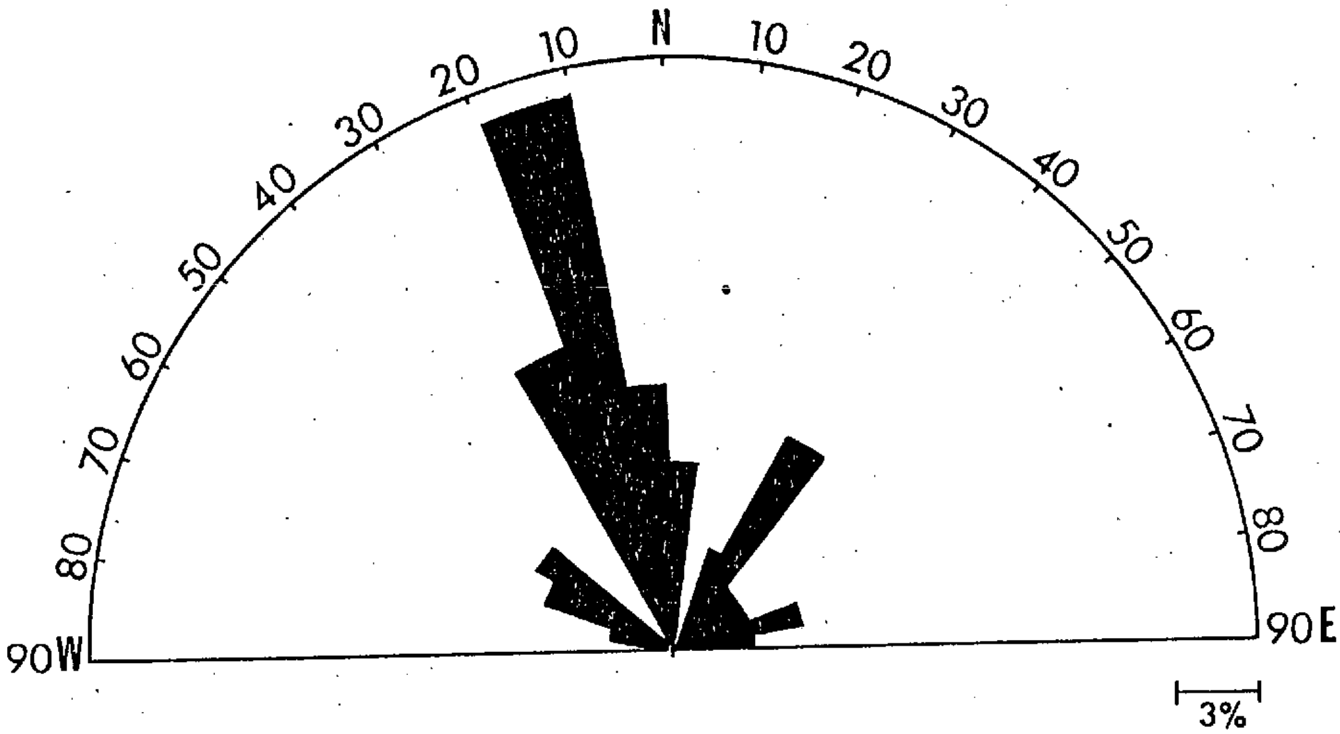


Figure 37.--Rose diagram of lineaments interpreted from U-2 photography of the Flat Creek area.

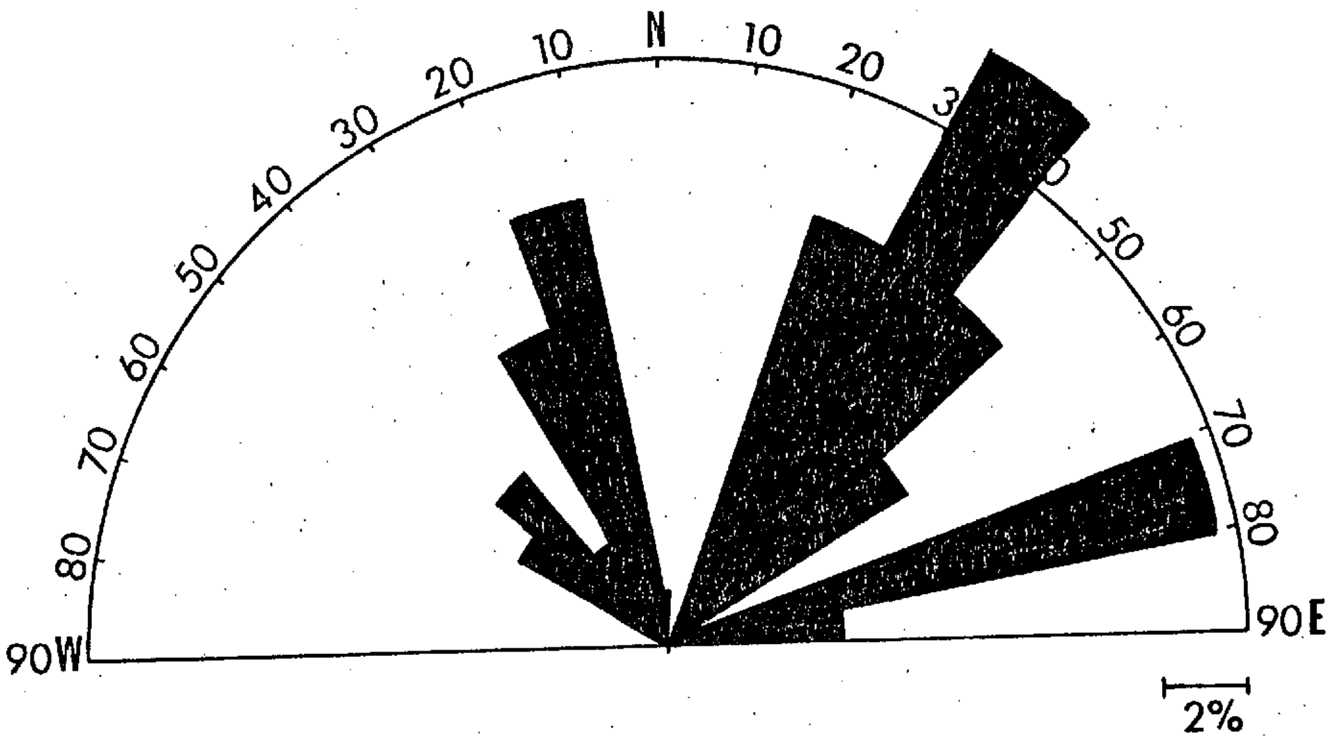


Figure 38.--Rose diagram of lineaments interpreted from ERTS-1 imagery of the Flat Creek area.

but closed N30°-50°W and N50°-60°E joint sets are locally very weakly expressed as lineaments, the one exception being the strongly expressed N30°-50°W lineament group interpreted from the topographic maps. Regionally these lineament groups as interpreted from ERTS are somewhat stronger. The strong N10°-30°W orientation of ERTS, U-2, and topographic lineaments are only very weakly expressed by the joints; however, these lineaments may be representing small-scale, high-angle normal faults. Blair (1929, map no. 2) mapped 12 such faults in the Flat Creek area that range from approximately N10°-30°W in orientation. Other similarly oriented but presently unmapped faults may be present in the area. A more detailed account of these features is discussed in a later section of this report.

In conclusion, the major coal cleat trends match with the major ERTS lineament trends. When all factors are considered, the joint data fits rather poorly with the lineament data for the area. The factors that seem to be important to the expression of joints as lineaments is the degree of openness and the spacing of joints. Joints which are closed and/or widely spaced apparently are not well expressed as lineaments; joints that are open and/or closely spaced, on the other hand, appear to be more readily expressed as lineaments. Small-scale normal faults appear to show up very well as lineament traces.

Interior Low Plateaus

Athens Area.--The Athens area lies in the Athens and Elkmont 7½-minute quadrangles in the northeastern part of Limestone County (fig. 25F). In the south, the area is underlain by deeply weathered Mississippian carbonates and to the north largely by Ordovician carbonates. A photogeologic study aimed at understanding the hydrology of the area has been published in which fracture traces were compared to joint data collected in the field (Sonderegger, 1970). The fracture traces were interpreted from infrared, color and black and white photography at scales of 1:12,000 and 1:20,000. The results from these three film types were all very similar and are represented by figure 39. Sonderegger (1970) measured 1,300 joints at 95 stations in the two-quadrangle area. The results of this investigation is present in figure 40. As part of this study, ERTS-derived lineaments were plotted for the area from ERTS-1 image 1158-15552-5 and 6 (December 28, 1972) and compared to the fracture trace and joint data (fig. 41).

The joint data exhibits a strong N60°-80°W orientation that is only partially matched by the ERTS lineaments. Again, the N80°W-oriented scan lines on the ERTS image may serve to obscure lineaments with similar orientations. It should be noted, however, that the fracture traces show only poor to moderate correlation with this joint set. The N10°-30°W joint set is completely absent on the lineament rose diagram but is moderately well represented by the fracture traces. The strong N40°-50°E and N40°-50°W lineament groups are both very well represented by the fracture traces but rather poorly represented by the joints. In general, the pattern shown by the ERTS lineaments is very similar to that shown for the fracture traces mapped on low-altitude photographs except that the peaks for the latter are not as marked. The lineament and fracture trace data show rather poor correlation with the joint data, but Sonderegger (1970, p. 15) noted that the higher frequency fracture traces, are coincident with open, but less numerous joint sets.

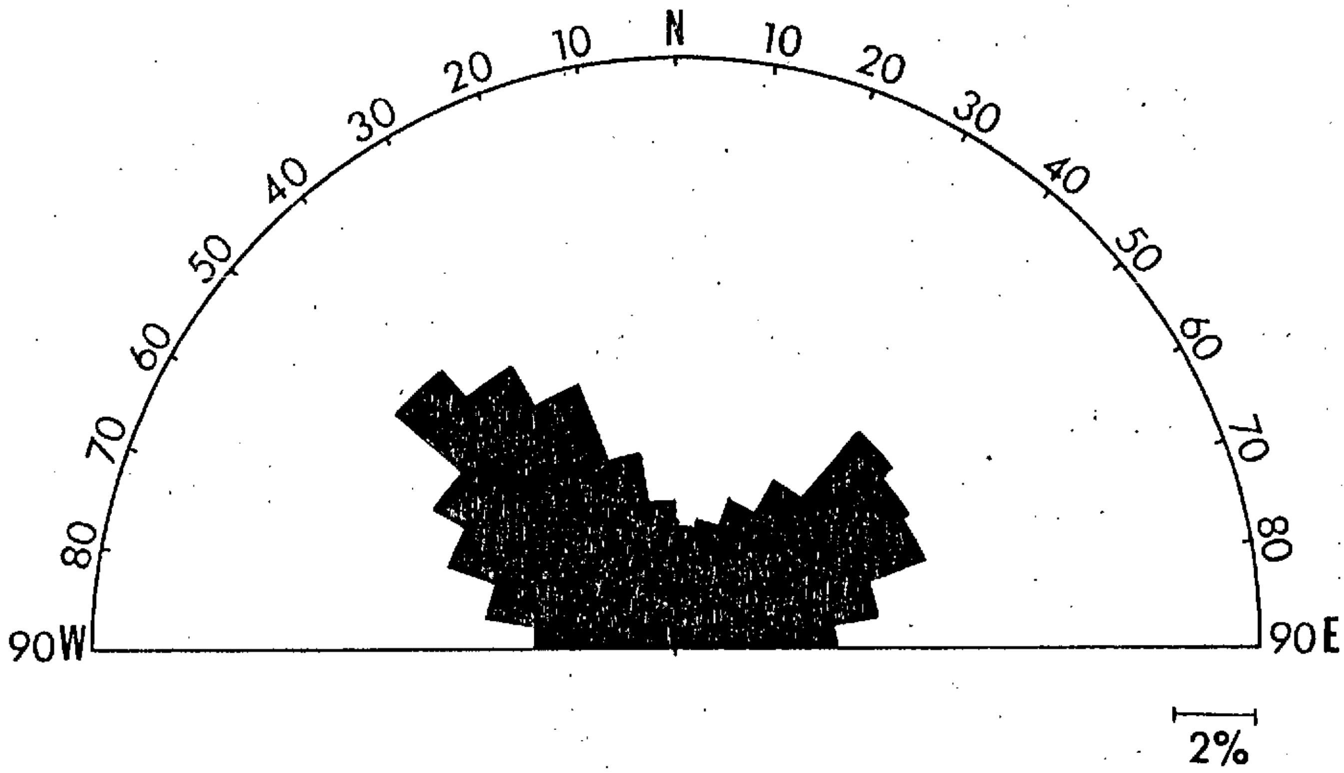


Figure 39.--Rose diagram of fracture traces interpreted from infrared photography of the Athens area. From Sonderegger, 1970, fig. 4.

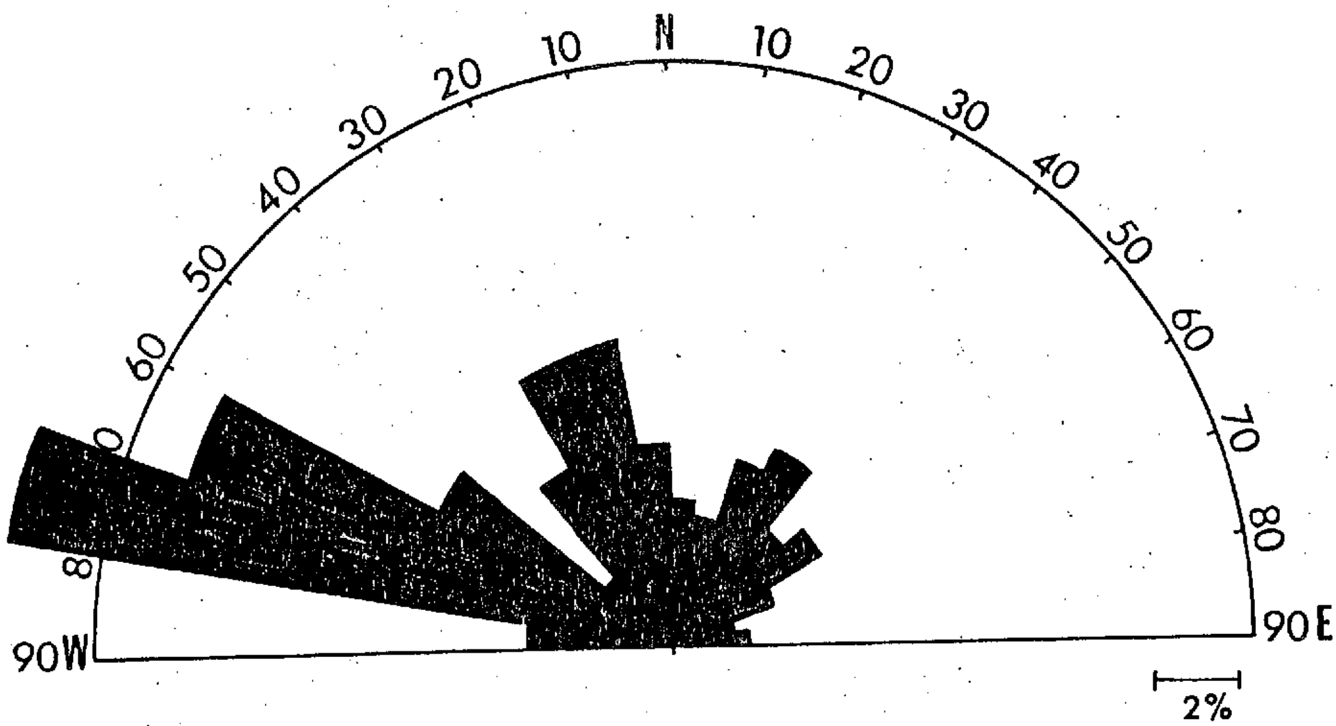


Figure 40.--Rose diagram of joint orientations for the Athens area. From Sonderegger, 1970, fig. 2.

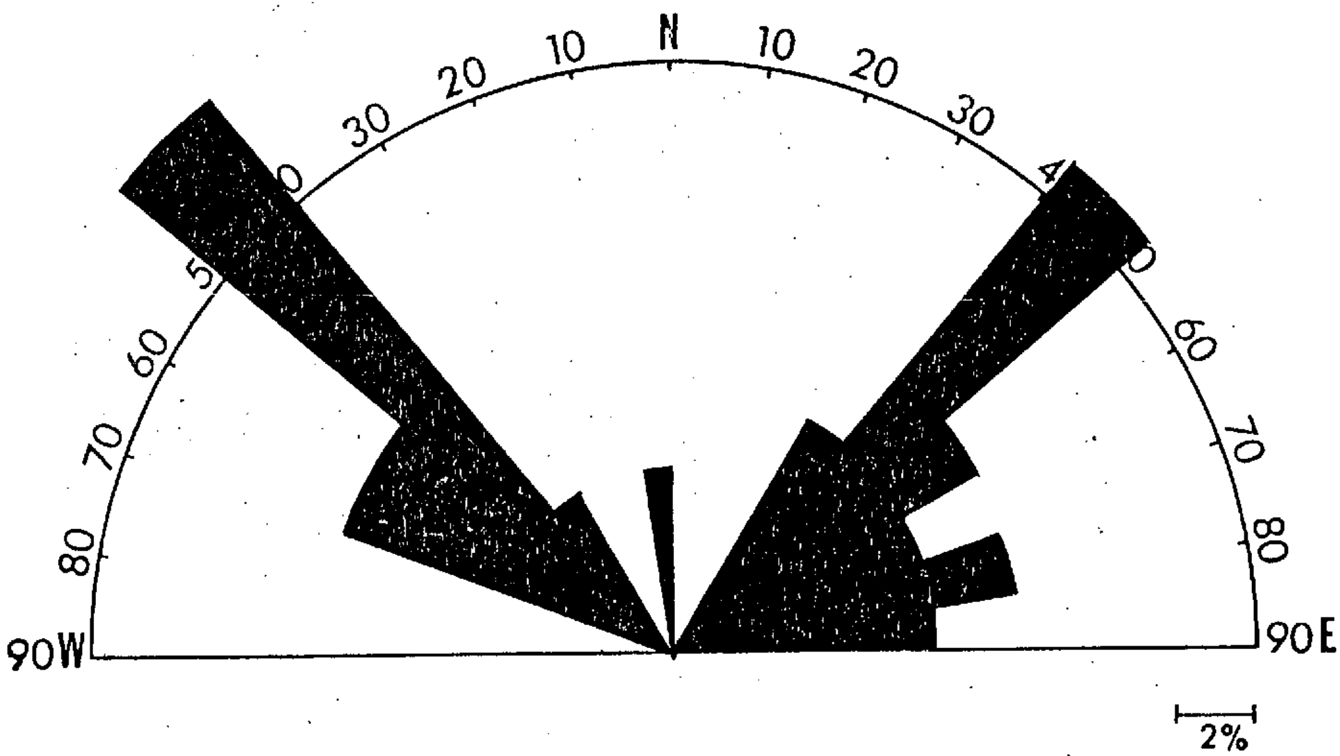


Figure 41.--Rose diagram of lineament orientations for the Athens area.

Major Lineament Complex Study

One of the major lineament complexes, the Anniston Lineament, was the subject of a joint study along its trace through the Interior Low Plateaus and Appalachian Plateaus provinces of Alabama (fig. 25G). Ten stations between Limestone and Etowah Counties were located that possessed continuous exposure for more than 12 meters and that were as near as possible to some trace of the lineament complex as interpreted from ERTS imagery. Lineaments were located as carefully as possible on 7½-minute quadrangle sheets. Precision in location was probably about within 150 m. The locations of the stations are as follows:

Station Number	Location	Distance From Lineament (Meters)
1	SE¼ sec. 11, T. 1 S., R. 5 W.	161
2	SE¼ sec. 19, T. 1 S., R. 4 W.	322
3	NE¼ sec. 32, T. 1 S., R. 4 W.	161
4	SW¼ sec. 35, T. 5 S., R. 1 W.	161
5	Cen. sec. 1, T. 6 S., R. 1 W.	805
6	SW¼ sec. 8, T. 6 S., R. 1 E.	643
7	SW¼ sec. 2, T. 8 S., R. 2 E.	161
8	SE¼ sec. 13, T. 8 S., R. 2 E.	322
9	SE¼ sec. 20, T. 8 S., R. 2 E.	161
10	NW¼ sec. 31, T. 10 S., R. 5 E.	805

At each station the differing joint directions were measured but no attempt was made to record joint spacing.

The most frequent joint set at the 10 stations was the N70°-90°W set (fig. 42). N20°-30°E and N40°-50°E sets were also moderately abundant. The

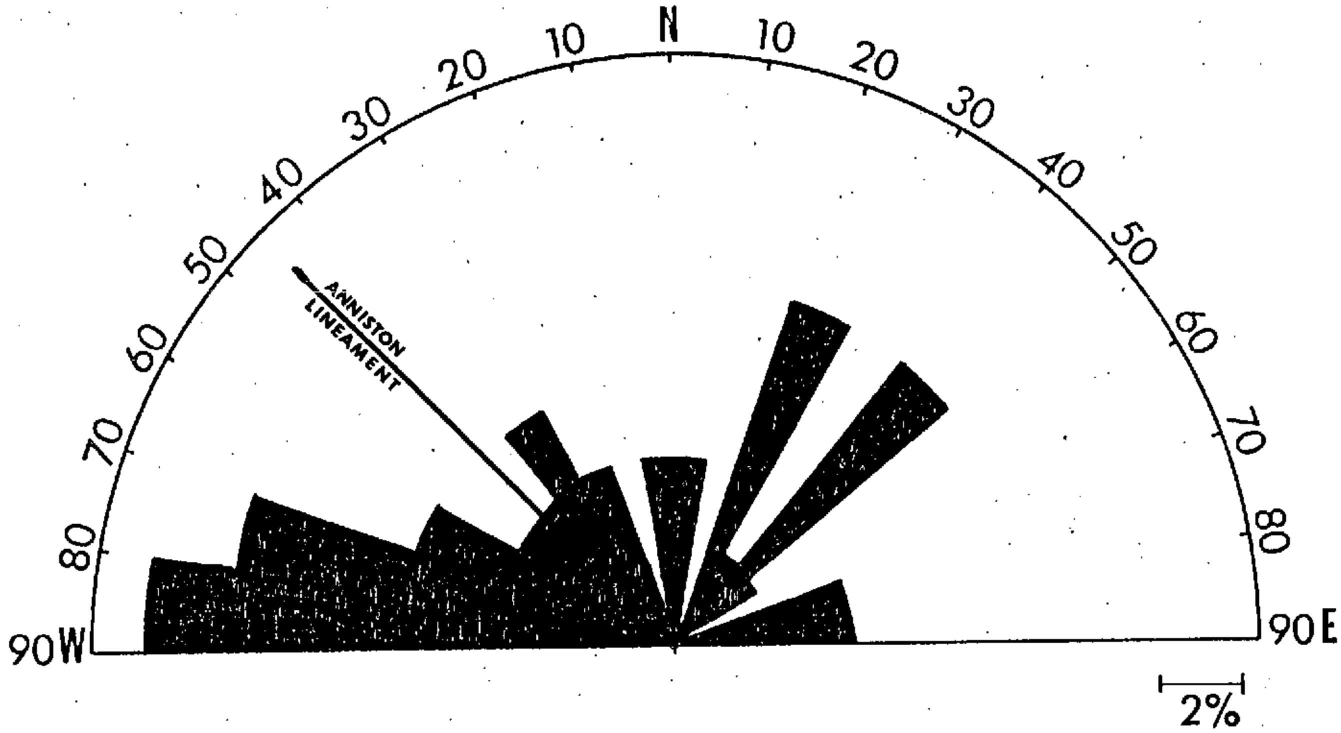


Figure 42.--Rose diagram of joint orientations along the Anniston lineament complex.

N45°W orientation shown by the Anniston lineament complex is relatively weakly expressed in the jointing. Regional lineament data, however, shows the N40°-50°W lineament group to be strongly expressed (fig. 9). In this case, the major lineament complex is not detectable through joint studies in its vicinity. At each of the 10 stations, it is impossible to measure any joints at the precise position that the lineament is interpreted to be located. In all cases, rock exposures were nonexistent, and topographic lows were noted. The major lineament complex may represent open jointing or a shattered zone along which solution has taken place to produce topographic lows and the development of thick residual material.

Conslusions

Based on the above study, the hypothesis that lineaments reflect jointing cannot be conclusively proven nor disproven, but certain conclusions can be drawn. The simple comparison of lineament and joint rose diagrams for an area is not a totally sufficient means of judging their correlation. It appears that the degree of openness and spacing is extremely important in the way joints are represented by lineaments. Unfortunately, this information is most often missing from the above presented studies. Where it is known, however, it appears that joints that are closed and/or widely spaced are not as well expressed as lineaments, as are the joints that are open and/or more closely spaced. The distribution of the spacing may also play an important role in lineament expression.

The fact that a number of the above joint studies showed relatively strong trends in the vicinity of N80°W may be significant regionally, but unfortunately, it is difficult to evaluate in terms of the lineaments because of the interference related to the ERTS scan lines in this direction.

Interpretations of Apollo 9 photography in central Alabama, however, show lineaments with east-west orientations to be strongly expressed (Powell and others, 1970).

Another reason that lineament orientation data may not reflect that of the joints measured in the field is that lineaments appear to often represent zones of weathering. When the location of individual member lineament traces of the Anniston lineament complex were attempted to be occupied in the field, it was found that rock exposures could not be found closer than 161 meters due to the presence of topographic lows. This suggests what is known to be true through drilling along the Kelly Creek lineament (Appendix 1) - that lineament zones may sometimes be areas of deep weathering and residuum development. Others (Mollard, 1957; Lattman and Parizek, 1964; Trainer and Ellison, 1967) have found that lineaments and fracture traces coincide with linear topographic depressions only a few feet deep. If this is the case, field data may be biased against trends characterized by open jointing or a shattered zone where solution is great enough to form valleys and thick residuum. The vast difference in scale between joints measured in the field and lineaments delineated on small-scale imagery may be of such a magnitude as to prevent reasonable comparison. Figure 43 illustrates this point. If the lineaments do represent fracture zones whose orientation and location are controlled by large-scale basement phenomena as has been suggested by many (e.g. Cloos, 1948 and Badgley, 1962), it is reasonable that orientation of the individual fractures composing the zone would not necessarily reflect the trend of the zone. The fractures themselves would more likely be controlled by local stresses present at the time of fracture developments. The relationship would be somewhat analogous to the development of <u>en echelon</u> fault zones such as the Lake Basin Fault zone of southern

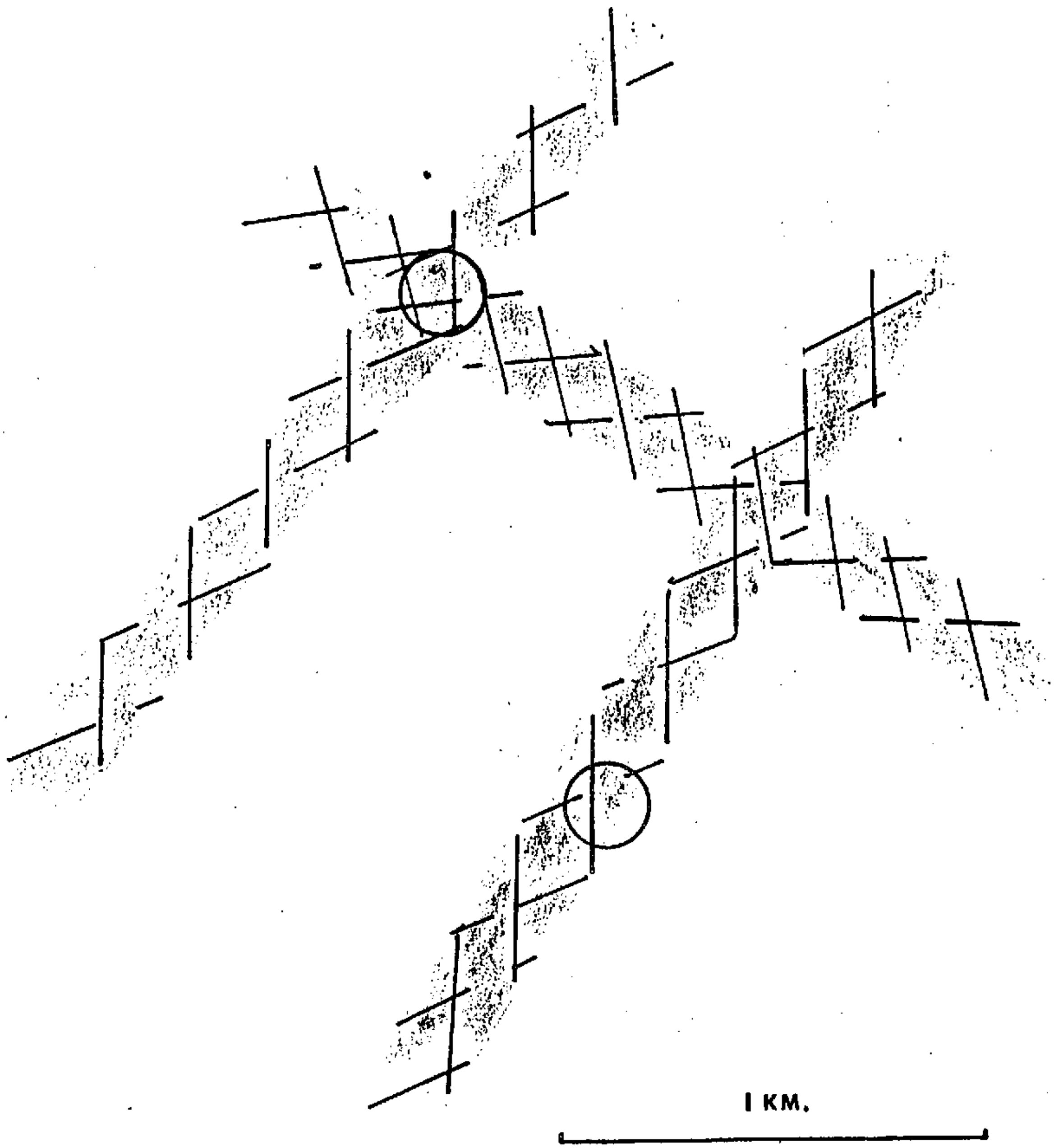


Figure 43.--Hypothetical relationship between joints (solid lines) and lineaments (shaded areas). Lineaments may represent en echelon joint sets in a highly fractured zone. The orientation of individual joint sets may be quite different from the orientation of the zone which is being controlled by larger scale phenomena. Joints measured in the field (circles) would not reflect the orientations of the lineaments.

Montana, where the individual faults have orientations at a high angle to the trend of the zone (Badgley, 1965, figs. 4-13 and 4-14). Wise (1969; 1974; oral communication, 1974) has also found that lineaments show little correlation in azimuth with any of the brittle fracture elements, except fault systems with at least 1-meter displacements. Wise also points out that microjointing, jointing and lineaments each possess their own characteristic strike directions.

In some cases the correlation between lineaments derived from ERTS-1 images and joints measured in the field appears to be quite remarkable. Although this correlation may be fortuitous, it is interesting to note that it occurs in the folded and faulted rocks, not in those areas underlain by flat-lying rocks. At least on the surface, this situation suggests that the contention held by some indicating that lineaments and joints do not correlate where rocks are folded does not hold up for all the areas studied in Alabama.

In any event, it is obvious that more and highly detailed joint studies, are needed from large areas to adequately assess the relationships between lineaments and jointing. In addition, studies similar to this one should be carried out with some of the more recent space photography or later ERTS imagery possessing a different scan orientation to determine the lineament-related significance of the N80°W joint sets.

LINEAMENTS AND STRUCTURAL GEOLOGY

Introduction

The Harpersville and the Anniston lineament complexes are major lineaments that show relationship to regional structural features. The relationships consist of offsets, terminations and changes in structural style along the major lineaments and have been discussed in previous studies (Powell and others, 1970; Drahovzal and others, 1974; Appendix 1). New developments are discussed in the following section. The two major lineaments have been found to be made up of subparallel, bifurcating, and *en echelon* member lineament traces and, therefore, do not appear on plate 1 as a single line. The traces of the complexes are indicated, however, in figure 1.

The myriad of shorter, less prominant lineaments shown on plate 1 are generally poorly known and appear to be of only local geologic significance. The nature of several of these minor lineaments has been previously discussed (Drahovzal and others, 1974; Appendix 1), but some new developments are presented in the following section.

Descriptions

Major Lineaments

Anniston-Gadsden Area.--Because of the complex nature of the geology in the Anniston-Gadsden area and because the Anniston lineament complex appears to be so strongly related to a series of cross-strike changes, a detailed geologic study of the area was undertaken as part of this project (fig. 44). The area includes parts of the Glencoe, Colvin Gap, Jacksonville, Wellington, and Anniston 7½-minute quadrangles and lies in the eastern part of the Alabama

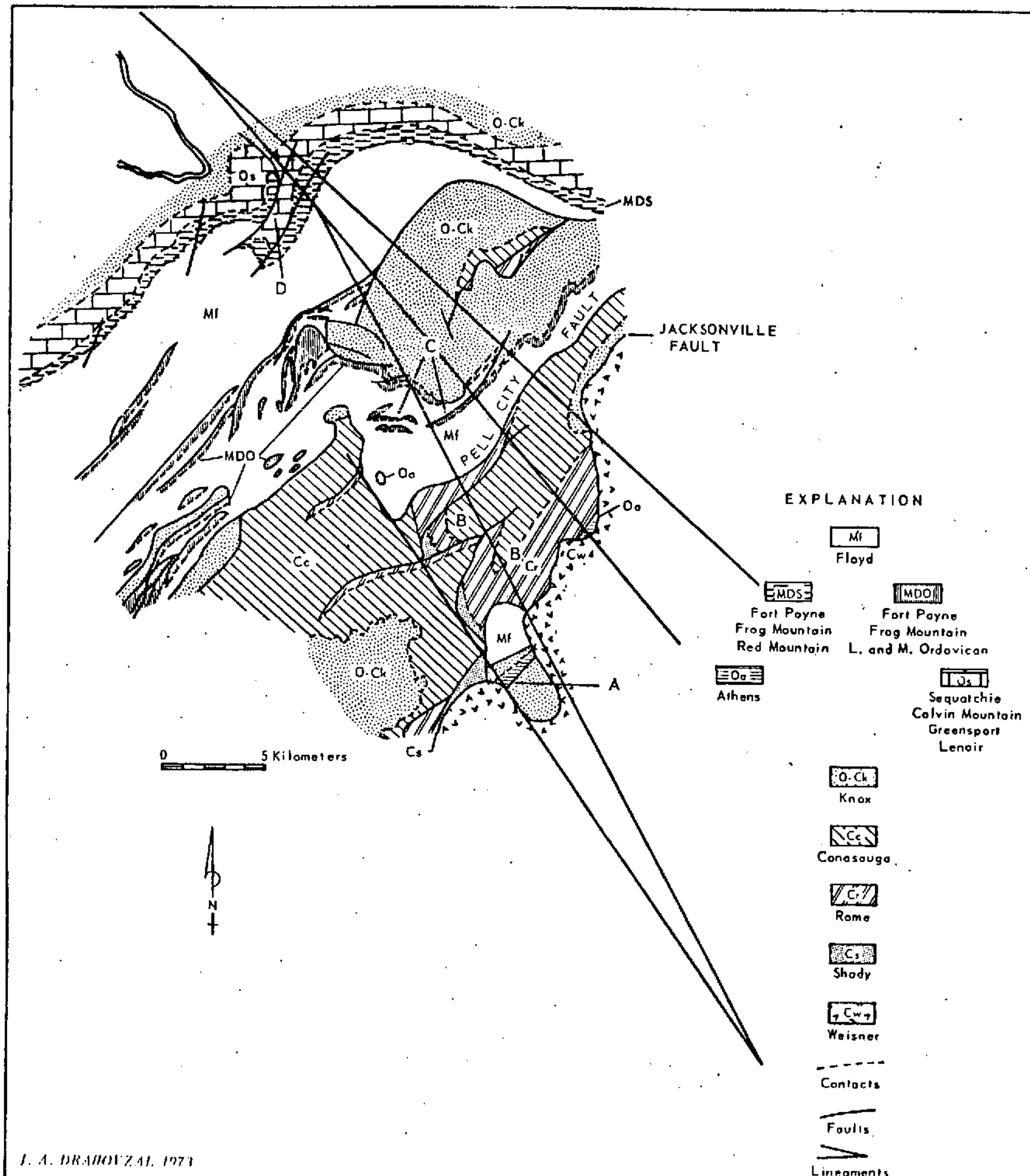


Figure44.–Generalized geology of the Anniston - Gadsden area, Alabama showing its relationship to the Anniston lineament complex. Geology modified from unpublished field maps of T. L. Neathery (1968) W.A. Thomas and J.A. Drahovzal (1969-1970) and J.A. Drahovzal (1971-1973).

Valley and Ridge (fig. 25H). All mapping was done on the 7½-minute quadrangle bases and is taken from unpublished field maps of T. L. Neathery (1968), W. A. Thomas and J. A. Drahovzal (1969-1970) and J. A. Drahovzal (1971-1973). Field stations included data on such things as strike and dip of bedding, lithology, unit thicknesses and structural features. Approximately five stations on the average were occupied and described in each square mile.

The area is underlain by rocks ranging in age from Cambrian through the Mississippian. The Weisner Quartzite, Shady Dolomite, and Rome and Conasauga Formations are all Cambrian in age. The Knox Group is Cambro-Ordovician in age. The Lenoir Limestone, Greensport Formation, Colvin Mountain Sandstone, Sequatchie Formation and Athens Shale are all Ordovician in age. The Red Mountain Formation is Silurian and the Frog Mountain Sandstone Devonian in age. The Fort Payne Chert and Floyd Shale are Mississippian in age.

The area is bounded on the south by a sinuous low-angle thrust fault called the Jacksonville fault. The fault brings the Weisner Quartzite into contact with a variety of formations on the downthrown block including the Shady, the Rome, the Conasauga, the Knox, the Athens, and the Floyd all within a 20-kilometer strip along strike. Between two splays of the Anniston lineament complex, a narrow 5-kilometer-deep recess in the Jacksonville fault is accompanied by a window (fig. 44A) on the downthrown block. The window exposes the Floyd, Athens and Knox in a strike belt where Knox is the youngest formation generally exposed. Another small window containing Athens occurs in a shallow recess along the fault about 7 kilometers to the northeast. Both windows occur in association with the member traces of the Anniston lineament complex. Both may be interpreted as folds in the Pell City thrust fault that have brought the younger, but underlying, rocks to the surface. Such folding is probably post-Paleozoic if the Pell City thrust fault is related to the Alleghenian tectonic event. In any case, the folding would be post-Floyd (Mississippian).

On the Pell City block, the structure is grossly synclinal, but thrusts and tear faults have complicated the geology. Two fault-terminated northeasterly plunging synclines (fig. 44B) are separated by a thrust fault. The tear faults terminating these structures coincide with the general trend of one of the major lineament traces of the Anniston lineament complex. Along this zone, the northeast block up relative to the southwest block, in each case placing the Shady in contact with the Conasauga. Away from the lineament, the tear faults change strike and merge into thrusts with northeast orientations. The vertical displacement represented by the tear faults is in the order of several hundreds of meters.

The entire composition of the Pell City block markedly changes in the vicinity of the Anniston lineament complex. South of the area mapped in figure 44, the Pell City block along its frontal edge is composed of Knox units for many tens of kilometers. In the vicinity of the lineament, however, older rocks compose the frontal edge and this situation continues northward beyond the area mapped. In addition, a very sharp 7-kilometer right-lateral displacement occurs in the trace of the Pell City fault near where the lineament complex intersects it. Except in the Harpersville area some 75 kilometers to the south, no such abrupt change in strike occurs at any other point along this fault. Both the change in composition to older rocks and the right lateral displacement of this east-dipping thrust fault suggest vertical uplift as the mechanism responsible. On the downthrown block of the Pell City fault lies the Coosa deformed belt (Drahovzal and Thomas, 1970, Thomas and Drahovzal, 1971) a narrow zone largely underlain by Floyd Shale but characterized by block klippen block faulting and thin imbricate thrust sheets composed of older rocks (fig. 44C). This zone regionally is generally linear and made up of simple imbricate thrust slices until it reaches the vicinity of the Anniston lineament where many of its structures change trend and the geology becomes complicated by a large thrust block composed primarily of Knox and older units. Farther to the south along strike, Knox is known in the belt only near the Harpersville area. In addition, several small blocks of Athens Shale occur tectonically mixed with the Floyd Shale in the vicinity of the lineaments. The abrupt appearance of Knox and older rocks in the midst of the Coosa deformed belt, a zone made up of Ordovician-Mississippian rocks, suggests that a deeper level of the Coosa deformed belt is exposed in the vicinity of the Anniston lineament complex. Again, the lineament complex appears to be associated with uplift to the northeast.

Just west of the intersection of the two main lineament traces of the Anniston lineament complex, an east dipping homocline shows offset where the complex crosses it. The offset is right lateral and exceeds 5 kilometers. The high-angle faults producing the offset are at about right angles to the lineament complex. It is not known whether the cross-faulting is characterized by horizontal or vertical movement, but if vertical motion is responsible, the northeast block would be uplifted with respect to the southwest block.

The Anniston-Gadsden vicinity in a relatively small area shows abundant evidence of some type of cross-structure that appears to affect rocks in several adjacent strike belts. Terminations, offsets and changes in structural style occur in association with the Anniston lineament complex and most suggest that the northeast part of the mapped area has been uplifted relative to the southwest part. Such evidence suggests that at least part of the Anniston lineament was active after the Alleghenian tectonic event and is probably post-Paleozoic in age. It also suggests that the lineaments are fundamental zones of vertical movement in the basement. The fact that the window containing Knox, Athens and Floyd rocks (fig. 44A) was also the epicenter of an earthquake in 1939 (Eppley, 1965) strengthens this concept and further suggests that differential vertical motion may still be taking place.

Harpersville Area.--Geologic studies in the Harpersville area have been underway since 1969, but due to the complex nature of the structure, poor exposures, deep weathering and relatively low relief, an accurate and consistent geologic map of the area is still not possible to produce. Part of this study involved some limited mapping in the area because of its relationship to the Harpersville lineament complex. In spite of the problems that exist in this area, it is possible to make several generalizations concerning it.

The Harpersville area lies at the southern end of the Coosa deformed belt (fig. 25I). The area is crossed by the Harpersville lineament complex at about right angles to regional strike. Even from the generalized geology of figure 1, it is possible to observe the change in local strike that occurs in the Harpersville area. The strike changes from about N45°E just north of the area to a strike of N20°-30°W in the vicinity of Harpersville. The Pell City fault splays and becomes less distinct in the area. One interpretation suggests that much of the Pell City block changes its structural style, being folded into a series of tight, overturned faulted synclines that include Athens Shale at their axes. Both to the northeast and southwest of this area the Pell City fault is more distinct and made up only of rocks of the Knox Group. According to this interpretation, the rather abrupt change in the composition of the Pell City block in the area suggests general downwarping where the lineament crosses the block. To the immediate west of the Pell City block, the Coosa deformed belt is made up of a series of folded and faulted overturned thrust slices. This is in contrast to the right-side-up thrust slices to the immediate northeast. Such a change in structural style may partly reflect the change in lithology that occurs to the southwest in the belt. To the southwest the Fort Payne Chert becomes much thinner and the Frog Mountain Sandstone pinches out. If one assumes that formation of the Coosa deformed belt occurred at depths of 2 or more kilometers, the absence of most or all of these units would result in a less competent mass that would react to regional stresses in a slightly different manner.

The Coosa deformed belt, itself, so distinct to the northwest becomes rather indistinct in the Harpersville area and does not recur farther to the southwest. This also points to a major change in structural style.

In the northwestern part of the Harpersville area, the lineament complex crosses the Coosa thrust fault at a point where it is left-laterally offset 3 to 4 kilometers. On the downthrown side of the Coosa fault in the Coosa synclinorium, the lineament passes through a narrow structural high separating two oppositely plunging synclines.

With the Harpersville lineament complex, as with the Anniston complex to the north, structural changes, including a major change in strike, changes in structural style, and the termination of small-scale as well as rather large scale structures occur. Much of this may be related to facies changes, but as it will be seen in a later section, the lineament-causing mechanism may play an important role in sedimentary facies patterns as well. Structural changes related to differential vertical uplift after the Alleghenian tectonic event might also be involved. An earthquake occurring in 1916, whose epicenter is not 10 kilometers from the northwestern edge of the Harpersville area and along the Harpersville lineament, strongly supports this concept and further indicates that the area may be involved in minor differential vertical motion even at the present time. If the main branch of Pell City fault is assumed to be the farthest east branch, it then shows a marked left-lateral offset of about 9 kilometers. The east-dipping Coosa fault also shows left-lateral offset, but of only approximately 4 kilometers. Both offsets could be explained by differential vertical uplift which would make the area to the northeast of the Harpersville lineament complex downthrown relative to the Harpersville area. If this is the case, the tight folds in the Knox and Athens mentioned previously as part of the Pell City block may be related to a deeper portion of the Coosa deformed belt that is now exposed at the surface due to uplift. More study of the Harpersville area will be required before a map consistent with all available data is possible. The relationship of the cross-structure, as represented by the Harpersville lineament complex, to the Appalachian trends should play an important role in producing any such map.

Trussville Area.--Several field-days were spent in the vicinity of Trussville, collecting information on the general geology of the area (fig. 25C). Initially, the study was precipitated by the fact that Butts (1910, p. 41) noted the absence of the Middle Ordovician Chickamauga Limestone along Red Mountain in the Trussville area where the Harpersville lineament complex crosses the structure. The area lies on the west flank of a shallow syncline developed on the Birmingham anticlinorium (fig. 1). Along the lineament to the southeast, the Chickamauga plunges out in a faulted anticlinal nose. Immediately southwest of the area where the Chickamauga was reported missing and also northwest across strike, the Chickamauga is represented by a substantial section of limestone 140 to 180 meters thick.

Field studies showed no Chickamauga to be present along the narrow zone, but did show that the dip of the underlying and overlying beds is markedly steeper where the lineament crosses area. The dips in the zone are more than 80°SE as opposed to 10°-15°SE along strike on either side of the zone. The study suggests that the limestone is simply masked in the area of steep dip by the thick mantle of colluvium derived from the sharp Red Mountain-Fort Payne ridge to the immediate southeast. Outcrop control suggest that sufficient horizontal distance is present in the area to accommodate a steeply dipping Chickamauga section.

Although a stratigraphic change does not appear to occur as Butts had suggested, a marked structural change is apparent. This latter change may be related to the presence of the Harpersville lineament complex in a fashion similar to those previously described for the Harpersville area.

Minor Lineaments

By far the most lineaments interpreted on plate 1 are considered minor lineaments, those which are shorter and which appear to have only local geologic significance. In interpreting the lineaments from ERTS-1 imagery, those linear features coincident with the major strike valleys and ridges of the Appalachians, which in effect represent topographic lineaments related to known major structure, were not included (pl. 2). Those lineaments that for a short distance parallel these major structures and which continue along the same trend even after the structure changes strike or are at low angles to them were, however, recorded.

A series of minor cross-structures in the Appalachian Plateau west of Birmingham were mapped by Butts (1910) and Blair (1929, map no. 2). These cross structures consist of high-angle normal faults striking between N10° to 30°W in orientation. Blair (1929, p. 191, 192) described these faults as consisting of zones a few meters to as much as 16 meters in width and with displacements of as much as 30 meters. He farther implies that they are extension fractures. The normal faults very closely match in orientation one of the prominant groups (167° or N13°W) of lineaments in the province (fig. 7 and 15; pl. 2). The Flat Creek area discussed previously is cut by a number of these faults and in several cases the faults perfectly coincide with segments of the lineaments as derived from the ERTS imagery. The relatively high lineament peaks between N10° and 20°W on the rose diagrams summarizing topographic-, U-2-, and ERTS-derived lineament orientations are probably related to these high-angle normal faults (figs. 36, 37, and 38). The excellent correlation suggests that several of the lineaments in the area with the N10°-20°W orientation may represent presently unknown normal faults. Unfortunately, time in the project cut short any farther attempt to locate any previously unmapped faults based on lineament information, but plans are now being formulated to complete this work in the near future.

Fairly extensive field data has been collected for two minor lineaments which have local geologic and environmental implications. The Kelly Creek lineament strikes along the axis of Logan Martin Dam in Shelby County, Alabama (fig. 1C). From the geologic, hydrologic, and geophysical data collected along this lineament, it is apparent that it represents a fracture zone that is both deeply weathered and solution widened. Another minor lineament, called the Wesobulga Creek lineament (fig. 10), correlates with a normal fault in the central Piedmont of Alabama. Appendix 1 (Drahovzal and others, 1974) presents accounts of the field studies associated with these lineaments. In the case of the Wesobulga Creek lineament, Neathery and Reynolds (1974) present a detailed discussion in another part of this volume.

LINEAMENTS AND STRATIGRAPHIC RELATIONSHIPS

Some initial work suggests that the two major lineaments coincide with variations in Paleozoic stratigraphy in the southern Appalachians, but unfortunately, time did not permit full field investigation of this possibility.

A succession that appears to show a strong relationship to the major lineament complexes is the Middle Ordovician. Over much of the southeastern United States, the Lower Ordovician is separated from the Middle Ordovician by a paleokarst unconformity, and the basal Middle Ordovician locally consists of conglomeratic beds having clasts that range from sand to boulder sizes. In Alabama, this unit is called the Attalla Chert Conglomerate Member of the Chickamauga Limestone. In general, the coarsest and thickest development of the Attalla in Alabama lies adjacent to the two major lineament complexes (fig. 45). The conglomerate is unknown northeast of the Anniston lineament complex. Immediately southeast of the Anniston lineament complex on Wills Valley anticline and near the termination of the Helena thrust fault, clast, ranging from 15 to 92 cm in diameter occur in pockets as much as 21 m thick (Drahovzal and Neathery, 1971, p. 11, 185). The conglomerate becomes finer and thinner southwestward, varying in thickness from 1 to 6 m. Immediately southwest of the Harpersville lineament, at the up-plunge end of Blount Mountain syncline, another locally coarse deposit approximately 13 m thick occurs with chert clasts ranging up to 50 cm (Thomas and Joiner, 1965, p. 13).

The thickest and coarsest development of the Attalla immediately adjacent to the major lineaments suggests that the lineament causing structures are in part responsible for the anomalous occurrences. Differential vertical

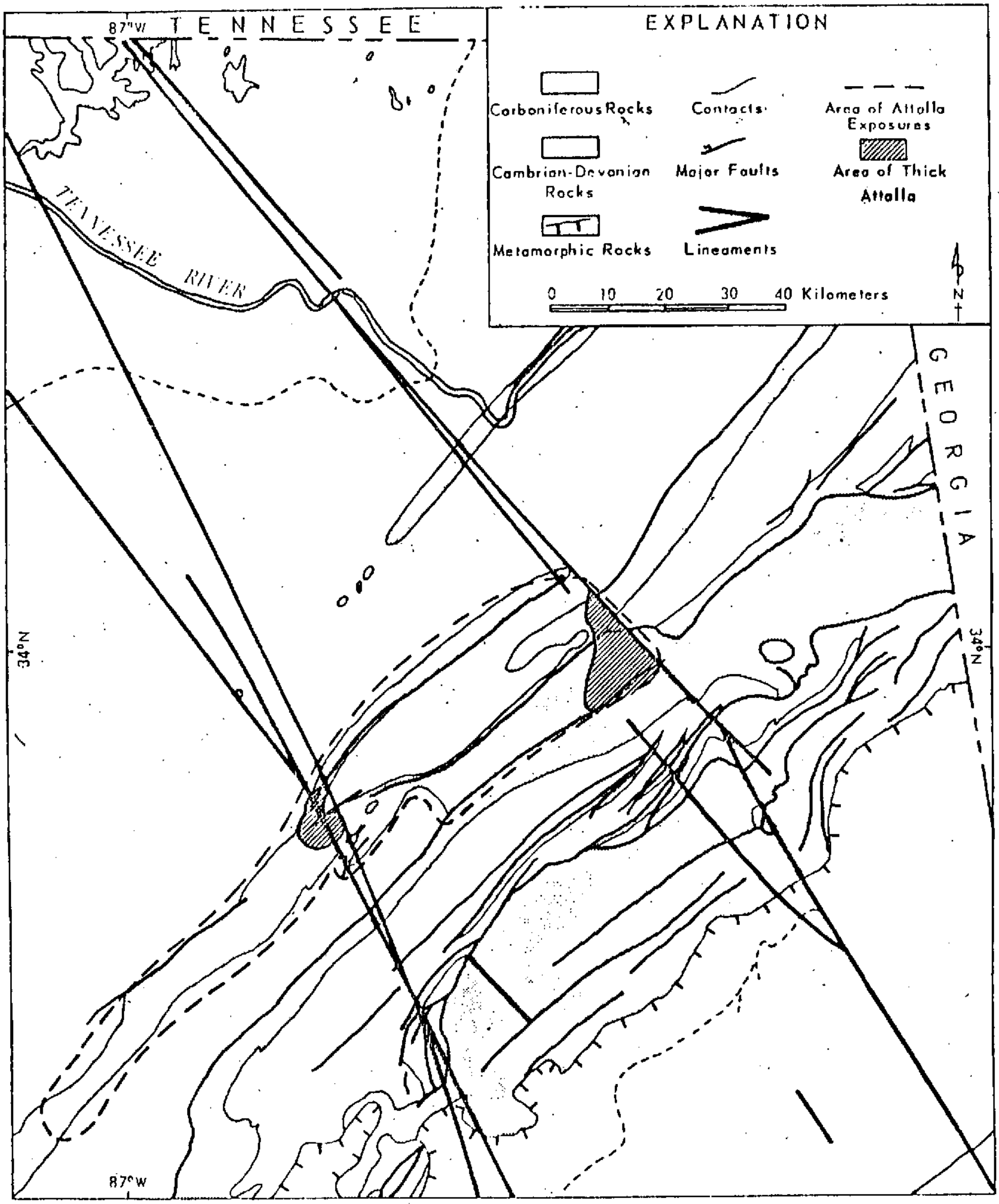


Figure 45.--Generalized geology of northeastern Alabama showing the approximate limits of the Attalla Chert Conglomerate Member of the Chickamauga Limestone and the areas of thick and coarse development. Data modified from Butts (1910), Thomas and Joiner (1965), and Drahovzal and Neathery, (1971).

movement of individual basement blocks contemporaneous with or prior to deposition may have formed the restrictive pockets, or selective karst development along lineament-related fractures during the Early Ordovician may be responsible for the anomalous distribution.

Similar lineament-related changes in lithologies and thicknesses for Cambrian, upper Middle Ordovician and Mississippian rocks of the Alabama Appalachians are known, but unfortunately time did not permit the collection of detailed field data. Much more data will be required before definite conclusions concerning this aspect of the study may be formulated.

LINEAMENTS AND MINERALIZATION

Some lineaments show remarkable correlation with many of the hydrothermal mineral deposits of Alabama. The occurrence of barite and lead and zinc sulfides in the Valley and Ridge and barite, gold, manganese, tin and copper, lead, zinc, arsenic and iron sulfides in the Piedmont has been related to lineaments derived from Apollo 9 photography (Smith and Drahovzal, 1972; Smith and others, 1973). Barite appears to show the closest correlation, with about 40 percent of the known prospects coinciding with the two major lineament complexes (Drahovzal and others, 1974; see Appendix 1 (fig. 1). The richest barite deposits known in Alabama occur in the Coosa deformed belt where the Anniston and Harpersville lineament complexes cross it. Many of the other barite prospects correlate with minor lineaments.

As part of the Apollo 9 study (Smith and others, 1973) to evaluate mineralization/lineament relationships, "B" horizon soil samples were collected in selected areas of the Valley and Ridge and Piedmont and geochemically analyzed. The results of some of these studies are presented in Drahovzal and others (1974; see Appendix 1). The excellent correlation between certain lineaments and geochemical highs suggests a genetic relationship. In many cases, however, no relationships exist.

As a part of this study, seven areas were chosen in the Piedmont and Valley and Ridge provinces for additional geochemical surveys. A detailed report of the geochemical studies is presented in another paper in this volume (Skrzyniecki, Nordstrom, and Smith, 1974). Six of the areas exhibited only limited correlation between geochemical anomalies and lineaments, however, in one area, correlation appears to be excellent. In the Harpersville vicinity (fig. 25I), an area known for its barite prospects, five traverses were made across individual member traces of the Harpersville lineament complex. The samples were analyzed for barium (Ba), manganese (Mn), strontium (Sr), copper (Cu), zinc (Zn), and lead (Pb). A series of anomalous highs for Ba, Cu, Mn, Zn, and Pb, all parallel to and consistently offset short distances from the member lineament traces were encountered. These anomalous highs very strongly suggest that mineralization in the area is related to the lineaments, and the slight offsets can be accounted for by the limitations of accuracy imposed by comparing 1:250,000 scale imagery with 1:24,000 scale maps.

On the basis of this work, it appears that the distribution of some potentially important mineral resources is related to lineament-causing structures. Not all lineaments, however, are significant as mineral indicators, and those that are, show a considerable range in metal concentrations along strike. The effects of lineament intersections has not been sufficiently tested in Alabama to determine their possible relationships to metal concentrations, but others (Kutina, 1968, 1974; Levandowski and others, 1973, 1974) have suggested this to be an important factor. The excellent relationship between mineral prospects and geochemical highs with some lineaments suggests that some lineament-causing structures are crustal penetrating fractures that have served as migration channels for mineralized fluids and sites of deposition for certain minerals. Further studies employing a closely spaced grid sampling technique in some of the geochemically anomalous areas should be undertaken in future studies. Nevertheless, it appears that lineament studies through the use of ERTS imagery constitutes an important tool for mineral exploration.

LINEAMENTS AND HYDROLOGY

Results of Apollo 9 studies in Alabama have shown relationships between the occurrence of water resources and lineaments in the Valley and Ridge and Piedmont provinces. High-yield springs and wells show a number of excellent correlations with major and minor lineament (Powell and others, 1970). In addition, it has been demonstrated that certain surface flow anomalies in eastern Alabama are directly related to lineaments. Detailed low-flow studies made in adjacent subdrainage areas along Talladega Creek in Talladega County, Alabama, have shown that there is an abrupt pickup in flow at a point where two lineaments intersect the stream. Pickup in the vicinity of the intersection point increases more than 70 times from a flow of 6.6×10^{-4} $m^3/s/km^2$ to 4.7×10^{-2} $m^3/s/km^2$ (Powell and LaMoreaux, 1971; U. S. Geological Survey, 1972, p. 190-191).

As a part of this study, an area including a segment of the Anniston lineament complex in southwestern Madison County was examined hydrologically. The area is underlain by gentle south dipping (less than 1°/mile) Mississippian carbonates and the ground water developed from these units occurs primarily in solution widened fractures. Of the 80 wells and springs in this relatively small area, nearly all of those exhibiting anomalously high yields lie within the 4-kilometer-wide zone of the Anniston lineament complex. Average yields in the zone are more than three times those in the surrounding area and the locations of the high-yield wells and springs trend parallel to the lineament complex. This excellent correlation suggests that the lineament complex represents a fracture zone in the near subsurface. Low variabilities in water-level fluctuation for some of the lineament-related wells appear to parallel the low-discharge variability noted by Powell and others (1970) for lineament-related limestone springs in the Valley and Ridge province. Low variabilities, uncommon for wells and springs in limestone terranes, suggest special recharge conditions. Some of the details of the above example may be found in Drahovzal and others (1974, see Appendix 1), and is discussed at length in another paper in this volume (Moravec and Moore, 1974).

In addition, lineaments just to the southeast of this area in Morgan County have been found to exhibit a remarkable relationship to the alignment of cave passages and sink valleys in a distinctive karstic terrane. A detailed report concerning this relationship is presented in another paper of this volume (Moravec and Moore, 1974). Similar results have been encountered in another study in Lauderdale and Colbert Counties, also in the Tennessee Valley, where ERTS-derived lineaments show a close relationship to the orientation of large limestone sinkholes and cave passages. A detailed report concerning this study is presented in another paper of this volume (Moser and Ricci, 1974). Cave passage orientations in Madison County do not, however, show very good correlation with the lineaments of the area (Moravec and Moore, 1974).

The occurrence of high-yield wells and springs coincident with lineaments and lineament complexes and the similar orientations of sinkholes and some cave passages with lineaments suggests that the lineaments represent solution-widened fractures in limestone terranes. The low variabilities in water-level fluctuation and low discharge variabilities suggest that sources supplying many of the lineament-related wells and springs must be very large and stable. In conclusion, lineaments, at least in certain areas, appear to be exercising a high degree of control over the distribution of water resources and the development of karstic features. Lineament investigations represent another important tool for water resources exploration and for the analyses of karstic terranes critical to responsible land-use capability, planning and pollution studies.

LINEAMENTS AND GEOPHYSICAL EVIDENCE

As part of this study, several gravity surveys were conducted to determine whether or not lineaments are related to gravity anomalies. A detailed report is presented in another paper of this volume (Wilson, 1974) and a preliminary report is presented in Appendix 1 (Drahovzal and others, 1974). Seven such surveys ranging from more than 2 to almost 13 kilometers in length and with an average station spacing of 160 meters were carried out over prominant lineaments. Five of the surveys were run across the Anniston lineament complex in Limestone, Madison and Marshall Counties. In much of this area, low relief prevented conventional field observations because of a lack of unweathered outcrops. The low relief also made gravity surveys easier to conduct and their results more reliable. Excellent correlations exist between certain member lineaments of the Anniston lineament complex and relatively small (0.2-0.4 milligal) gravity anomalies in the Tennessee Valley area. From analysis of the gravity data, the anomalies are thought to represent normal faults at the top of the Knox Group some 460 meters below the surface. The faults probably dip at about 60° with throws in the order of 45-90 meters at the Knox horizon. The surveys along several traverses suggest a series of horst and graben structures at the Knox level. Several magnetic surveys also show anomalies which may relate to vertical offsets in the basement, however, data was not sufficiently complete to confirm this. The occurrence of Knox block faulting in the northern Appalachian Plateaus and Interior Low Plateaus was reported by Boland and Minihan (1971) based on geomorphological and seismic work (pl. 2). Conversations with geologists from major oil companies confirm the concept that the basement in this area consists of a series of horsts and grabens, but the supporting seismic data remains confidential.

The coincidence of gravity anomalies with certain lineaments suggests that some of the lineaments represent surface fracturing related to low-magnitude subsurface faults. The surface fracturing in the Tennessee Valley probably shows little or no displacement, but several normal faults in the vicinity of and on trend with the Anniston lineament complex just across the line in Tennessee show low-magnitude displacement (Miller and others, 1966) (fig. 46). If the 60° dip for the Knox faults is correct, it does not appear that the lineaments are simple surface expressions of them. The very straight character of the lineaments, regardless of terrain, suggests that they are vertical in nature and therefore are perhaps related to the deeper normal faults only by virtue of the stresses produced by them and not as simple extensions of the deep fault plane to the surface.

Both extensive gravity and magnetic studies are needed to assess the nature of the basement in the northern Alabama area. The release of currently confidential seismic and deep drilling data would also greatly clarify the basement picture, and its possible relationship to surface features.

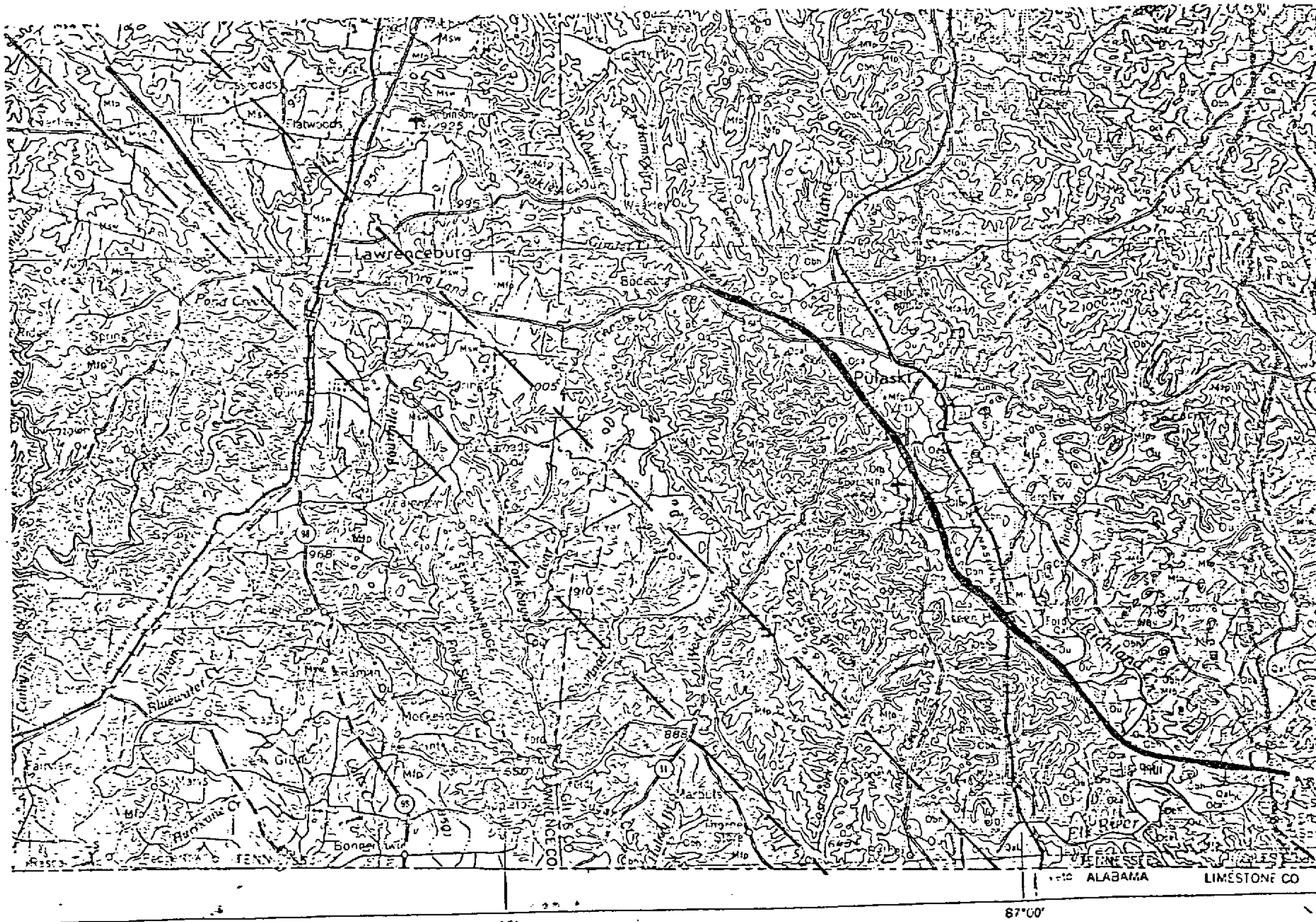


Figure 46.--The relationship of the Anniston lineament complex (defined by the dashed lines) in south-central Tennessee with two low magnitude normal faults mapped at the surface (prominent solid lines). From Miller and others, 1966.

LINEAMENTS AND SEISMICITY

Between 1886 and 1971, 17 separate earthquake epicenters have been reported in Alabama (Eppley, 1965; U. S. Department of Commerce, written communication, 1971; G. A. Bollinger, written communication, 1971-1973). Of this number, four were "felt" reports and one was highly questionable. The remaining 12 had intensities ranging from I to VII on the Modified Mercalli Intensity Scale of 1931. In the area of this study in northern Alabama, 13 epicenters are present but two of these are "felt" reports and one is highly questionable. The ten epicenters for which intensities exist are present in the Valley and Ridge, Appalachian Plateaus and Interior Low Plateaus provinces (fig. 1; table 1). Not a single earthquake epicenter has been reported in the Piedmont province.

Earthquake focal depths are unknown for any of the Alabama epicenters, but a 1964 earthquake just east of the Alabama-Georgia line occurred at a depth of 15 kilometers (U. S. Department of Commerce, written communication, 1971). It is assumed that most of the earthquakes in Alabama occur at similar depths. If this is true, the earthquake foci are apparently occurring well within the Precambrian crystalline basement, because its depth beneath land surface in northern Alabama is no where greater than 7 kilometers (King, 1969).

Although consistent reports of surface faulting associated with earthquakes are unknown for Alabama, Butts (1927, pl. 10) stated the following concerning Red Gap near Irondale, "The Red Gap fault on which the movement causing the earthquake in 1914 took place, is near and along the highway." Because no other report on an earthquake occurring in 1914 is known, it is assumed that Butts was speaking of the 1916 event. No other report, however, mentions this movement.

Table 1. Significant Seismic Events in Northern Alabama

Date	Location Lat.	Location Long.	Intensity*	Comments
Jan. 27, 28, 1905	34.0	86.0	VII	3 shocks,
Oct. 18, 1916	33.5	86.5	VII	1 aftershock Oct. 22 3 aftershocks Nov. 4
Oct. 28, 1923	34.9	88.1	III	
June 16, 1927	34.7	86.0	V	
May 5, 1931	33.7	86.6	V-VI	
May 4, 1939	33.7	85.8	V	
June 24, 1939	34.7	86.7	IV	
Feb. 6, 1952	33.5	86.8	IV	
April 23, 1957	34.5	86.8	VI	
Aug. 12, 1959	35.0	87.0	VI	

*Modified Mercalli Scale

Of the 10 epicenters described in table 1, four are located along the Anniston lineament complex and two along the Harpersville lineament complex (Drahovzal and others, 1974, see Appendix 1) (fig. 1). This high rate of coincidence strongly suggests that the major lineaments are related to fundamental basement structures that may be currently active. The activity that has occurred within the last century may be related to the crustal uplift in the Atlanta area reported by Meade (1971, fig. 9). His results, based on partial releveling of the first-order network for the eastern United States over a 50-year period, depicted at 7.0 mm/year uplift centered near Atlanta, Georgia. The effects of this uplift extend well into northern Alabama and may be responsible for much of the seismic energy release in the area (fig. 47). The differential flexure and slip that may be occurring along pre-existing lines of fundamental weakness in the Precambrian basement are very likely being in turn expressed as lineaments in the surface cover rocks. The traverse seismic zone coincident with the Anniston lineament on the southwest flank of the Atlanta uplift may be a weaker expression of but comparable to Bollinger's (1973) traverse South Carolina-Georgia seismic zone that lies on the northeast flank of the uplift. Similar traverse seismic zones have been recently described by Sbar and Sykes (1973) along the eastern North American continent but have been related to horizontal compressive stresses associated with extensions of oceanic fracture zones.

Microseismic surveys of the northern Alabama region should be carried out to evaluate the current seismic activity, if present, along the two major lineaments. Such a study is an important part of proposed ERTS-B research (NASA proposal no. 22660, Investigations of the Geologic and Hydrologic Significance of Lineaments in Alabama).

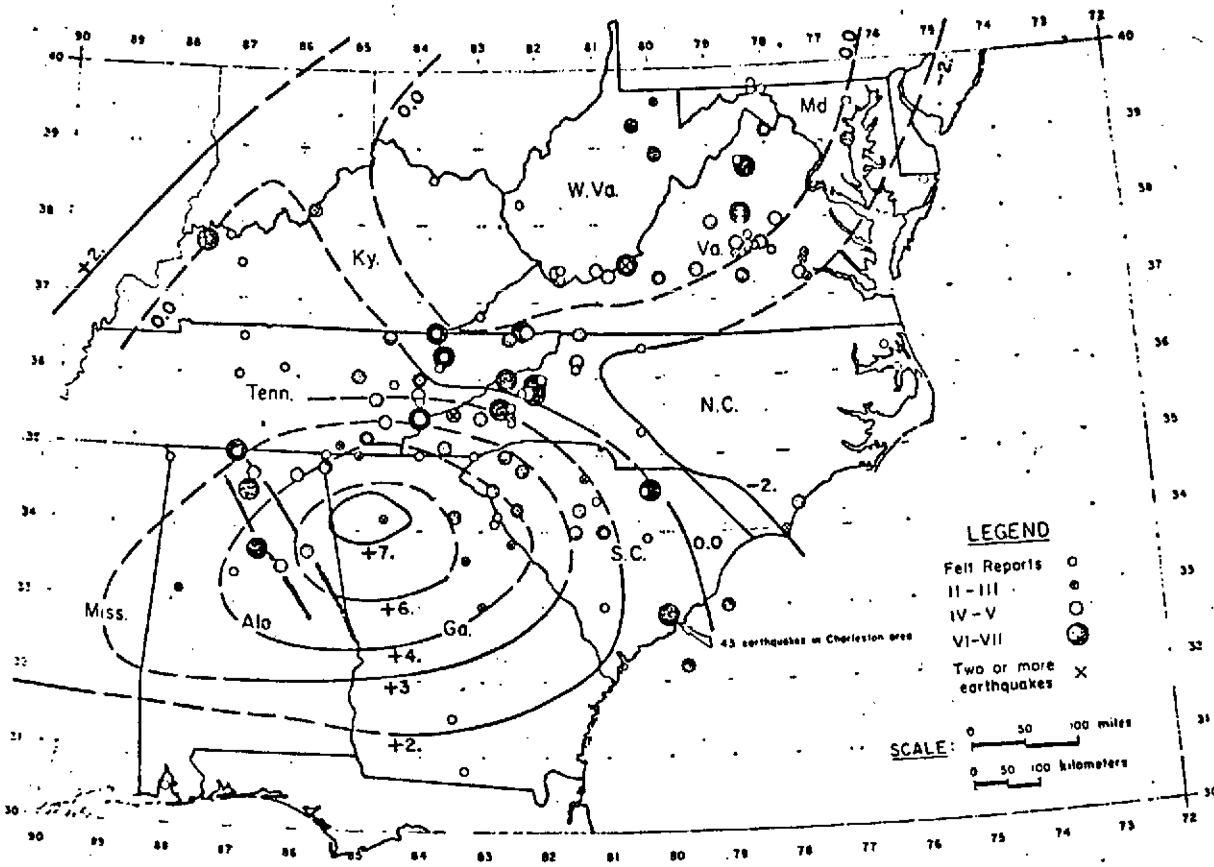


Figure 47.--Earthquake epicenters occurring between 1920 and 1970 and crustal movement rates (from Meade, 1971) for southeastern United States. Isobase contours (solid and dashed) in mm./yr. are from geodetic levelings in 1915 and 1965. Straight solid lines approximate the two major lineaments of Alabama. From Bollinger, 1973, fig. 5.

THE IMPLICATIONS AND ORIGINS OF LINEAMENTS

Based on this study, little can be contributed to the origin of all lineaments; however, several clues of their implications and relationships are revealed by factors associated with the two major lineaments. The Anniston and Harpersville lineament complexes are probably related to basement structures. Because offsets along the individual complexes are not in the same direction and, often involve rocks of differing ages, and because faults and folds terminate rather abruptly or change in style near the major lineaments, vertical, rather than horizontal movement of basement blocks appears to be the dominant form of displacement. Offsets in opposite directions along the same lineament may be explained by block rotation along basement geofractures in the vertical plane.

Such a conclusion has definite implications for the concepts of Appalachian structural styles. Abrupt terminations of structures have been described by Gwinn (1964, p. 891) in the Central Appalachians, but have been attributed to "thin-skinned" faults that connect two decollement-glide levels along strike. The present work suggests that changes in the decollement-glide levels of local sole thrusts or higher branching stepped thrusts both across and particularly along strike, is the result of vertical movement in basement blocks. In addition to the effect of basement faulting on ramp formation, the former may also have served as buttresses which impeded horizontal movement along decollement surfaces in the cover. Besides tectonic effects at the time of deformation, geofractures may have also exercised control over sedimentation to such an extent that it has had an affect on the location and configuration of decollement development. The very driving force for the "thin-skinned" tectonics of the Appalachians may have been derived from primarily vertical movement along these basement geofractures. Vertical uplift and the attendant development of tectonically unstable conditions in the overlying Paleozoic cover may have resulted in horizontal forces that expressed themselves in the formation of decollement-glide planes in the incompetent units of the Valley and Ridge synclinorium. Such a concept is counter to that of most workers in the Appalachians who either believe that the basement was not involved in Appalachian cover tectonics -- "thin-skinned" tectonics (Gwinn, 1964, 1970; Rodgers, 1950, 1953, 1963, 1970) or who believe that basement involvement is essential to all cover tectonics, -- "thick-skinned" tectonics (Cooper, 1961, 1964, 1968, 1970, 1971). Partial basement involvement in surface tectonics or horizontally induced structures resulting from vertical displacements have been described before (Cloos, 1948; Boos and Boos, 1957; and Eardley, 1963) but generally not for the Appalachians. Recently, however, Jacobeen and Karnes (1974) described the development of first- and second-order structural features of central Pennsylvania and western Virginia as having resulted from basement-controlled decollement ramping.

Coincidence of high-yield wells and springs, hydrothermal mineral deposits, geochemical highs and geophysical anomalies with the major lineaments suggest that fracturing of the basement is also expressed in the Paleozoic cover. Seismic activity along the same major lineaments indicates that they are related to basement geofractures that are still active.

An understanding of the major lineaments may also have implications for certain aspects of new global tectonics. Numerous suggestions exist that transform faults of the present Mid-Atlantic ridge have continental extensions. In the original definition of transform faults, Wilson (1965) clearly showed that the pattern of offset along the Mid-Atlantic ridge defined by transform faults is merely the reflection of the shape of the original break of the continents and is controlled by "lines of old weakness" that are present on the continental blocks before rifting. The "lines of old weakness" preserved on the continents after rifting and rotation represent less tectonically active continental equivalents of the more active transform faults. LePicheon and Fox (1971) have interpreted the fracture zones extending off the continental margins of North America and Africa to be first-order basement structures that are genetically related to the transform faults and the early opening of the Atlantic during the Mesozoic (fig. 48). They further assume that these marginal fracture zones lie along small circles of early Atlantic opening (fig. 49).

Many of the marginal fracture zones apparently show landward extensions, but some of these have been variously interpreted. The Newfoundland fracture zone of LePicheon and Fox, a sedimentary ridge underlain by a basement ridge (Auzende and others, 1970), appears to be aligned with the only large continental offset of the North American margin. Here the margin is offset approximately 460 kilometers and corresponds to a major change in the trend of the Appalachian system (Drake and Woodward, 1963). Sbar and Sykes (1973) have, in addition, pointed out that the Grand Bank earthquake of 1929 is near the continental extension of the Newfoundland fracture zone.

The Kelvin fracture zone of LePicheon and Fox is composed of a row of large conical seamounts that trend southeastward from the vicinity of Georges bank, defining a zone of weakness in the oceanic crust. Drake and Woodward (1963) have suggested that the Kelvin zone extends on to the continent as the Cornwall displacement which corresponds to a 130- to 150-kilometer offset in Appalachian structures in Pennsylvania and that may connect westward with the Paint Creek-Irvine fault zone of the eastern Interior.

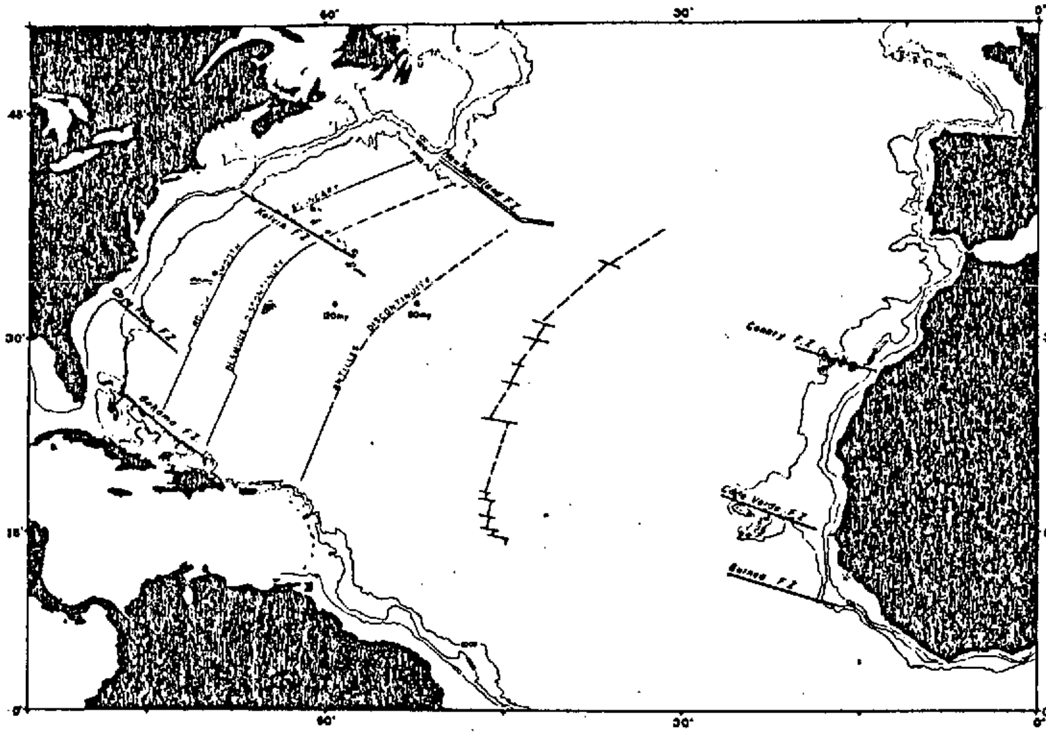


Figure 48.--Map showing the first-order basement structural features lying off the Coasts of North America and Africa. These have been interpreted by LePichon and Fox (1971) to be fracture zones related to the early opening of the Atlantic. The rough-smooth magnetic boundary is taken from Heirtzler and Hayes (1967) and Emery and others (1970). The boundary of the Bermuda and Antilles discontinuities is from Vogt and others (1970). The age of basement dates are from Joides drilling results (Peterson and others, 1970; Ewing and others, 1970). The lines near the center of the Atlantic represent the trace of the Mid-Atlantic ridge and associated transform faults. From LePichon and Fox (1971, fig. 1).

Figure 49.--The first phase of opening in the North Atlantic, beginning about 180 m.y. ago (Ewing and others, 1970). The length and trend of the arrows describe the movement of South America relative to North America. The linking of fracture zones now on either side of the Atlantic coincide with small circles of opening about a pole to the north of the map. From LePichon and Fox (1971, fig. 6a).

Others (Diment and others, 1972; Sbar and Sykes, 1973) suggest that a continental seismic belt, the Boston-Ottawa trend, lies along the extension of the Kelvin fracture zone and sea-mount chain and that both lie along a small circle of early opening for that part of the Atlantic during the Mesozoic (LePicheon and Fox, 1971) (fig. 50).

The Cape Fear fracture zone of LePicheon and Fox is thought to correspond to a basement ridge beneath the continental shelf that continues southeastward from the Cape Fear arch in the Piedmont of North Carolina to the Blake-Bahama outer ridge, postulated to be also underlain by a basement ridge (LePicheon and Fox, 1971). Others (Sbar and Sykes, 1973) point out that the South Carolina-Georgia seismic zone (Bollinger, 1973) lies along another small circle of early opening and that it is located near the continental extension of the Cape Fear fracture zone, also interpreted as lying along a small circle of early opening. Sbar and Sykes (1973), in addition, point out that several fracture zones in the vicinity, the most prominant being the Blake fracture zone (Johnson and Vogt, 1971), trend toward Charleston, South Carolina, and may be related to the South Carolina-Georgia seismic zone.

Further support for the extension of oceanic fracture zones on to continental blocks has been provided by the recent work of Burke (1969) and Fuller (1971, 1972) in Africa and deLoczy (1970) in South America. These workers describe seismic zone, boundaries of crustal blocks, major structures and volcanism along these continental extensions.

Seismic zones, basement highs and offsets in the trend of the Appalachian system appear to be located along possible continental extensions of marginal fracture zones described above. The furtherest south fracture zone described by LePicheon and Fox (1971) is the Bahama fracture zone which

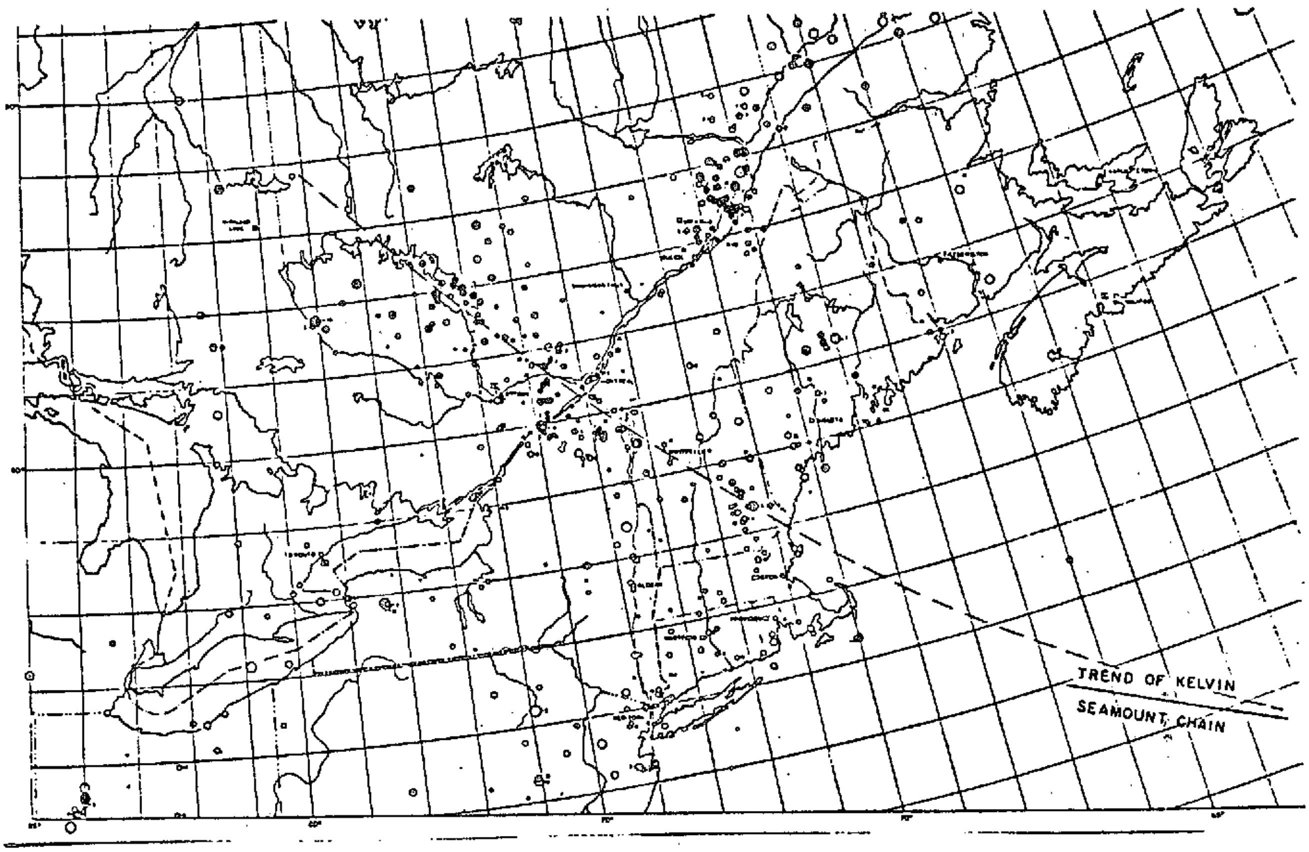


Figure 50.--The extension of the Kelvin fracture zone and seamount chain into the Boston-Ottawa seismic belt along a small circle of early opening (dashed line) for the North Atlantic (based on LePichon and Fox, 1971). The earthquake epicenters for northeastern North America shown here occurred between 1928 and 1959 (Smith, 1966). The solid circles have an uncertainty of $< \pm 20'$; open circles an uncertainty of $\geq \pm 20'$. Symbol size indicates relative intensity. From Sbar and Sykes, 1973.

corresponds to a sharp northerly facing scarp at the northeast edge of the Bahama platform. The scarp is the site of a series of magnetic highs which appear to be controlled by the fracture zone (LePicheon and Fox, 1971; Bracey, 1968). This fracture zone, too, may have a continental extension (fig. 51). The long axis of Central Georgia-Ocala-Peninsula arch in southern Georgia and northern Florida (Murray, 1956) lies along the small circle extension of the Bahama fracture zone. Murray (1956) suggested that this uplift is related to the Rome recess of the Appalachians along a northwest-southeast trending geological lineament. The small circle extension of the Bahama fracture zone through the uplift, however, projects into the area of and is parallel to the two major lineaments of Alabama just to the south of the Rome recess. The two major lineaments define the limits of a 10-kilometer deep recess in the metamorphic front in Alabama. In addition, the two lineaments show other offsets, terminations and changes in structural style along their traces as have been discussed previously. As also seen previously, these two zones appear to make up a seismic zone that is transverse to Appalachian structure in Alabama. In addition, the only earthquake epicenters known in Florida occur along the extension of the small circle of opening and along the axis of the Central Georgia-Ocala-Peninsular uplift in the northern part of the state. Bollinger (1973) has also shown two earthquake "felt reports" in southern Georgia that are directly in alignment with the small circle extension. The two "felt reports" constitute the only indication of seismic activity in south Georgia. Thus, the Bahama fracture zone, like the others farther to the north along the east coast of North America appears to have a continental extension which is characterized by seismicity, basement highs, and changes in Appalachian structural patterns.

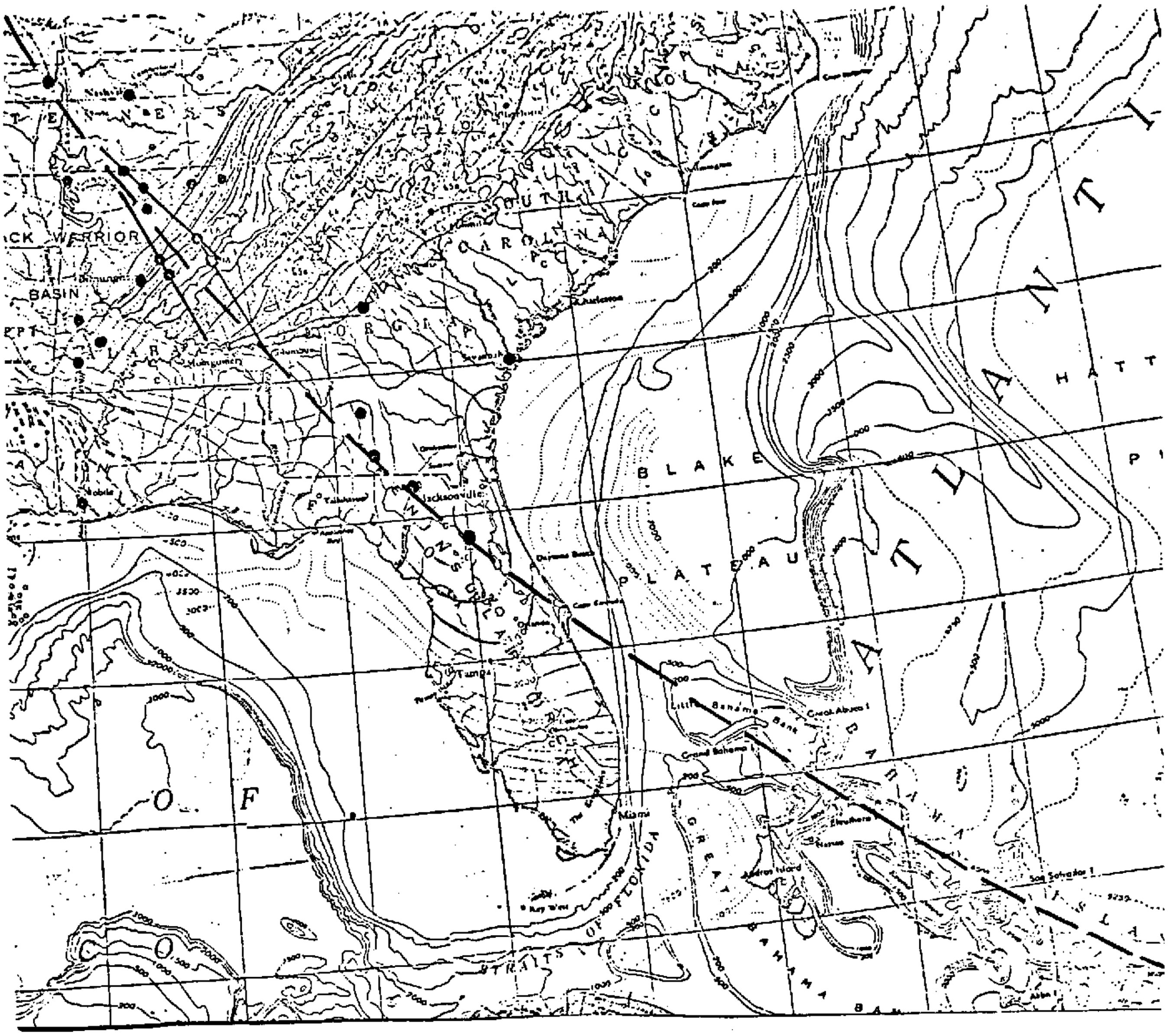


Figure 51.--The continental extension of the Bahama fracture zone defined by LePichon and Fox (1971) along a small circle of early opening (dashed lines). Earthquake epicenters (dots) for Florida, Alabama, southern Georgia and western Tennessee (from Bollinger, 1973, fig. 3). Solid lines are the two major lineaments of Alabama. Base map is from the Tectonic Map of North America (King, 1969).

Sbar and Sykes (1973, p. 1876) theorize that a change in the driving forces during the period of early opening, (when a continental block is present on at least one side of an active part of a transform fault) could create large stresses near the ends of major fracture zones. These stresses then could be one mechanism for locating tension and for creating or reactivating fault zones on the continent. They also admit that the alignment of the oceanic fracture zone with a continental seismic belt may suggest that both were controlled by a pre-existing fault zone formed prior to the Mesozoic opening of the North Atlantic. Our data seems to support the latter interpretation.

The mechanisms responsible for the formation of lineament-related features are not definitely known and this study has contributed little to this understanding. Periodic variations in rotational velocity of the Earth have been proposed as being responsible for lineament formation by Stokyo (1932, 1936) and Esclangon (1932). Oscillatory stresses, especially involving earth tides, is one of the most widely accepted mechanism for their formation (Blanchet, 1957). Hodgson (1961) considers earth tides, either alone or along with other tidal forces and cyclic stresses resulting from these tides to be the mechanism for producing joints as a result of rock fatigue. Haman (1974) believes that the sun's position relative to the galactic center produces rhythmic expansions and contractions of the Earth due to changes in gravity. Rance (1967) has shown that the pattern of physiographic lineaments in the Pacific Ocean can be explained by failure due to torsion caused by motions of subcrustal convection currents.

Most of the workers who propose oscillation as the prime mechanism agree with Mollard (1957) in suggesting that oscillatory forces continuously propagate fracture patterns from the basement upward but that initial fracturing in the basement may not be due directly to oscillatory forces. Upward propagation probably occurs as the result of both tensional and compressional stresses in a manner similar to that described by Bone and others (1954) for reflection cracking in newer bituminous surfaces covering older cracked concrete highways. The process is similar to the "bridging" mechanism proposed by Gay (1973, p. 97, 98). Isacksen (1974) has suggested that fracture systems originate near the surface in the Adirondacks and are propagated downward into the older rocks during gradual erosion. Scheibner (1974), on the other hand, sites evidence suggesting that older continental fracture zones are propagated laterally into the younger oceanic crust.

At the present time, the upward propagation concept has received the widest acceptance. Because basement structures are assumed to be propagated upward from basement and are related to structures formed throughout the geologic past as well as in relatively young sediments, the forces responsible are thought to be of high frequency and operating at the present time. Earth tides with their 23-36 cm. amplitudes appear to be the most widely accepted explanation. Wise (1969) has pointed out that even in the new crust of Iceland, lineaments are present and presumably reflect the wide-spread stress systems of the present or comparatively recent past. In older areas, lineaments are inherited from basement structures through selective reactivation related to modern stress systems and/or are created by modern stress systems.

The fact that lineaments are visible across much of Alabama including the colluviated areas attests to their recent, even present-day origin. The fact that at least some may be related to basement structures as suggested by the associated transverse earthquake zone further implies that their surface expression may form by upward propagation of basement faults.

The orthogonal patterns described in this report, so frequently mentioned by other workers, and emphasized by Gay (1973), may be the result of extensile stresses being relieved along one fracture set and forming another set at right angles due to the natural reorientation of the minimum stress (Wise, 1964, p. 302). Such pairsets resulting from stresses active in the formation of the older basement may then be selectively propagated upward through younger rocks as they are affected and perhaps modified by modern stress systems.

It is quite doubtful that lineaments all have a common origin and age. Only through detailed field work and the combined efforts of many workers can these factors be successfully worked out. The potential significance of lineaments not only to our understanding of the processes that have influenced the geology of our Earth but to the occurrence resources and to environmental hazard assessment makes their study critical.

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A COMPARISON OF LINEAMENTS AND FRACTURE TRACES TO JOINTING IN THE APPALACHIAN PLATEAU OF ALABAMA--DORA-SYLVAN SPRINGS AREA

By C. C. Wielchowsky

Introduction

In recent years, several workers (Lattman and Nickelson, 1958; Hough, 1960; Boyer and McQueen, 1964; Sonderegger, 1970) have shown that the dominant modes for trends of fracture traces and lineaments generally correspond to the dominant modes for the strike of joints in relatively flat lying sedimentary rocks. These fracture traces and lineaments were usually mapped from low altitude, large scale black and white panchromatic positive prints, although work has also been done with other film types and imaging systems. With the collection of high altitude and orbital imagery, larger scale features of the earth's crust, such as the longer lineaments, can now be analyzed; therefore, this study was undertaken to compare jointing to lineaments and fracture traces mapped from orbital and high altitude imagery.

The study area (fig. 1) selected includes the Dora and Sylvan Springs quadrangles located about 25 km northwest of Birmingham, Alabama. This particular area was selected for the following reasons:

1) Most of the rocks are horizontal or dip very gently.

2) Excellent exposures are afforded by the large number of coal strip pits in the area.

Figure 1.--The location of the two-quadrangle study area in Jefferson and Walker Counties is shown above. Dora is the northern quadrangle and Sylvan Springs is the southern.

3) Underground coal is being actively mined in parts of the area; therefore, jointing at depth could be measured.

4) Other Geological Survey of Alabama projects are underway in the area, thus providing additional data.

5) ERTS and U-2 data, plus recent $7\frac{1}{2}$-minute topographic quadrangle maps were available for this area.

General Geology

The Dora and Sylvan Springs 1:24,000 topographic quadrangles are located in the Warrior Basin of the Appalachian Plateau physiographic province of Alabama. The rocks exposed in the area are all units within the Pottsville Formation of Pennsylvanian age and consist chiefly of an alternating sequence of sandstone and shale with lesser amounts of siltstone, coal, underclay, conglomerate, and limestone. Regionally, these units dip gently to the south and southwest and thicken to more than 1,800 m in that direction in Pickens County. In the area of the two quadrangles, the Pottsville thickens from about 390 m in the north (Dora quadrangle) to approximately 750 m in the south (Sylvan Springs quadrangle). In the Warrior Basin, the Pottsville has been divided into several stratigraphic intervals (fig. 2) by Metzger (1965). Metzger's (1965) units A, B, C, D, and E are exposed in the two quadrangle study areas. The general geology of the Warrior Basin is also discussed by Butts (1911), Adams and others (1926), and Semmes (1929).

The Warrior Basin as a whole is broadly synclinal and plunges very gently to the southwest. Structures within the basin consist chiefly of nearly symmetrical anticlines and synclines that also plunge to the southwest (Blair, 1929). In addition, a series of en echelon normal faults crop out in the basin and strike generally about N20W. The northern part of the study area is influenced by the southwesterly plunging Sequatchie anticline (fig. 2), although dips are seldom greater than 10 degrees. Blair (1929) shows the axis changing strike from about N45E in the northern part of the study area to about N15E in the southern part. Thomas and Bearce (1969) and Thomas (1972, plate 1) show the axis striking fairly constantly about N45W through the study area. For the purpose of the interpretation of stress axes, the anticlinal axis is assumed to strike N45E. According to Blair (1929), at least 12 normal faults are exposed in the study area. These faults strike on the average N25W (fig. 3) and their length is generally proportional to the amount of displacement. For example, a fault with a displacement of 30 m usually has a length of about 3.2 km (Blair, 1929).

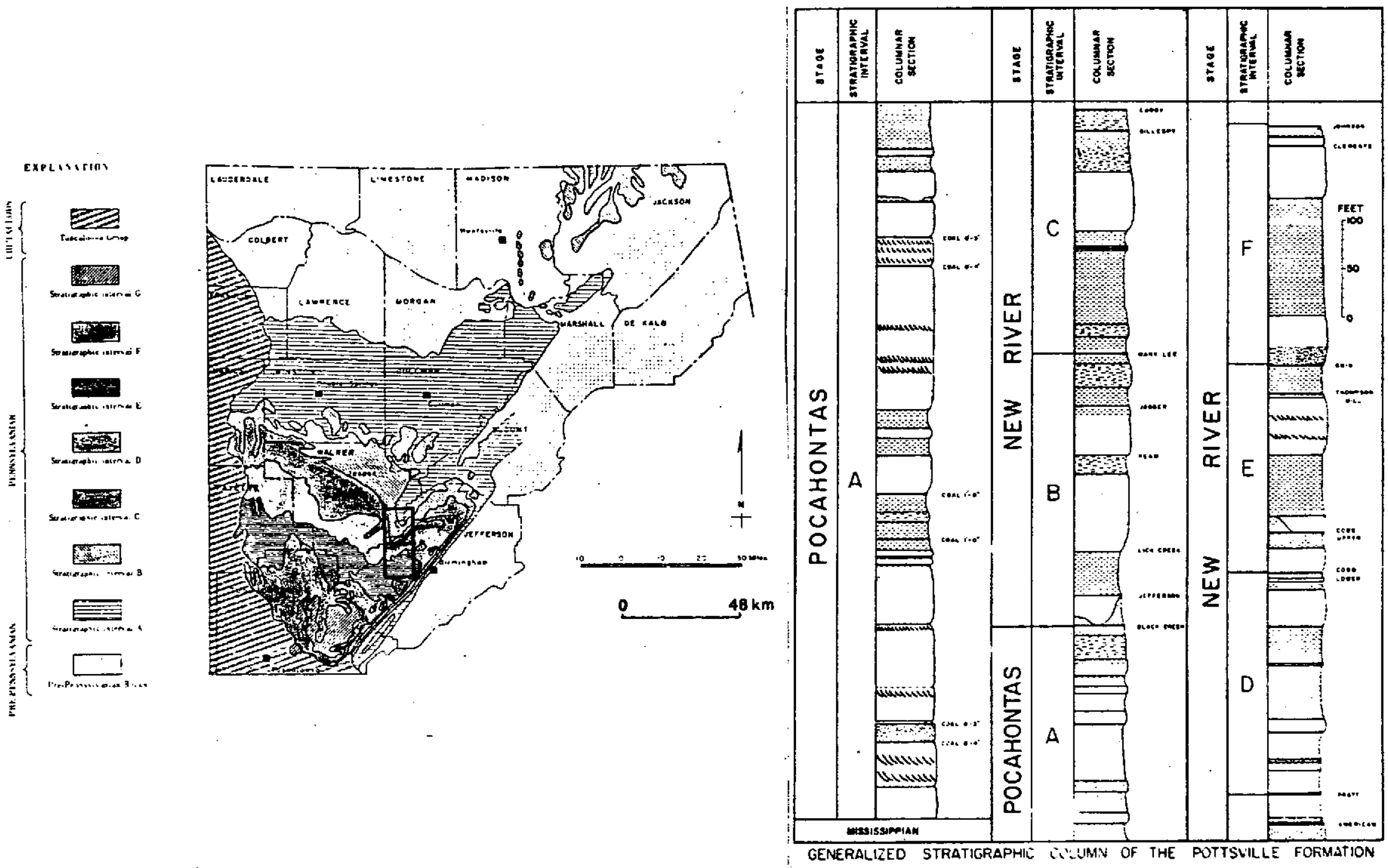

Figure 2.--Geologic map of the Warrior Basin with generalized stratigraphic section after Metzger (1965). Study area is outlined in black.

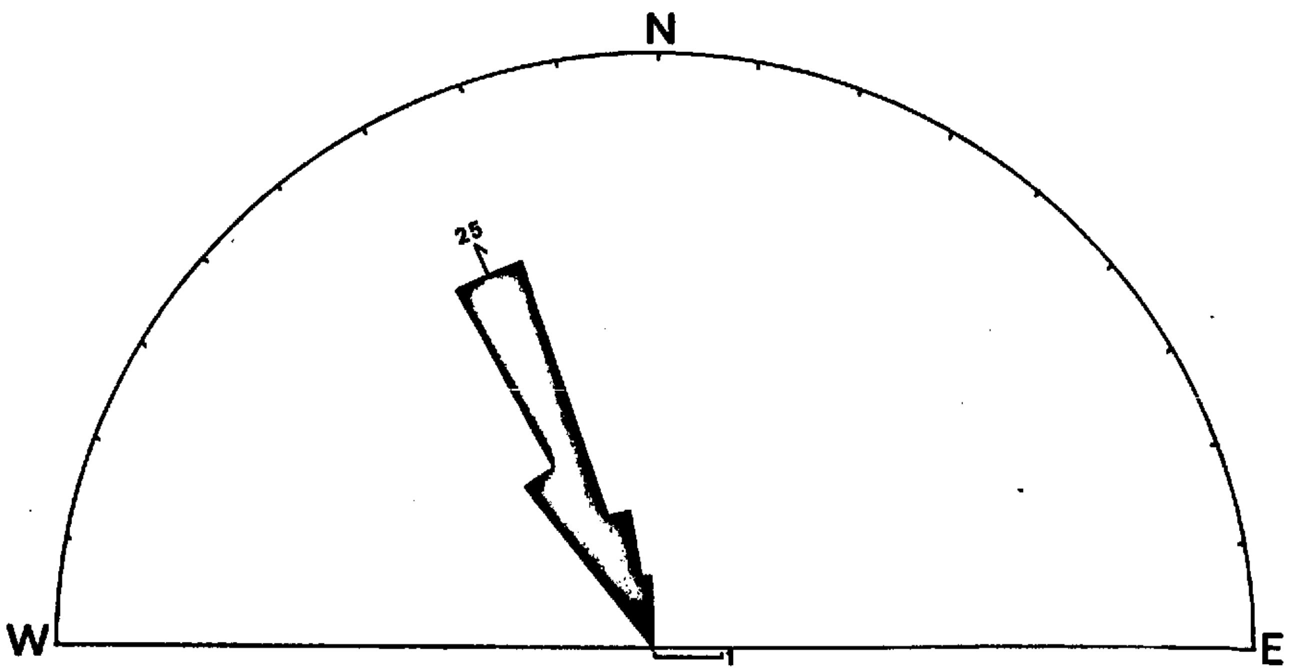

Figure 3.--Rose diagram showing orientations of the 12 normal faults exposed in the study area mapped by Blair (1929). The arrow refers to the mean direction of all faults and the bar scale at the bottom refers to the interval in number of faults.

Procedure and Results

ERTS band 5 data (1176-15553-5; 15 Jan 73) were used to map topographic and tonal lineaments and fracture traces, as defined by Lattman (1958), at a scale of 1:250,000. These were then transferred to a 1:250,000 AMS sheet and finally to the two 1:24,000 scale topo sheets where they could be compared to topographic and cultural features. All lineament and fracture trace orientations were measured and plotted on a rose diagram (fig. 4). Dominant modes occur at N40-50W, N10-20W, N30-40E, and N70-80E. Averages for each mode and surrounding intervals were calculated and are also shown in figure 4. To be included in the average, an interval must contain at least one-half the number of lineaments found in the adjacent dominant mode. (This averaging technique was also used for U-2, topo-sheet, and joint data.) It should be noted that two relatively equal dominant modes separated by an interval that is greater than one-half their height are averaged together.

Color infrared photography, collected by a U-2 flying at 19,500 m (Flight No. 73-023; FSR-237) on 22 February 1973, was also used to plot topographic and tonal lineaments and fracture traces at a scale of 1:130,000. These were then transferred directly to the 1:24,000 sheets. Dominant modes occur at N50-60W, N10-20W, N30-40E, and N70-80E. These data are presented in figure 5.

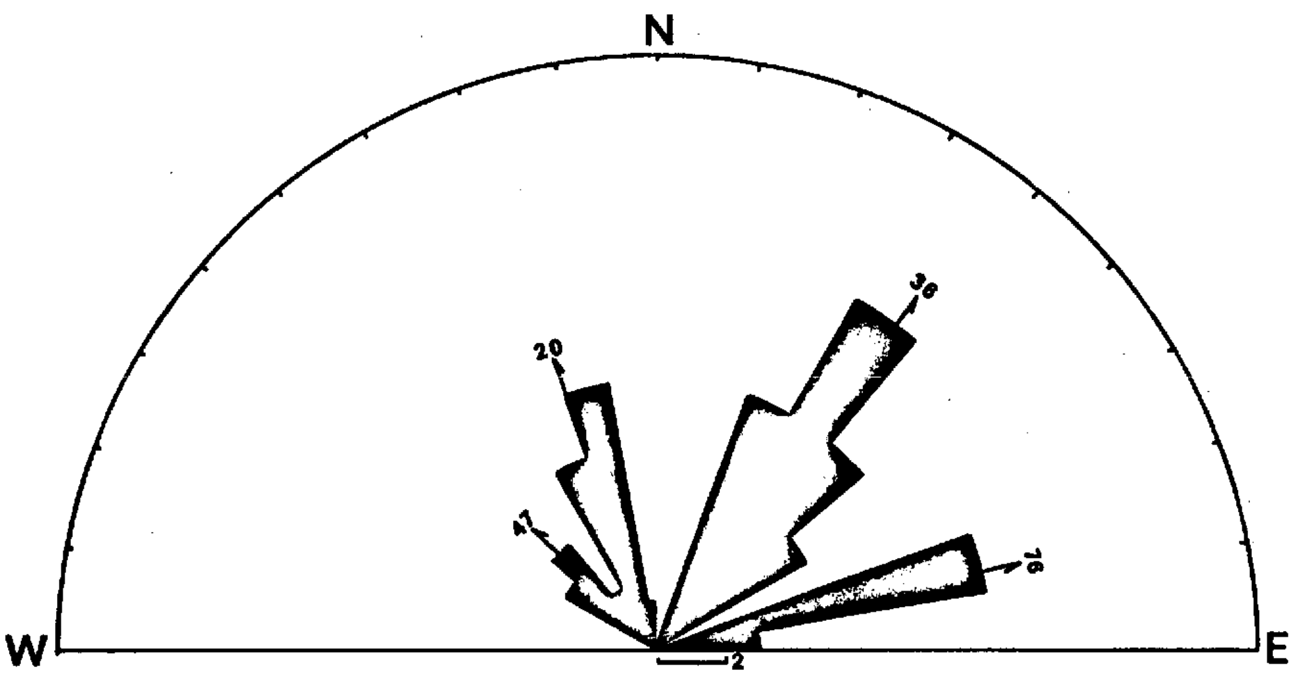

Figure 4.--Rose diagram showing orientations of all lineaments and fracture traces mapped from ERTS data. Arrows refer to mean direction for each mode and surrounding 10° intervals. Bar scale at bottom refers to interval in number of lineaments and fracture traces.

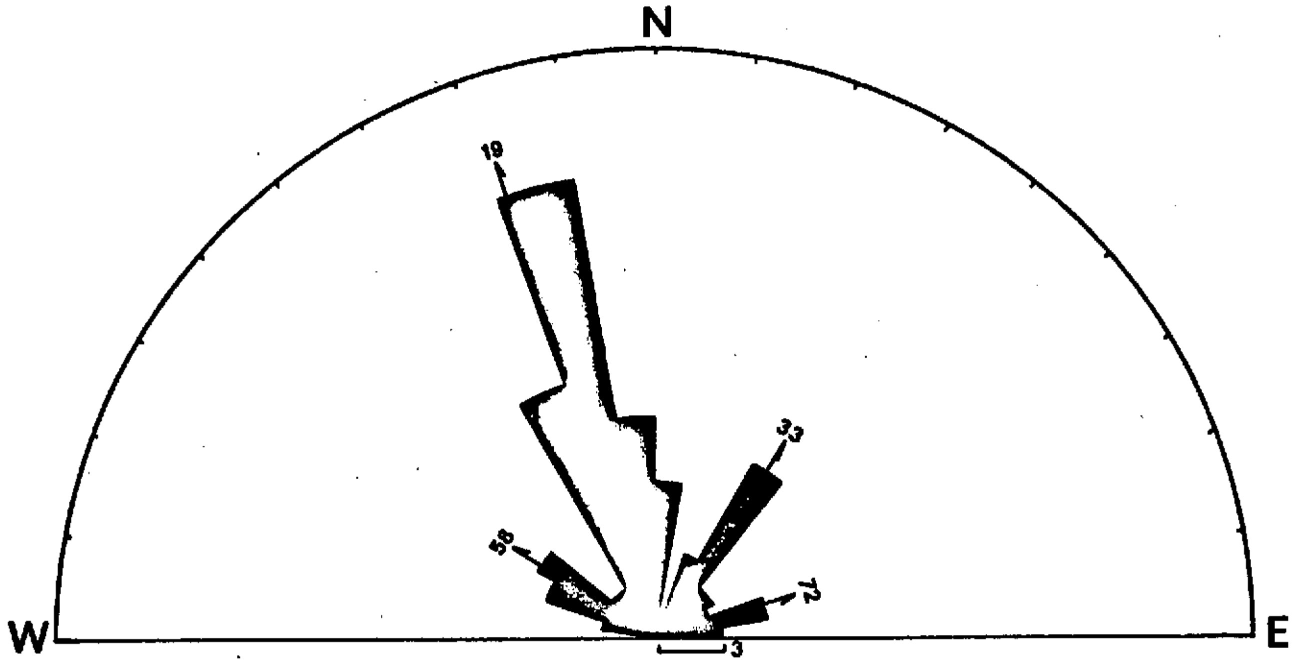

Figure 5.--Rose diagram showing orientations of all lineaments and fracture traces mapped from U-2 data. Arrows refer to mean direction for each mode and surrounding 10° intervals. Bar scale at bottom refers to interval in number of lineaments and fracture traces.

Topographic linear elements were mapped directly from the topographic sheets. Dominant modes occur at N20-30W, N30-40E, N50-60E, and N70-80E (fig. 6). All lineaments and fracture traces are shown in plates 3 and 4, as well as rose diagrams of joints and coal cleats, all known faults, and structural axes.

Joint data were collected at 18 surface outcrops and in one underground coal mine (Bessie Mine, of the U.S. Pipe & Foundry Co.) in the two-quadrangle area (plates 3 and 4; figs. 7 and 8). At each surface station all joints were measured in a 12-meter traverse (Hoblitzell, 1970) and frequencies were either directly determined or estimated. Where coal units were exposed, coal cleats were also measured. (Nickelsen and Hough (1967) have also measured coal cleats and compared them to jointing in the Appalachian Plateau of Pennsylvania.) These data are presented in figures 9 and 10. Frequency data were normalized by estimating joint frequency as if each joint set was normal to the 12-meter traverse. The following information was recorded for each joint set,as defined by Billings (1972), on previously prepared joint data sheets:

1) Joint attitude - dip and strike of joint surface.
2) Joint type - systematic or nonsystematic nature (Hodgson, 1961).
3) Joint spacing - relative spacing and thus frequency of joints.

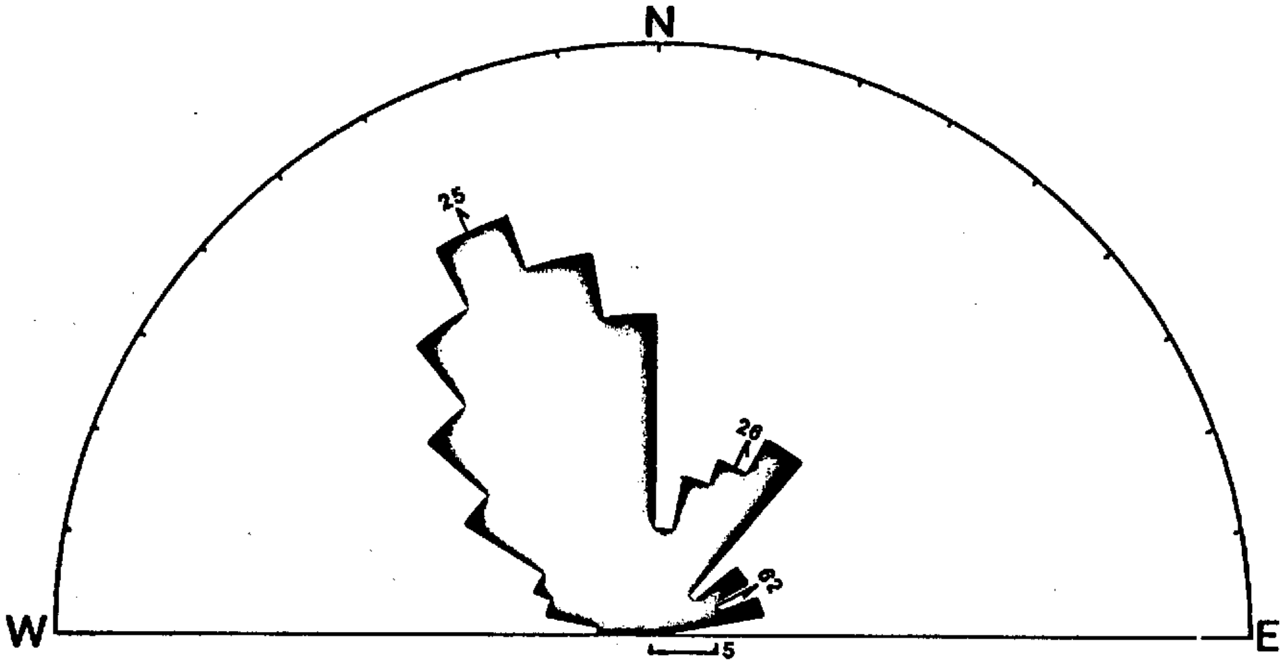

Figure 6.--Rose diagram showing orientations of all topographic lineaments and fracture traces mapped from the two quadrangles. Arrows refer to mean direction for each mode and surrounding 10° intervals. Bar scale at bottom refers to interval in number of lineaments and fracture traces.

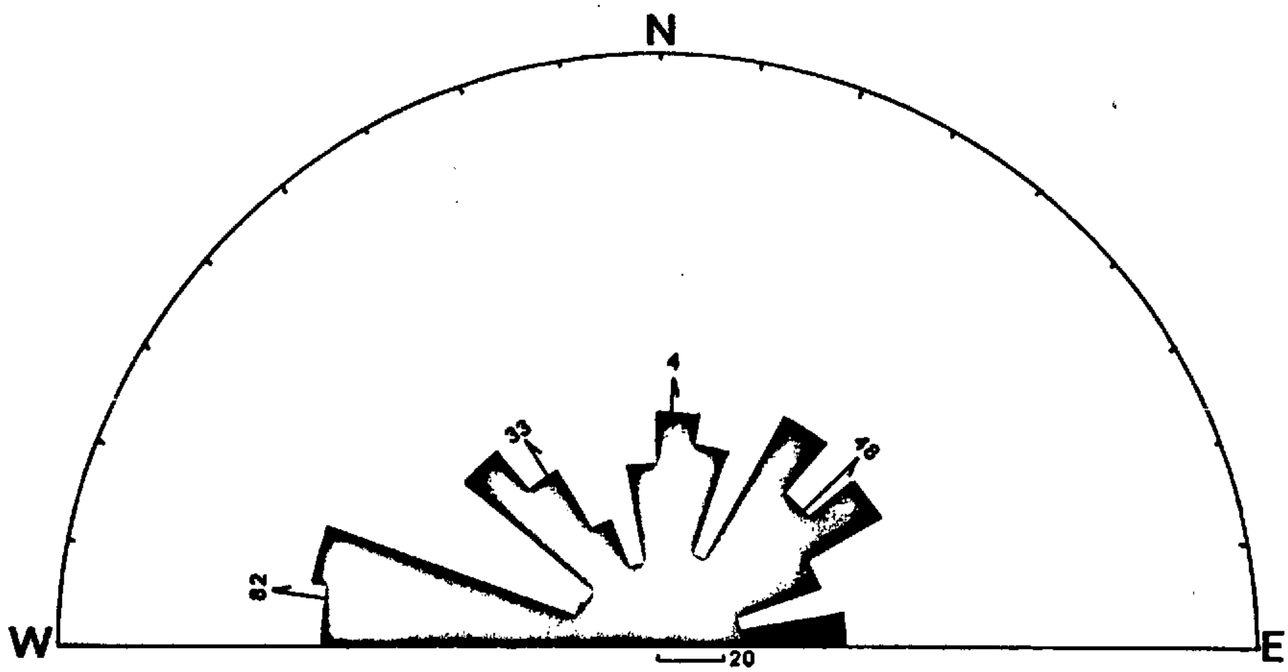

Figure 7.--Rose diagram showing orientations of all surface joints measured in the two-quadrangle study area. Arrows refer to mean direction for each mode and surrounding 10° intervals. Bar scale at bottom refers to interval in number of joints.

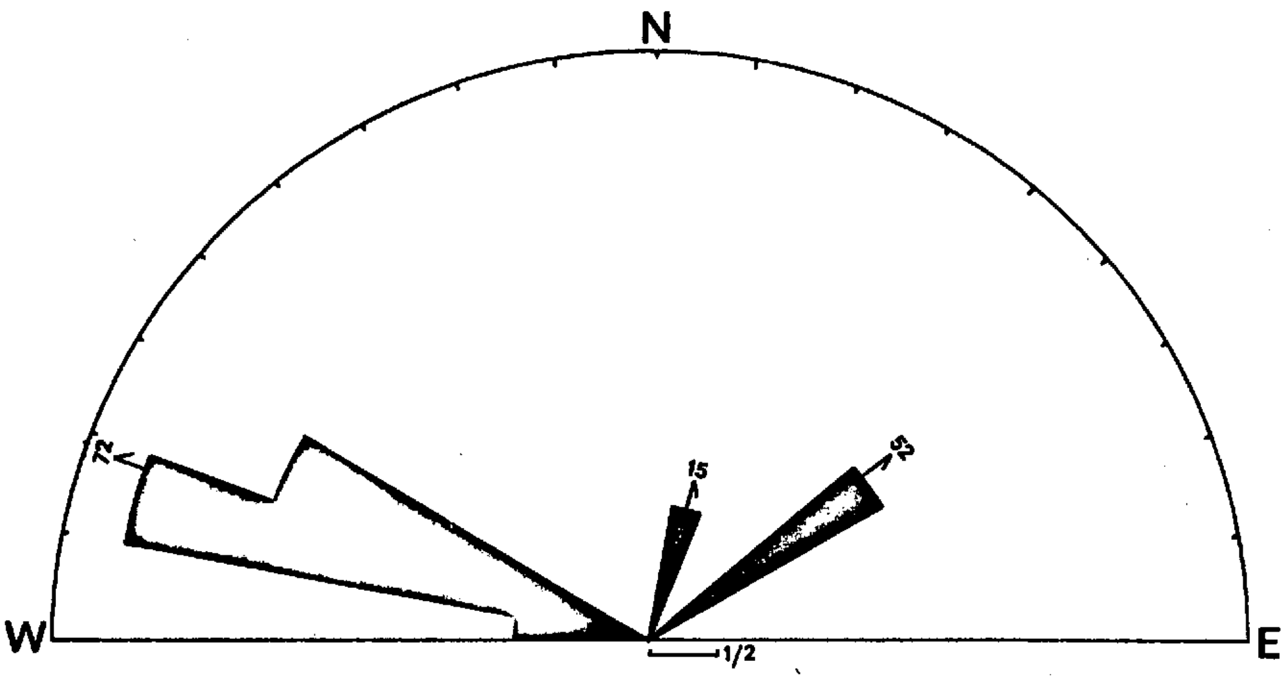

Figure 8.--Rose diagram showing orientations of all subsurface joints measured at the Bessie Mine. Arrows refer to mean direction for each mode and surrounding intervals. Bar scale at bottom refers to interval in number of joints.

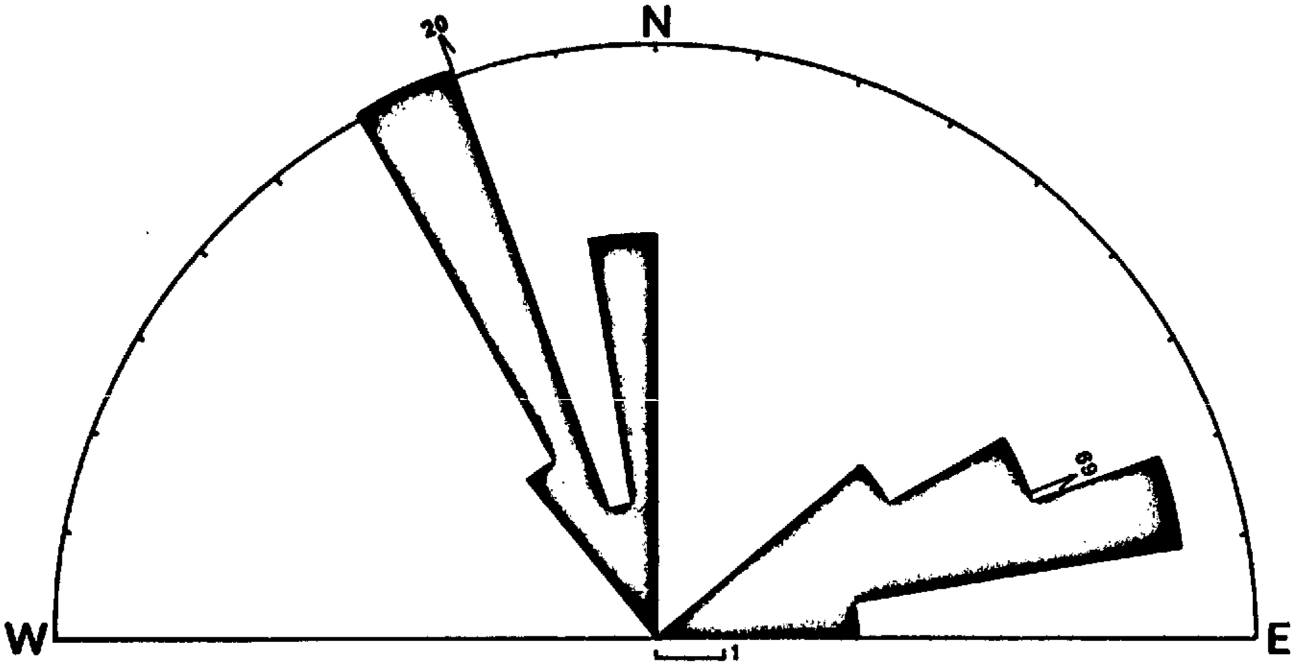

Figure 9.--Rose diagram showing orientations of all surface coal cleats. Arrows refer to mean direction for each mode and surrounding intervals. (All cleats in the NW quadrant were averaged.) Bar scale at bottom refers to interval in number of cleats.

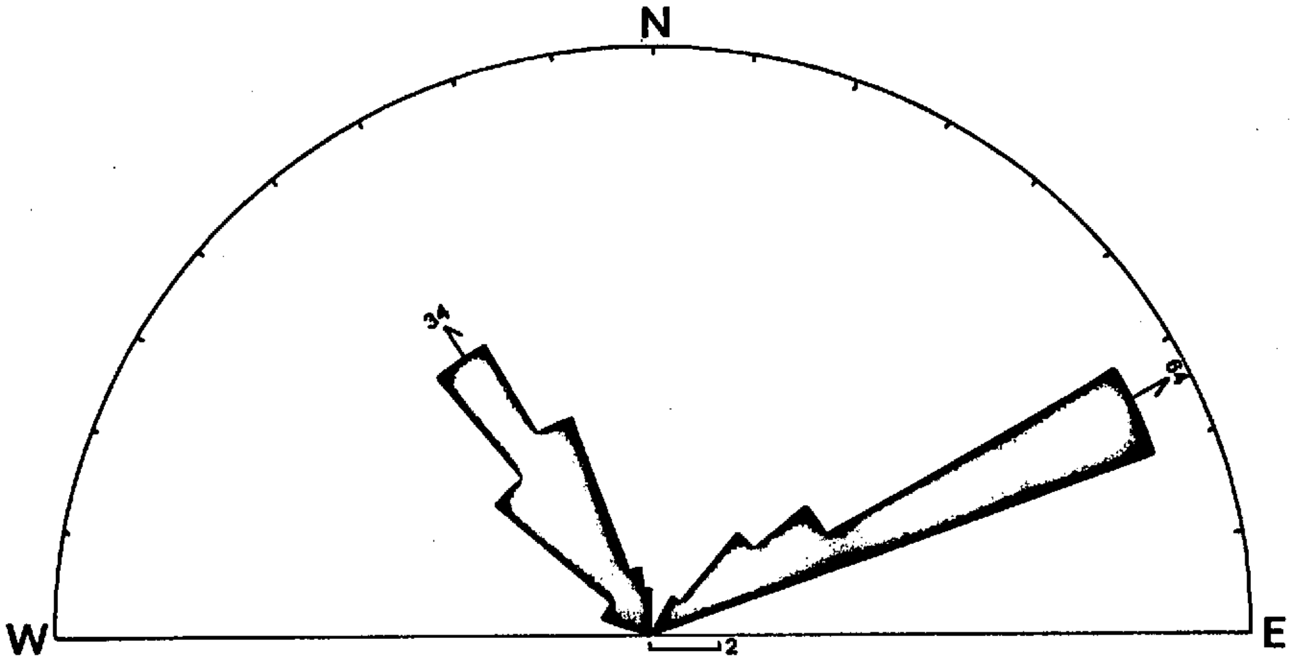

Figure 10.--Rose diagram showing orientations of all subsurface coal cleats measured at the Bessie Mine. Arrows refer to mean direction for each mode and surrounding intervals. Bar scale at bottom refers to interval in number of cleats.

4) Persistence - master joints - extend through at least 6 m of strata; major joints - extend through strata from .03 m to 6 m in thickness; minor joints - extend through less than .03 m of strata (Hoblitzell, 1970).

5) Regularity - how regular the joint surface is in both strike and dip.

6) Nature of surface - description of the surface features of the joint plane, and whether the joint is opened or closed.

7) Nature of filling - if the joint is filled, a description of the filling.

In addition, at each locality the lithology, bedding thickness, and formation attitude and name were recorded. Dominant modes occur at N70-80W, N40-50W, N0-10E, N30-40E, and N50-60E. The master systematic joint set strikes about N70-90W. This trend was extremely persistent throughout the study area and was also observed in many outcrops outside the study area.

In general, both open (sometimes filled) and closed joints were noted, and in some cases, plumose structures were observed. Most systematic joints were open in nature. Some master systematic joints were actually zones as much as .3 m wide, containing closely spaced irregular fractures. At times these fractures splayed off at 90° to either side of the master joint to parallel the topographic surface and form what are apparently sheeting surfaces (Billings, 1972, p. 170). These were not included in the rose diagrams. Table 1 shows average joint spacing, range of joint spacing, and the frequency of occurrence of a mode over the 18 stations.

Discussion

Joints

Figure 11 shows the relationship between the average strike of joint sets, normal faults, and the axis of the Sequatchie anticline. The four average joint directions may be classified geometrically as follows (Badgley, 1965):

N48E - Longitudinal joints

N33W - Cross joints

N82W - Diagonal joints

N04E - Diagonal joints

This classification, however, is geometric and not genetic, though Billings (1972, p. 168), and Badgley (1965, p. 99), by implication, suggest genetic relationships. Thus, the N33W set might represent extension joints, the N48E set might represent release joints, and the N82W and N4E set could represent a conjugate shear fracture system (Griggs, 1935). The angles involved between joint averages,

Table 1.--Comparison of average joint spacing, range of joint spacing, and relative frequency of occurrence of each mode out of 18 stations.

	Average joint spacing (m)	Range of joint spacing (m)	Relative frequency of occurrence out of 18 stations
N70-90W* N80-90E	1.8	.3-6	100
N20-50W	.9	.3-2.4	28
N0-10W N0-20E	.9	.3-2.4	50
N30-70E	1.5	.3-6	89

*These orientations include all 10° intervals that were averaged to yield a single mode.

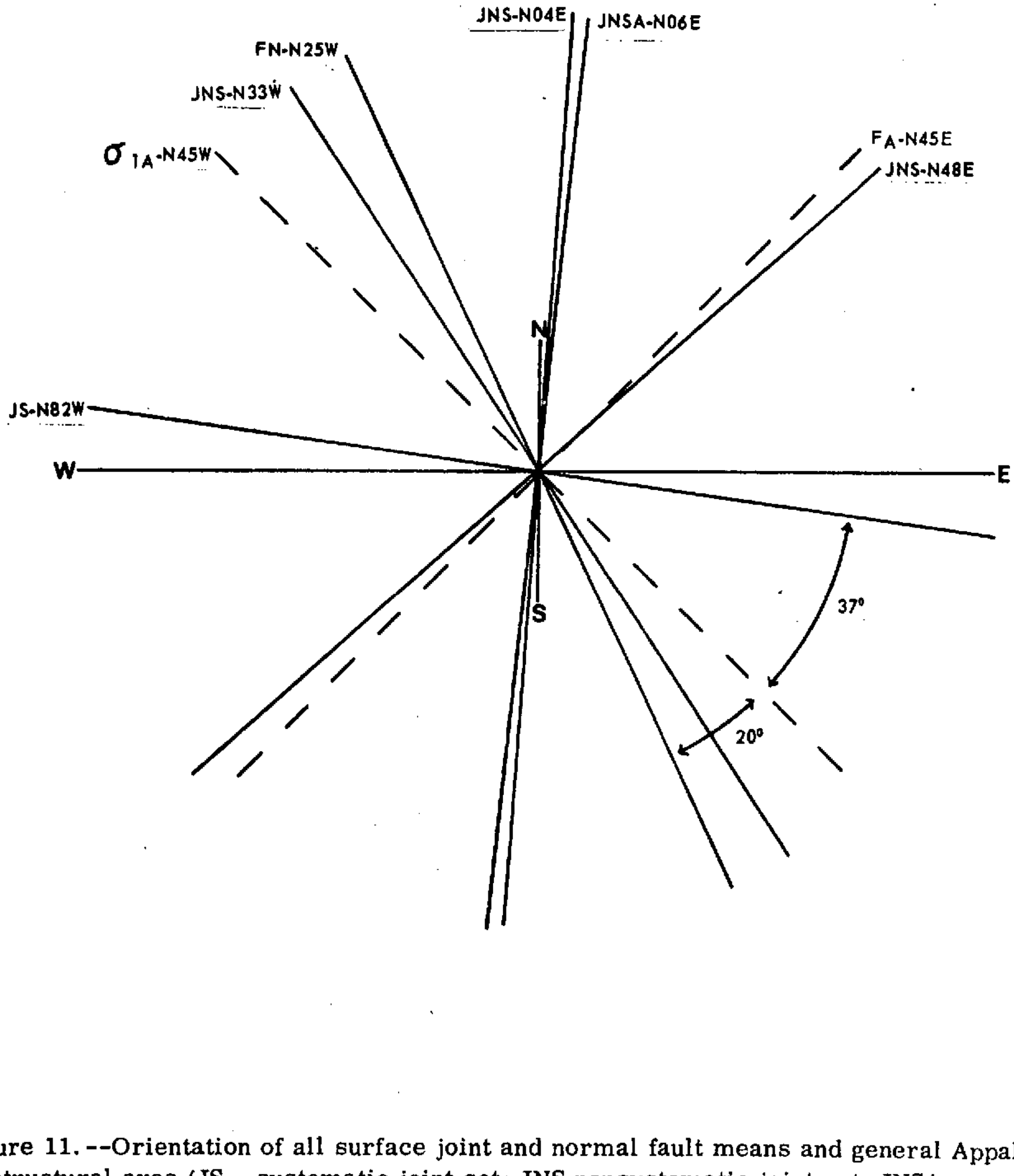

Figure 11.--Orientation of all surface joint and normal fault means and general Appalachian structural axes (JS - systematic joint set; JNS-nonsystematic joint set; JNSA-average of nonsystematic joint sets; FN - normal faults; σ_{1A} - theoretical orientation of major Appalachian compressive stress; F_A - general strike of Appalachian fold axes and the Sequatchie anticline).

C.36

however, seem to mitigate against such an interpretation (i.e., the angle between σ_{1A} and JNS-N33W is 12° which is probably too great for these joints to be pure extensional features. Muehlberger (1961), however, has shown that some fractures make small angles with σ_1 and that there is a continuous spectrum between tensional and shear failure. Perhaps this joint set could be one of these fracture types. In addition, the angle between JS-N82W and JNS-N04E is 86°, which is 26° greater than the theoretical 2θ).

If the major principal stress (horizontal) that caused jointing was from the south (i.e., Appalachian stress from the southeast is not related to jointing), then the N4E joint set would represent extension fractures, the N82W joint set would represent release fractures, and the N48E and N33W sets would represent a conjugate shear system. In this interpretation, the angles fit much better, but there is little evidence for such a southerly major principal stress. Simpson (1963), however, does suggest just such a southerly major stress axis based on his study of jointing along the southeastern flank of the Birmingham anticline. Carrington (1972) also suggests a southerly major stress axis based on his study of the metasedimentary rocks associated with the southern extremity of the metamorphic front in Alabama.

If the major systematic joints (N82W) are interpreted as extension fractures, as Nickelsen and Hough (1967) did for the Appalachian Plateau in Pennsylvania, and if it is assumed that the three major nonsystematic sets (N33W, N4E, and N48E) are really part of one nonsystematic set of release joints with an average orientation of

N6E (calculated by averaging N33W, N04E, and N48E), then there is just one fundamental joint system (Nickelsen and Hough, 1967, p. 615) which could have resulted from a nearly east-west compressional force. Again, however, there is little evidence to suggest such a major principal horizonal stress direction.

Thus far, compressional forces have been invoked to explain the stresses essential for fracturing. An alternative mechanism by which the stress necessary for fracturing may be obtained is to have a decrease of lateral pressure due either to the warping of the sedimentary basin or to vertical growth of basement structures (Griggs and Handin , 1960). Lateral stress should lead to extension joints approximately perpendicular to the axis of structures, whereas warping or vertical basement growth should lead to extension joints paralleling the axis of warping. Meade (1971) has shown that profound recent upwarping has occurred in the southeast. Moreover, the incised river channels in the Warrior Basin attest to this broad uplift; however, the axis of this upwarping trends to the northeast, and not along the N82W trend of the major systematic joint set. The normal faults, in the area, have probably been formed by either this vertical uplift which caused movement of previously formed fractures, or by relaxing of horizontal stresses.

It appears that lateral compression from two directions and vertical basement growth must be invoked to explain the origin of the four major joint sets and the normal faults that occur in the Dora-Sylvan Springs area. Appalachian principal stress from the southeast (approximately S45W) probably caused the formation of a conjugate shear set of fractures represented now by the N82W set of systematic joints and the N33W joints plus N25W normal faults. (The question now arises as to whether or not the N82W joints, which are the major systematic joints in the area, have resulted from shear failure. A few plumose markings were observed on these joint surfaces, but plumose patterns have been used to support both a shear (Parker, 1942) and a tensional (Muehlberger, 1961) origin of joints. Some of the systematic joints can be interpreted as narrow cataclastic zones, which are indicative of shear failure (Badgley, 1965).) The angle between the N82W joints and N25W faults is 57°, which is very close to the theoretical 2θ of 60° for shear fractures. The N48E joint set represents release fractures perpendicular to the major principal stress. The N4E joint set may represent extension fractures that were formed by a principal stress direction that originated somewhere to the south as Simpson (1963) and Carrington (1972) proposed. Whether this stress is pre- or post-Appalachian is not known at this time; however, if this southerly stress is post-Appalachian, perhaps some shear strain was taken up by the N33W joints plus N25W faults and the N48E joints. Possibly the N82W systematic set was also strained again, but this time as release joints. Finally, regional upwarp caused the N33W-N25W jointing to slip vertically and form a set of normal faults striking N25W. Those that did not slip remain as the N33W joint set.

The joints measured underground (approximately 120-150 m below land surface) in the Bessie Mine of the U.S. Pipe & Foundry Company correspond generally to the modes measured at the surface (fig. 12). Again the major systematic set was in the N-70-90W direction.

Coal Cleats

Surface coal cleats show a counter-clockwise rotation of about 20° from the northern part of the study area to the southern part (plates 3 and 4). Apparently the Sequatchie anticline has either passively affected the formation of the cleats or the stress responsible for Sequatchie folding also caused the formation of the coal cleats. According to Nickelsen and Hough (1967), differences in joint patterns from one lithology to another (e.g., shale to coal) reflect either different strengths, times of lithification, or origin of stress differential. They felt that coals are relatively weak and are capable of being jointed early (Nickelsen and Hough, 1967, p. 627); therefore, coal cleats are relatively sensitive indicators of early, small stress differentials. These stresses may result from warping of the basin or some other type of epeirogenic activity (Nickelsen and Hough, 1967, p. 627). On the other hand, the nonsystematic cleats (N20W) may represent extensional fractures formed by early Appalachian stress and the systematic cleats (N60E) may represent release fractures, though the systematic set would be expected to be extensional in origin.

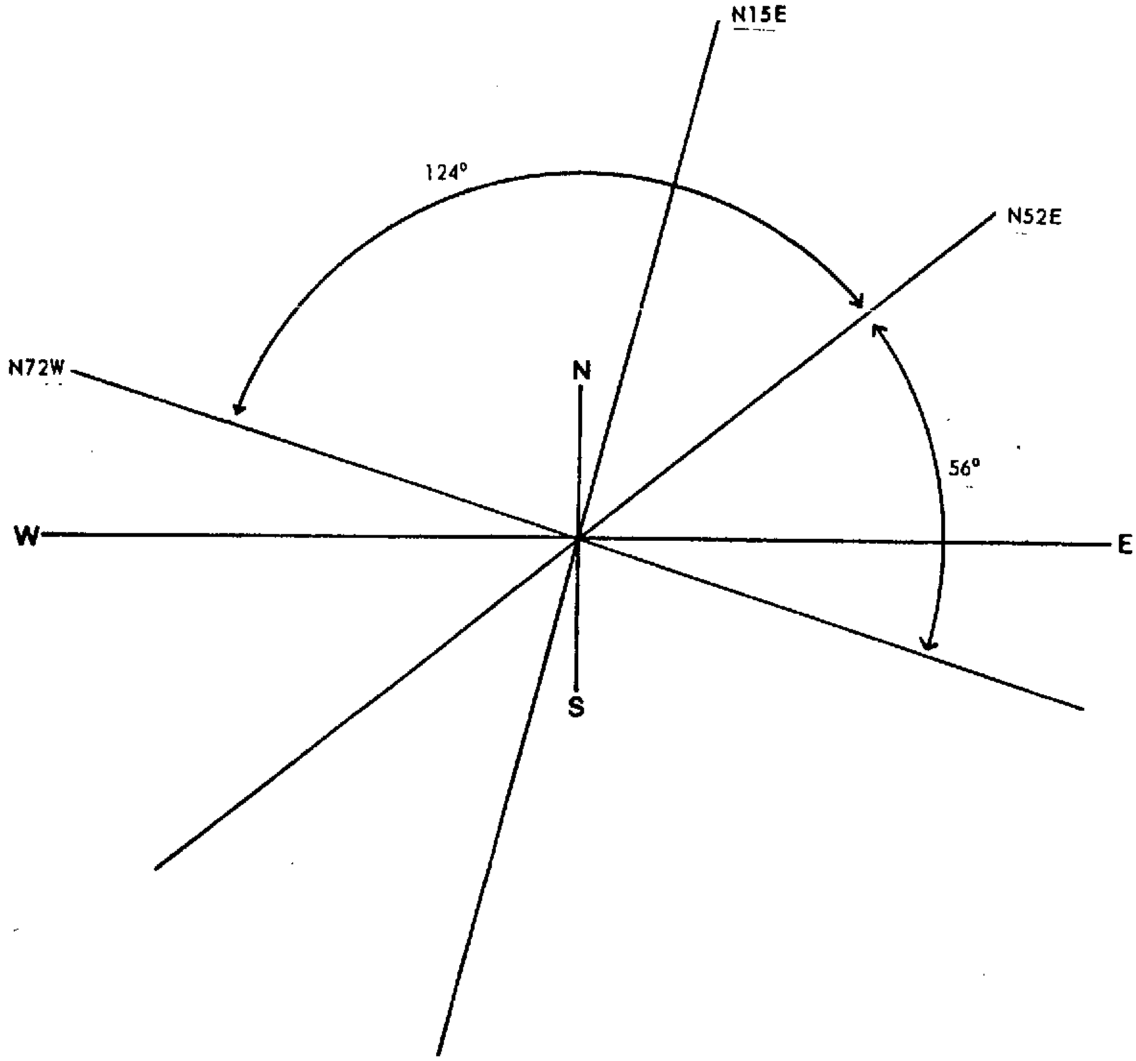

Figure 12.--Orientation of all subsurface joint means.

The strike of underground coal cleats generally corresponds to surface coal cleat strikes (fig. 13). The slight differences are due to the influence of the Sequatchie anticline on the northern surfacial coal cleats.

The nonsystematic coal cleats (N34W and N20W) seem to correspond generally to the N33W joint and N25W fault trends; however, the systematic coal cleats (N69E and N64E) do not seem to correspond to any joint mode. This is probably due to the previously mentioned differences given by Nickelsen and Hough (1967).

Comparison of Joints to Lineaments and Fracture Traces

Table 2 and figures 14, 15, and 16 compare the lineaments and fracture trace modes from ERTS, U-2, and topographic data (similar modes from these three data types were averaged) to fracture modes. In general, two of the four modes seem to correspond fairly well with the fracture modes. The N48E joint mode is within 16° of the N32E average lineament and fracture trace mode. Given the inherent errors and biases in this type of analysis, plus the fact that the N48 E joint mode was calculated from a bimodal distribution, it is felt that the 16° discrepancy is small enough for there to be a reasonable certainty that the N48E joint mode and N32E lineament and fracture trace mode coincide. The N33W joint and N25W fault modes are within 12° and 4°, respectively, of the N21W lineament and fracture trace

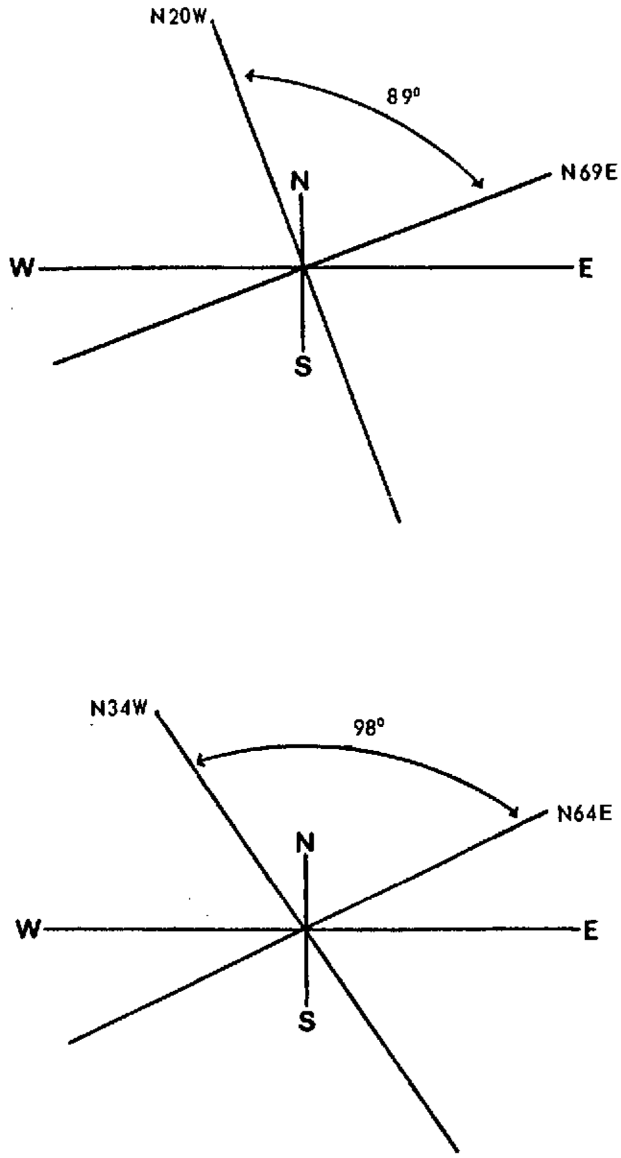

Figure 13.--Orientation of all surface and subsurface coal cleat means.

Table 2.--Comparison of lineament plus fracture trace modes to fracture modes.

ERTS	U-2	Topo	Av.	Fracture mode
N76E	N72E	N62E	N70E	—
N36E	N33E	N26E	N32E	N48E
N20W	N19W	N25W	N21W	N33W N25W
N47W	N58W	—*	N53W	—

*This mode is either masked by the large N25W mode present on the topographic map or in reality does not exist topographically.

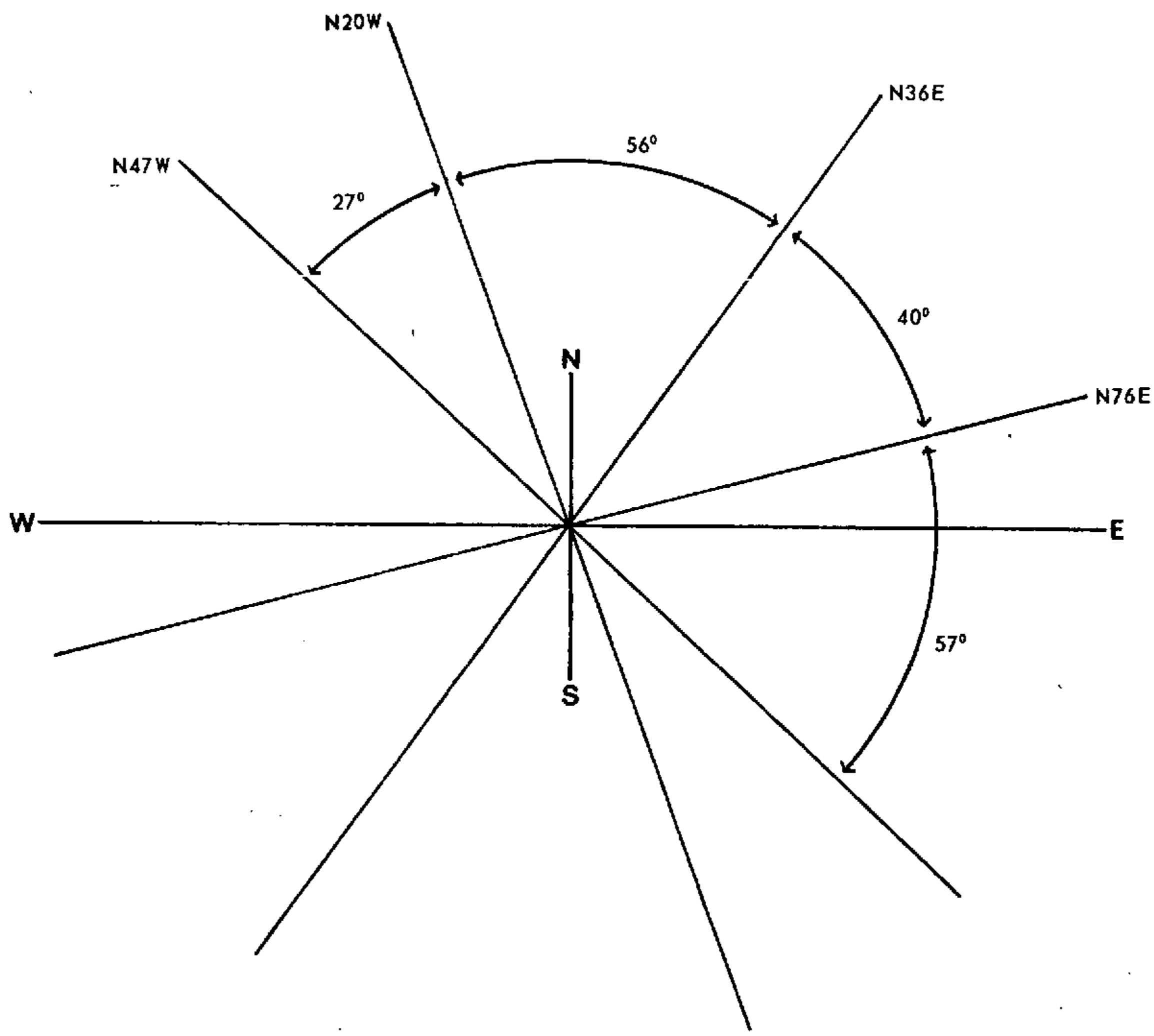

Figure 14.--Orientation of all lineament and fracture trace means mapped from ERTS data.

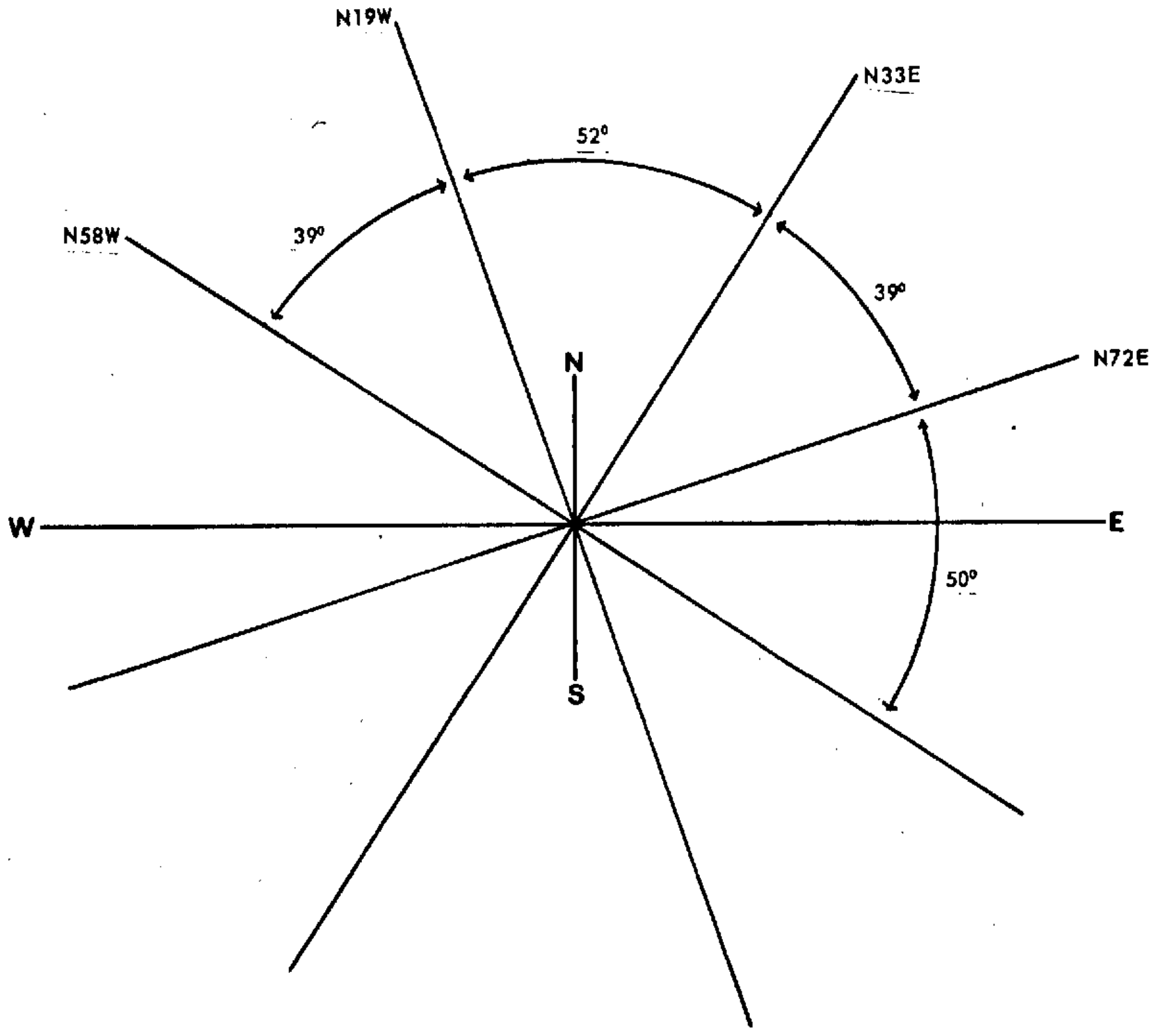

Figure 15.--Orientation of all lineament and fracture trace means mapped from U-2 data.

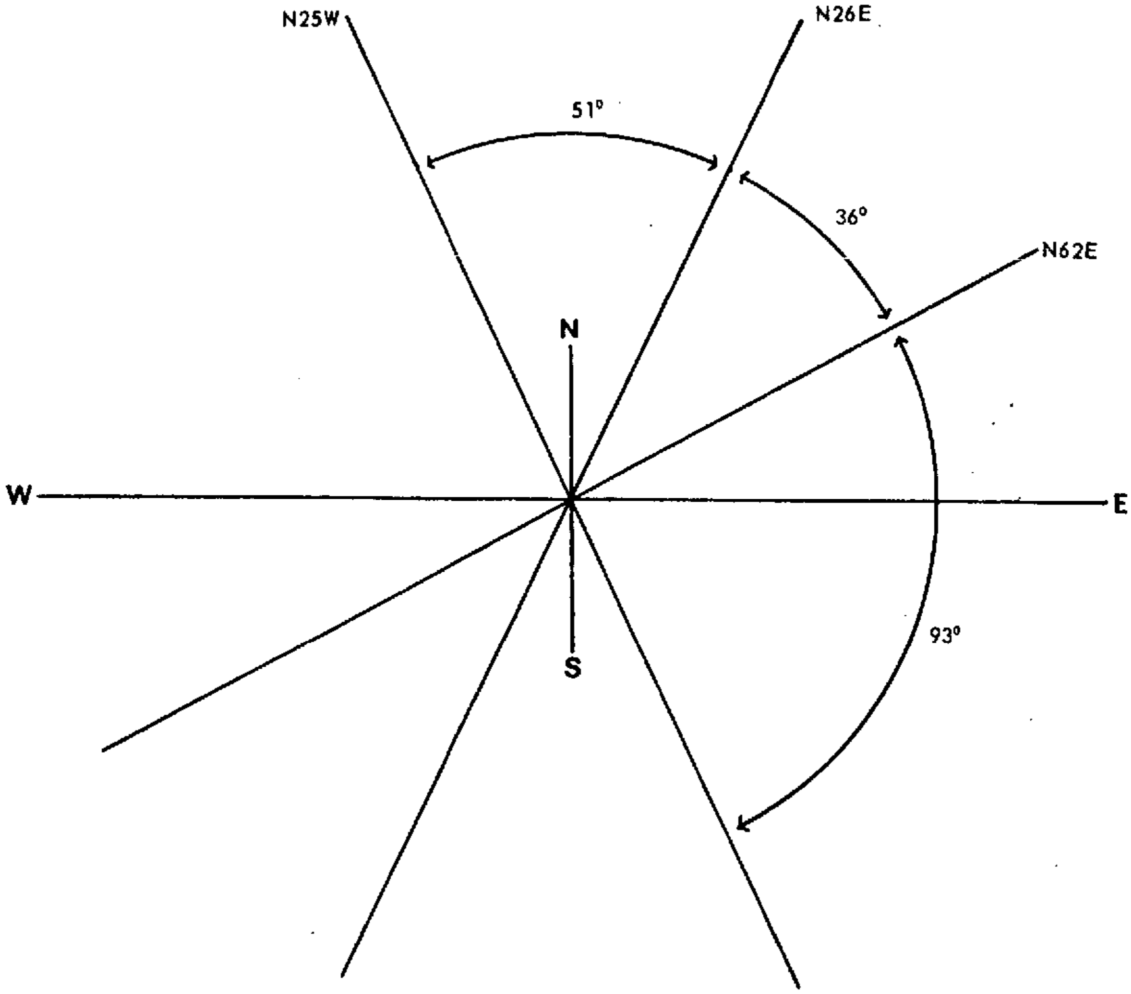

Figure 16.--Orientation of all topographic lineaments and fracture trace means mapped from the two quadrangles.

mode. The N70E and N53W average lineament and fracture trace modes do not seem to have fracture mode analogs. They may, however, be series of short, en echelon fractures whose regional trend is different from individual joint strike (fig. 17). The greater perspective and relatively poorer resolution provided by high altitude and orbital data could allow these features to appear as a single lineament or fracture trace. If these lineament and fracture trace modes are geologically fortuitous, and are thus not true lineaments and fracture traces, they may reflect land-use patterns or bias introduced by the interpreter.

It is interesting to note that the N4E nonsystematic and N82W master systematic joint sets do not appear to be represented at all on the remotely sensed data. This can probably be explained by the fact that most of the master systematic joints (N82W) are fairly widely spaced (see table 1), whereas the nonsystematic joints are relatively more closely spaced. Thus it appears, with the exception of the N4E joint set, that the more closely spaced, small, irregular, nonpersistent joints tend to control topography and show up both as topographic and tonal lineaments and fracture traces on ERTS and U-2 data rather than the more widely spaced, large, regular, persistent joints. No explanation can be offered for the fact that the N4E joint set did not show up on the remotely sensed or topographic data.

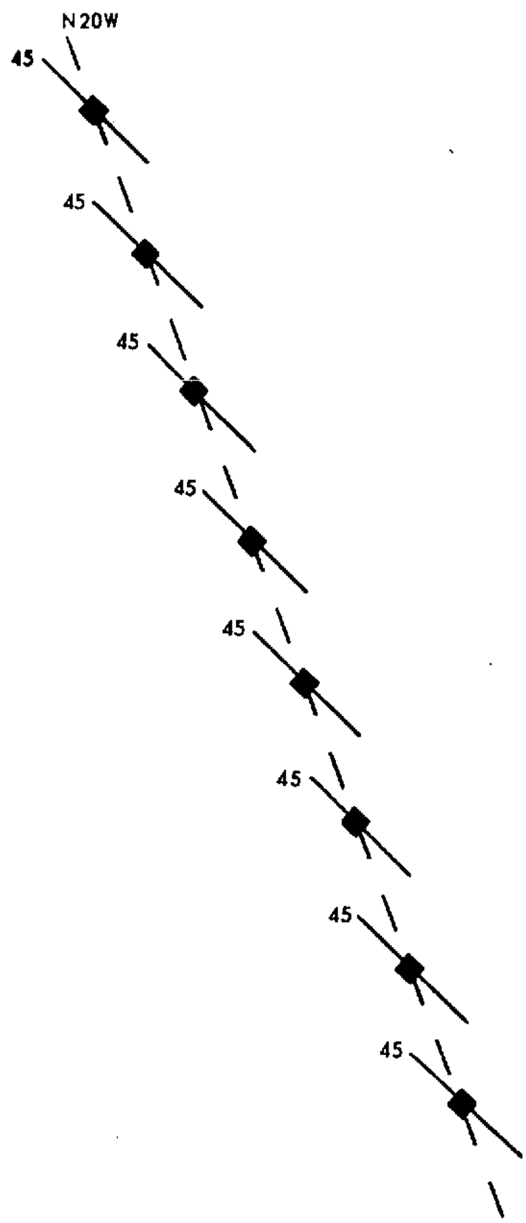

Figure 17.--When viewed from a distance, a series of short en echelon fractures striking N45W may appear as one lineament striking N20W.

Conclusions

The following conclusions can be reached with respect to the relationship of jointing in the Dora-Sylvan Springs area to lineaments and fracture traces mapped from high altitude and orbital imagery:

1) All joint sets do not show up as lineament or fracture trace modes.

2) All lineament and fracture trace modes do not have joint analogs.

3) Apparently, more closely spaced, irregular, non-persistent nonsystematic jointing shows up more clearly as fracture traces and lineaments than does widely spaced, regular, persistent systematic jointing.

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LINEAMENT ANALYSIS OF ERTS-1 IMAGERY OF THE ALABAMA PIEDMONT

By Thornton L. Neathery

INTRODUCTION

ERTS imagery of the crystalline area of Alabama shows many previously unrecognized but well defined rectilinear and curvilinear features cross cutting the tectonic and structural fabric of the region. Most of the rectilinear features are short, whereas the curvilinear features tend to be of greater length. Detailed examination of a 1:250,000 scale enlargement of an ERTS image shows that lineament concentration varies with type of bed rock. Many of the shorter linears are concentrated in areas underlain by competent granitic rocks, whereas the longer lineaments tend to transect terrane underlain by less competent rock.

Numerous linear features coincide with lithologic units or boundaries and define the principal lithologic and structural grain of the Piedmont. Many of the composite large linear features are indistinct on conventional aerial photographs due to the large scale of the imagery. It is only with the smaller scale, high altitude imagery that the regional significance of the smaller, disconnected micro-lineaments become discernable.

This report presents a preliminary analysis of ERTS I satellite imagery of east-central Alabama. Because photogeologic interpretation is dependent on the skill of individual interpreters, slight differences in interpretation or recognition for specific linears is assured. Most of the linear features defined on plate 5 appear on repetitive multispectral

ERTS imagery for the region. The effects of sun angle, sun azimuth and variation in vegetative color could not be evaluated for the entire year due to cloud cover and poor imagery.

The method of study was divided into two phases. All the known structural data for north Alabama was compiled on a 1:250,000 base map (plate 2). This map was the data base for evaluation of the lineament map prepared for satellite imagery. Correspondence of features was then noted and cataloged. Lineament features without structural correspondence were then carefully checked and evaluated to ascertain if they represented overlooked significant tectonic features that had been overlooked initially or unresolved lineament features.

GEOLOGIC SETTING

Physiography

The Alabama Piedmont is divided into two major physiographic districts: the Northern Piedmont Uplands (Sapp and Emplaincourt, 1974) (Ashland Plateau or Johnston, 1930) and the Southern Piedmont Uplands (Sapp and Emplaincourt, 1974) (Opelika Plateau of Johnston, 1930). These physiographic districts are easily recognized on the ERTS-1 imagery, and in part, correspond to the two major areas of lineament concentration.

Briefly, the physical characteristics of each are:

Northern Piedmont Uplands - a maturely dissected terrain disordered on a complexly folded and faulted metasedimentary crystalline rock. Locally, it has regions of strong relief developed over areas underlain by resistant rock units and moderate to weak relief developed over areas of highly feldspathic schist and gneiss.

Southern Piedmont Uplands - a submaturely dissected terrain disordered on a complexly folded and faulted, highly feldspathic metavolcanic crystalline rock and wide zones of cataclastic rocks. Generally the division has a moderate relief but an occasional area showing strong rugged relief dots the region.

The boundary between the two physiographic divisions is the Brevard fault.

Geology

The geology of the Alabama Piedmont has a pronounced influence on the evaluation of the lineament signature reflected on the ERTS-1 imagery. A brief discussion of the regional geology, therefore, will aid in understanding the apparent variation in lineament resolution.

The crystalline rocks of Alabama can be divided into three major lithotectonic provinces, northern Piedmont, inner Piedmont, and southern Piedmont (Neathery, and others, 1974a)(fig. 1). Each of these subprovinces can be divided into two or more subprovinces on the basis of degree of degree of metamorphism, variation in stratigraphy, and structural complexity (fig. 2).

Northwest of the main area of crystalline rock in Talladega, Shelby, and Chilton Counties, is a thick pile of generally undeformed low grade metasedimentary rock of controversial age (A. fig. 3). These rocks have lithologic affinities to both Cambrian and Mississippian clastic sequences common to the Valley and Ridge and appear to behave geologically very similar to them. They rest unconformably upon folded and faulted lower Paleozoic carbonates and include limestone, metasiltstone, metapelites, and other fine-grained metaclastic rocks. For the purpose of this report they are included with rocks of the main Talladega belt.

The northwestern boundary between the crystalline rocks and unmetamorphosed rocks of the Valley and Ridge is marked by a series of low angle faults (Gilbert, 1973, 1974). Rocks exposed within the faulted zone along the front include phyllonites and exotic blocks of carbonate. In some areas, especially in the north (C. fig. 3), the boundary relationship between the Valley and Ridge rocks and Talladega belt rocks is unclear.

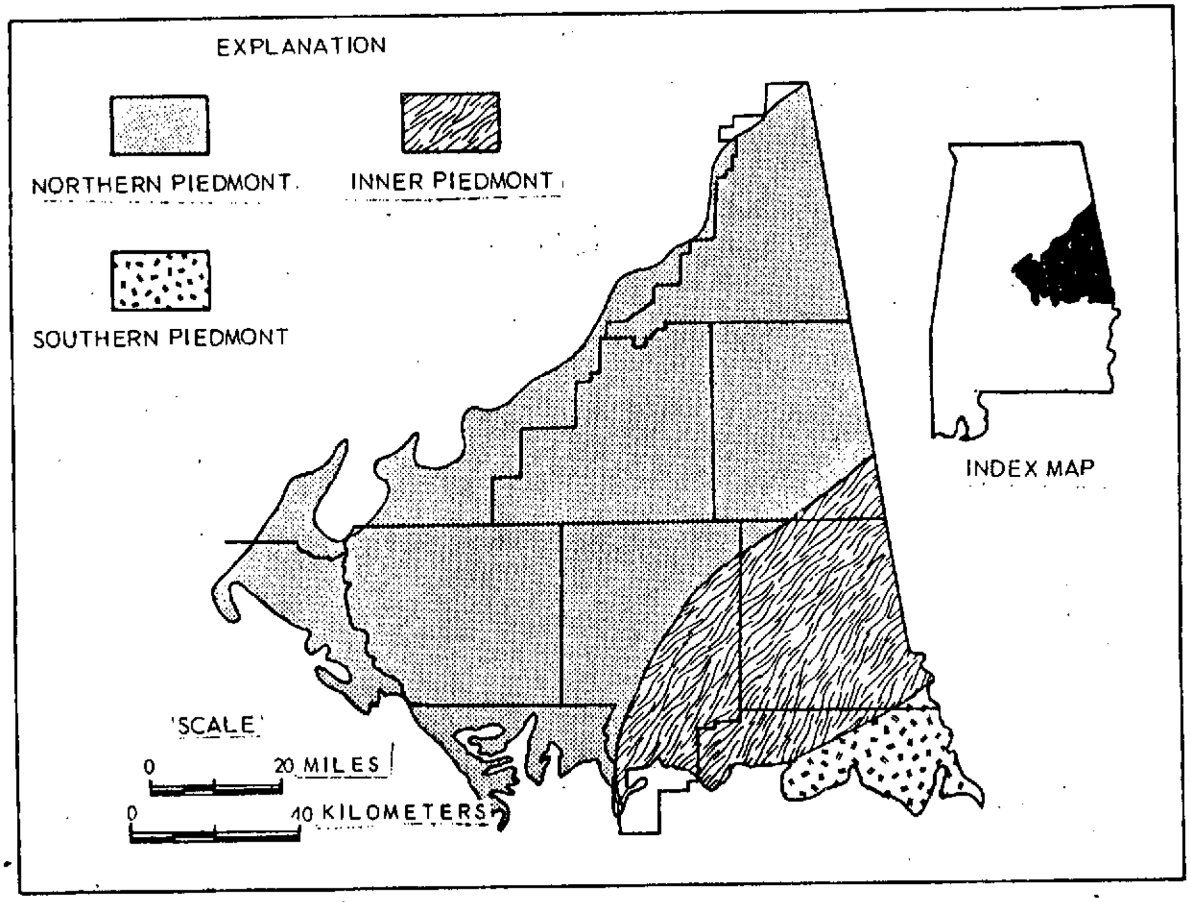


Figure 1. Three major geologic provinces of the Alabama Piedmont.

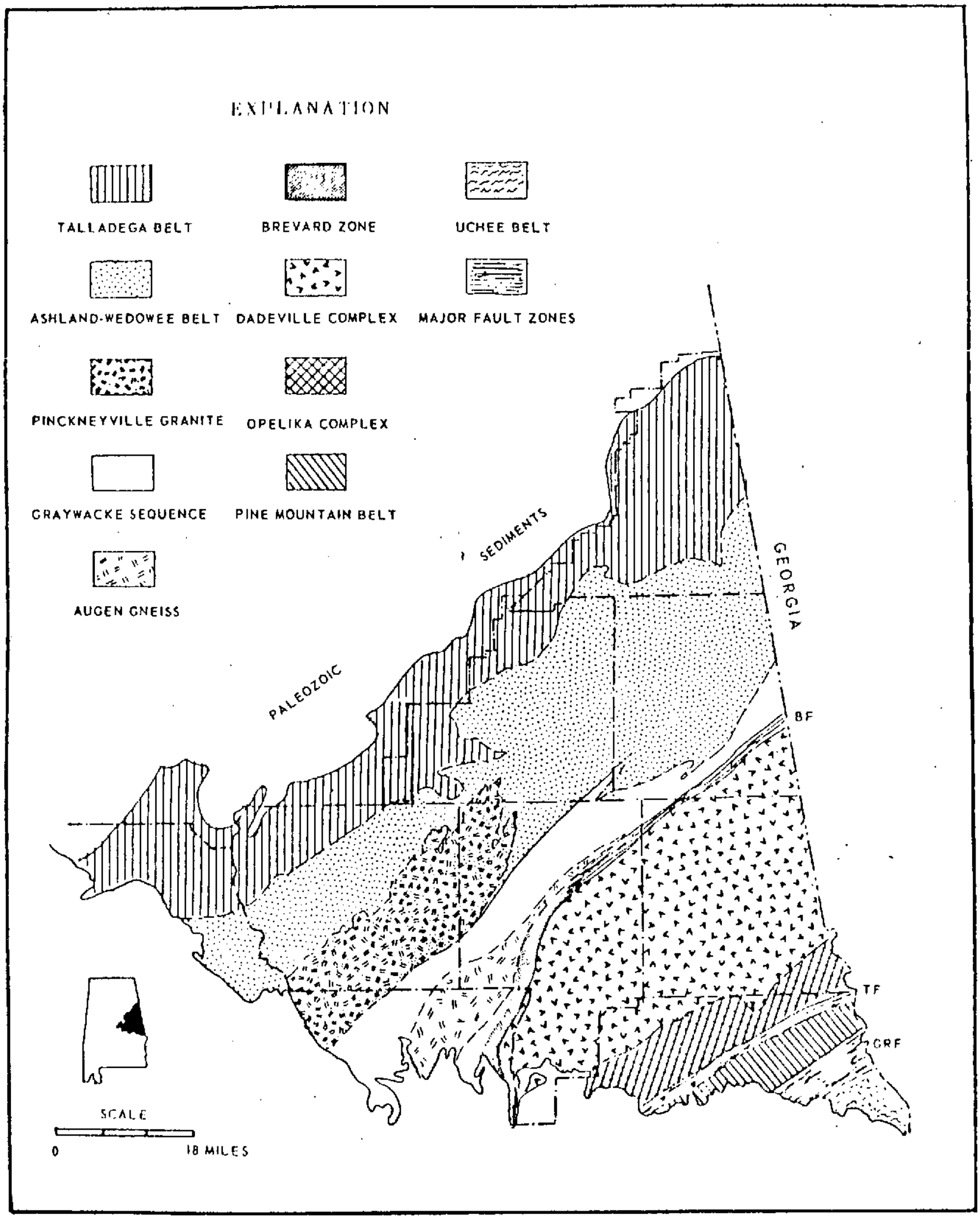


Figure 2. Major lithotectonic subdivisions of the Alabama Piedmont.

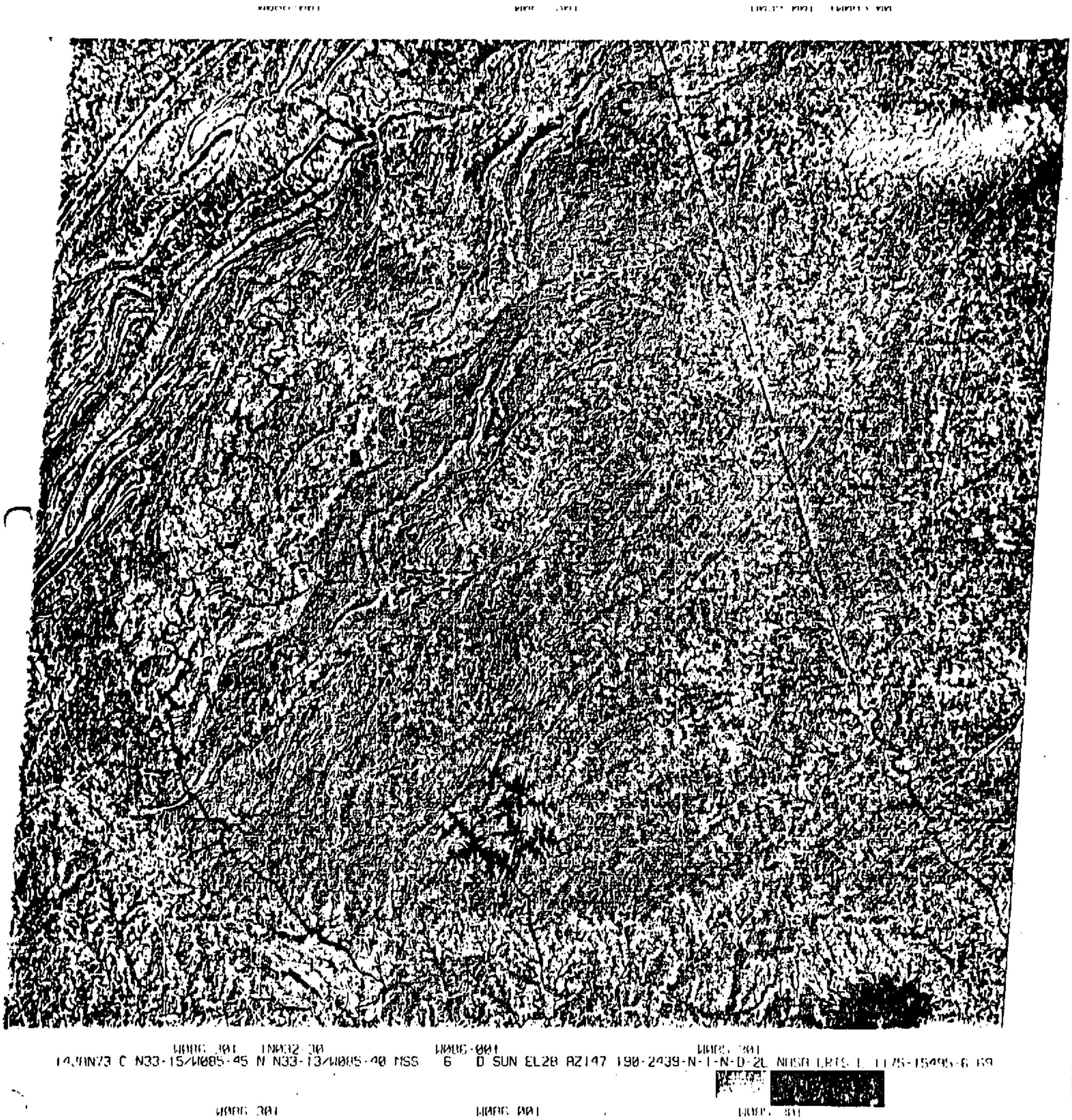


Figure 3. MSS band 6 (0.7 to 0.8 mm) ERTS-1 image of the Alabama Piedmont. (A) Area of Mississippian metaclastics; (B) Talladega front, main northern lithotectonic boundary of the Alabama Piedmont; (C) area of questionable boundary relationship.

The northern Piedmont (fig. 1) is underlain predominantly by a thick sequence of metasedimentary rocks locally interspersed with small bodies of mafic rock and granitic intrusives. This province is divided into the low-rank Talladega belt and the high-rank Ashland-Wedowee belt (fig. 2).

The Talladega belt is divided into a lower calcareous metagraywacke-fine grained arkosic sequence which locally contains carbonaceous phyllites and dolomites, a middle metapelitic-metapsammitic sequence characterized by massive lenticular horizons of quartzite and conglomeratic quartzite, and the upper Hillabee volcanic-volcaniclastic - clastic sequence characterized by the occurrence of quartz schist, sericite chlorite phyllite, and discontinuous greenstone. The southeastern side of the metavolcanic sequence marks the boundary between the low-rank Talladega belt and the southward lying high-rank Ashland-Wedowee belt. The metamorphic grade ranges from chlorite to biotite.

The contact between the volcaniclastic sequence and the southward lying Ashland-Wedowee belt is typically marked by a steep metamorphic gradient, phyllonites, mylonites, and transportation structures. Locally, however, structural and stratigraphic relationships indicate that the volcaniclastic sequence grades upward into graphitic rocks of the Wedowee Group.

The Ashland-Wedowee belt contains three major rock units; a predominantly graphitic sequence, an amphibolite or mafic-rich phyllite zone, and a non-graphitic sequence.

The most extensive rock group is the Wedowee. It is exposed over 50 percent of the belt and consists of a thick sequence of fine- to medium-grained graphitic metapelitic and meta-psammitic units that have undergone areally varying metamorphism and structural dislocations. With increasing deformation and accompanying metamorphism, many of the Wedowee units loose much of their graphitic character and change to garnet muscovite schist.

Structurally, and apparently stratigraphically underlying the Wedowee Group is a horizon of discontinuous mafic rock, usually amphibolite. These rocks typically exhibit a cataclastic fabric where they form thick or massive outcrops.

Underlying the Wedowee and amphibolite rock are non-graphitic rocks composed essentially of garnet-biotite-muscovite-feldspathic schist and gneiss and interpreted as an original graywacke sequence. Along the southern boundary of the northern Piedmont these rocks have been extensively sheared by movement associated with the Brevard fault. Metamorphic grade in the northern Piedmont varies widely from chlorite to sillimanite and retrogressive mineral assemblages are common.

Two large granitic masses, the Pinckneyville Granite complex and the Kowaliga augen gneiss, dominate the southwestern part of the northern Piedmont. Scattered throughout the Ashland-Wedowee belt are a number of late plutons that show areally varying composition and texture.

The structural style of the northern Piedmont is typical of the central region of orogenic belts. The area has been affected by at least two major periods of deformation with accompanying metamorphism, as recognized in the Wedowee and Talladega rocks. Over most of the region a system of late upright folds of large magnitude are superimposed on an earlier system of recumbent isoclinal folds.

Post-metamorphic brittle deformation is also common throughout the northern Piedmont. Conjugate joint systems, composed of systematic and non-systematic joints are readily observed. Normal faults have been recognized in many areas. The most prominent feature is the Wetumpka impact structure, which is exposed at a boundary between the crystalline and Coastal Plain provinces (Neathery, and others, 1974b).

The southeastern boundary of the northern Piedmont is the Brevard fault zone and the Jackson's Gap Group (fig. 2). The characteristic cataclastic rocks that typify the Brevard through Georgia extend into Alabama as far south as Horseshoe Bend. Beginning near Horseshoe Bend and extending southward to the Coastal Plain onlap in Elmore County, the rocks of the Brevard become a mappable stratigraphic sequence consisting principally of graphitic phyllonite, chlorite sericite phyllonite, quartzite, and conglomeratic quartzites. Near its southern end, the Jackson's Gap turns eastward and bears strong resemblance to rock units of the Pine Mountain Group of the southern Piedmont.

The inner Piedmont is divided into two rock groups: the Dadeville metavolcanic group and the Opelika metasedimentary group. These two rock groups are separated by a structural discontinuity termed the Stonewall line (Bentley and Neathery, 1970).

The Dadeville Group consists of a complex sequence of rocks with a volcanic affinity: amphibolite, hornblende gneiss, biotite gneiss, and felsic gneiss, all of which have been intruded by granite, gabbro, norite, and pyroxenite plutons.

Principal foliation data in the Dadeville Group defines a broad, gently NE plunging synform, the core of which contains a thick sequence of thinly bedded amphibolite and aluminous schist. A similar, but smaller synform structure occurs in southern Chambers County. The north side of the Dadeville outcrop belt has been strongly sheared by movements apparently associated with the Brevard, resulting in retrogressive metamorphism of the amphibolite and felsic gneisses.

The structural style throughout the Dadeville is one of tightly oppressed noncylindrical isoclines apparently formed under conditions of passive flow.

The Opelika Group lies south of the Dadeville Group (fig. 2), and consists of a narrow zone of metasedimentary rock that includes aluminous schist, fine-grained biotite gneiss or metagraywacke, and discontinuous lenses of quartzite and occasional amphibolite. Although a relatively minor part of the inner Piedmont belt in Alabama, this sequence becomes more expansive eastward in west Georgia. Locally, these rocks have been intruded by a series of granitic rock of varying composition and texture. In general, the Opelika rocks dip NW following the attitudes defined in the Dadeville Group.

The <u>southern Piedmont</u> (fig. 1) is characterized by a strong shear fabric that defines two major fault zones which separate structural blocks composed of dissimilar metamorphic rocks. The shear zone incorporates three major faults and is approximately 20 kilometers wide. The oldest and youngest known crystalline rocks in Alabama occur in this province.

The northern boundary of the southern Piedmont is the Towaliga fault zone, an 8 kilometer wide band of cataclastic rock derived principally from metasediments. Random tectonic slices of relatively undeformed rock which is similar in lithology to the southwestern assemblages of the Jackson's Gap Group of the Brevard zone, occur scattered throughout the zone. Within the fault zone, axial surfaces and foliations dip northwestward. Locally, many of the mylonites have been refolded by later deformation.

South of the Towaliga fault zone is the Pine Mountain structural block containing two distinct series of rocks; a lower complex group of rocks described as porphyroclastic blastomylonites, which appear to represent "Greenville Basement," and a sequence of metasedimentary rock termed the Pine Mountain Group. Although the contact relationship is conjectural, the metasediments appear to unconformably overlie the blastomylonites.

South of the Pine Mountain block is an 18 kilometer wide zone of cataclastic rock termed the Goat Rock fault zone. This zone contains two major faults; the Bartletts Ferry fault on the north side and the Goat Rock fault near the south side. In contrast to the rocks of the Towaliga fault zone, rocks of the Goat Rock fault zone appear to have been derived from granitic and mafic rocks.

The Goat Rock fault zone grades southeastward, through a zone of pencil gneiss into a large migmatite complex of undefined origin. The migmatite complex contains many of the basic rock types found in the Goat Rock fault zone but appears to pass westward into a less migmatized sequence of metasedimentary rock.

Diabase dikes, ranging from 2 meters to as much as 20 meters in width, strike N 10° - 15° W across the southern and inner Piedmont before dying out just south of the Brevard fault zone. Most of the diabases are quartz tholeities and contain moderate amounts of magnetite.

The structural framework for the Alabama Piedmont was defined during an earlier field mapping program (plate 2). All of the regional structures were established and most of the major faults and large folds delineated. Since acquisition of the ERTS data, the traces of several faults have been more accurately located and several previously unrecognized structures defined. Further refinement of the structural grain is anticipated as the analysis of the imagery data continues.

IMAGERY

Imagery used in this study was obtained by the ERTS-1 satellite during December 1972 and January 1973 and are as follows:

NASA ERTS 1157-15500-6-7, December 27, 1972

NASA ERTS 1175-15495-4-5-6-7, January 14, 1973

Prints were made from 70 mm chips of the respective MSS bands 6 and 7 at scales of 1:500,000 and 1:250,000. The 1:500,000 scale enlargement was compared to the 1926 Geologic Map of Alabama to ascertain general geologic trends and surface to lithologic signatures.

The 70 mm chips of bands 6 and 7 of the January 14, 1973 imagery, which covered the crystalline area of Alabama, were enlarged to a scale of 1:250,000. The enlargements were compared to a geologic map compiled at a scale of 1:250,000 to see if geologic boundaries and known structural features coincided with any of the topographic or tonal features visible on the enlargements. Many of the lineaments seen on the 1:500,000 scale imagery were quickly recognized on the enlarged copy, however, a great number of small (short) lineaments became noticeable at the larger scale. It should be noted that the larger scale imagery suffers some degrading of the image texture due to magnification of the transmission grain and linears parallel or near parallel to the grain are questionable.

Band 7 highlights the water bodies and subdues the topographic contrast. However, a number of lineaments can be mapped, especially in the Piedmont area and in the adjacent Valley and Ridge. In the Piedmont, the lineaments are marked by notches and offsets in the ridges and sharp offsets along stream courses. Several lineaments mark the traces of known faults in the high rank metamorphic belt of the northern Piedmont. Best lineament resolution was obtained by using the band 6 imagery and subsequently this imagery was used for compilation purposes. Other MSS imagery, notably bands 4 and 5, although not enlarged to 1:250,000, were carefully studied and anomalous lineaments plotted on a 1:250,000 band 6 base. Many of the lineaments observed on the ERTS 1 imagery were further studied by the use of conventional RB 57 multispectral imagery, and low altitude black and white aerophotographs.

LINEAR FEATURES

The various features shown on plate 5 include both tonal and topographic linear elements. These elements include aligned streams or segments of streams; aligned offsets along several adjacent streams; aligned ends of consecutive ridge spurs; anomalous alignment of groups of topographic features, such as continuous straight line ridge crests, aligned tributaries over long distances, aligned saddles and ridges and other geomorphic ridges; and other geomorphic features used in photo geologic work to indicate fracture joint or fault systems. Sharp linear tonal contacts are included on the map as linear features, if they can be identified on two or more sets of images taken at different times of the year. Linear features commonly associated with bedding and sedimentary rocks, or those which could be equated to contact boundaries of the various metamorphic rocks were excluded.

Nearly horizontal planar features, such as thrust faults, could only be detected when they separated rocks with gross lithologic differences which showed as tonal or textural differences on the images, or if the traces of the planar surfaces separated anomalous geomorphic domains. Linear, man-made features such as pipe lines, power line right-of-ways, and highways, were carefully excluded from the compilation.

Although the criteria used to define the linear features observed on the ERTS imagery are those commonly used to define fractures, joints, or faults from aerial photographs, the geologic reason for most of the linear features is not known. However, because of the care with which image was examined, the features are assumed to be geologically controlled. Some detailed work along one lineament in Clay County, Alabama, indicated a coincidence of a linear feature with a minor structural feature. The details of this examination are included in another section of this report (Neathery and Reynolds, 1974; see Appendix 1).

As a part of the overall program to interpret the linear features of the Alabama Piedmont, a structural map of the area, together with adjoining areas in the Valley and Ridge and Plateau areas of northeast Alabama, was prepared based on mapped and published geologic structural features and is included as plate 2 for the purpose of comparison and definition. The ERTS interpreted linear elements were also compared to topographic features underlain by resistant geologic units. The high proportion of coincidence between known mappable structural features and recognized lithologic features lends creditability to the assumption that many or most of the linear features are geologically controlled.

LINEAR ANALYSIS

Introduction

At first look, the Piedmont imagery, at a 1:500,000 scale size, shows the complex structural grain of the region. Much of this structural grain has been seen before on Apollo 9 imagery and conventional airphotos mosaics. However, the ERTS imagery is superior to the other imagery because of the relatively flat field of the scan and even tonal quality. Also the ERTS imagery is superior in that it covers the entire region of study in one frame, permitting a regional synthesis of the study area. Geologic features on the 1:500,000 imagery are clear and generally distinct. The northern part of the Alabama Piedmont is by far the most prominently defined region of the area. This is due to the resistant weathering of the numerous metaclastic units which make up bed rock of the area. The southeast side of the northern Piedmont is equally well defined because of the enhancement of the structural grain by back water of Lake Martin. The inner Piedmont and southern Piedmont are less well defined. The bed rock in these areas is highly feldspathic and weathers deeply to produce a subdued profile. A few of the slightly more resistant gneissic units define the core of the Tallassee synform in the inner Piedmont. The major structural elements of the southern Piedmont are only weakly defined.

Northern Piedmont

The rock units of the Talladega belt are generally well defined on the various ERTS 1 images. The thick quartzite units within the belt stand in sharp topographic relief among the more feldspathic metaclastic rocks and divide the belt into three basic rock groups. The rocks of the Talladega Group, along the frontal edge of the Piedmont, are uniformly chopped up by a series of short lineaments which appear to begin at the edge of the phyllite belt to the west and extend only as far as the outcrop pattern of the extensive Cheaha Quartzite which forms the crest of Talladega Mountain. Some of the lineaments pass northwestward into the Valley and Ridge where they appear to change from topographic lineaments to tonal lineaments.

The contorted northwest trending regional strike of the northern Piedmont is dissected by a number of linear features that are oriented N 20° W and N 80° E. Several of the linears are more than 160 kilometers long, cutting across the Piedmont and passing into the adjacent Valley and Ridge. At many places where these lineaments cross major topographic expressions, notches occur in the ridges. At several places prominent topographic ridges terminate or appear to be thickened as if telescoped by faulting.

By far the most numerous lineaments observed within the Talladega belt are topographic features which correspond to lithologic units or major topographic alignments. Most of these features were recognized on conventional photography or topographic sheets.

The greater part of the northern Alabama Piedmont is underlain by rock of the Ashland-Wedowee belt (fig. 2). These rocks represent a wide variety of metasedimentary rock ranging from meta-arenites to meta-pelites to highly feldspathic gneiss and schist. The arenaceous units typically form long prominent topographic features that generally define the structural grain of the belt. The more feldspathic rocks rarely display any significant topographic expression. In several areas tonal lineaments mark the boundary between the highly feldspathic rock and the more arenaceous, less feldspathic rock. The relationship is not, however, everywhere defined. A greater number of tonal features have been recognized in the Ashland-Wedowee belt than in the Talladega belt, partly because of land use and its enhancement of tonal linears.

The large granite areas of the northern Piedmont are not easily distinguished except as regions of subtle or soft relief. Comparing the lineament distribution to the bed rock geology of the region it was found that a greater density of short east-west lineaments occurred in the areas underlain by the granitic rock. A large area of granitic rock in southeastern Coosa and northwestern Elmore Counties (the Pinckneyville complex) is extensively cross-hatched by short lineaments (micro-lineaments) suggestive of the series of conjugate joint sets. Field observations in the same area during the past five years have found mylonite gneiss and microbreccia zones scattered throughout the area. Several of the mylonite localities appear to coincide with the trace of these lineaments.

The large body of Kowaliga augen gneiss which appears in the southern end of the northern Piedmont is partially masked by the backwaters of Lake Martin. Close study of the ERTS imagery indicates that in this area the granitic rock is cut by short topographic and tonal lineaments parallel with the regional structural grain of the Brevard fault zone. The characteristic crosshatch pattern seen in the Pinckneyville Granite complex is not obvious in the Kowaliga. The smaller granitic areas in south-central Clay County (Bluff Springs Granite) appear to have similar concentration of shortparallel lineaments.

The structural grain of the southeastern side of the northern Alabama Piedmont and Brevard zone is distinct. The quartzose units of the graywacke sequence stand as topographic linears across the entire width of the Alabama Piedmont. From the Tallapoosa River to just south of Kowaliga Creek on Lake Martin the topographic linear trend defines the structural configuration of the belt. Adjacent to Lake Martin the linear trend is enhanced by the configuration of the Lake Martin shoreline. The topographic expression of the graywacke sequence south of Kowaliga Creek becomes subdued and less well defined as it becomes more and more covered by the sediments of the Coastal Plain. The trace of the Brevard zone across Alabama is clearly marked by a series of arcuate lineations formed by the differential weathering of the various rock units comprising the fault zone. Near the Alabama state line and extending as far south as Horseshoe Bend on the Tallapoosa River, the principal mylonite zone of the Brevard is clearly defined by a very straight linear expression. South of Horseshoe Bend, the trend appears to swing abruptly southward and finally becomes indistinguishable near the southern end of Lake Martin.

Several tonal lineaments coincide with known microbreccia zones that splay off of the Brevard near Horseshoe Bend and cut across the graywacke sequence to the west. Some of the tonal lineaments that cut the graywacke sequence appear to be extensions of topographic lineaments which cut the granite body to the west. Field evidence regarding possible structural connections is inconclusive. Numerous scattered lineaments originating outside the belt of graywacke rocks of the southeastern side of the northern Alabama Piedmont area cut across the area with no apparent offset. The arcuate configuration of the Wetumpka astrobleme (Neathery, and others, 1974b) in the southwest part of the central Piedmont is clearly defined as are the two small graben-like structures on its southwest side, which are defined by sharp contrasts in tonal quality.

Inner Piedmont

Structural and lithologic variations in the inner Piedmont are not as well defined as the structures and lithologies of the northern Piedmont and Brevard zone. Within the inner Piedmont schist and gneiss units of the Dadeville Group which form the core of the Tallassee synform are faintly visible. The resistant mafic and ultramafic rocks which ring the central core of schist-gneiss stand in sharp relief in contrast to the deeply weathered felsic rock underlying the greater part of the Dadeville Group. There is no easily recognized distinction between the mafic and felsic rocks over the vast majority of the Dadeville Group. Locally, linear topographic highs coincide with mafic rock and generally define some regional structural character such as the Boyd Mountain synform in the southeastern part of the Dadeville Group.

The rocks of the Opelika Group likewise are not clearly defined on the ERTS imagery. The lithologically prominent Stonewall line that separates the Dadeville Group from the Opelika Group is not visible on any imagery inspected. There is some topographic expression within the Opelika Group which appears to be coincident with rock type. However, the very prominent Andrews fold which has been mapped geologically is not defined by the ERTS imagery.

The vast majority of the tonal lineaments strike N to N 20° E. A few trend N 40-50 W. The northwest oriented linears generally cut across the entire width of the Piedmont with no apparent offset of rock units of other structural features.

Southern Piedmont

The southern Alabama Piedmont is generally poorly defined on the ERTS 1 imagery. The lithologic units underlying the area are typically feldspathic in content and weathers deeply, to produce a subdued topographic expression. The exceptions are quartzose units associated with the Pine Mountain Group. They commonly form very narrow and short ridges.

A series of short, northeast trending linear features, confined primarily to the Chattahoochee River Valley, parallel the structural grain of the region. Neither the Towaliga nor Goat Rock fault zones are clearly distinguished. Some suggestion of a major structural change between the inner and southern Piedmont is indicated by the very subtle variation in topographic signature north and south of the Towaliga fault. Careful observation of the various imagery yields two distinct signatures suggesting different sets of geologic parameters affecting each area. Very few linear elements other than those associated with the known structural grain can be discerned on any imagery. Besides the strong alignment of topographic lineaments to the regional structural grain only three tonal lineaments appear to transect the southern Piedmont. These lineaments are a part of larger lineaments that cut across the entire Piedmont.

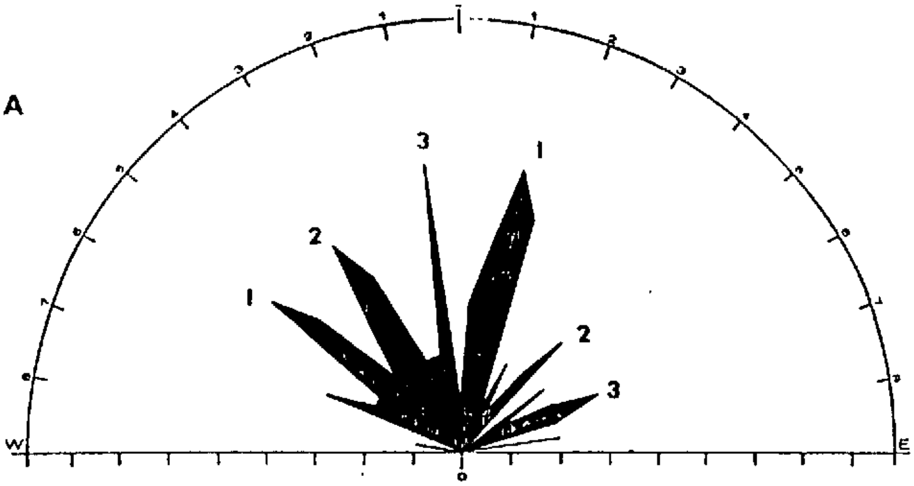
ANALYSES OF LINEAMENTS

There appears to be at least two systems of lineaments superimposed on the structural grain of the Alabama Piedmont. Although a detailed study of the individual features is beyond the scope of this report, some general statement can be made concerning their regional relationship and possible chronology.

If linear features are assumed to be geologically controlled they may reflect certain stress fields in existence at the time of their development. Although extensive field checks were made over a great number of lineaments in the northern Alabama Piedmont only a few occurred in areas of anomalous structure, and only one lineament was found which was related to a definite structural feature (Neathery and Reynolds, 1974). The correspondence between lineament trends and joint directions over an area of approximately 250 square miles in the northern Alabama Piedmont tends to reinforce the geologic implication of the lineaments (Drahovzal, 1974).

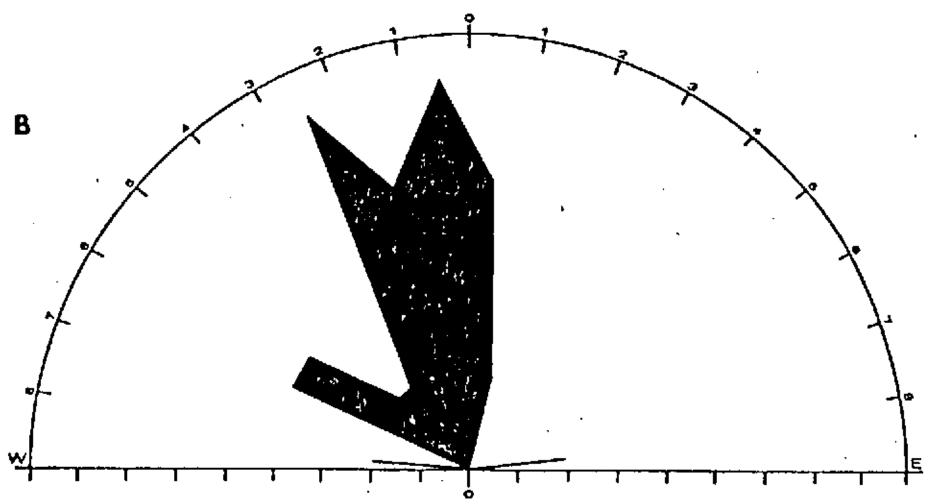
The evidence seems to indicate that the lineaments were formed in recent times. They formed at least post-last major metamorphic event in the Alabama Piedmont (ca 300 million years; Wampler and others, 1970), because they cut across all metamorphic structures. Some significant variations exist when the direction and number of bounded lineaments (fig. 4A) are plotted against direction and number of lineaments that transect one or more structural regimes (regional lineaments) (fig. 4B). The structural bounded lineaments appear to form three distinct systems, none of which appear to dominate over the other. These systems are made up of orthogonal sets that are slightly less than 90^{o} apart. Drahovzal (1974) in another paper in this volume discusses these patterns. System no. 1 in figure 4A appears to be best developed because it shows equal development in both quadrants. Systems 2 and 3, however, appear to have only a dominant northwest component and very weak northeast components. The northeast

A



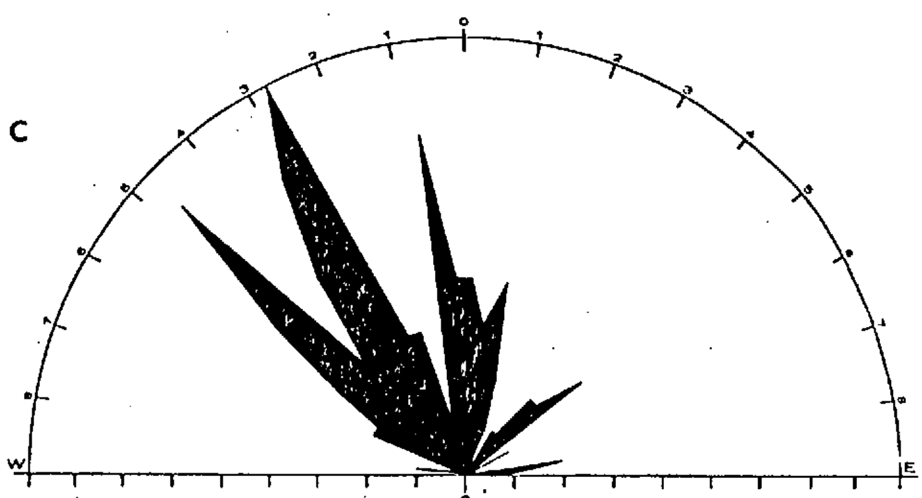
Rose diagram for all structurally bounded lineaments

B



Rose diagram for lineaments that transect one or more structural boundaries (regional lineaments)

C



Rose diagram for all lineaments in northern Alabama Piedmont

Figure 4. Rose diagrams for lineaments in the Alabama Piedmont.

component of systems 2 and 3, however, are parallel to near paralle to the regional strike of the Piedmont and therefore may be masked by the regional structural grain.

The structural bounded lineaments may represent a manifestation of an earlier period of stress imposed on the region. Replotting the structural bounded lineaments by structural province (fig. 4C), a strong correspondence is noted between the maximum orientation of these lineaments and the geologic province in which they occur. The lineament set with the N 10° E direction (fig. 4A) appears to lie predominantly in the area south of the Brevard, in the inner and southern Piedmonts, where the regional structural grain is very disturbed. This would suggest that the regional structural grain may impart a certain bias to lineament recognition. In areas such as the northern Alabama Piedmont where the northeast regional structural grain is well developed the lineaments normal to regional grain tend to be prominently displayed and those corresponding to the direction of the regional structural grain are weakly defined. In the inner and southern Alabama Piedmonts there is no preferred structural grain and all lineaments are equally well developed.

The regional lineaments (fig. 4B) appear to plot in one principal direction, north to N 30° W, with a weaker defined direction of N 50° W. Interestingly, the regional lineaments appear to converge to the southeast (plate 5). These lineaments, in crossing all the tectonic provinces overprint the structural bounded lineaments and structural grain of the region and are therefore interpreted as the youngest lineament system developed in the Alabama Piedmont. Interestingly, these lineaments appear to have some correspondence with a theoretical position of the tensional joint direction produced by SSW compressional force, as suggested by Simpson (1965) for the last major compressional direction in the southern Appalachians.

Although there is some indication of correspondence between joint direction and lineament direction there has been no definite correlation established. Detailed joint analyses in two parts of the Alabama Piedmont in recent years (Neathery, 1973; Neathery and Reynolds, 1974; Drahovzal, 1974) suggest a probable relationship. This relationship is not substantiated by the present data. In a more detailed joint analysis program (Neathery and Reynolds, 1974; Drahovzal, 1974) the ERTS data was augmented by SLAR imagery and low altitude conventional photography and many of the smaller limeaments are plotted as a rose diagram that some regional correspondence between lineaments and joints is suggested.

CONCLUSIONS

This analysis of the ERTS imagery of the Alabama Piedmont indicates that a great deal of structural data can be obtained from the imagery. The micro-jointing of the area is clearly visible, also fault traces can be mapped with greater accuracy since a larger area can be viewed and smaller segments joined. Definition of rock type, however, is conjectural. Only where the bed rock contains significant proportions of resistant units does the lithology become recognizable. With further work, it may be possible to differentiate some of the less prominent bed rock units and discriminate the less obvious structural features.

In summary, the ERTS imagery has contributed significantly to the total mapping efforts in the Alabama Piedmont.

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LINEAMENT ANALYSIS IN THE CROOKED CREEK AREA,

CLAY AND RANDOLPH COUNTIES, ALABAMA

By T. L. Neathery and J. W. Reynolds

INTRODUCTION

As a part of a geologic study in the Crooked Creek area, Clay and Randolph Counties, Alabama (Lineville East, Mellow Valley, Wadley North, and Ofelia 7 1/2 minute quadrangles), a detailed investigation was made along the traces of a number of lineaments derived from ERTS-1 and side-looking airborne radar (SLAR) imagery supplemented by low-altitude conventional photography (plate 6). Two-hundred-forty-two lineaments were transferred from various imagery and plotted on 7 1/2 minute topographic maps for field checking. More than 30 major linear elements were investigated from June to September, 1973. The trace of linear elements were checked to see if there were any structural manifestation that coincided with the lineament or if structural changes could be noted across the lineaments.

Lineaments observed on the various imagery bands are due principally to two phenomena: 1) a linear tonal variation, or 2) a linear topographic feature. The topographic lineaments are commonly related to a late structural cleavage that has been enhanced by erosion.

Lineament Analysis

One major tonal lineament crosses the area of study, the Anniston lineament (Drahovzal, 1974; Drahovzal and others, 1974; see Apprndix I). This lineament is more than 280 kilometers long, extending from Blanton, Chambers County, northward to the Alabama state line near Elk River. A very careful inspection was made along the project trace of this feature through the study area. No abnormal structural manifestation could be detected that would produce a tonal variation.

Most of the lineaments recorded in the study area are of the topographic type. For convenience of field work and as an order of investigative priority, the lineaments were divided into two general classifications: 1) those less than 6 kilometers long, and 2) those longer than 6 kilometers. All the type-2 lineaments were carefully checked at every accessible location. No structural discordance or unique structural event was observed that could not be found in areas not transversed by a lineament. On the traces of some of the shorter type-1 lineaments, some structural disturbance was seen that that could not be attributed to regional structural development.

In order to evaluate the lineaments in terms of possible structural significance, approximately 2,500 structural stations were established. The structural data of potential significance to lineament analysis are the open joints. More than 270 open joints were recorded from throughout the Crooked Creek area. A contoured spheroidal projection, on an equal area net, of the strike and attitude of these features (fig. 1) shows two principal joint sets - (NW-SE; NE-SW) and (N-S; E-W). The northwest-northeast set is dominant and would suggest that the primary regional stress field has a N-S compressional component.

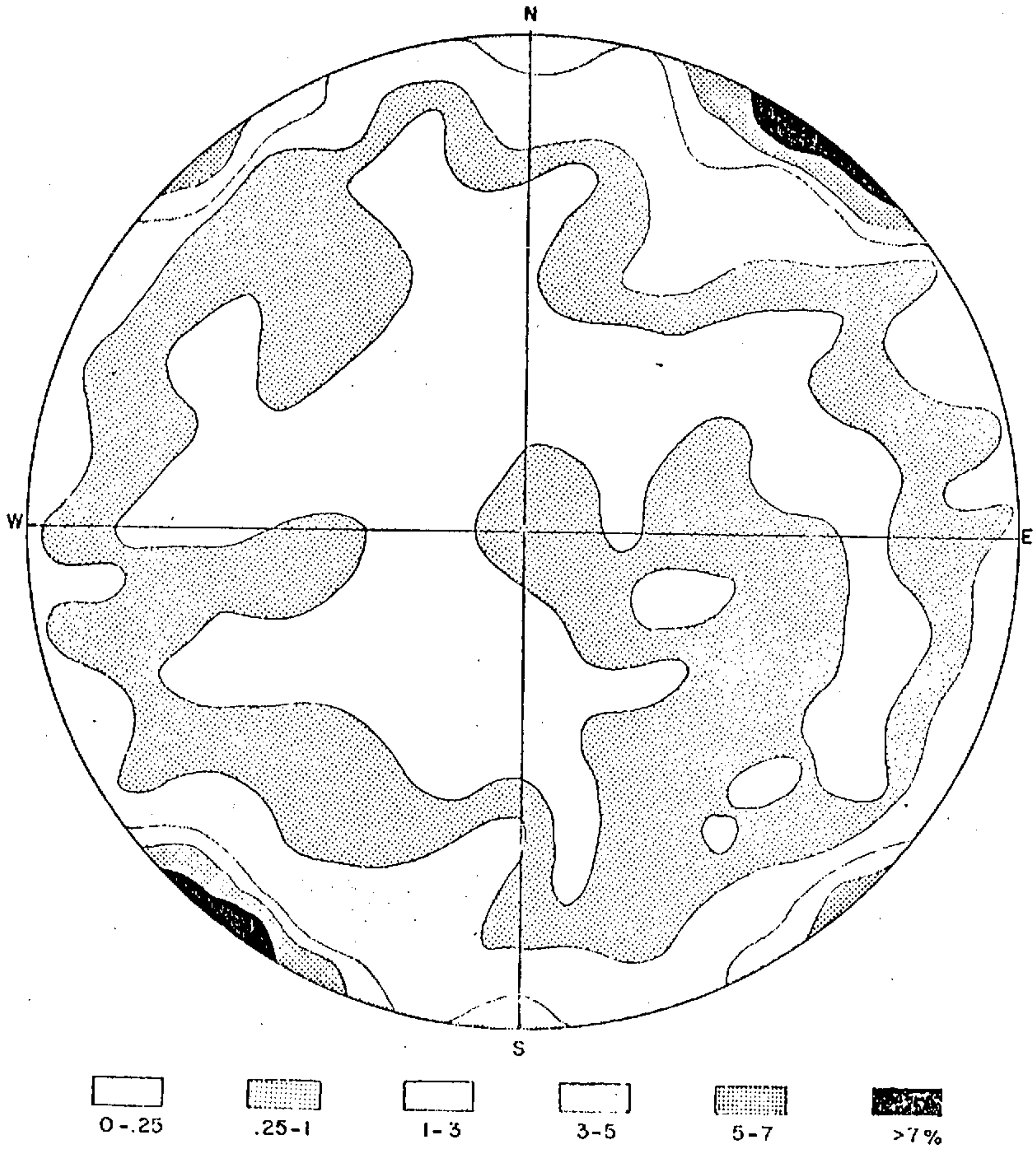

Figure 1. - Contoured stero net showing density, attitude, and direction of joints in the Crooked Creek area, Clay and Randolph Counties, Alabama.

The N-S joint set reflects the weaker defined stress field and it appears to have had a WNW-ESE compressional component. A joint rose diagram (fig. 2A) shows a greater number of joints to have a NW strike. The asymmetrical symmetry of the rose diagram is due in part to the masking of the NE joint direction by regional foliation and bedding.

An analysis of the joint data indicates a significant correlation between joints and lineaments. The primary joint direction appears to coincide with the major lineament orientation (fig. 2B) and suggests that the topographic lineaments represent erosional enhancement of a late, brittle tectonic event (s) (see also Drahovzal, 1974). Some of the lineaments appear to follow major stratigraphic boundaries. No mylonite or shear zones were found in this area that coincided with any lineament trace. Most of the late structural elements appear to be tension release features.

Structural Implication

As a part of this investigation a detailed search was made over approximately 195 km^2 of the study area for surface manifestation of any of the image-derived lineaments. A small normal fault was found exposed in a road cut (fig. 3), southwest of Cragford, Mellow Valley 7 1/2 minute quadrangle (fig. 4). It coincides with the trace of a lineament expressed both on ERTS-1 and SLAR imagery. The lineament referred to as the Wesobulga Creek lineament by Drahovzal and others (1974), is approximately 4 kilometers in length on SLAR imagery and corresponds with an ERTS lineament about 15 kilometers in length. On both SLAR and ERTS data, orientation of the lineament averages N 45° W. The Wesobulga lineament is no more prominent than many other such features for which no structural evidence exists.

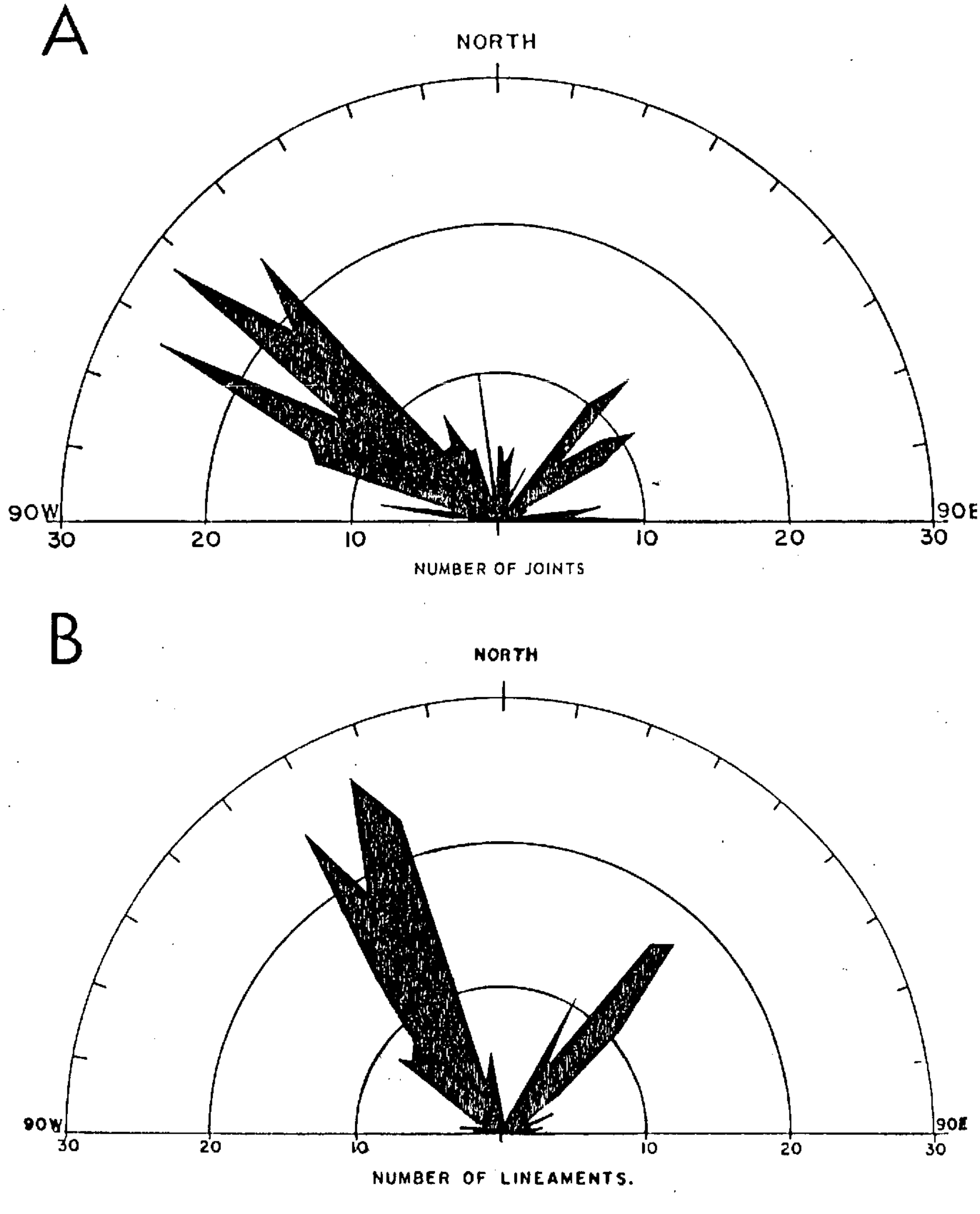

Figure 2. - Rose diagrams comparing joint direction and lineament direction.

Figure 3. - Panoramic view of Wesobulga Creek shear zone exposed in road cut, NW 1/4 sec. 11, T. 21 N., R. 9 E., Mellow Valley 7 1/2 minute quadrangle.

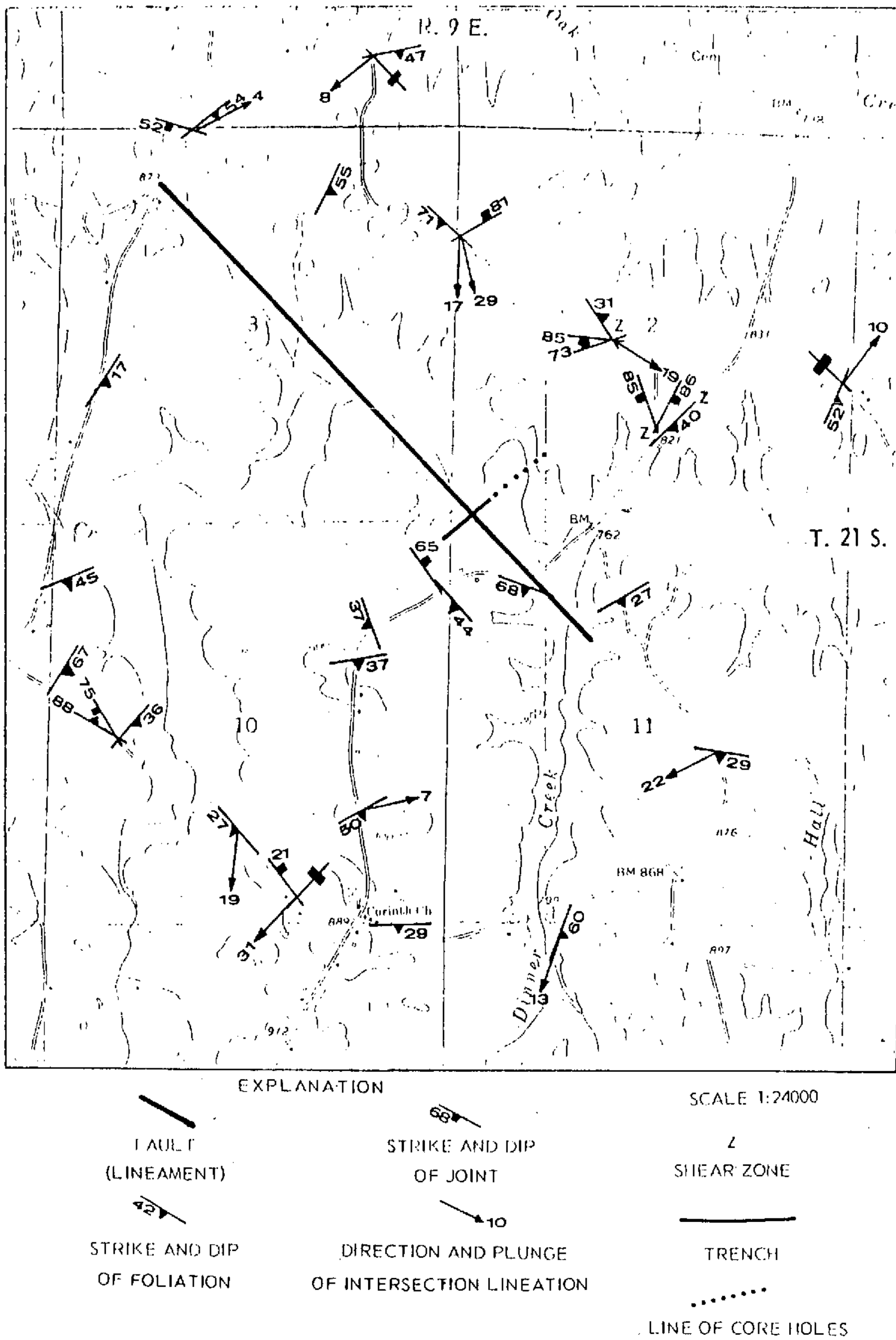

Figure 4. - Location of lineament having structural origin, secs. 2, 3, and 11, T. 21 S., R. 9 E Mellow Valley 7 1/2 minute quadrangle.

The fault is a late structural element offsetting both the foliation and joints. The structure could not be followed beyond the outcrop in which it is exposed, however, a linear topographic valley, trending parallel to the trace of the fault plane occurs to the northwest (fig. 2). The corresponding Wesobulga Creek fault zone is approximately 3 meters wide and has an approximate strike of N 40-45° W with displacement of 3-15 meters in the roadcut. The principal zone of movement occurs on the east end of the fault zone where a mylonite-phyllonite zone 10 cm wide marks the fault. The remaining 2.9 meters of the zone is composed of a series of closely spaced vertical shear joints that decrease in number to the west (figs. 5 and 6).

To fully investigate the orientation and extent of the fault, eight trenches were dug across its projected trace (fig. 7). Six of the eight trenches nearest to the road exposure cut the fault (fig. 8). One trench, 90 meters long, located approximately 700 meters north of the road (fig. 4) failed to intersect the fault trace. The trenches show tha the fault zone narrows in both directions from the 3-meter-wide zone at the road cut to a half-meter-wide kink band in trench TN-4 and to a disturbed zone less than 2 meters wide in trench TS-3. The trend of the fault, as exposed, coincides with the orientation of the lineament derived from both SLAR and ERTS data. The general shape of the fault zone and its topographic position along the flank of a steep-sided valley suggest that the feature may not be tectonic, but may represent a recent rotational shear related to slumping. Samples of mylonitic rock from the principal fault zone were collected for radiogenic age dating (K/Ar). Approximately 500 meters east of the fault, on the adjacent valley wall, another small fault and drag fold (fig. 2) are exposed in a road cut, but the relationship of this feature to the Wesobulga Creek fault is unknown at this time.

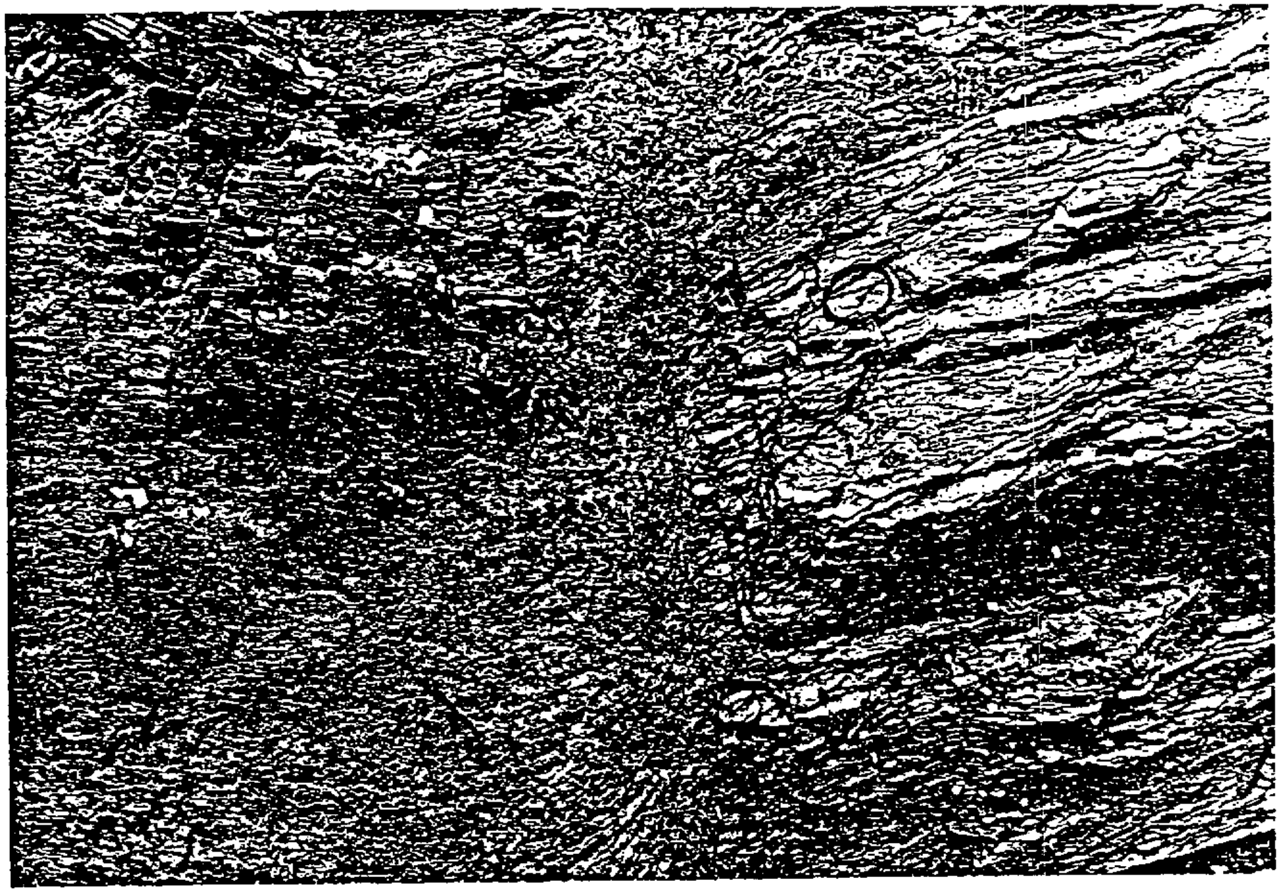

Figure 5. - Close up of left side of fault zone in figure 31. Sense of movement left side up. Note joints splaying off main fault and coarsening of phyllite adjacent to fracture zone.

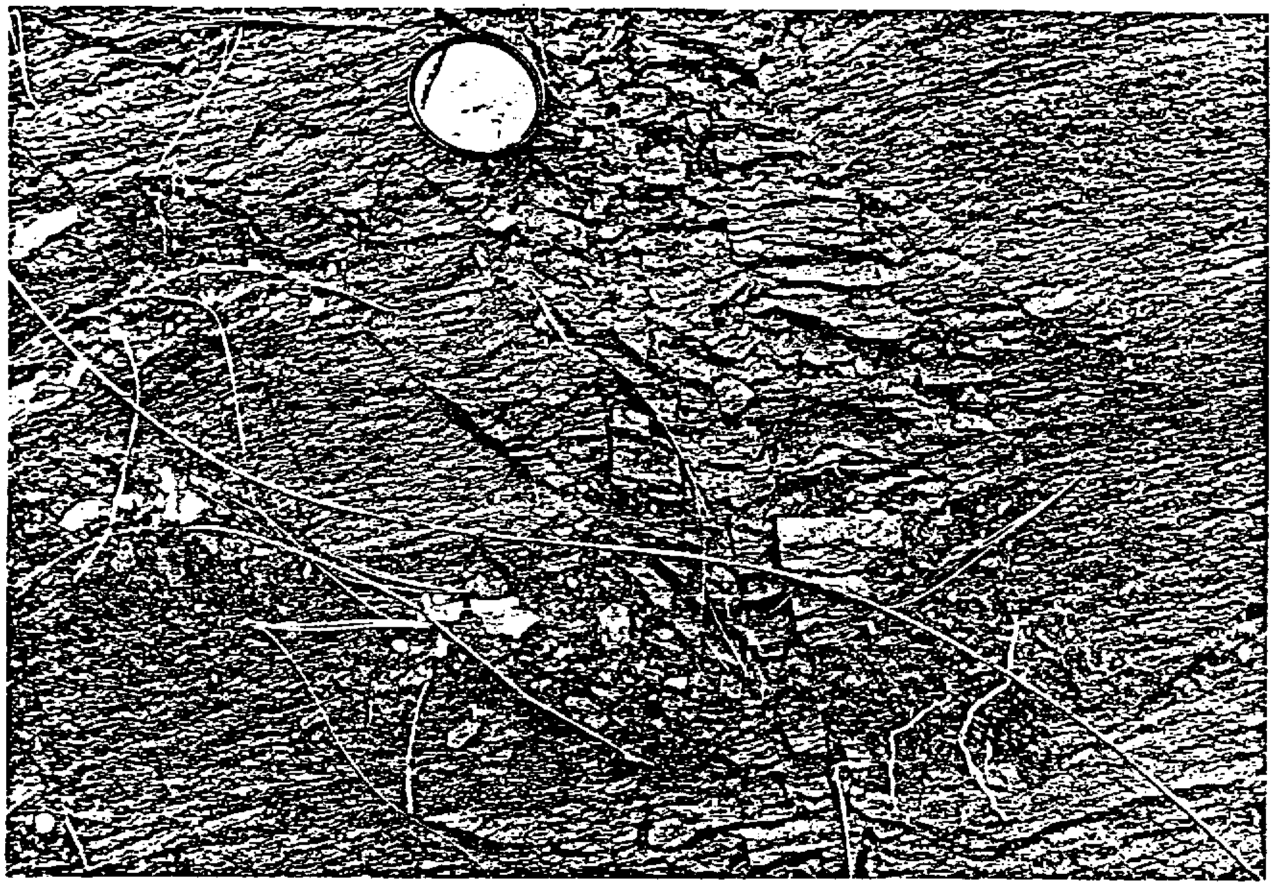

Figure 6. - Close up of feather joints adjacent to fault surface. Sense of movement between blocks in fault zone and hanging wall; right side up.

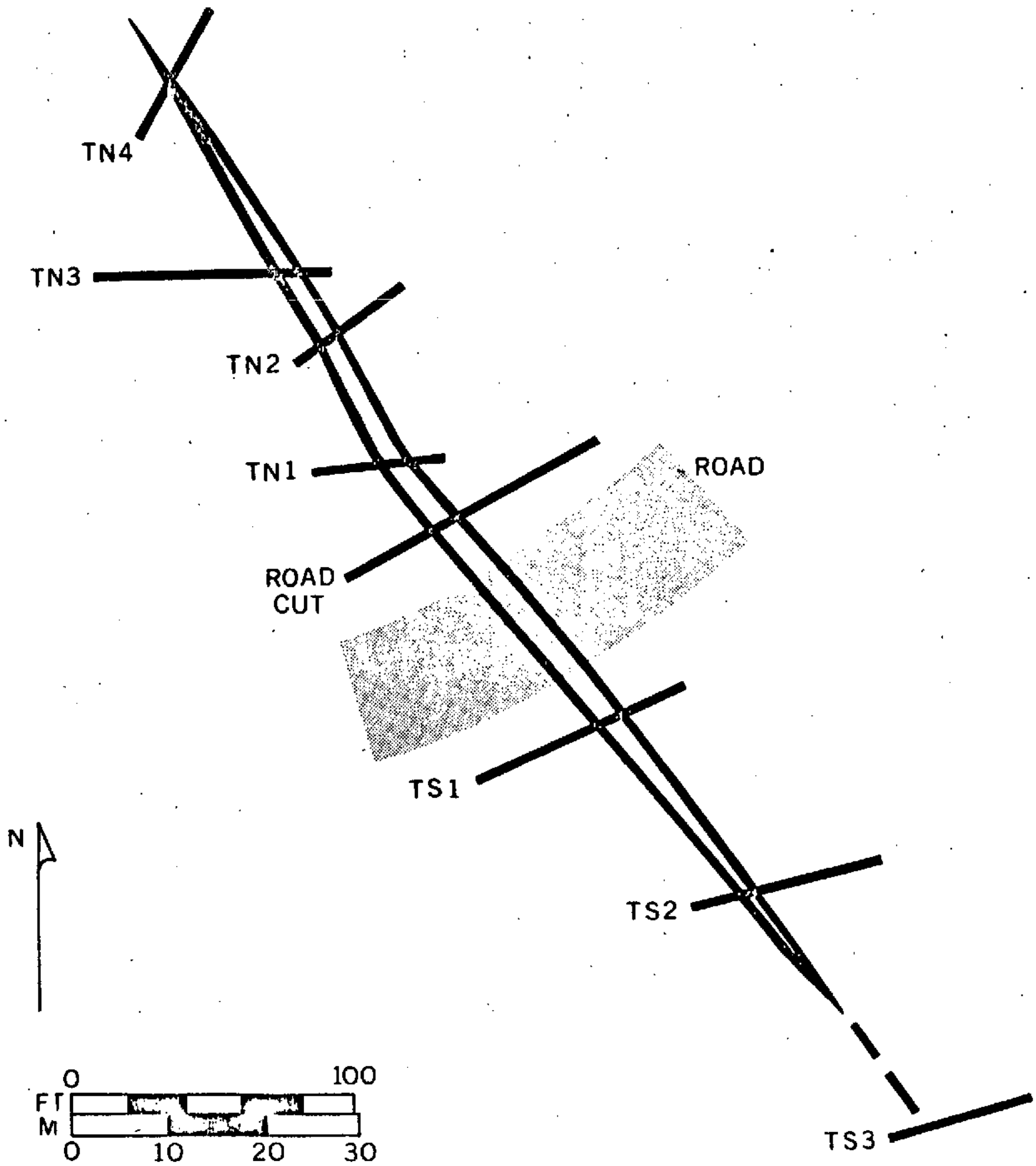

Figure 7. - Map of Wesobulga Creek shear zone showing location of 8 of 9 trenches dug to intersect zone. Trench 10 was approximately 200 meters north of TN-4 on NE trending spur ridge (see fig. 4).

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A. - Trench TS-2, looking easterly, shear zone exposed at "A".

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B. - Trench TN-3, looking east, shear zone crosses trench at point "A", small flexure exposed at point "B".

Figure 8. - Photograph showing two of the trenches excavated to examine the Wesobulga Creek lineament, Clay County, Alabama.

The U.S. Soil Conservation Service drilled a series of holes across the projected lineament (fig. 4) as a part of an ongoing program to develop watershed control dams. These holes indicated the rock was more jointed or sheared nearer the creek. Visual inspection of drill cores showed minor slickensides and neorecrystallization of low temperature minerals.

The major zone of movement is well developed in trenches TS-1, TN-1, TN-2, and TN-3. In each of these trenches the principal zone of sheared rocks (fig. 9), mylonite (fig. 10) and offsetting foliation (fig. 11) attesting to the existence of the fault zone, occurred on the east side of the fault zone exposed on the road (fig. 3). In each trench where the fault zone could be defined, intensity of shearing and number of shear joints decrease to the west. A second cross-cutting fault was observed in TN-4. The strike of this fault or shear zone diverged approximately 25° from the road cut fault but is still within the general strike direction of the lineament trace transferred from ERTS-1 imagery.

Discussion

Although the data presented here and the conclusions drawn from the data represent only a small area in the Alabama Piedmont, the apparent correlation between topographic lineaments and joints indicates a direct application of ERTS imagery to geologic mapping and delineation of areas of potential haz ard.

This example of a positive relationship of one ERTS-derived lineament to a small fault is noteworthy, but certainly not statistically significant. It should not be regarded as an indication that all or even most lineaments are related to faulting. On the contrary, evidence based on this test area suggests that most of the minor lineaments are not related to obvious structural features.

Figure 9. - Shear zone, TN-2, south wall, zone dips left (pencil).

Figure 10. - Shear zone exposed in TN-1, mylonite approximately 10 cm wide (knife). Rock saprolite "A" dips right, mylonite zone "B" vertical dip.

Figure 12. -Road cut, point Z, fig. 4, hammer on shear, small fold to left.

Figure 11. -Shear zone, hammer, TN-2, note broken phyllite adjacent to hammer.

Summary

The ERTS-1 imagery provided a wide areal observation of the structural grain of the Alabama Piedmont (Neathery, 1974). Many of the lineaments detected on the imagery could not have been so easily detected by conventional means, as topographic quadrangles or low altitude imagery. The ERTS imagery focused attention to areas of potential hazzards, thereby saving a number of man-field days.

Although field checking the lineament traces was generally inconclusive, the fact that one lineament is associated with a late brittle fault and that the direction of the late joint system generally coincides with the lineament orientation, indicates some degree of correspondence between structure and lineament features. This correspondence does not indicate, or should not be accepted as a restriction on construction programs without more comprehensive field studies.

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GEOCHEMICAL EVALUATION OF LINEAMENTS

By

Alan F. Skrzyniecki, Harold E. Nordstrom and W. Everett Smith

INTRODUCTION

Smith, Drahovzal and Lloyd (1973) found geochemical anomalies associated with certain lineaments in the Valley and Ridge and Piedmont provinces of Alabama. Locations of known hydrothermal mineralization in Alabama exhibit close spatial relationship to lineaments and to intersections of lineaments. The present study was undertaken to investigate possible lineament control in mineralized districts.

Seven areas were chosen for investigation (fig. 1). Area 1, the Harpersville district of Shelby County, exhibits barite mineralization in thrust faulted carbonate host rocks spatially associated with intersecting lineaments. Area 2, near Leeds in Jefferson County, exhibits barite veins in carbonate host rocks closely associated with one of the lineaments passing through area 1. Area 3, near Odenville in St. Clair County, exhibits copper mineralization in the same stratigraphic carbonate unit as at Leeds, and is also spatially associated with lineaments. Area 4, southeast of Talladega in Talladega County, encompasses the intersection of two lineaments associated with nearby copper and gold deposits. The intersection is in carbonate host rocks. These four areas were chosen partially because carbonate rocks are favored hosts for localization of epigenetic mineral deposits. Area 5, the Crafgord district of Randolph and Clay Counties, is the principal base and precious

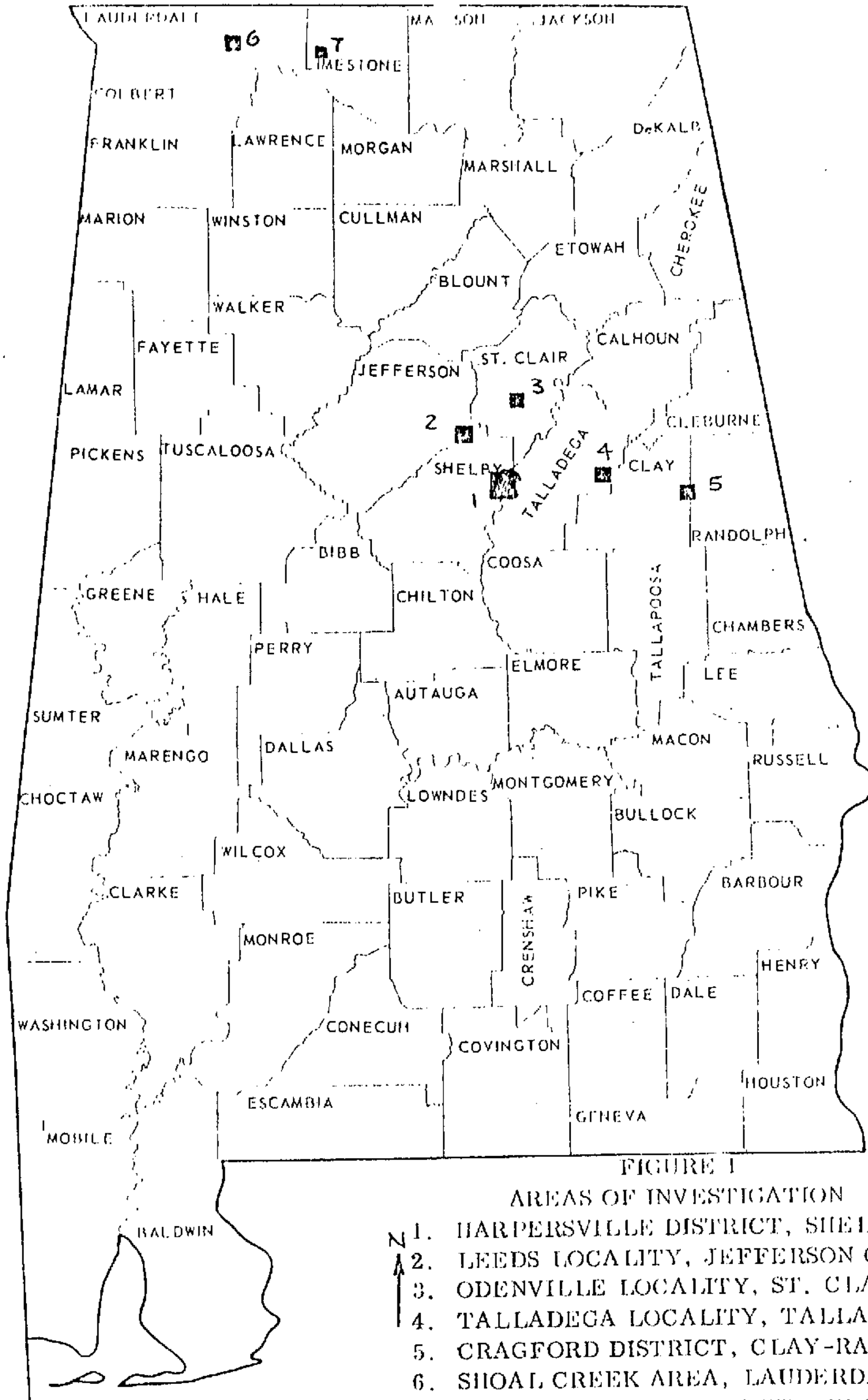


FIGURE 1

AREAS OF INVESTIGATION

1. HARPERSVILLE DISTRICT, SHELBY CO.
2. LEEDS LOCALITY, JEFFERSON CO.
3. ODENVILLE LOCALITY, ST. CLAIR CO.
4. TALLADEGA LOCALITY, TALLADEGA CO.
5. CRAGFORD DISTRICT, CLAY-RANDOLPH CO
6. SHOAL CREEK AREA, LAUDERDALE CO.
7. ELK RIVER AREA, LIMESTONE COUNTY

metal district in Alabama. Hydrothermal veins are hosted in phyllite and five lineaments pass through the district. Areas 6 and 7 are in northern Alabama. Several large scale lineament features traverse the northern Alabama region, and are potential zones of base metal mineralization, particularly where they traverse sequences of carbonate rock.

The hypothesis to be investigated is that the lineaments may represent deep seated fracture systems which may have served as channelways for mineralizing fluids. If such fracture systems exist one would expect to find geochemical anomalies associated with some of the lineaments. A geochemical soil sampling program was designed to investigate this hypothesis. Lineaments investigated were chosen from those delineated on plate 1.

GEOCHEMICAL SAMPLING PROCEDURE

Tonal lineaments to be investigated were derived from ERTS-1 imagery (pl. 1) and plotted on 1:62,500 and 1:24,000 base maps together with the known hydrothermal metal deposits. Traverses were made along roads which came as close as possible to mines and prospects and to lineament intersections. Samples were generally collected at intervals of 0.1 to 0.2 mile and well off the road from undisturbed areas. Care was taken to avoid sampling contaminated areas such as drainage areas from culverts, dumps, old wire, etc. Samples were taken from the upper "B" soil horizon from at least a foot below the surface to minimize contamination. The soil samples were placed in polyethylene bags and labeled for transport to the laboratory.

Samples of the freshest possible rock obtainable from outcrops and road cuts in the study areas were collected to aid in the interpretation of the geochemical behavior of the elements and to aid in the estimation of threshold values.

Sample Preparation

Samples were air-dried, crushed in mullite utensils, and sieved to -100 mesh in stainless steel screens. Because aluminum, iron, or chromium were not to be analyzed, it is felt that these methods caused little contamination.

Analytical Methods

All samples were digested in HF-H_2SO_4 mixtures and diluted to appropriate concentrations. Duplicate samples from Shelby and Jefferson Counties were also prepared by fusion with lithium metaborate and acid digestion. The dissolved samples were then analyzed on a Perkin-Elmer model 303 atomic absorption unit equipped with digital concentration readout. For a further discussion of the theory and methods of atomic absorption analysis, the reader is referred to available books on the subject, notably Rubeska and Moldan (1967), Slavin (1968), Ramirez-Munoz (1968), Angino and Billings (1963), and Morrison (1965). A variety of elements were analyzed, depending on the area of investigation. The choice of elements will be discussed in sections on each area.

ANALYTICAL RESULTS AND DISCUSSION

Area 1: Harpersville

The Harpersville district of Shelby County is located on figure 1. Locations of lineaments, barite occurrences, and traverses are shown on figure 2.

In all, 5 traverses were made, consisting of 63 soil samples. Eight rock samples were also collected from the area for comparison. The Harpersville district is in the Coosa deformed belt of the Valley and Ridge province. The area is underlain by limestones and dolomites of Cambrian and Ordovician ages and is extensively thrust faulted (Drahovzal, J. A., 1974, personal communication). The thrust faults are subparallel to several member traces of the Harpersville lineament complex in the area (Drahovzal, 1974). The possibility thus exists that some of these lineaments may be traces of thrust faults and that the thrust faults could be favorable areas for localization of mineralization. Barite is known to occur in the area. Strontium and manganese can substitute for Ba in barite (Deer, Howie and Zussman, 1962). Strontium also commonly associates with calcium (Goldschmitt, 1954) and can give an indication of amount of leaching of carbonate rocks. A common limestone replacement association is Zn-Pb-Ba-F-Sr (Krauskopf, 1955). Further, Cu, Pb, and Zn ores are known to occur in the Valley and Ridge province and these elements were found to be enriched in rocks from areas of barite mineralization in Alabama (Hughes and Lynch, 1973). Therefore rock samples prepared by fusion and soil samples prepared by fusion and by acid digestion were analyzed for Ba, Mn, Sr, Cu, Zn, and Pb. Analyses are given in tables 1 to 6. Because two of the rock samples (table 1) were

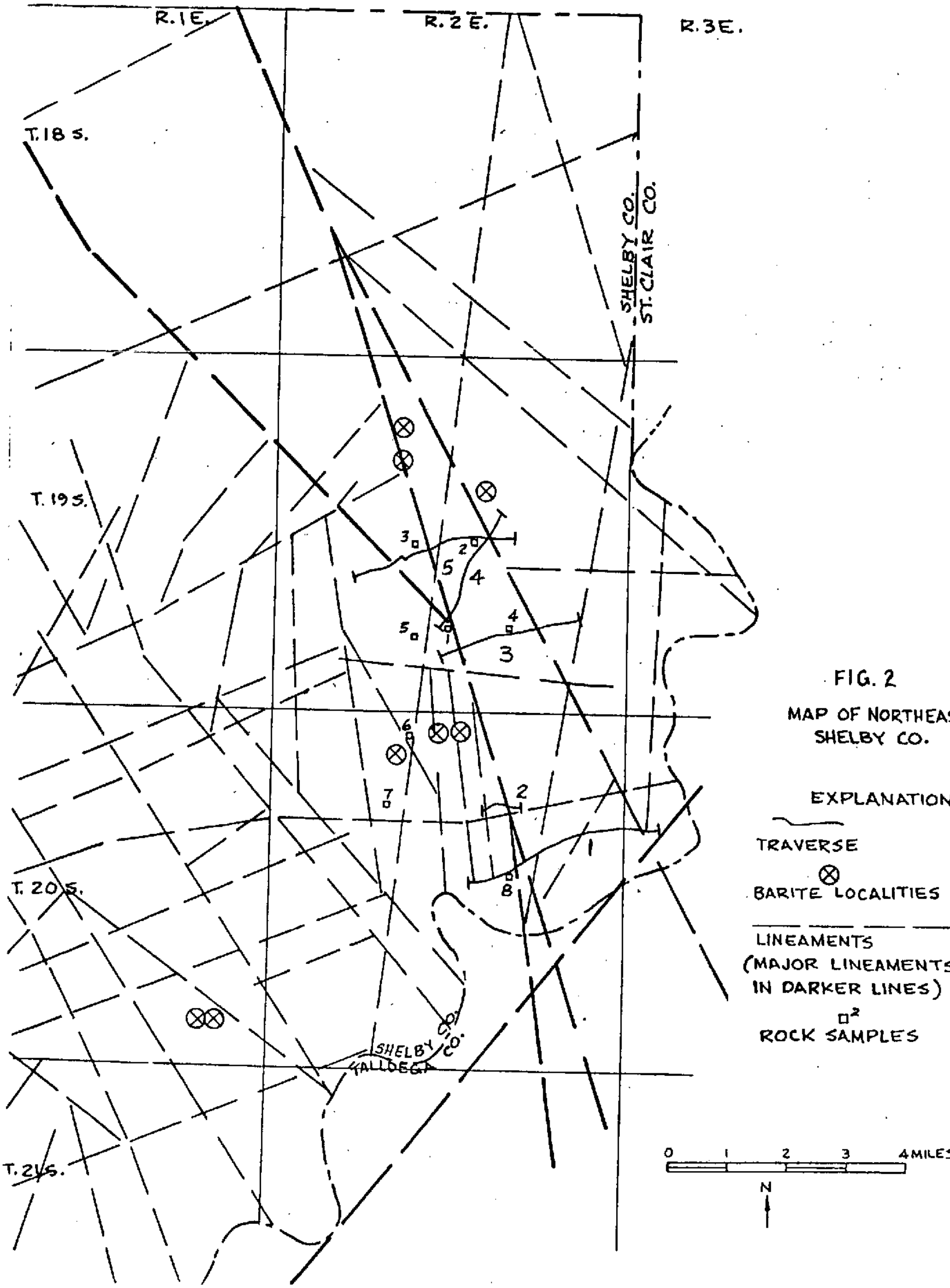


FIG. 2

MAP OF NORTHEAST SHELBY CO.

EXPLANATION

TRAVERSE

BARITE LOCALITIES

LINEAMENTS (MAJOR LINEAMENTS IN DARKER LINES)

ROCK SAMPLES

Table 1
Chemical Analyses of Rocks (in parts per million)

Harpersville	Ba	Mn	Sr	Zn	Cu	Pb	Remarks
Rock 1	ND	8.5	3.0	13.0	18.0	125	Chert
Rock 2	190	58.0	446.5	28.0	32.0	95	Limestone
Rock 3	60	48.0	454.5	22.5	29.0	105	Limestone
Rock 4	10	80.0	439.5	16.0	24.0	90	Dolomite
Rock 5	50	226.0	180.5	15.0	20.5	35	Dolomite
Rock 6	45	31.5	355.5	14.5	0.5	35	Limestone
Rock 7	35	29.5	444.5	13.5	36.5	100	Limestone
Rock 8	5	9.5	2.5	4.0	28.0	100	Chert

	Ba	Mn	Sr	Cu	Zn	Pb	Total metal
Mean	65	79	387	23.8	18	77	650
Median	50	50	450	27.5	15	100	650
High	190	226	454	36.5	28	105	850

Analyst: G. Thomas, Geological Survey of Alabama

Table 2
Chemical Analyses of Soils (in parts per million)

Harpersville Traverse 1	Ba		Mn		Sr		Zn		Cu		Pb	
	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid
1-1	70	50	566.0	682.0	8.0	8.5	29.5	43.0	35.3	3.5	ND	5
1-2	77	150	63.0	118.5	19.5	21.5	58.0	70.0	31.5	11.0	ND	ND
1-3	50	35	109.5	179.5	4.0	18.0	37.5	83.0	46.0	6.5	ND	35
1-4	20	30	222.0	270.5	4.5	9.0	35.0	48.5	26.5	2.5	5	ND
1-5	15	35	164.0	151.0	4.5	16.5	33.0	46.0	45.0	2.5	70	ND
1-6	335	375	34.5	13.5	16.0	20.5	37.5	50.0	41.5	8.0	115	ND
1-7	340	120	321.5	484.5	29.5	29.5	44.5	85.5	29.0	20.0	65	20
1-8	595	485	256.0	443.5	9.5	18.5	155.0	157.5	96.0	61.0	ND	ND
1-9	660	515	34.0	34.5	4.0	3.5	117.5	183.5	164.0	62.5	ND	30
1-10	155	180	27.5	52.0	1.5	ND	92.0	99.5	56.5	35.0	ND	ND
1-11	40	ND	504.0	745.0	10.0	6.0	49.5	88.5	44.0	2.0	20	20
1-12	25	55	2,269.0	2,421.5	4.5	ND	110.0	77.0	32.0	14.5	100	50
1-13	15	20	308.0	522.0	4.5	1.5	56.0	58.0	73.0	8.5	15	90
1-14	ND	40	418.5	554.5	2.0	15.0	86.0	107.5	45.5	20.5	ND	90
1-15	ND	55	440.5	518.5	3.0	8.0	42.5	51.5	47.0	12.0	150	50
1-16	ND	20	320.0	463.0	1.0	13.5	68.5	70.0	30.0	10.0	100	15
1-17	ND	ND	50.0	64.0	1.0	4.5	35.0	39.5	57.0	2.0	90	10
1-18	ND	15	78.0	108.5	8.0	18.5	62.5	53.5	47.5	13.5	130	ND

Analyst: G. Thomas, Geological Survey of Alabama

Table 3
Chemical Analyses of Soils (in parts per million)

Harpersville Traverse 2	Ba		Mn		Sr		Zn		Cu		Pb	
	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid
2-1	600	800	28.5	39.0	7.5	39.5	64.5	69.5	66.5	50.0	45	15
2-2	15	10	63.0	43.5	10.5	15.0	29.0	36.5	37.5	9.5	120	ND
2-3	570	550	21.0	20.0	5.0	22.0	50.5	60.5	65.5	55.0	85	15
2-4	25	40	135.5	147.0	10.5	7.5	39.5	52.5	22.0	2.0	15	50
2-5	ND	20	421.5	572.5	ND	6.5	45.5	59.5	21.0	13.0	25	50

Analyst: G. Thomas, Geological Survey of Alabama

Table 4
Chemical Analyses of Soils (in parts per million)

Harpersville Traverse 3	Ba		Mn		Sr		Zn		Cu		Pb	
	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid
3-1	ND	125	239.0	295.5	4.0	25.5	58.0	39.0	29.5	14.0	75	15
3-2	70	100	691.0	839.0	7.0	16.5	19.5	41.0	24.0	18.0	15	15
3-3	25	140	312.5	375.5	1.0	12.5	45.5	88.5	32.5	17.0	75	15
3-4	840	295	16.0	25.8	13.5	1.5	60.5	103.0	104.0	65.5	50	ND
3-5	ND	35	42.0	46.0	5.0	13.0	19.0	28.0	35.0	16.5	80	ND
3-6	ND	10	47.0	52.0	3.5	3.0	60.0	75.5	39.0	31.5	245	ND
3-7	70	30	833.0	842.5	5.0	17.5	64.0	78.0	25.5	11.5	60	ND
3-8	70	20	2004.0	1863.0	5.5	7.0	42.5	50.0	37.5	2.0	5	35
3-9	ND	ND	196.0	272.0	ND	4.0	37.5	53.5	26.0	6.0	70	ND
3-10	40	20	312.0	416.0	1.5	8.5	36.0	52.5	42.5	4.0	190	10
3-11	ND	20	51.0	65.0	1.0	6.5	41.0	51.5	45.0	11.0	ND	ND
3-12	ND	65	50.0	54.0	6.0	7.5	16.0	19.0	33.5	9.5	30	ND
3-13	5	70	215.5	301.0	7.5	7.5	47.0	61.5	29.5	21.0	75	5

Analyst: G. Thomas, Geological Survey of Alabama

Table 5
Chemical Analyses of Soils (in parts per million)

Harpersville Traverse 4	Ba		Mn		Sr		Zn		Cu		Pb	
	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid
4-1	ND	ND	48.5	75.0	3.0	9.0	43.5	69.5	32.0	8.0	15	ND
4-2	ND	90	53.5	69.0	3.0	16.0	15.5	41.5	42.0	2.0	ND	10
4-3	30	80	88.5	63.5	15.5	12.5	23.5	16.0	20.0	7.0	95	50
4-4	ND	85	26.0	44.0	4.0	13.0	6.0	37.5	30.0	3.0	15	ND
4-5	845	440	10.5	16.5	17.5	ND	46.5	60.5	88.5	76.0	18	ND
4-6	20	280	63.5	88.5	2.0	17.5	36.0	34.0	45.0	8.5	75	40
4-7	360	695	27.0	35.0	0.5	6.0	93.5	115.0	72.0	61.5	190	ND
4-8	130	290	87.5	122.5	3.0	22.5	37.0	66.0	38.0	14.0	265	15
4-9	1380	385	28.5	37.5	27.0	ND	130.0	139.0	96.0	71.0	20	ND
4-10	320	230	70.5	74.5	15.0	17.5	62.5	56.5	45.5	22.5	45	ND
4-11	5	25	166.0	185.0	8.0	1.5	30.0	36.0	24.5	9.0	180	ND
4-12	5	30	376.5	427.0	ND	1.5	37.0	56.5	34.0	7.5	150	ND
4-13	35	25	326.5	381.5	ND	10.5	29.5	44.5	19.0	28.0	15	30

Analyst: G. Thomas, Geological Survey of Alabama

Table 6
Chemical Analyses of Soils (in parts per million)

Harpersville Traverse 5	Ba		Mn		Sr		Zn		Cu		Pb	
	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid
5-1	285	155	35.0	41.5	7.0	11.0	60.5	99.5	42.0	35.0	95	ND
5-2	15	5	72.5	71.0	4.0	ND	17.5	33.5	7.5	7.5	105	ND
5-3	30	ND	70.0	114.5	5.5	4.5	57.0	63.5	31.5	3.0	65	70
5-4	10	25	35.0	52.5	4.5	12.0	22.5	56.5	28.5	7.0	105	ND
5-5	65	210	453.5	769.5	14.0	9.5	54.0	94.5	44.5	19.0	40	40
5-6	10	5	95.5	94.9	5.0	1.5	22.0	67.0	46.5	1.5	60	20
5-7	20	95	70.5	106.5	3.5	7.0	38.0	35.5	41.0	9.5	60	75
5-8	220	160	31.5	48.0	17.5	18.0	42.5	61.0	40.0	ND	60	45
5-9	40	ND	79.5	112.0	13.0	4.5	35.5	52.0	46.0	ND	105	10
5-10	35	ND	74.5	77.5	10.0	7.0	26.0	41.0	40.0	ND	100	5
5-11	35	55	87.0	94.0	ND	7.0	29.0	43.5	28.5	0.5	175	ND
5-12	190	520	652.0	1019.0	8.5	10.0	91.5	126.5	55.5	21.0	25	ND
5-13	5	20	91.0	112.5	4.0	17.0	7.5	39.5	23.5	ND	235	ND
5-14	ND	ND	52.0	66.0	4.0	13.5	33.0	66.5	39.0	0.5	65	ND

Analyst: G. Thomas, Geological Survey of Alabama

from chert pods (No. 1 and No. 8) they were excluded from further consideration. Means, medians, and high analyses from the other rocks are also shown in Table 1.

These rock values can give an indication of threshold values in the soil as well as an indication of the relative mobility of these elements in this area. Further, the rock analyses are in fair agreement with values suggested by Krauskopf (1967), Green (1959), and Vinogradov (1956) as averages for carbonates or all sedimentary rocks world wide.

The soil analayses (tables 2 to 6), when compared to the rock analyses, indicate strong leaching of strontium from the soils. This suggests that calcium and magnesium as well as other relatively mobile elements are also leached from the soil. Therefore, in this area strontium cannot be used as an indicator of mineralization, but does show that highs of mobile elements are not the result of differential leaching.

The fusion method of preparation ordinarily should yield values for a sample as high as or higher than samples prepared by $HF-H_2SO_4$ digestion. This generally holds true for barium and copper. Manganese and zinc values are often the reverse of this, though they are predictable. Strontium and lead values are often erratic. These phenomena are apparently the result of interference by one or more elements not analyzed, possibly aluminum (Thomas, G. 1974, personal communication). Therefore, greater credibility is assigned to the analyses for barium, copper, manganese, and zinc.

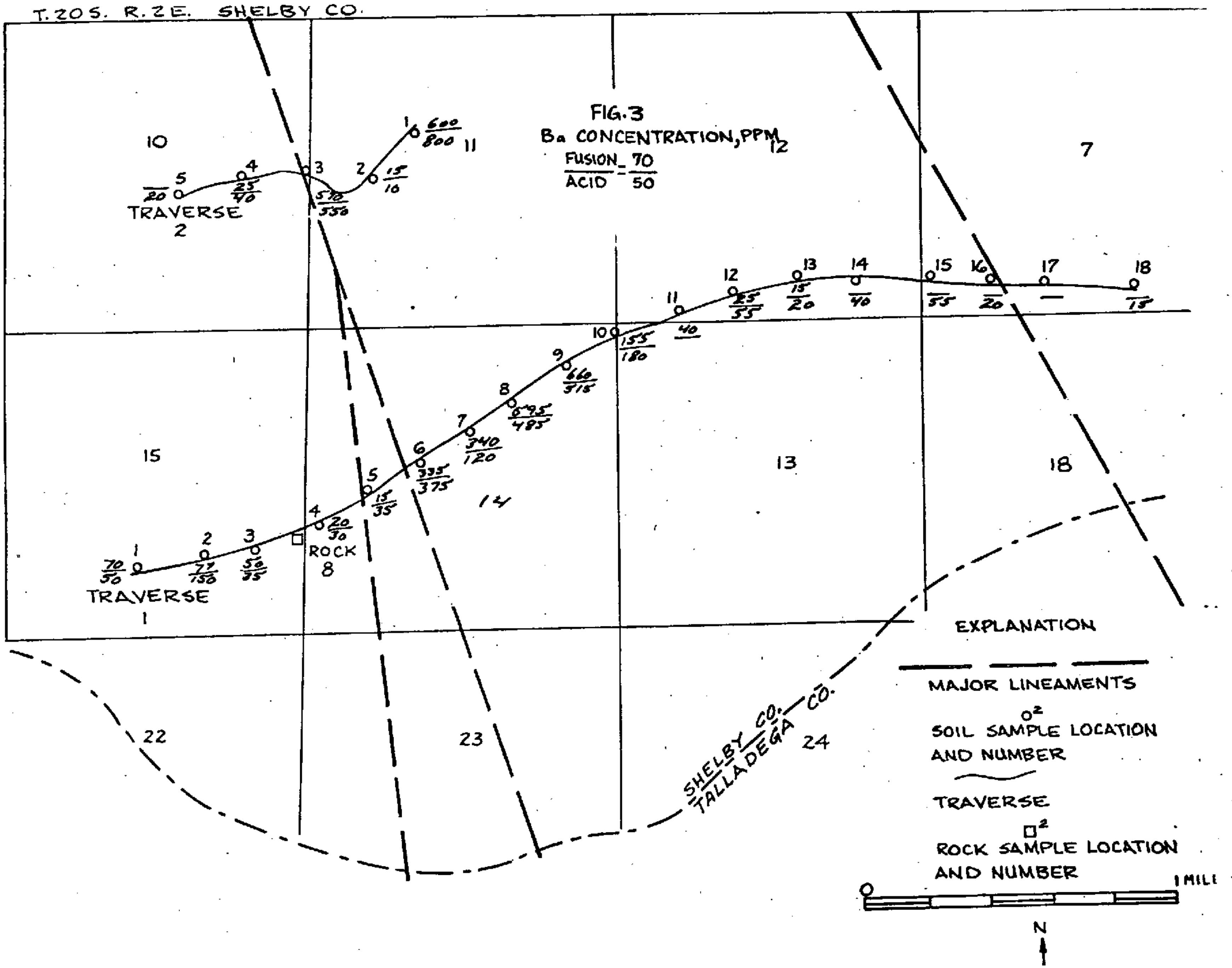
Mitchell (1955) reports ranges of elemental concentration found in soils. The Ba, Mn, Sr, Cu, Zn, and Pb concentrations of the Harpersville district are all below or near the low end of Mitchell's estimates. However, all the Harpersville concentrations agree well with estimates of Ginzburg (1960) and Hawkes and Webb (1962).

Ginzburg (1960) suggests that lead, barium, and strontium are relatively immobile and that copper and zinc are variable depending on pH and clay content. Hawkes and Webb (1962) suggest that lead and manganese are immobile, zinc is moderately mobile, barium is highly mobile, and copper is variable depending on pH. The present study, based on limited data, suggests that in the Harpersville district, strontium is highly mobile, that barium, manganese, and probably lead are immobile, and that copper and zinc are intermediate. These estimates were made by comparison of soil and rock concentrations, and by inspection of peak height and breadth.

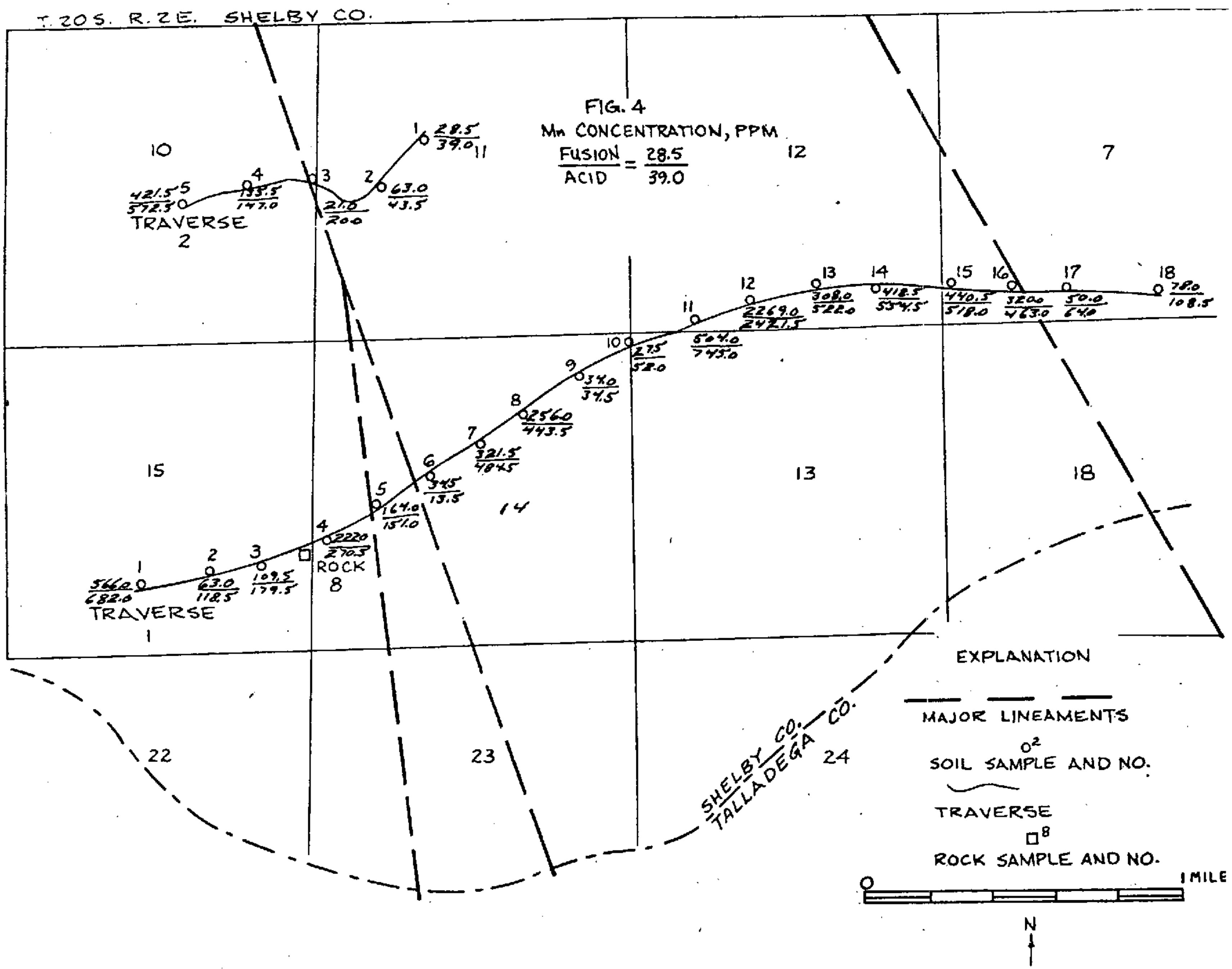
Because only 8 rock samples and 63 soil samples from this area were analyzed, no detailed statistical analysis has been attempted.

Traverse 1

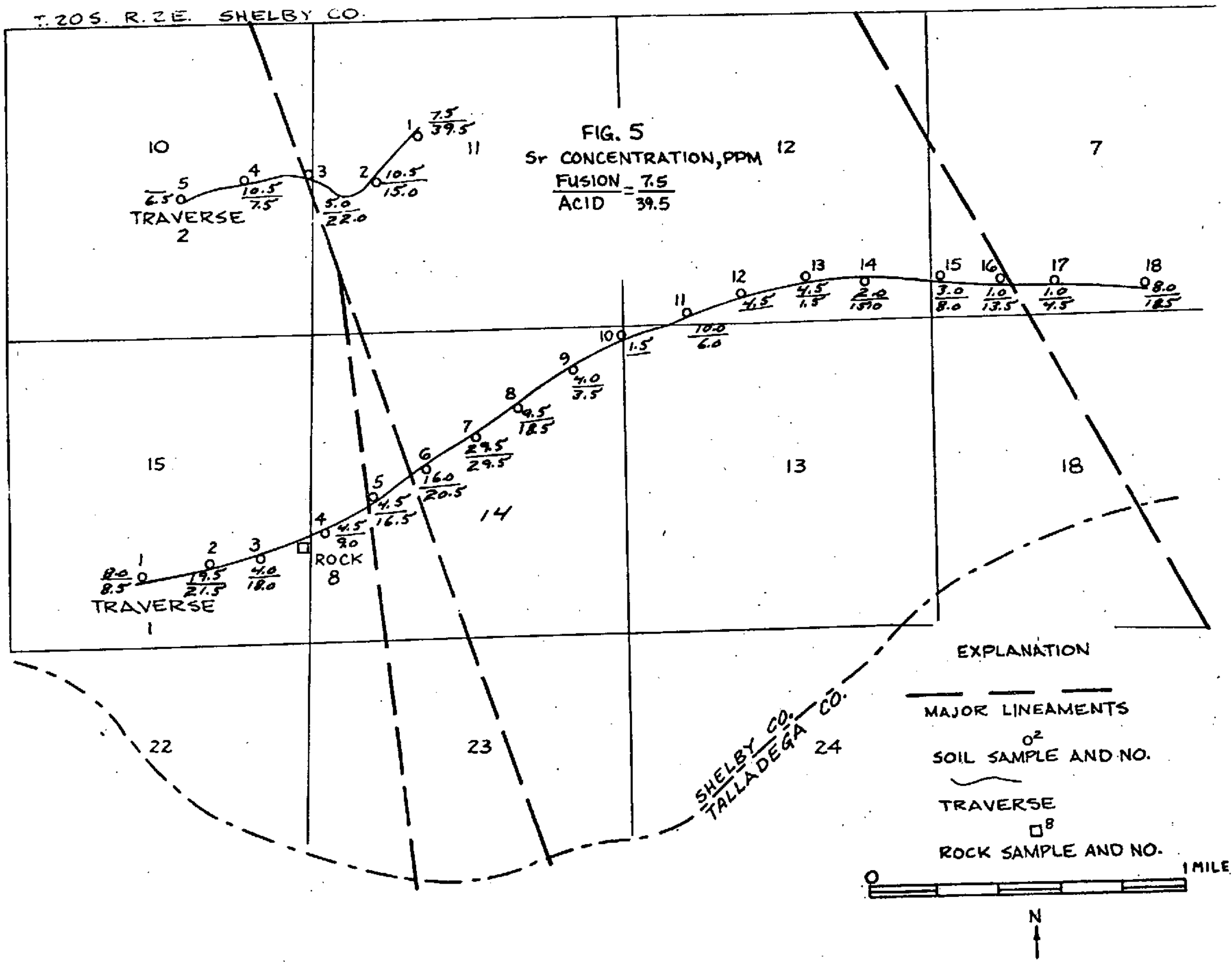
Chemical analyses are shown on maps on figures 3 to 9 and plotted as graphs on figures 10 to 16. Also plotted on figures 10 to 16 are mean, median, and high rock analayses as well as indicated threshold values for each element. Examination of these graphs indicates barium highs at points 6, 7, 8, and 9; manganese at point 12; copper highs at 8, 9, and 13; zinc highs at 8, 9, 12, and 14; lead highs at 15; and total metal highs at 8, 9, and 12.


T. 20 S. R. 2 E. SHELBY CO.
FIG. 3
Ba CONCENTRATION, PPM
FUSION 70
ACID 50
TRAVERSE 2
TRAVERSE 1
ROCK 8
SHELBY CO.
TALLADEGA CO.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE LOCATION AND NUMBER
TRAVERSE
ROCK SAMPLE LOCATION AND NUMBER
0
1 MILE
N

12-242



T. 20 S. R. 2 E. SHELBY CO.
FIG. 4
Mn CONCENTRATION, PPM
FUSION / ACID = 28.5 / 39.0
TRAVERSE 2
TRAVERSE 1
ROCK 8
SHELBY CO.
TALLADEGA CO.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
0
1 MILE
N



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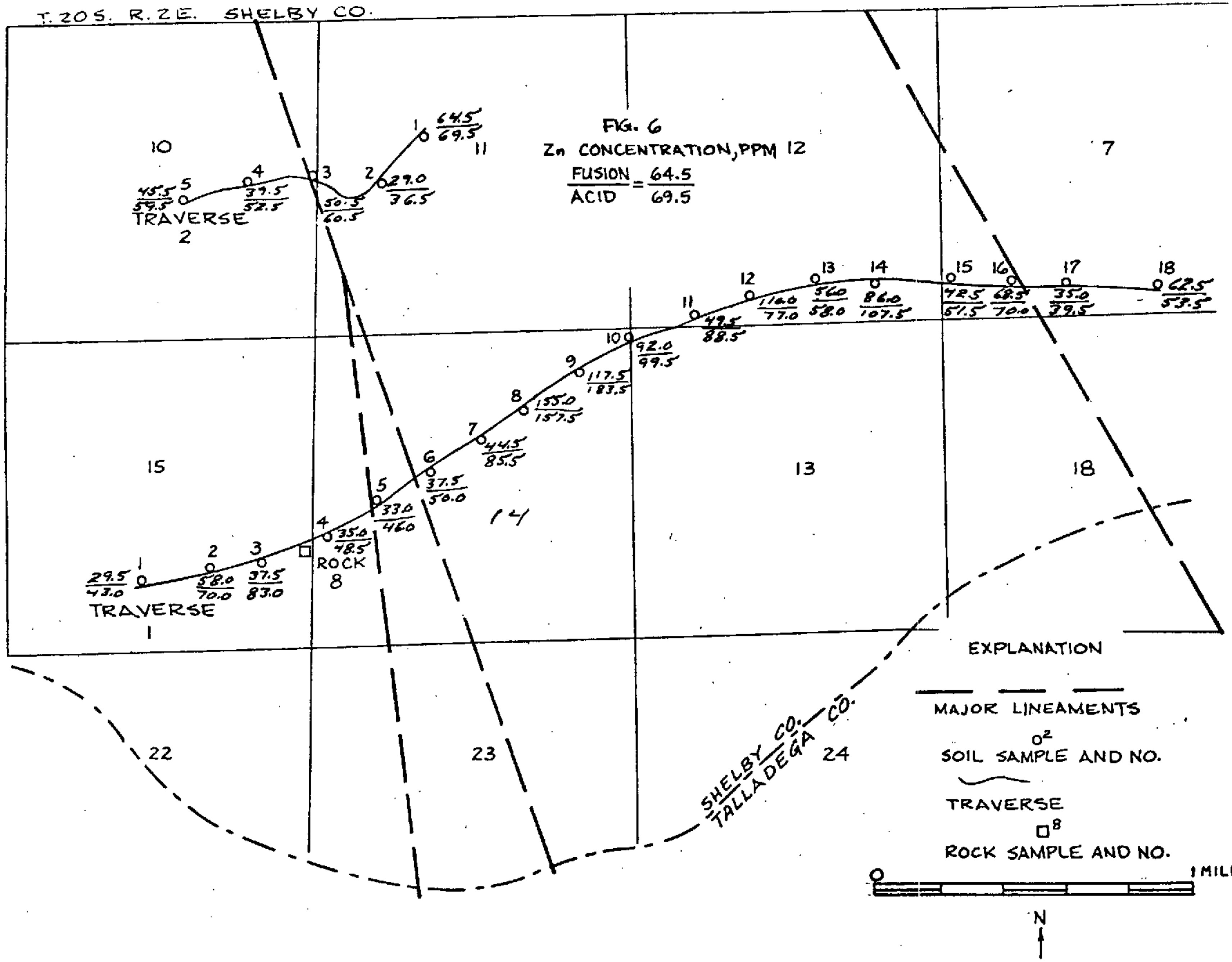
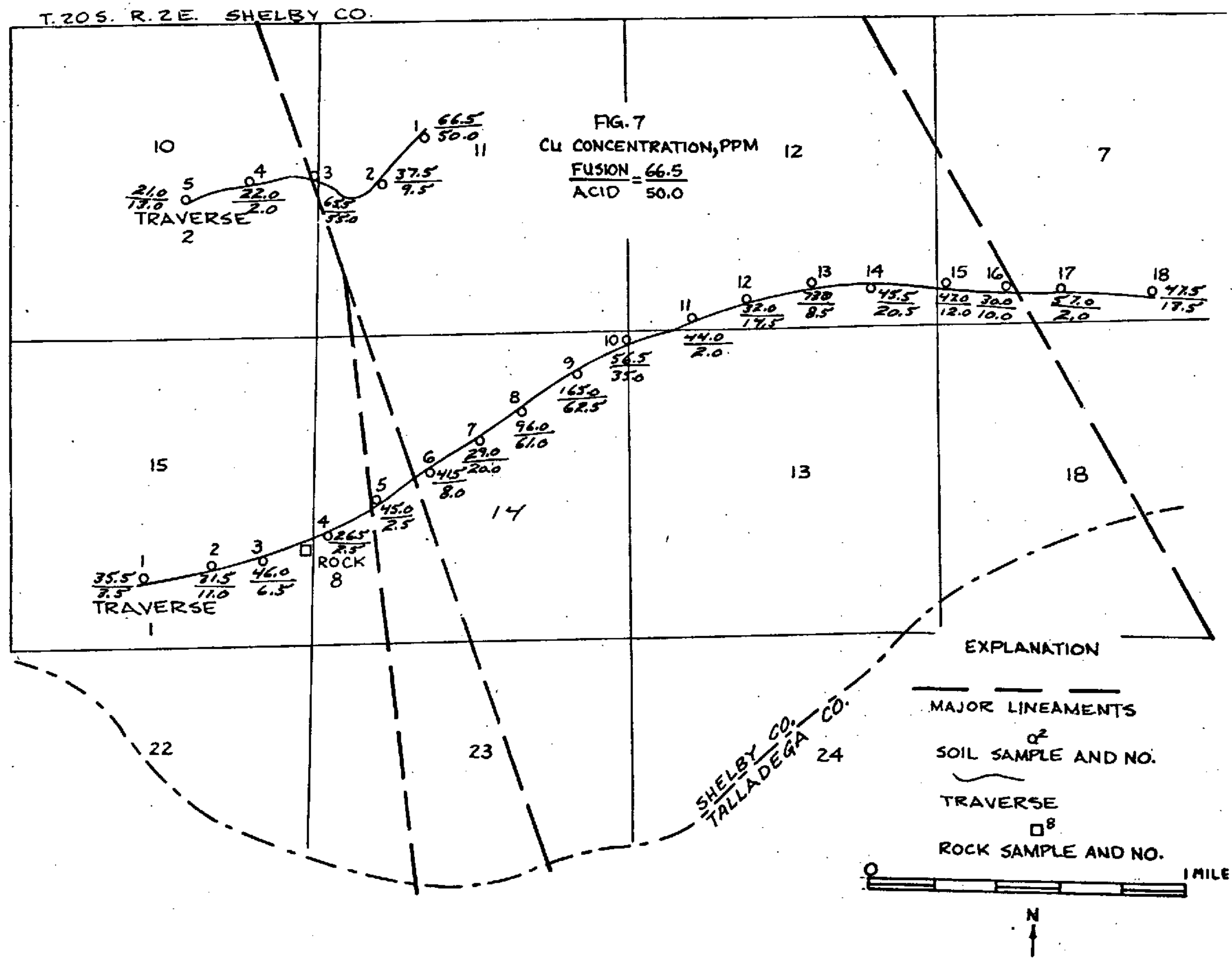
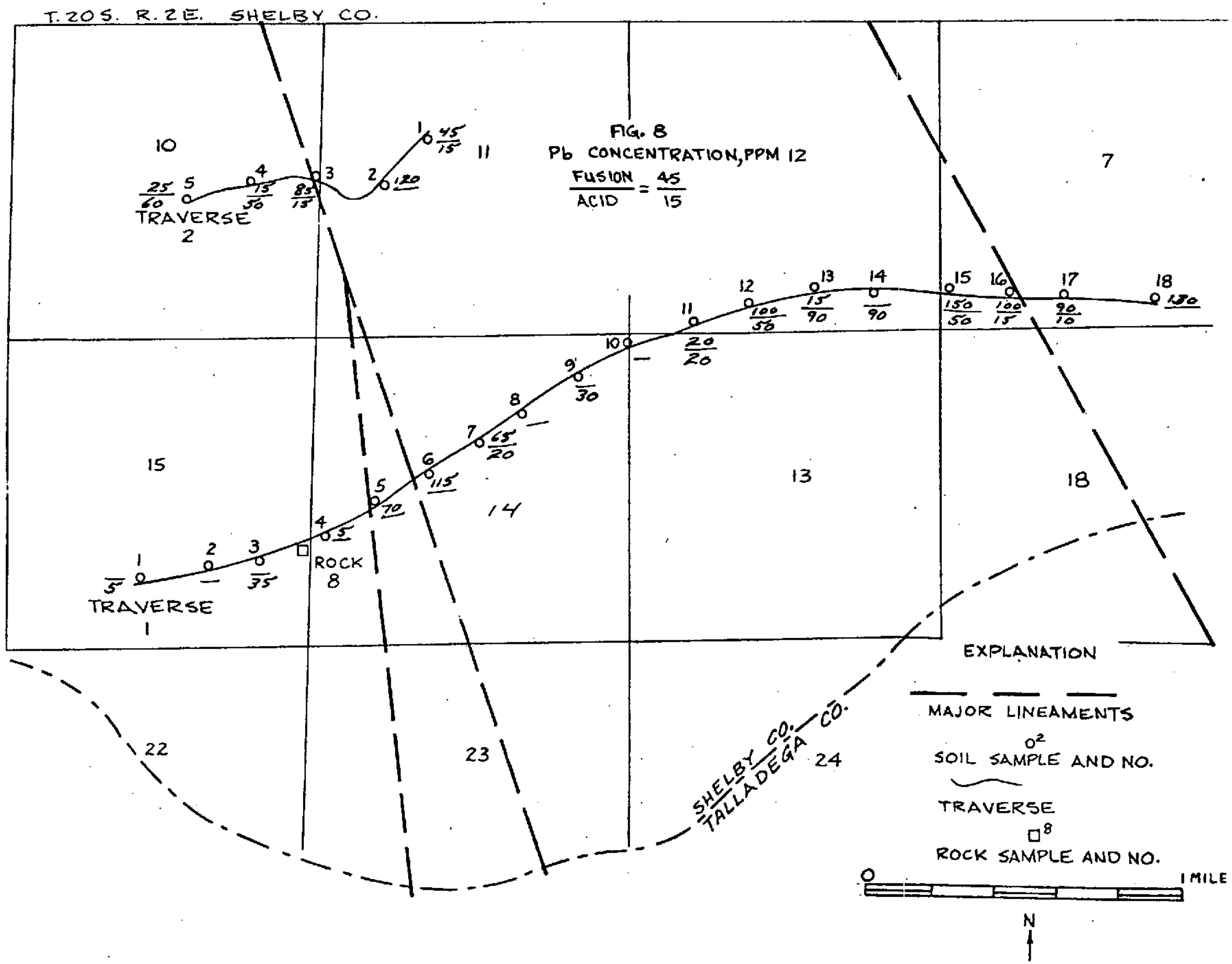

T. 20 S. R. 2 E. SHELBY CO.
FIG. 6
Zn CONCENTRATION, PPM
FUSION / ACID = 64.5 / 69.5
TRAVERSE 2
TRAVERSE 1
ROCK 8
10
11
12
7
15
14
13
18
22
23
24
SHELBY CO.
TALLADEGA CO.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
0
1 MILE
N

12-245


T.20S. R.2E. SHELBY CO.
FIG. 7
Cu CONCENTRATION, PPM
FUSION / ACID = 66.5 / 50.0
TRAVERSE 2
TRAVERSE 1
ROCK 8
10
11
12
7
15
14
13
18
22
23
24
SHELBY CO.
TALLADEGA CO.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
0
1 MILE
N



T. 20 S. R. 2 E. SHELBY CO.
FIG. 8
Pb CONCENTRATION, PPM
FUSION / ACID = 45 / 15
TRAVERSE 2
TRAVERSE 1
ROCK 8
SHELBY CO.
TALLADEGA CO.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
0
1 MILE
N

12-246

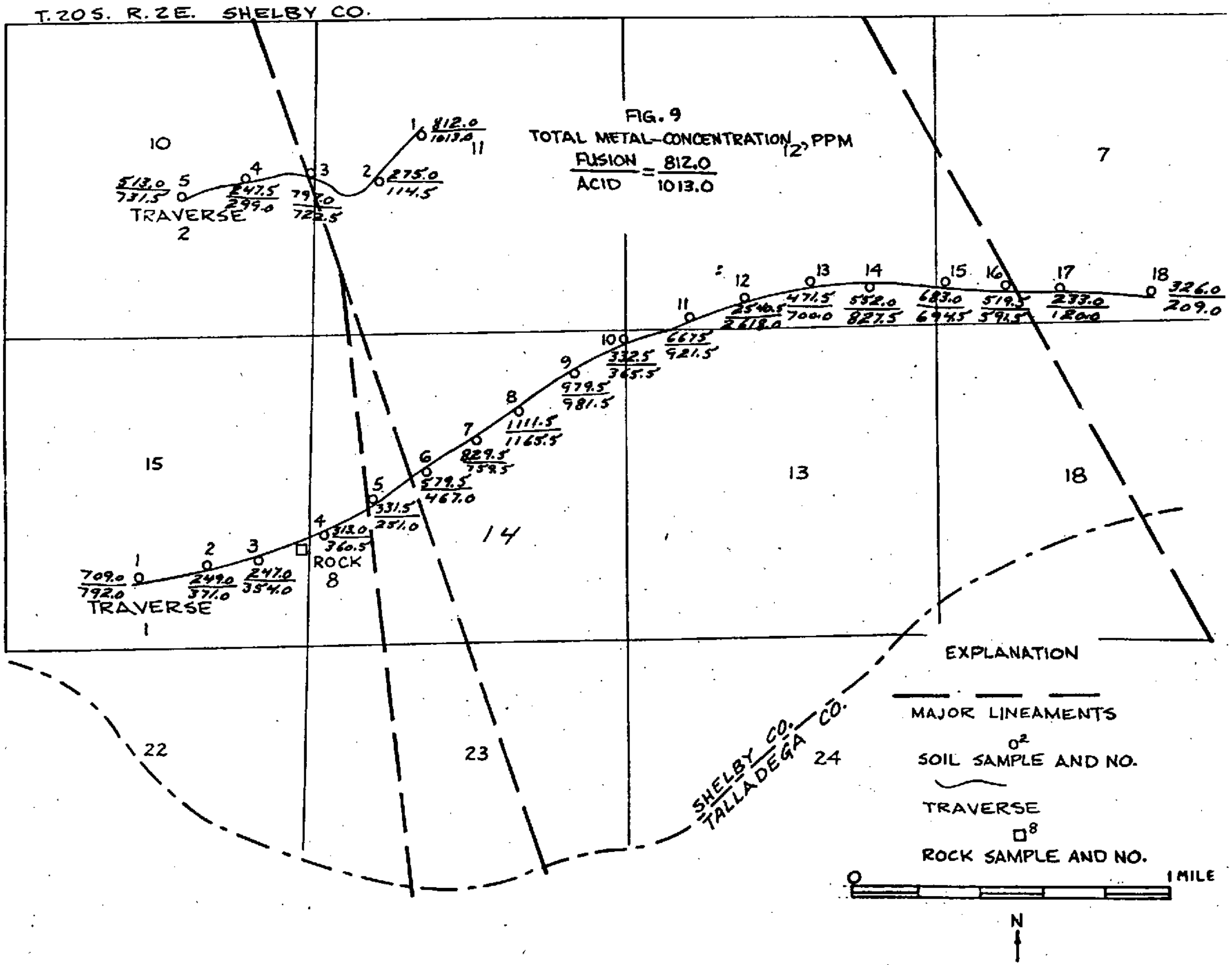

T. 20S. R. 2E. SHELBY CO.
FIG. 9
TOTAL METAL-CONCENTRATION, PPM
FUSION / ACID = 812.0 / 1013.0
10
11
12
7
15
14
13
18
22
23
24
TRAVERSE 2
TRAVERSE 1
ROCK 8
SHELBY CO.
TALLADEGA CO.
513.0 / 731.5
247.5 / 299.0
797.0 / 722.5
275.0 / 114.5
812.0 / 1013.0
709.0 / 792.0
249.0 / 371.0
247.0 / 354.0
312.0 / 360.5
331.5 / 251.0
579.5 / 467.0
829.5 / 758.5
1111.5 / 1165.5
979.5 / 981.5
332.5 / 365.5
667.5 / 921.5
2540.5 / 2618.0
471.5 / 700.0
552.0 / 827.5
683.0 / 694.5
519.5 / 591.5
233.0 / 120.0
326.0 / 209.0
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
0
1 MILE
N

FIG. 10
HARPERSVILLE TRAVERSE I
Ba CONCENTRATION

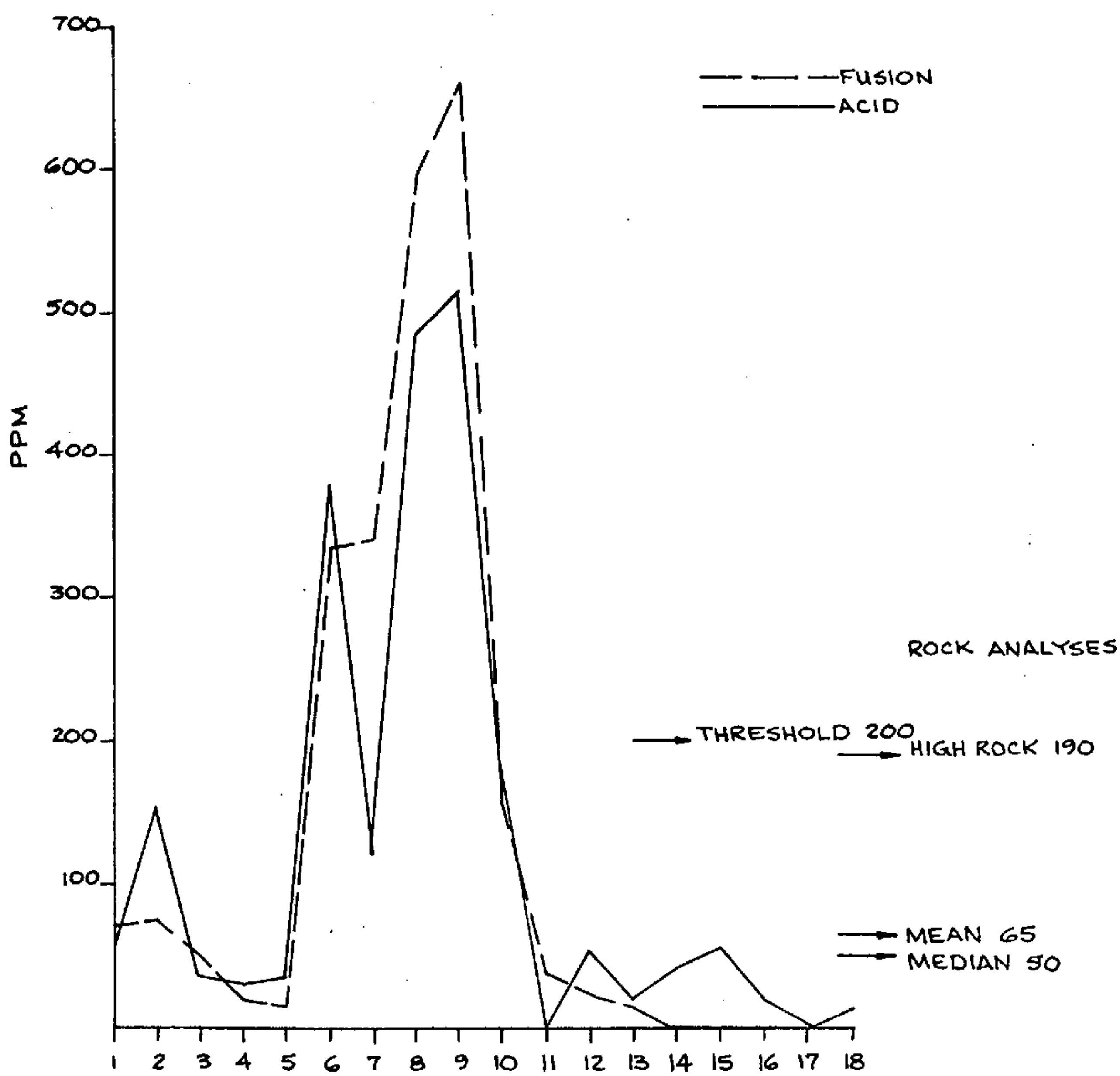


FIG. 11
HARPERSVILLE TRAVERSE 1
Mn CONCENTRATION

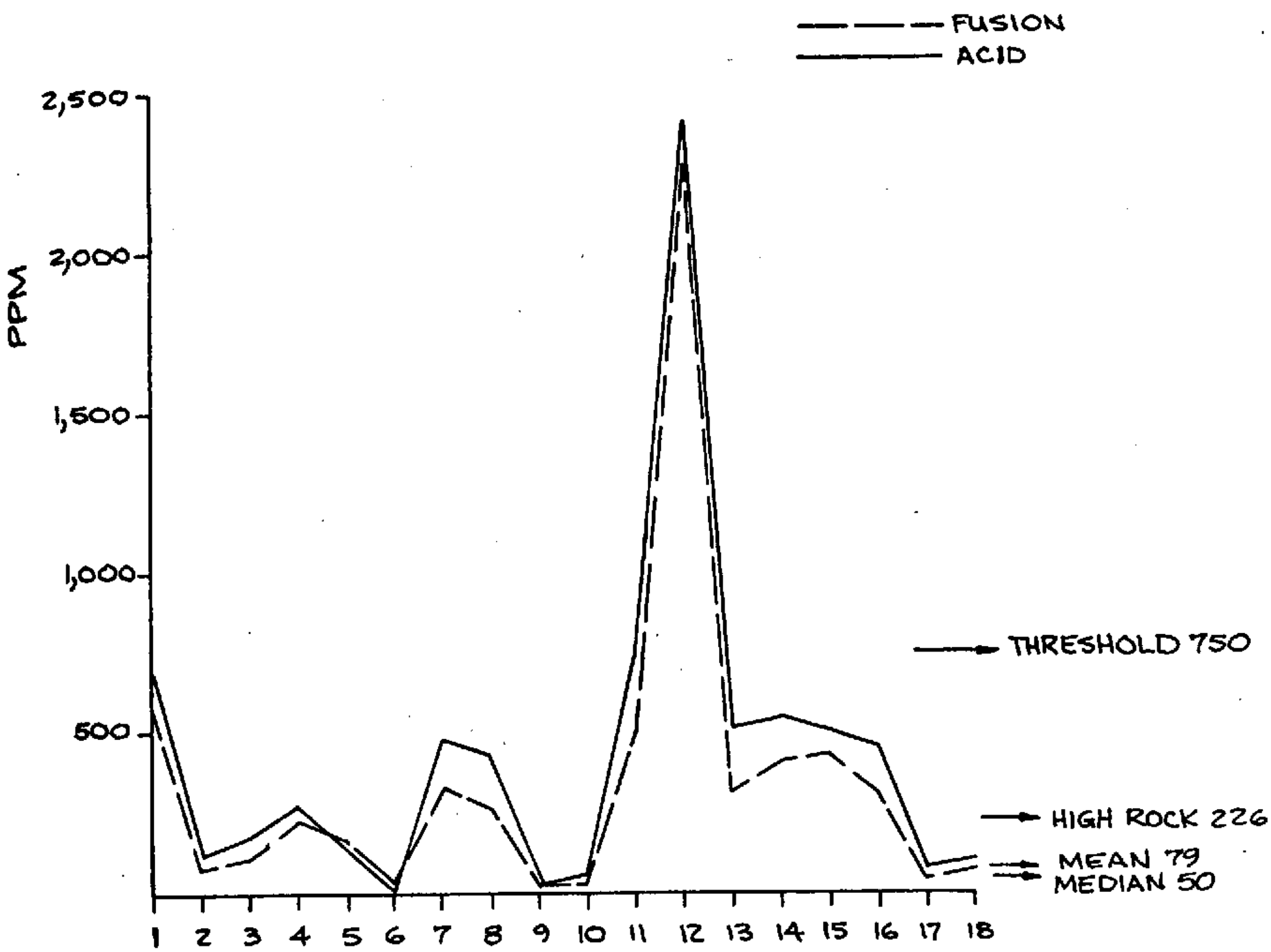


FIG. 12
HARPERSVILLE TRAVERSE
Sr CONCENTRATION

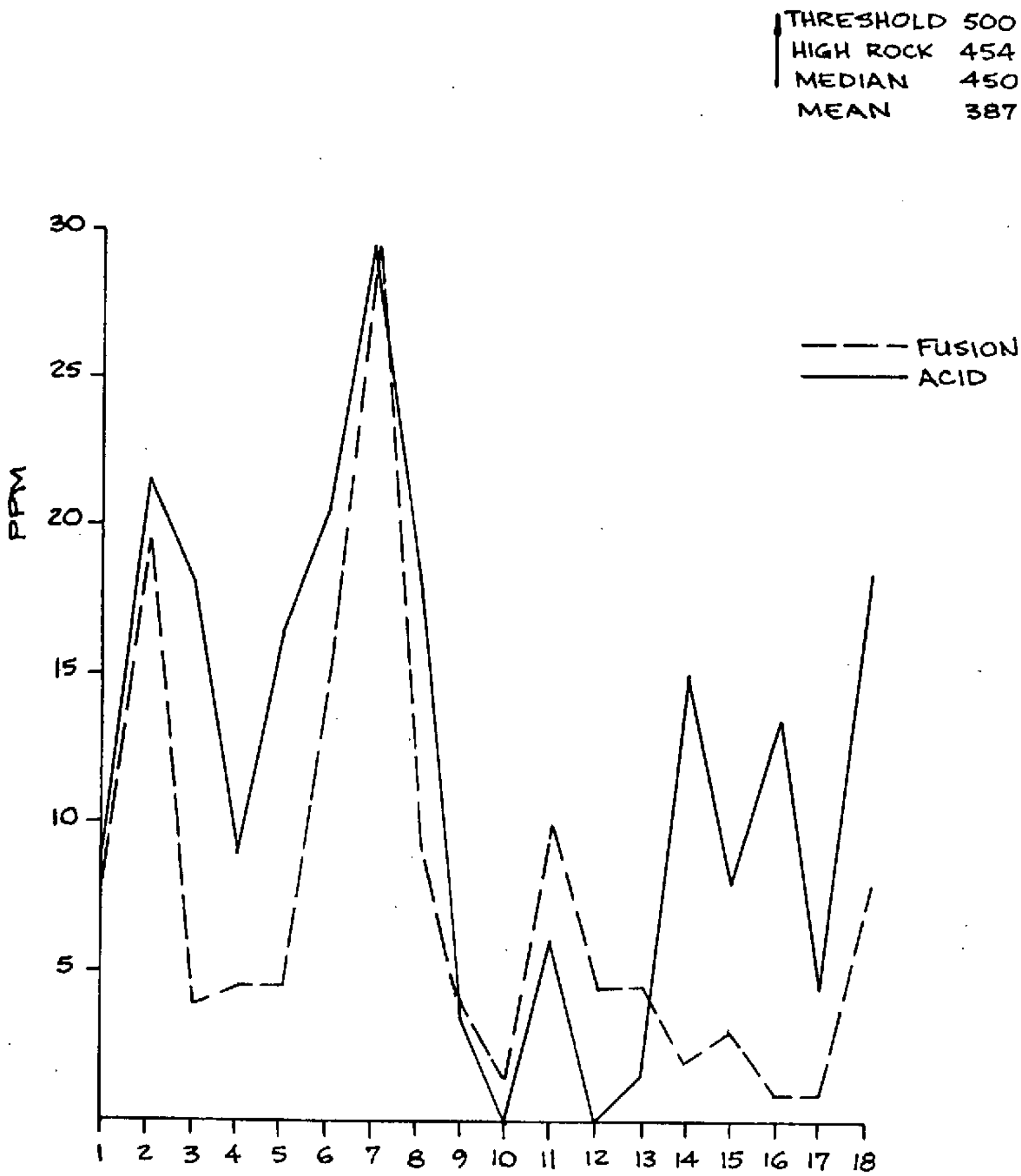


FIG. 13
HARPERSVILLE TRAVERSE 1
Cu CONCENTRATION

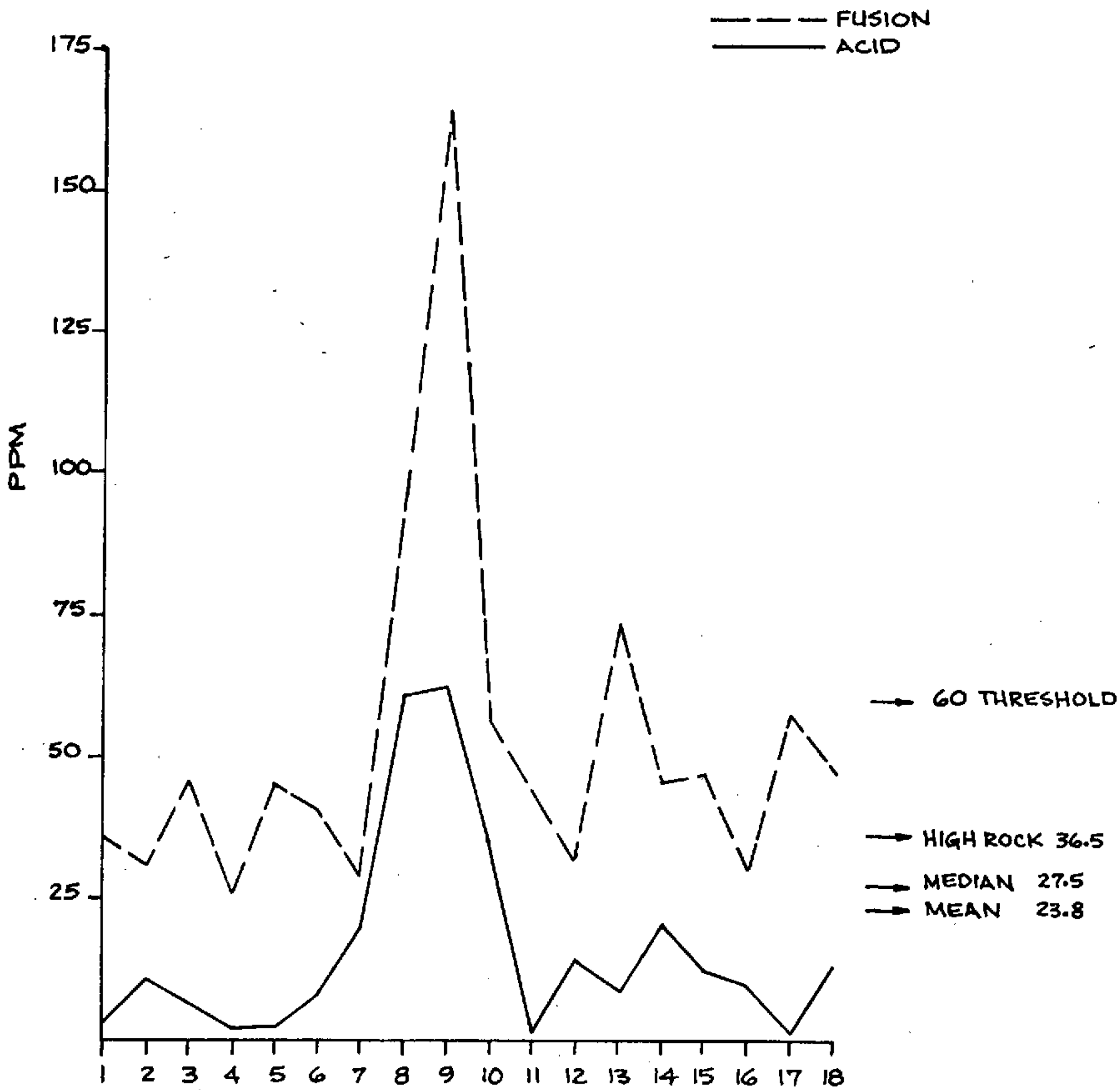


FIG. 14
HARPERSVILLE TRAVERSE I
Zn CONCENTRATION

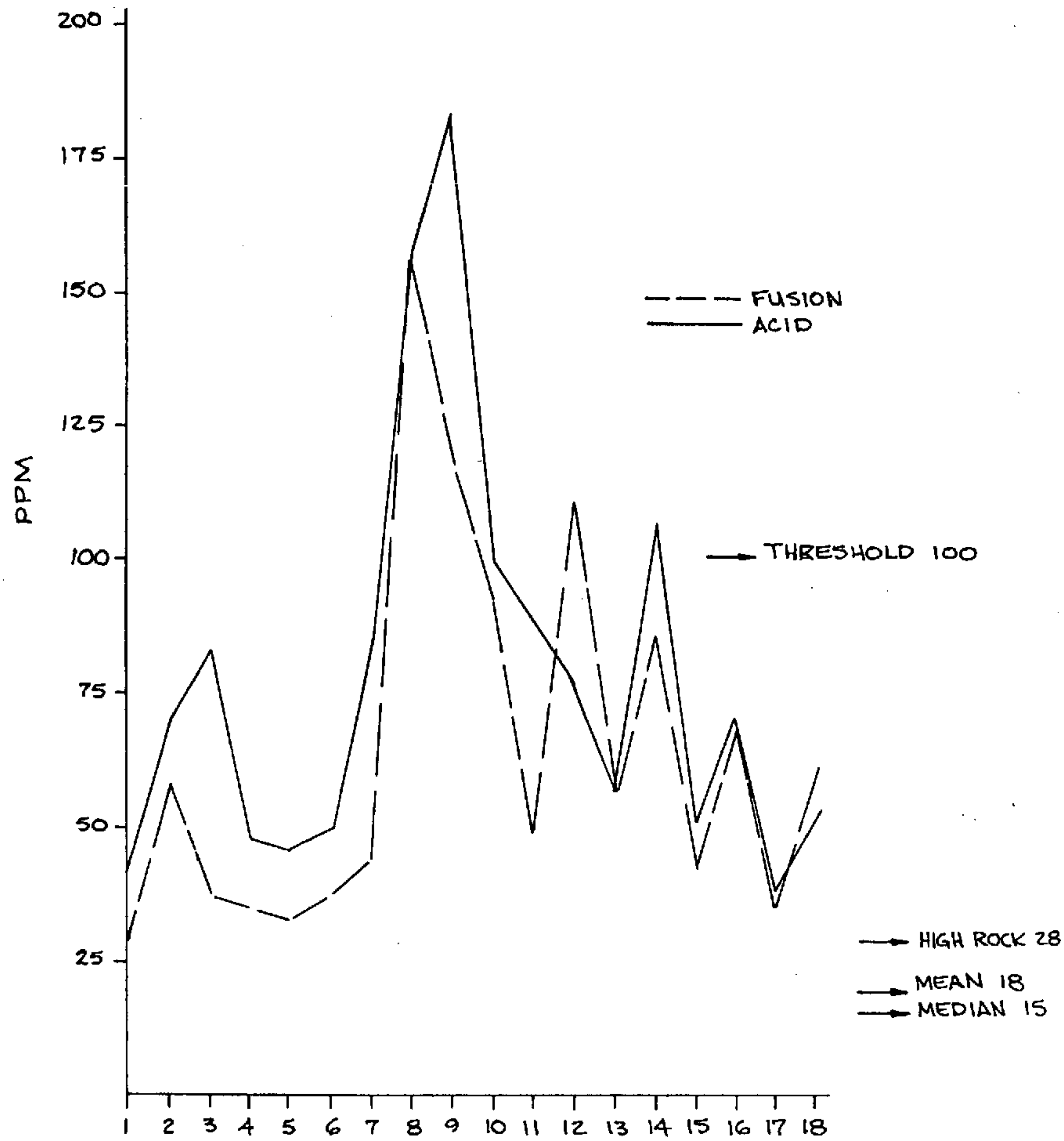


FIG. 15
HARPERSVILLE TRAVERSE I
Pb CONCENTRATION

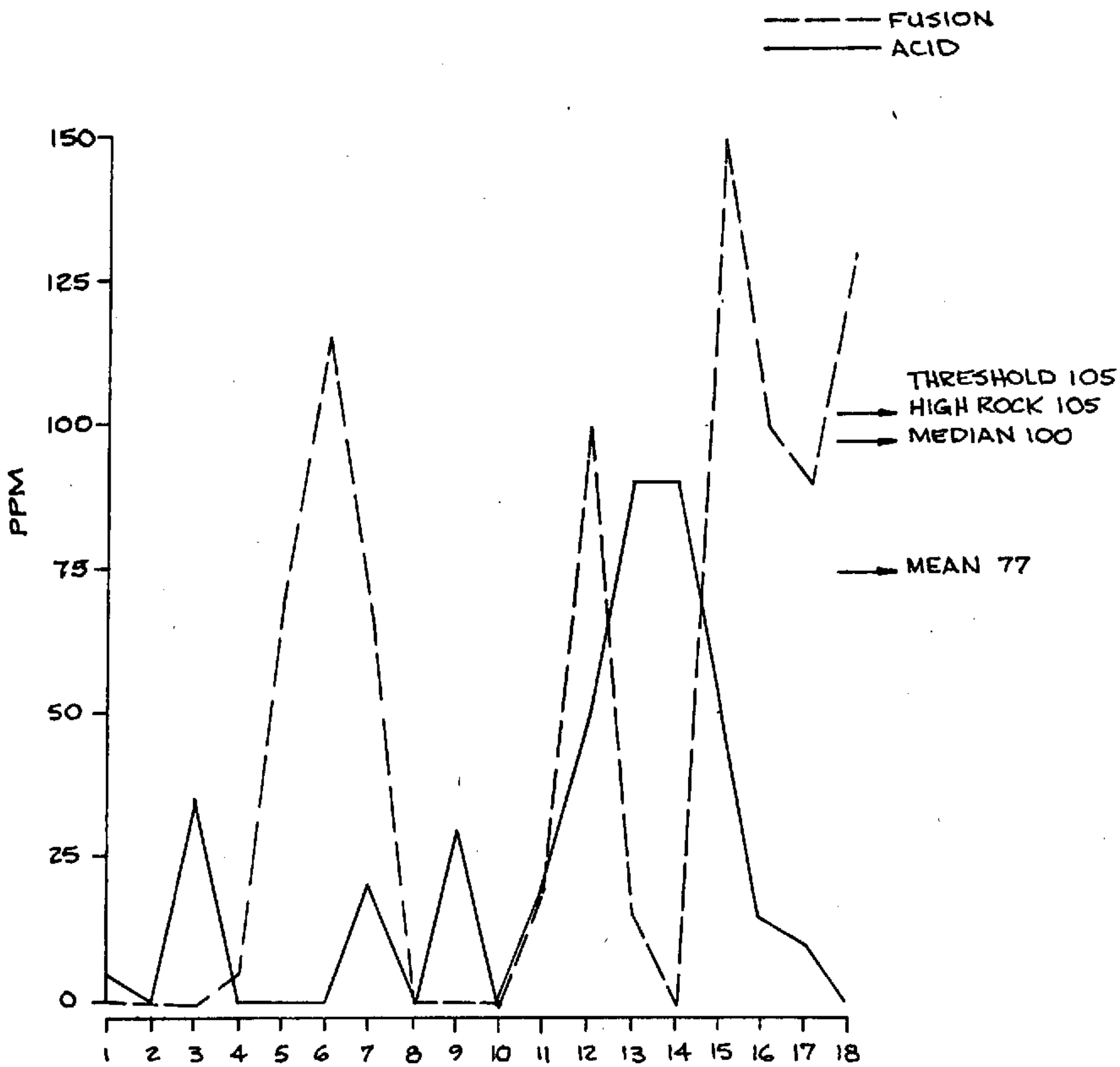
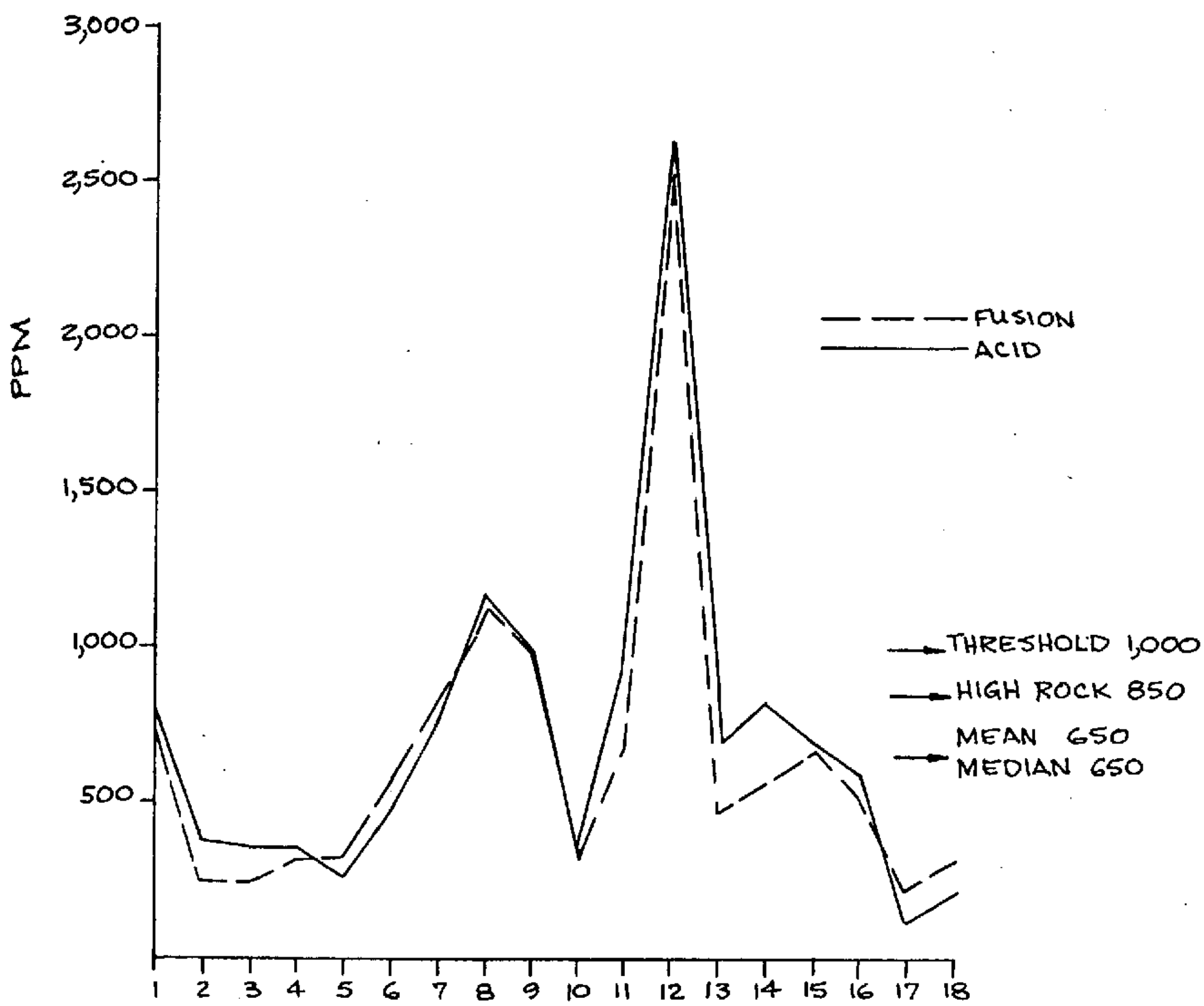


FIG. 16
HARPERSVILLE TRAVERSE I
TOTAL METAL CONCENTRATION



Traverse 2

Chemical analyses are shown as maps on figures 3 to 9 and plotted as graphs on figures 17 to 19. Mean, median, and high rock as well as threshold values are plotted. Because this traverse is very short, threshold values as well as peaks are more difficult to locate. However, there appear to be barium highs at points 1 and 3; manganese at 5, copper at 1 and 3; lead at 2; and total metal at 1.

Traverse 3

Chemical analyses are shown as maps on figures 20 to 26 and as plotted graphs on figures 27 to 33. There is a barium high at point 4; manganese at 2, 7, and 8; copper at 4; zinc at 4; lead at 6 and 10; and total metal at 2, 4, 7, and 8.

Traverse 4

Chemical analyses are shown as maps on figures 20 to 26 and plotted as graphs on figures 34 to 40. There are barium highs at points 5, 7, and 9; copper highs at 5, 7, and 9; zinc highs at 7 and 9; lead highs at 7, 8, 11 and 12; and total metal highs at 5 and 9.

Traverse 5

Chemical analyses are shown as maps on figures 20 to 26 and plotted as graphs on figures 41 to 47. There barium highs at points 1, 5, 8, and 12; manganese highs at 5 and 12; a copper high at 12; zinc highs at 1, 5, and 12; lead highs at 11 and 13; and total metal highs at 5 and 12.

In summary, barium highs occur at points 1-6, 1-7, 1-8, 1-9, 2-1, 2-3, 2-4, 4-5, 4-7, 4-9, 5-1, 5-5, 5-8, 5-12. Manganese highs occur at 1-12, 2-5,

FIG. 17
HARPERSVILLE TRAVERSE 2

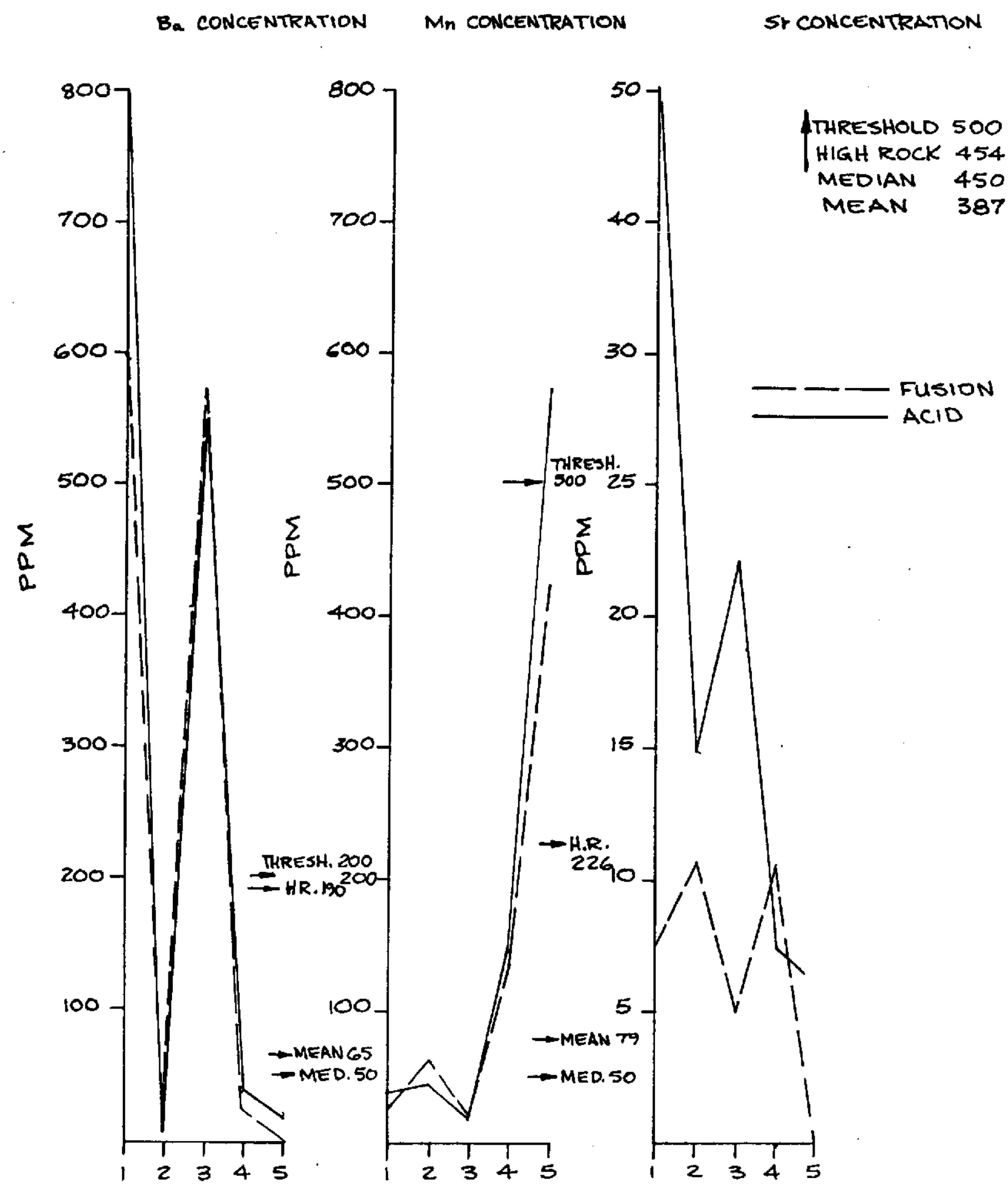


FIG. 18
HARPERSVILLE TRAVERSE 2

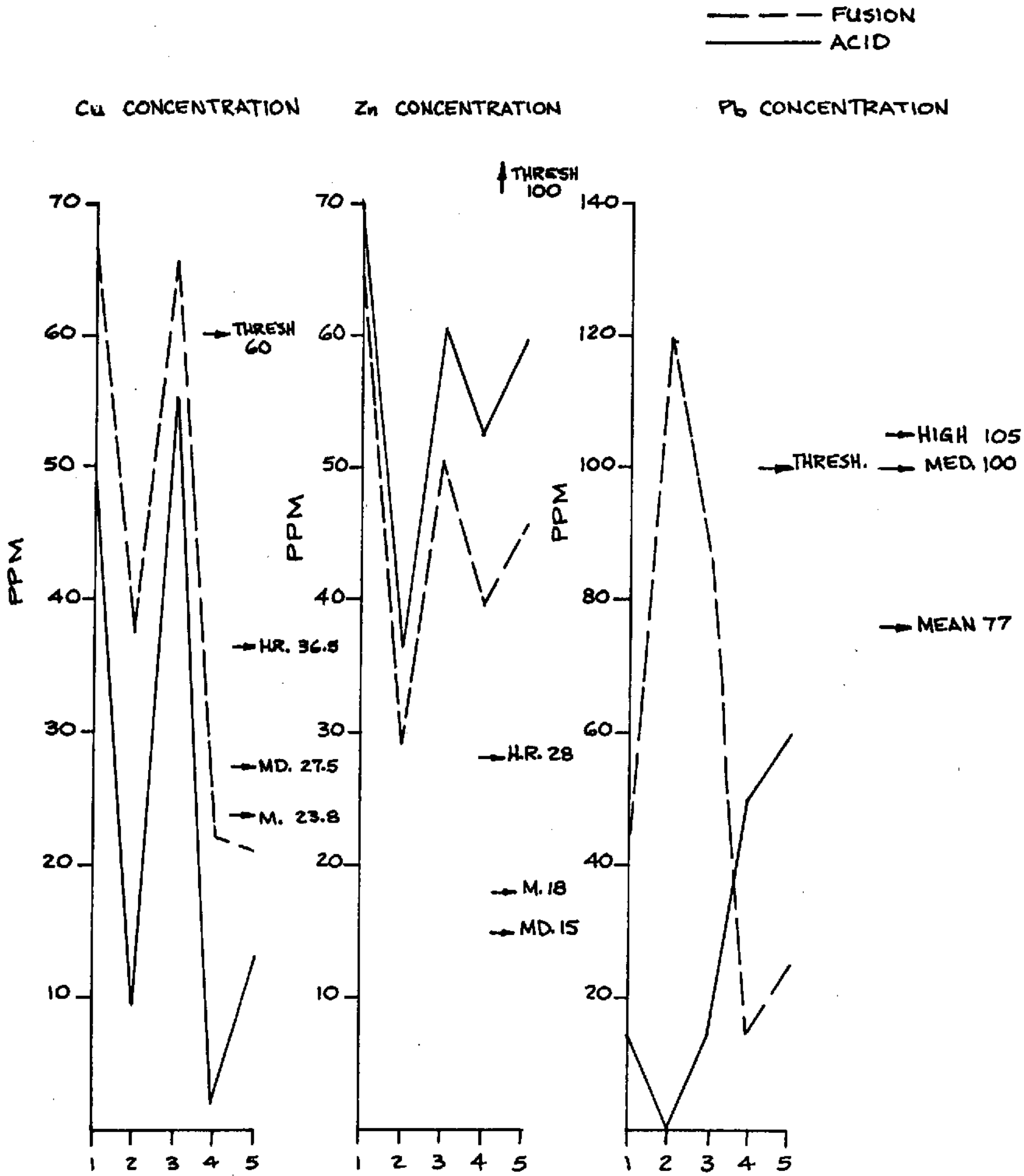
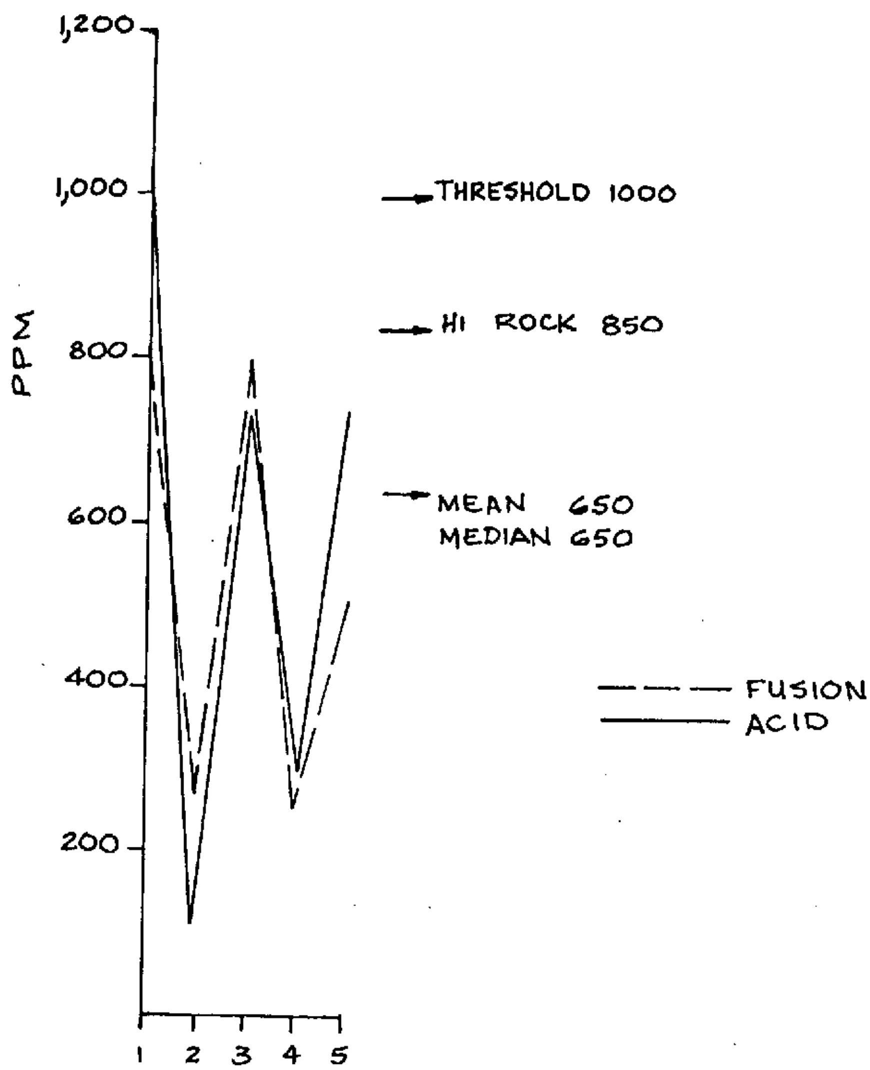


FIG. 19
TOTAL METAL CONCENTRATION
HARPERSVILLE TRAVERSE 2



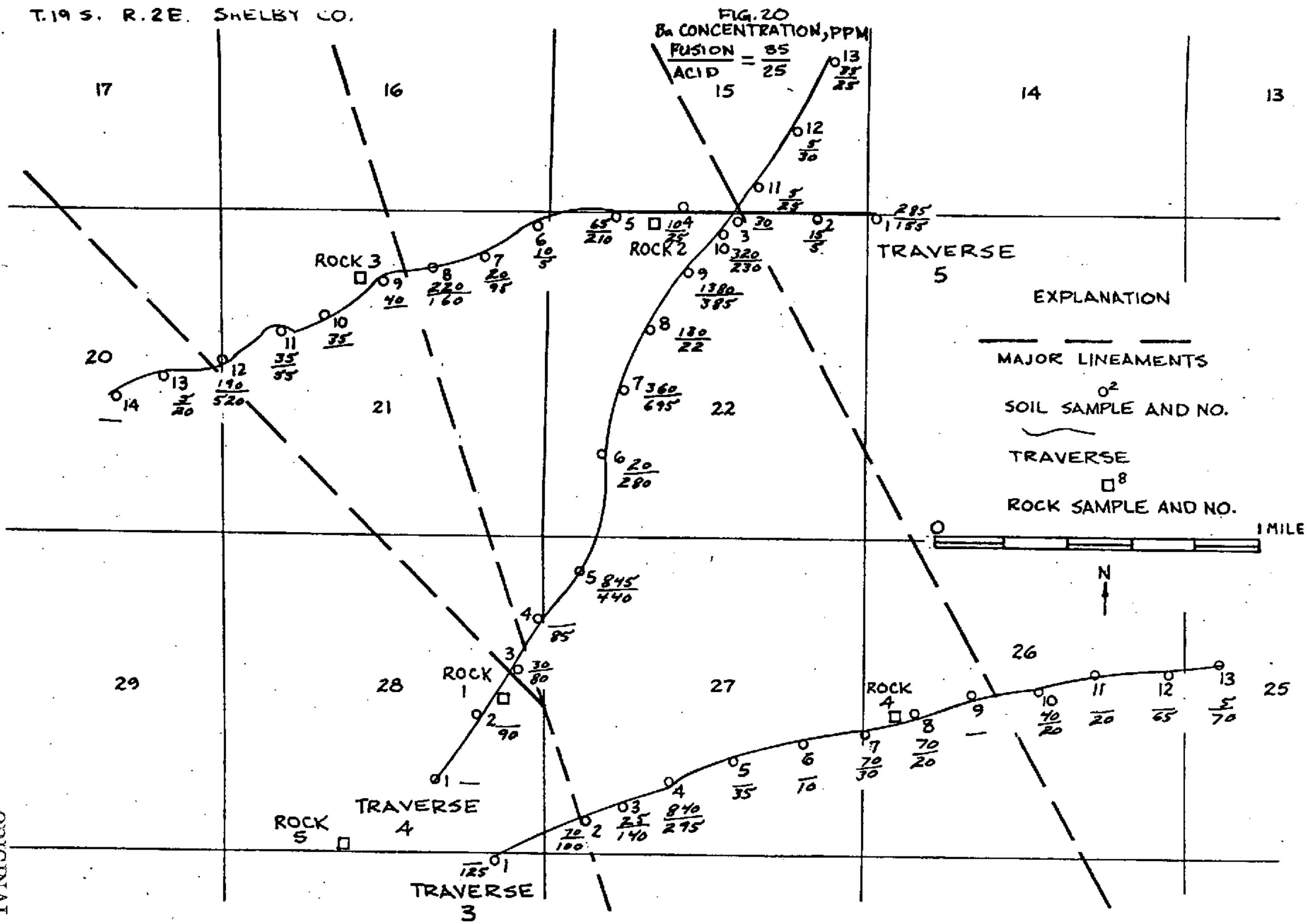
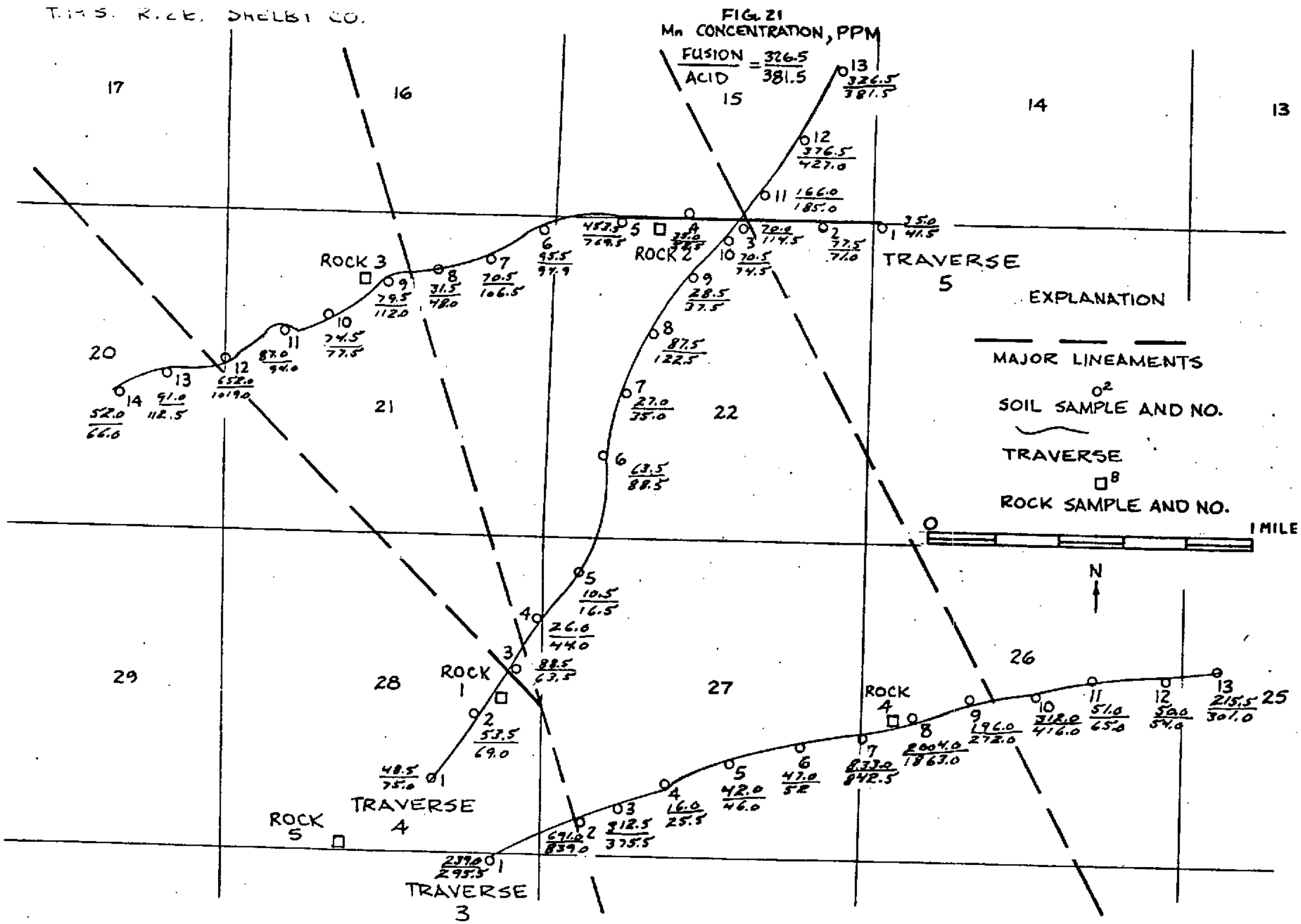


FIG. 20
Ba CONCENTRATION, PPM

12-259

ORIGINAL PAGE IS OF POOR QUALITY

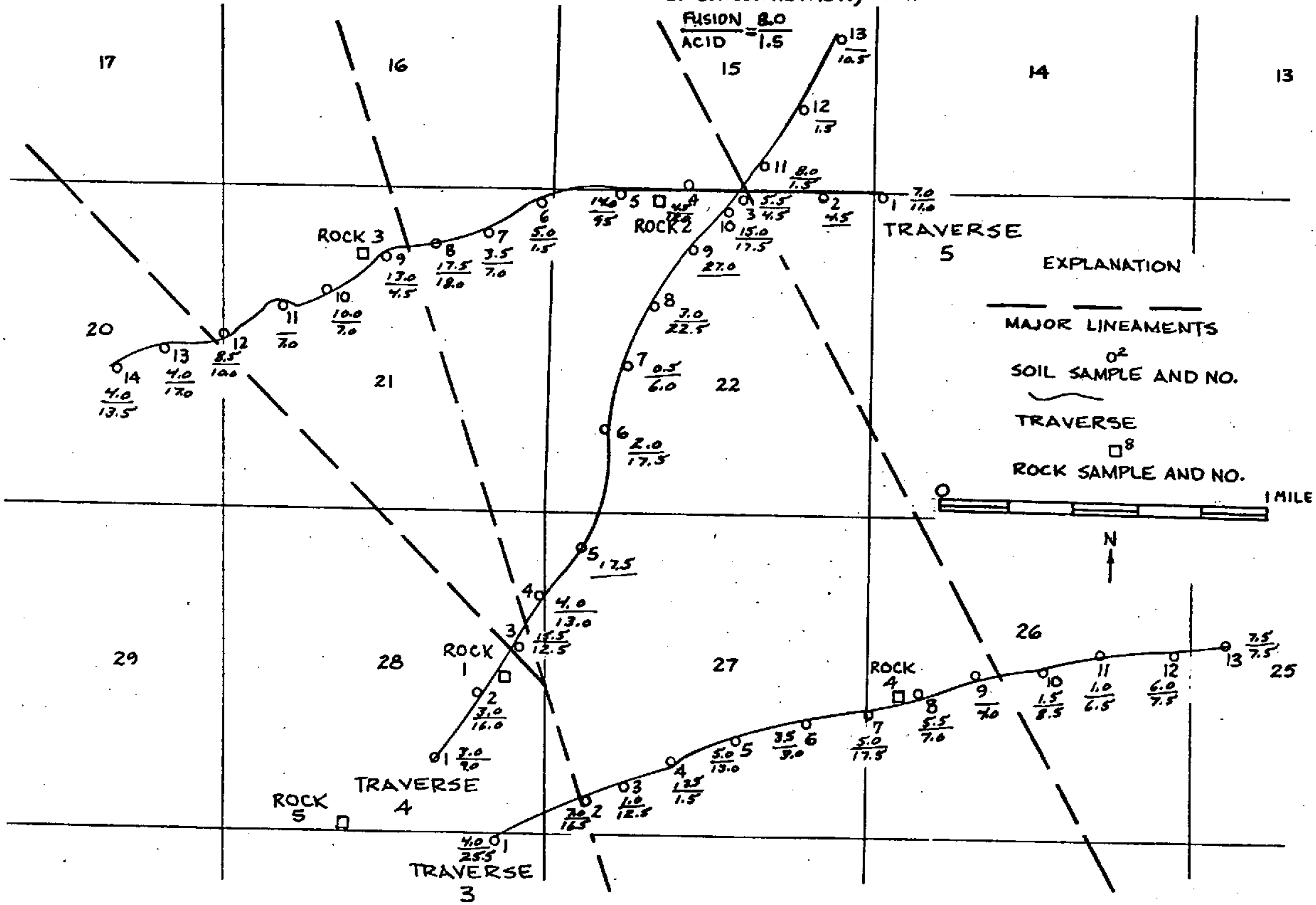

T.14S. R.2E. SHELBY CO.
FIG. 21
Mn CONCENTRATION, PPM
FUSION / ACID = 326.5 / 381.5
17
16
15
14
13
20
21
22
29
28
27
26
25
ROCK 3
ROCK 2
ROCK 1
ROCK 4
ROCK 5
TRAVERSE 5
TRAVERSE 4
TRAVERSE 3
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
0
1 MILE
N

12-260

37

T.14S. R.2E. SHELBY CO.

FIG. 22
Sr CONCENTRATION, PPM

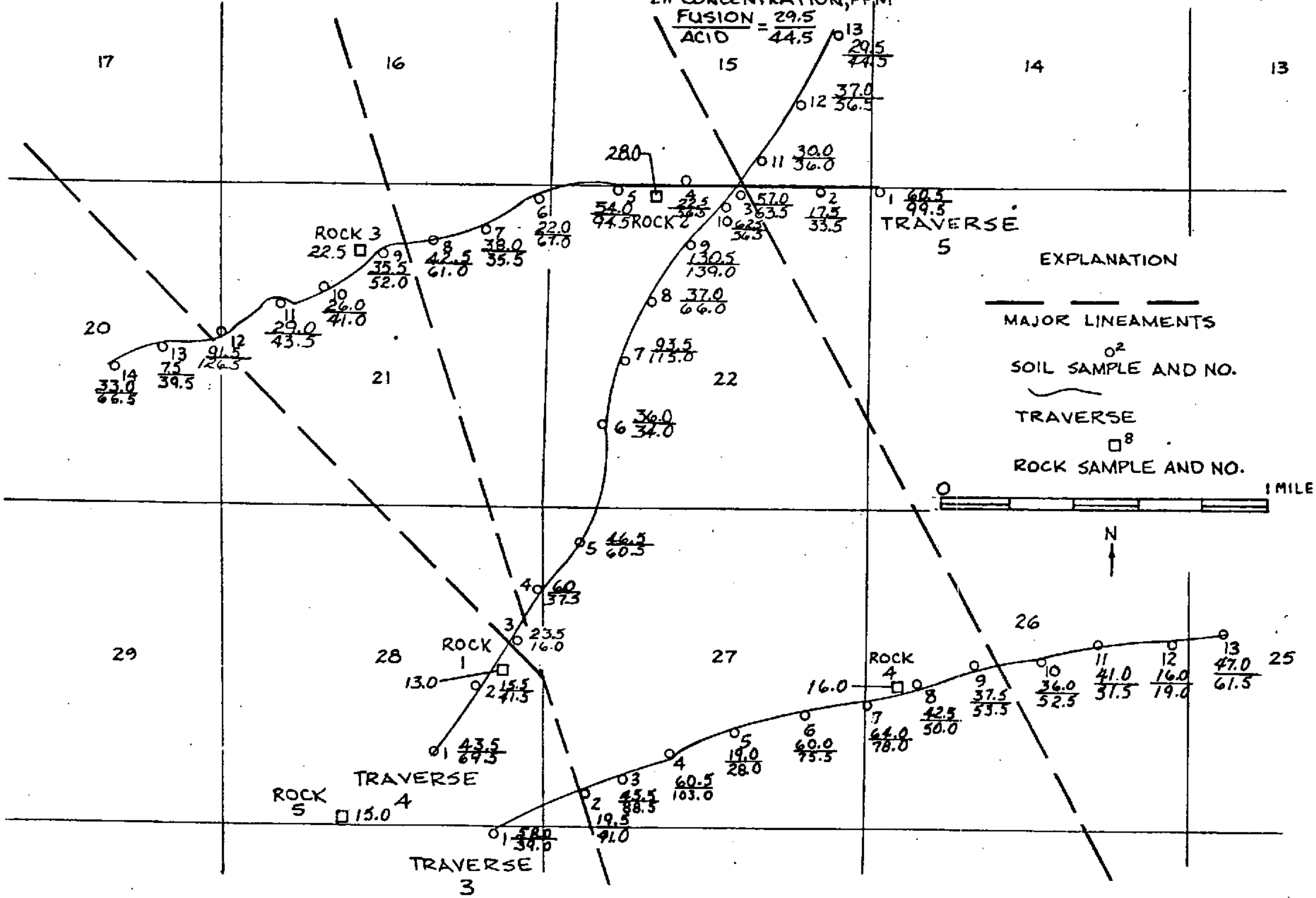


12-261

T. S. R. 2 E. SHELBY CO.

FIG. 23

Zn CONCENTRATION, PPM

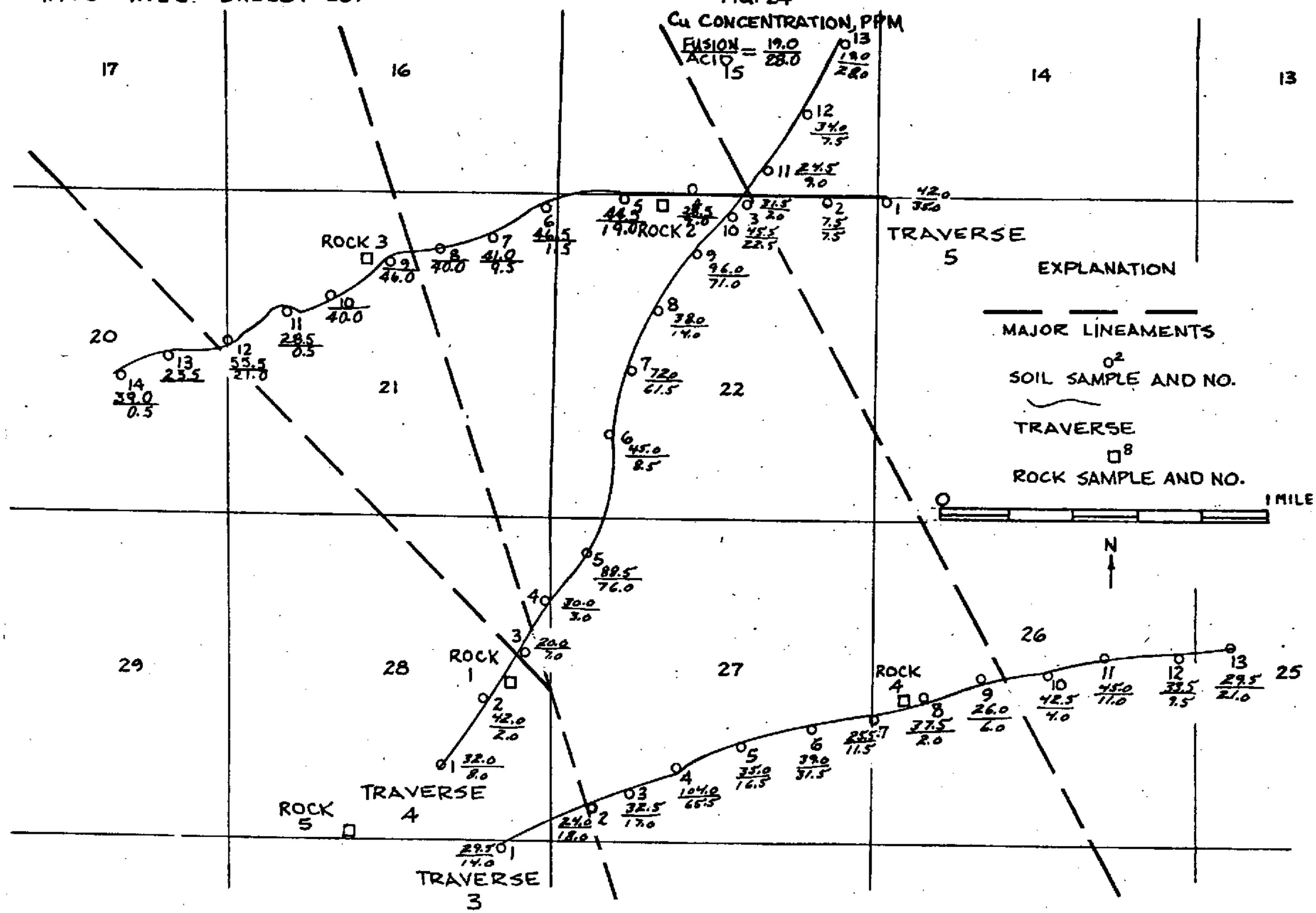


12-262

T. 9 S. R. 2 E. SHELBY CO.

FIG. 24
Cu CONCENTRATION, PPM

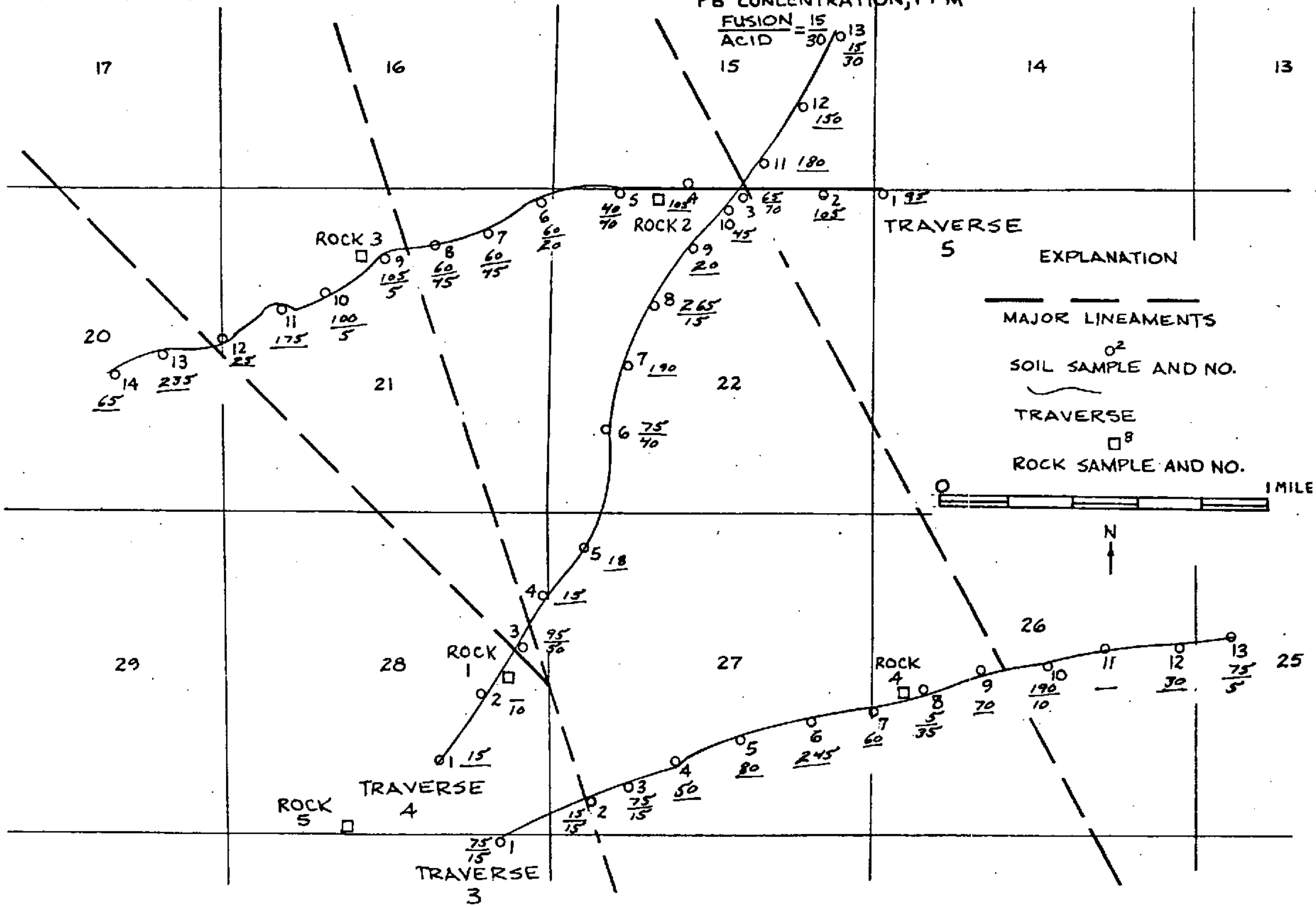
$\frac{\text{FUSION}}{\text{ACID}} = \frac{19.0}{28.0}$



12-263

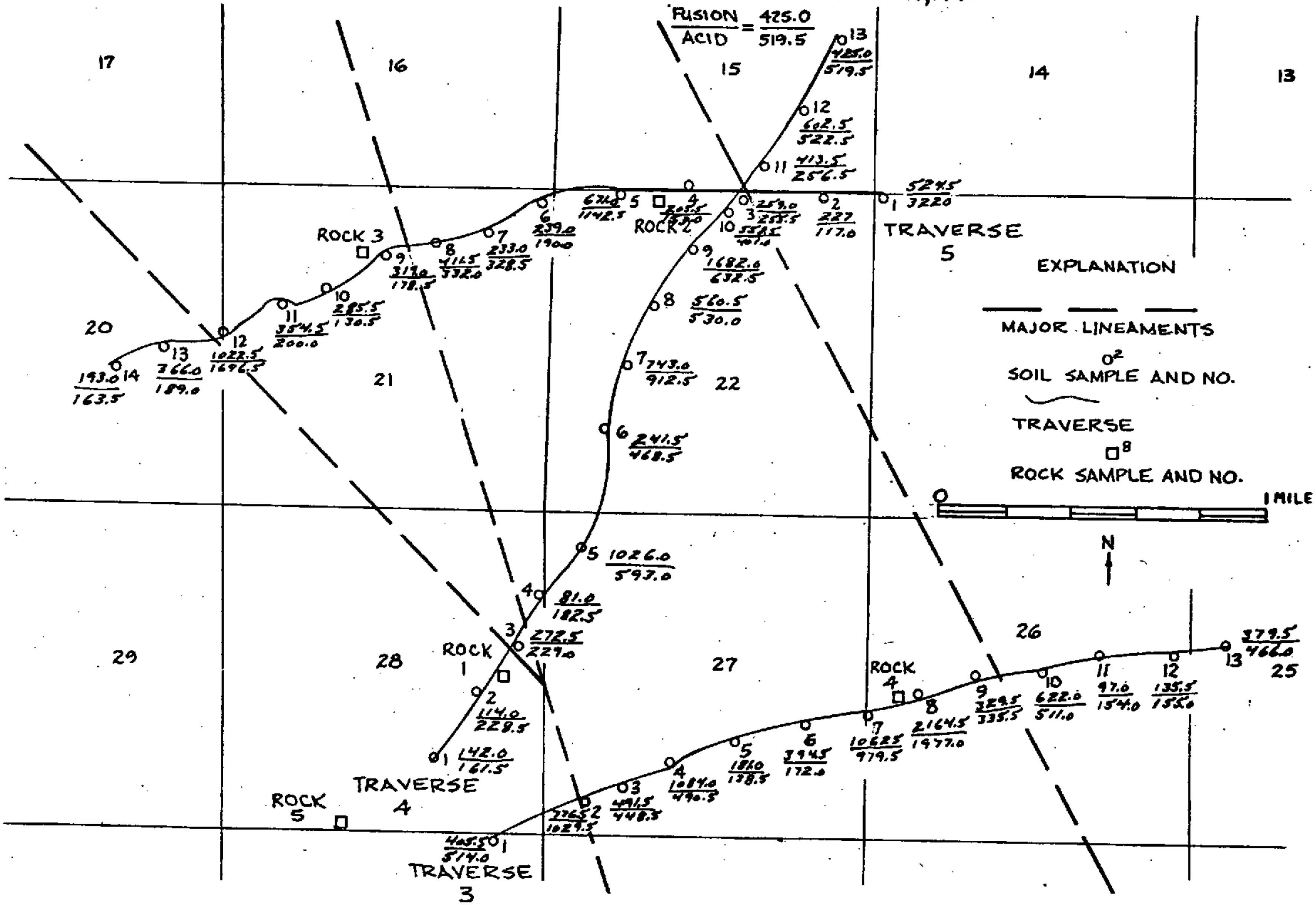
T.4S. R.2E. SHELBY CO.

FIG. 25
Pb CONCENTRATION, PPM



T.19S. R.2E. SHELBY CO.

FIG. 26
TOTAL METAL CONCENTRATION, PPM



12-265

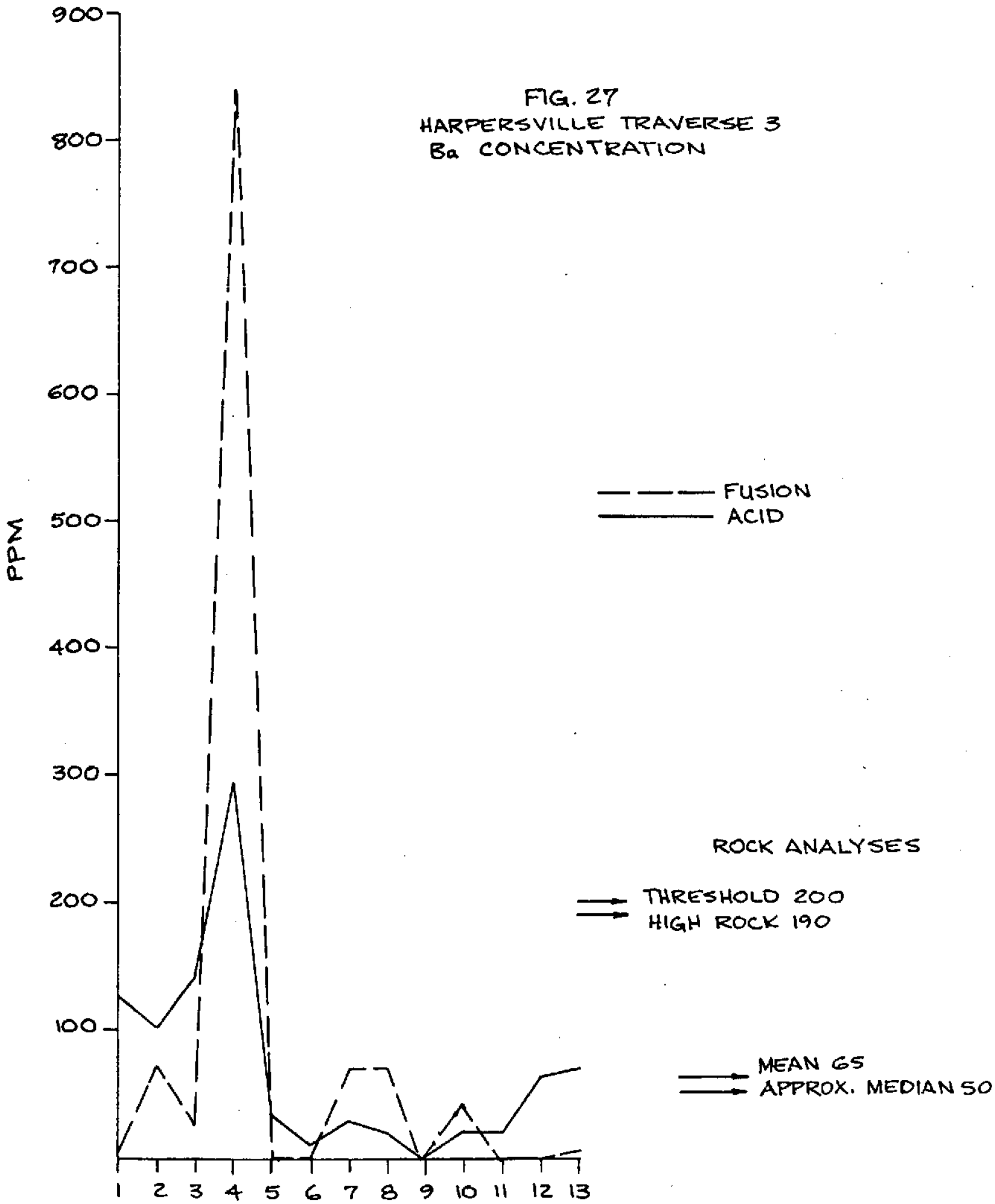


FIG. 27
HARPERSVILLE TRAVERSE 3
Ba CONCENTRATION
FUSION
ACID
ROCK ANALYSES
THRESHOLD 200
HIGH ROCK 190
MEAN 65
APPROX. MEDIAN 50
PPM
900
800
700
600
500
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13

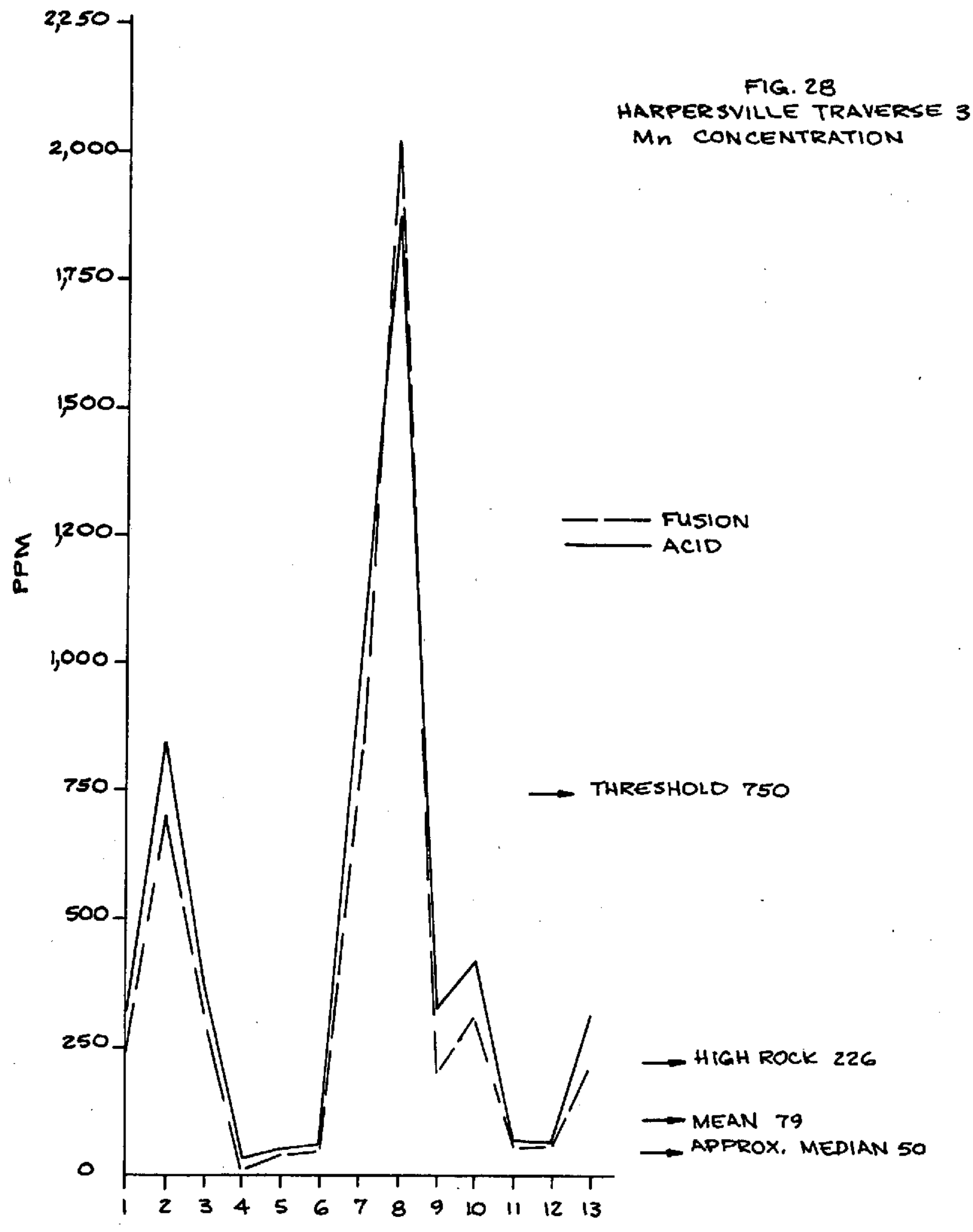


FIG. 28
HARPERSVILLE TRAVERSE 3
Mn CONCENTRATION
2,250
2,000
1,750
1,500
1,200
1,000
750
500
250
0
PPM
FUSION
ACID
THRESHOLD 750
HIGH ROCK 226
MEAN 79
APPROX. MEDIAN 50
1
2
3
4
5
6
7
8
9
10
11
12
13

FIG. 29

Sr CONCENTRATION
HARPERSVILLE TRAVERSE 3

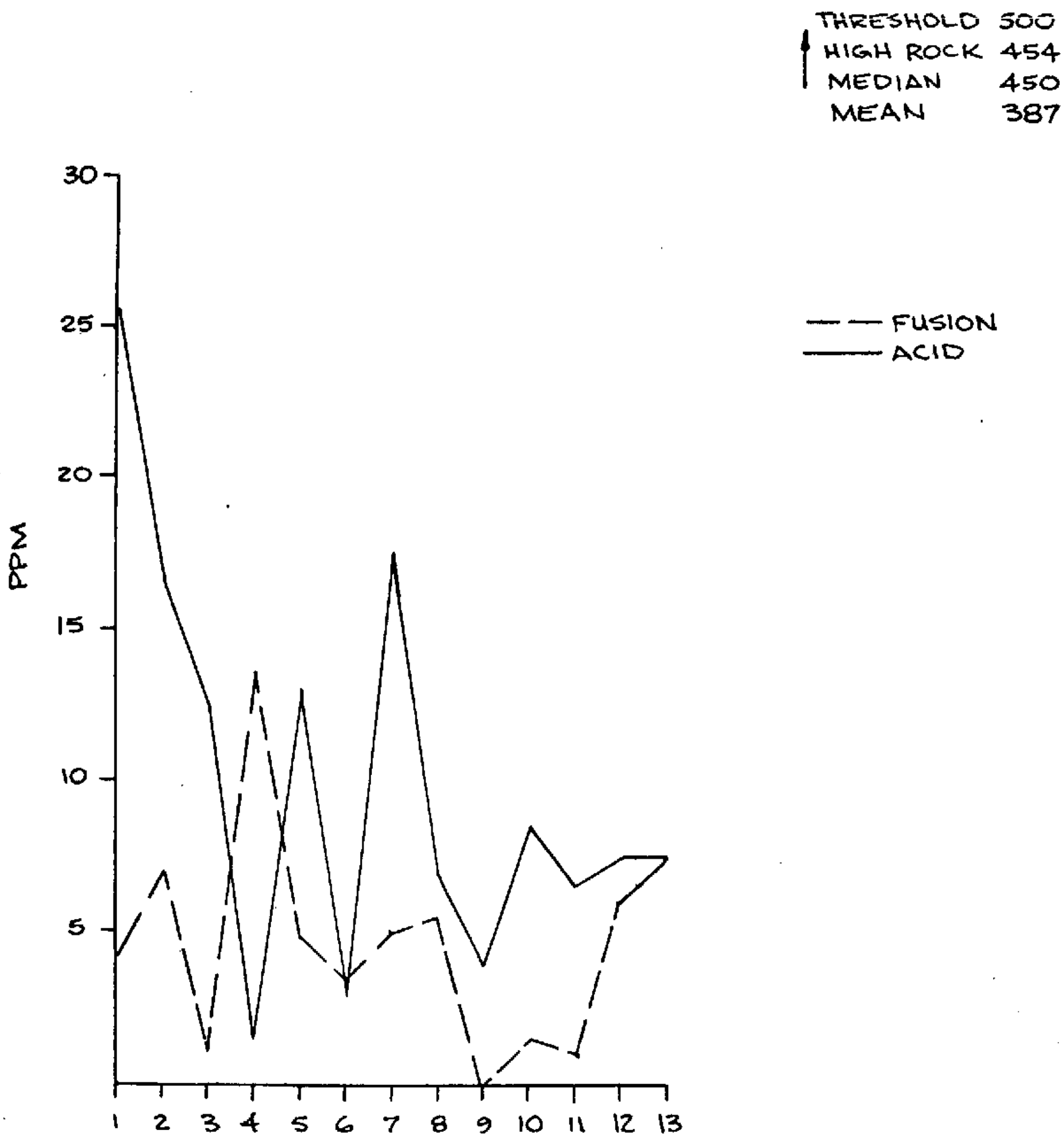


FIG. 30

CU CONCENTRATION
HARPERSVILLE TRAVERSE 3

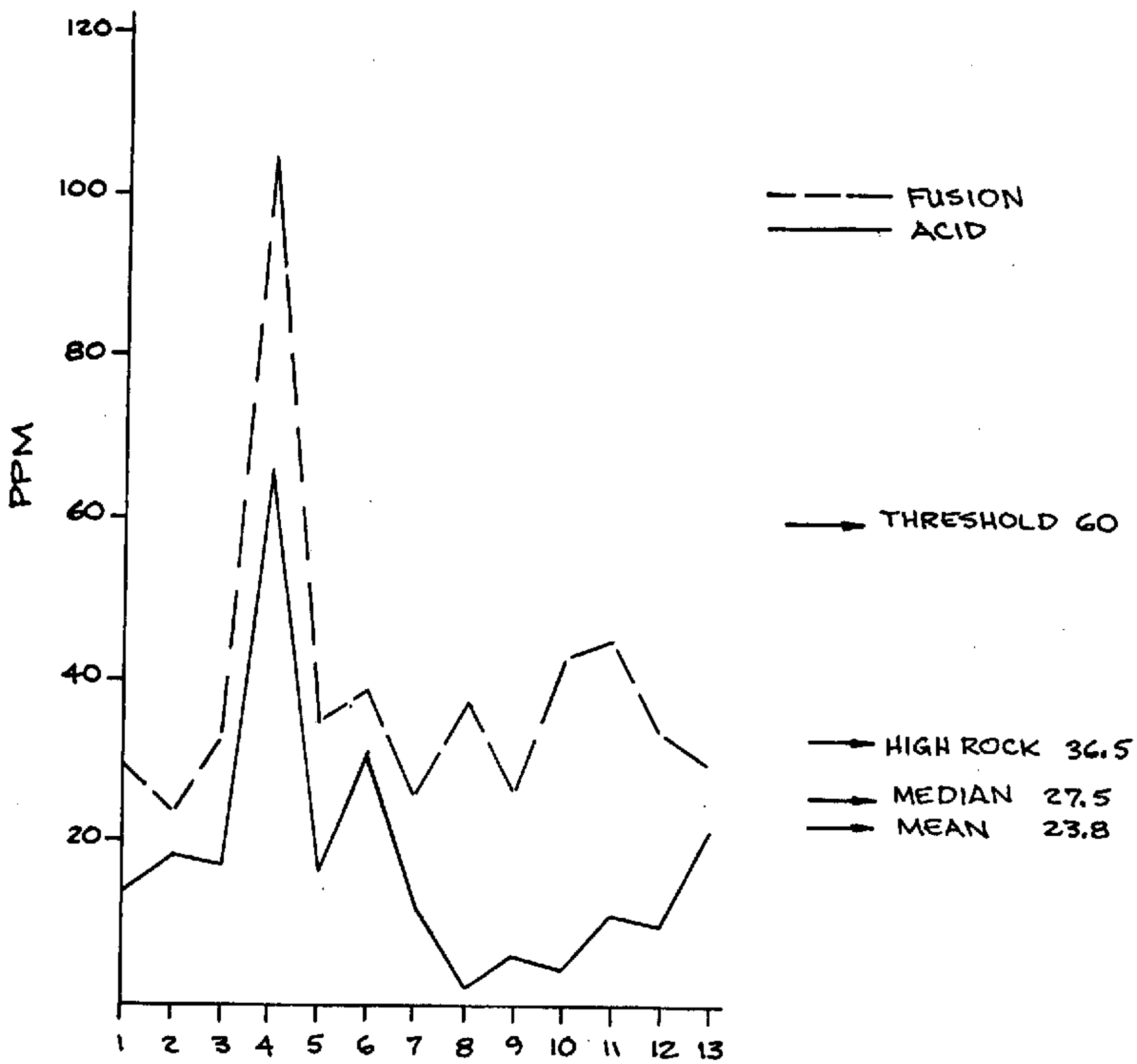


FIG. 31

ZN CONCENTRATION
HARPERVILLE TRAVERSE 3

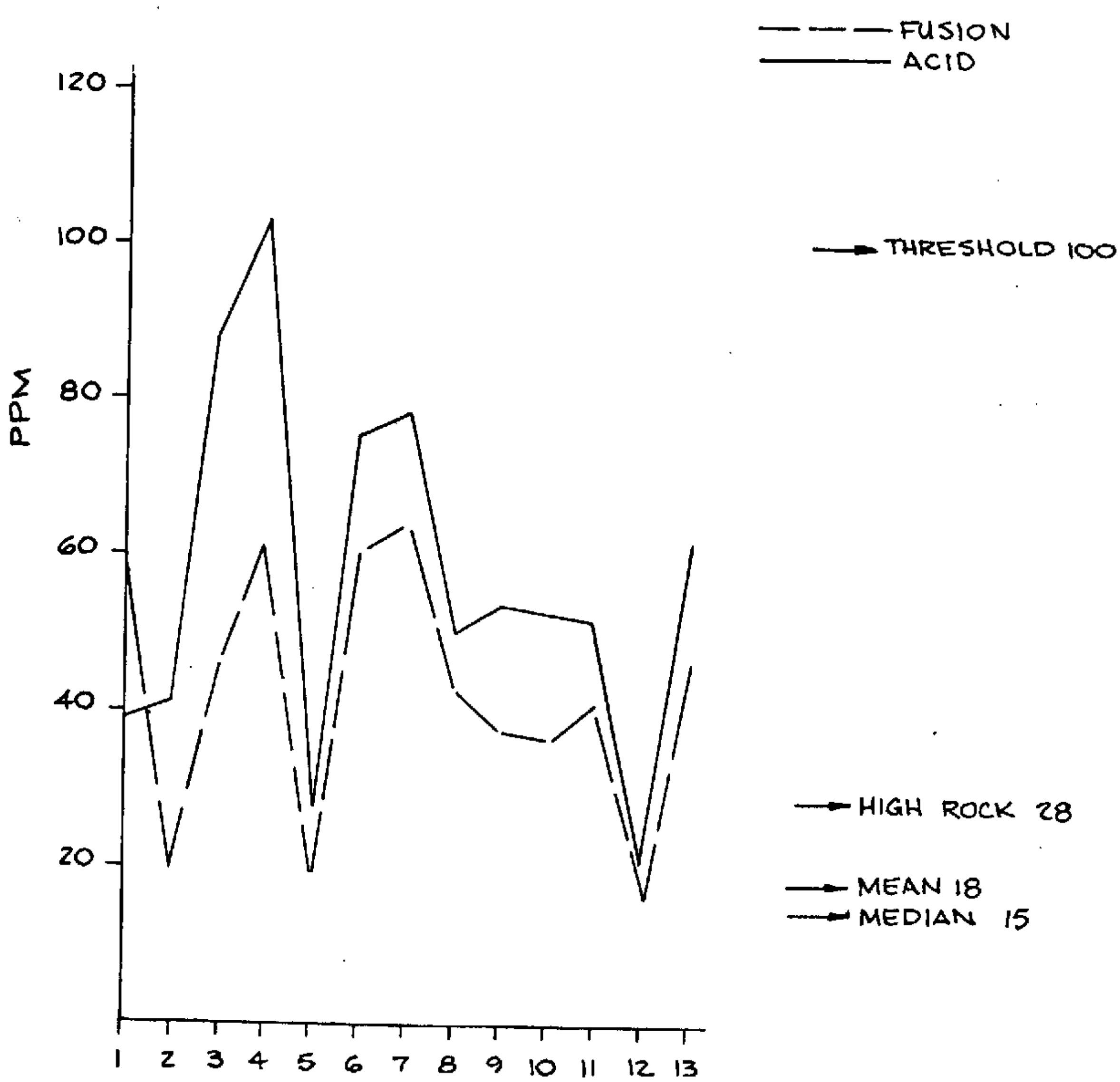


FIG. 32
Pb CONCENTRATION
HARPERSVILLE TRAVERSE 3

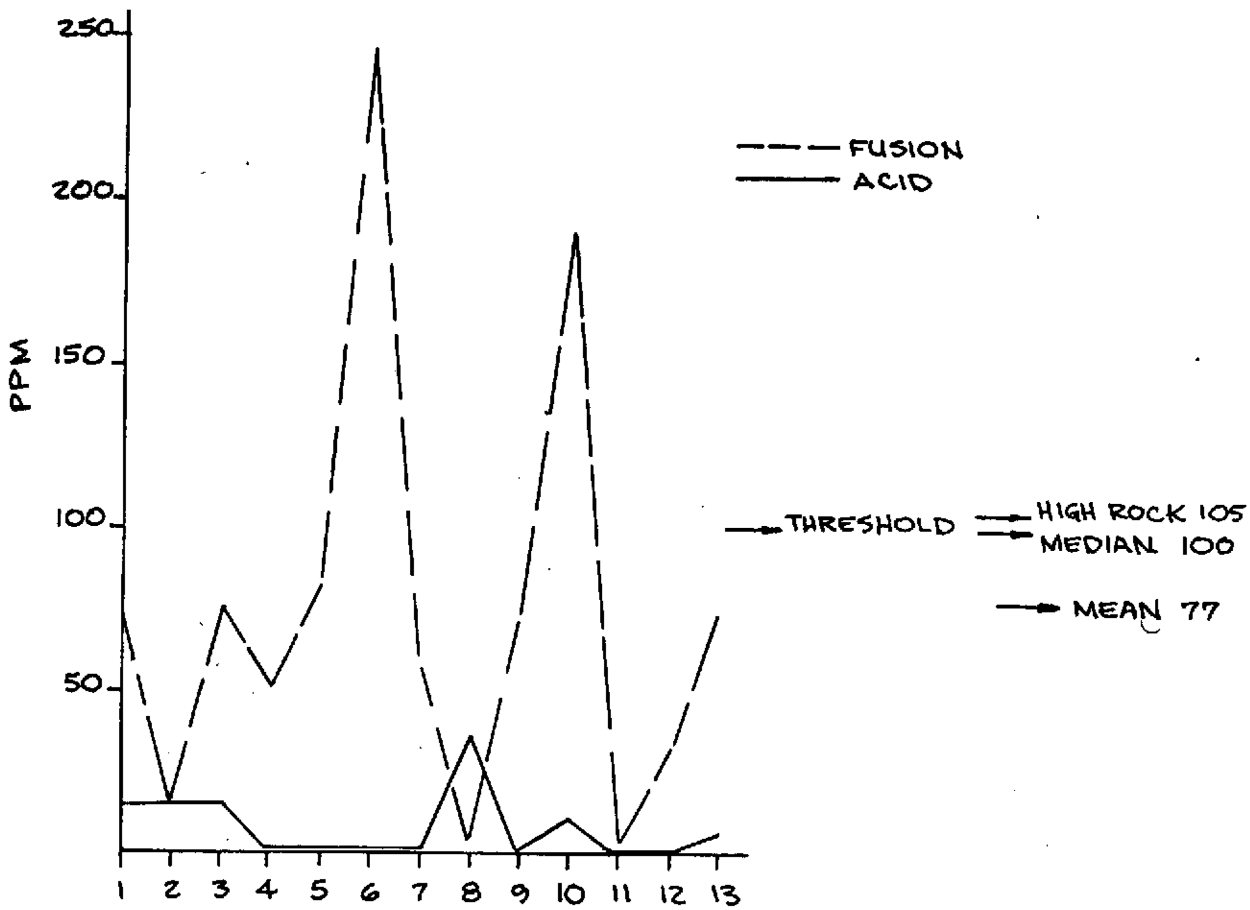


FIG. 33
TOTAL METAL
CONCENTRATION
HARPERSVILLE TRAVERSE 3

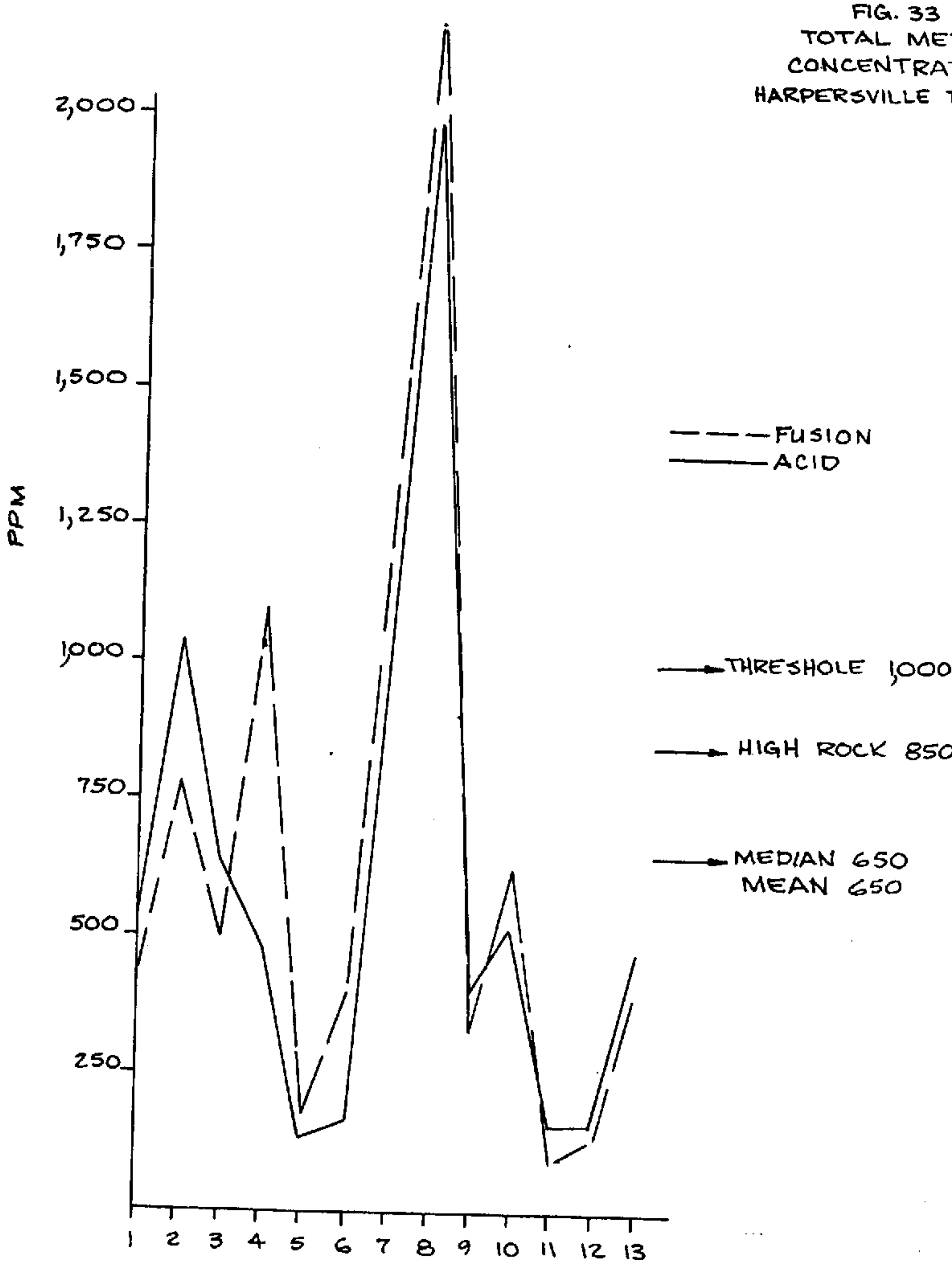


FIG. 34
HARPERSVILLE TRAVERSE 4
Ba CONCENTRATION

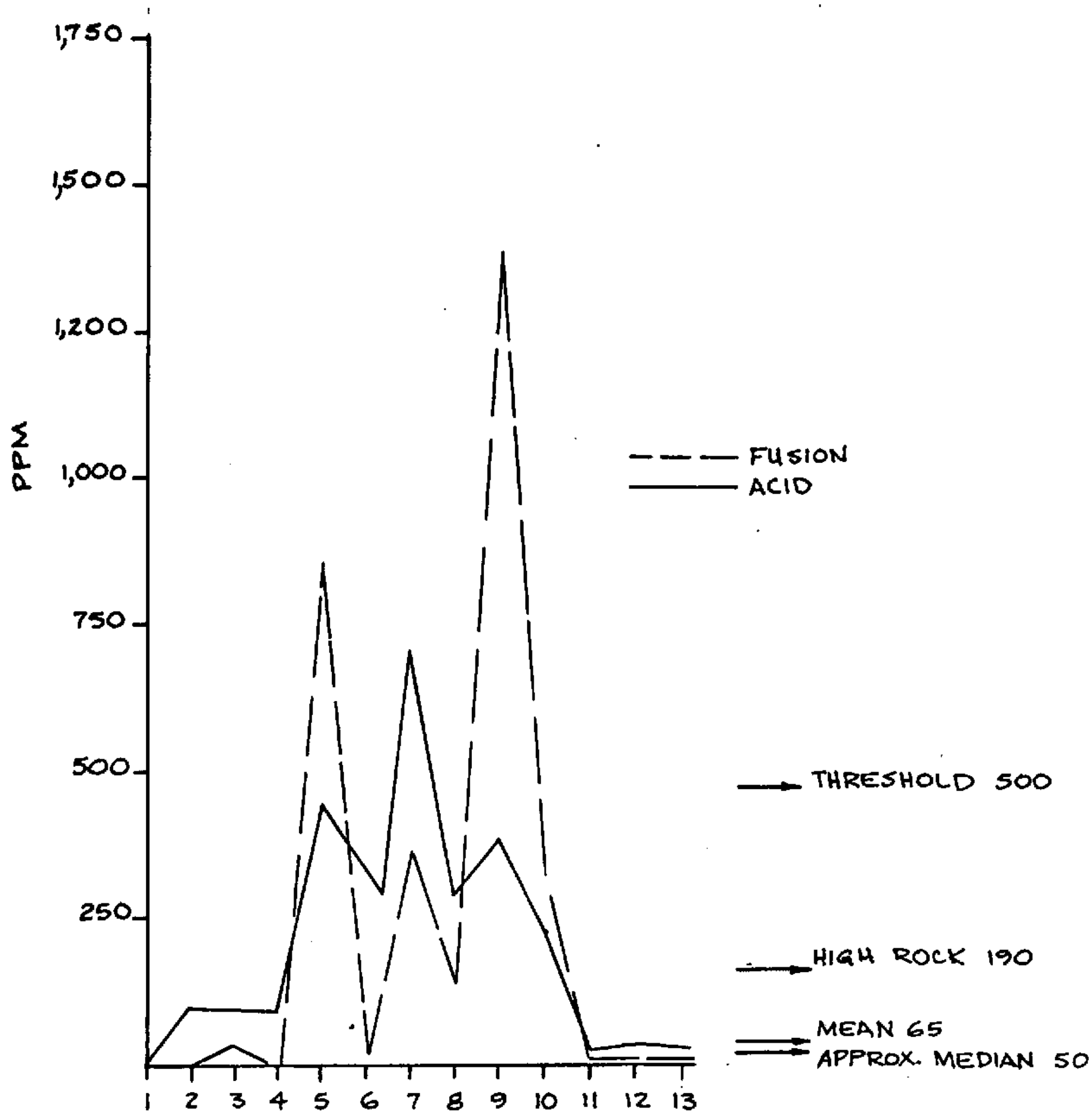


FIG. 35
HARPERSVILLE TRAVERSE 4
Mn CONCENTRATION

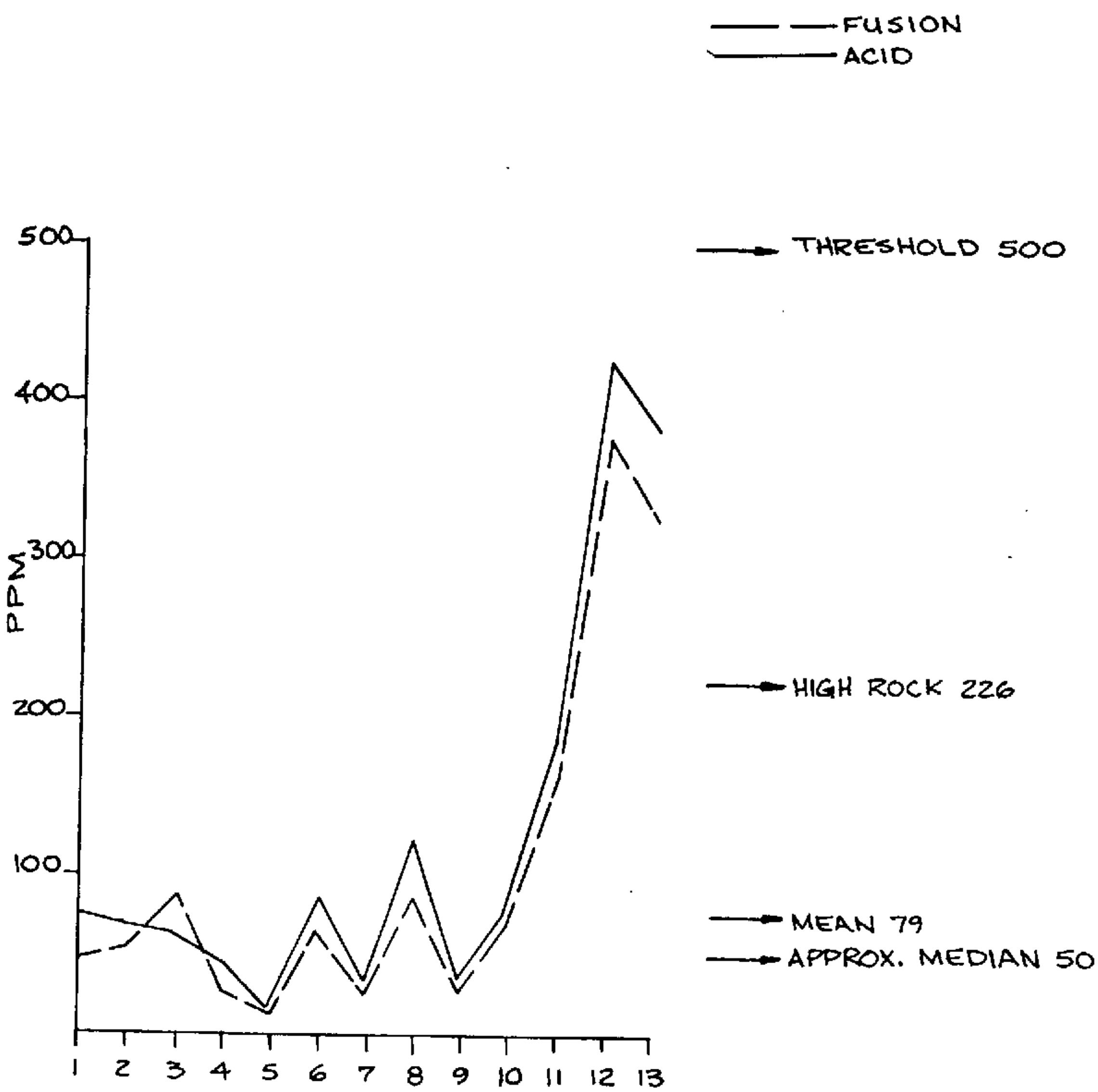


FIG. 36
Sr CONCENTRATION
HARPERSVILLE TRAVERSE 4

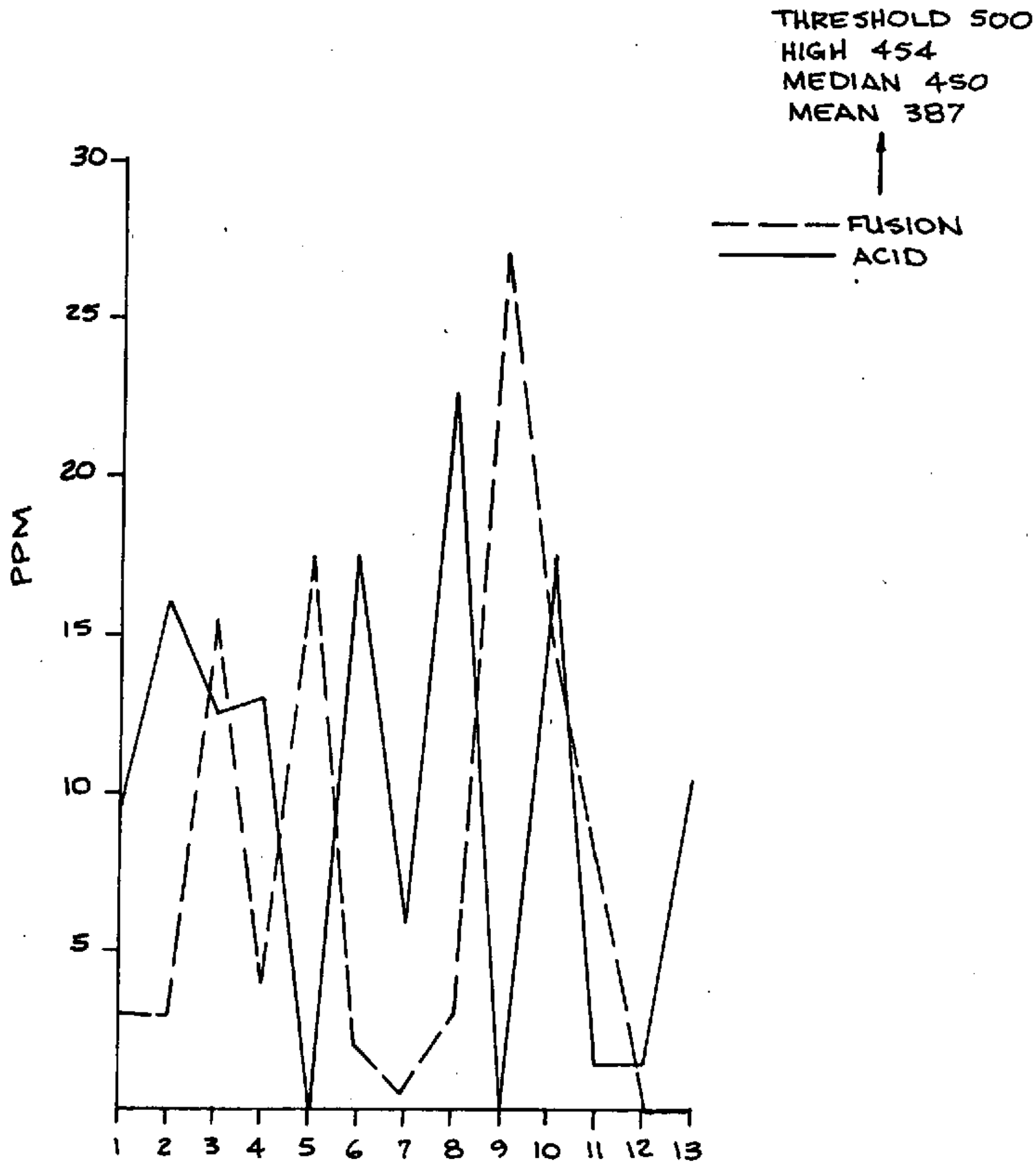


FIG. 37

Cu CONCENTRATION
HARPERSVILLE TRAVERSE 4

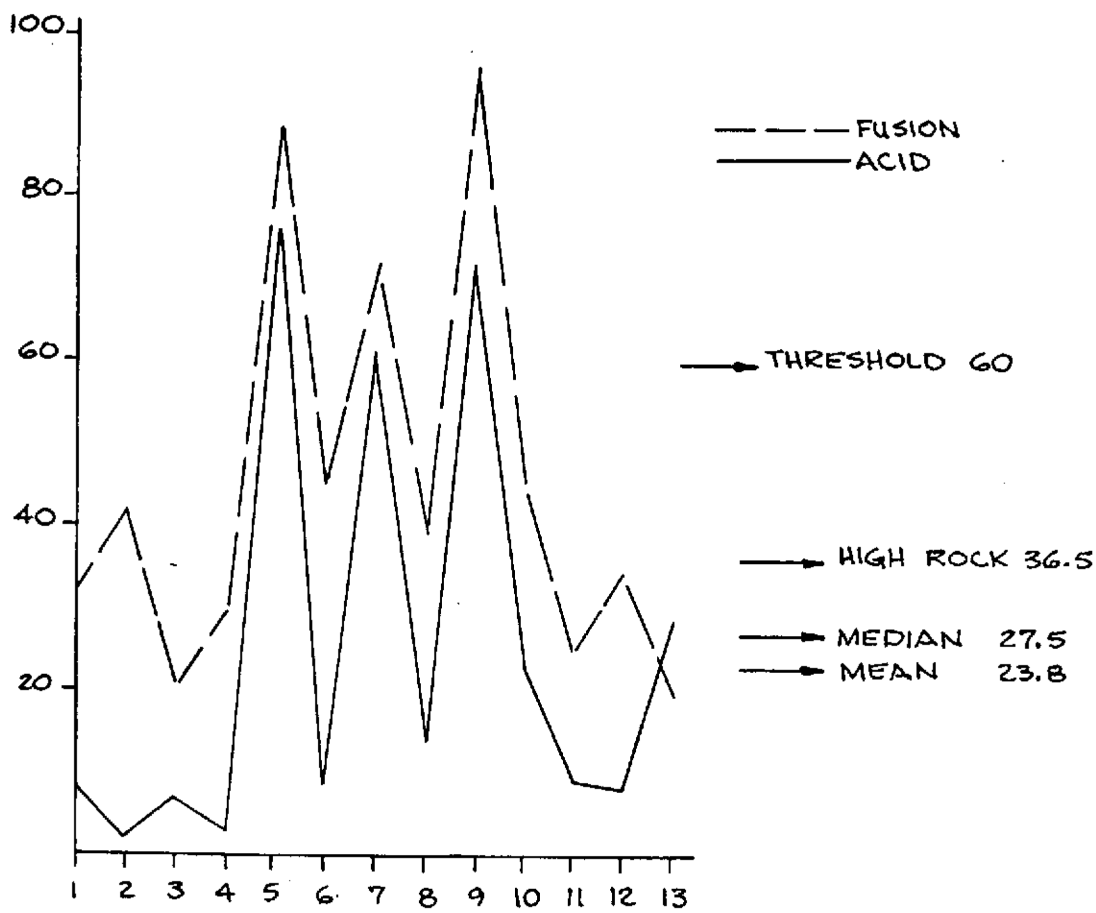


FIG. 38

HARPERSVILLE TRAVERSE 4
Zn CONCENTRATION

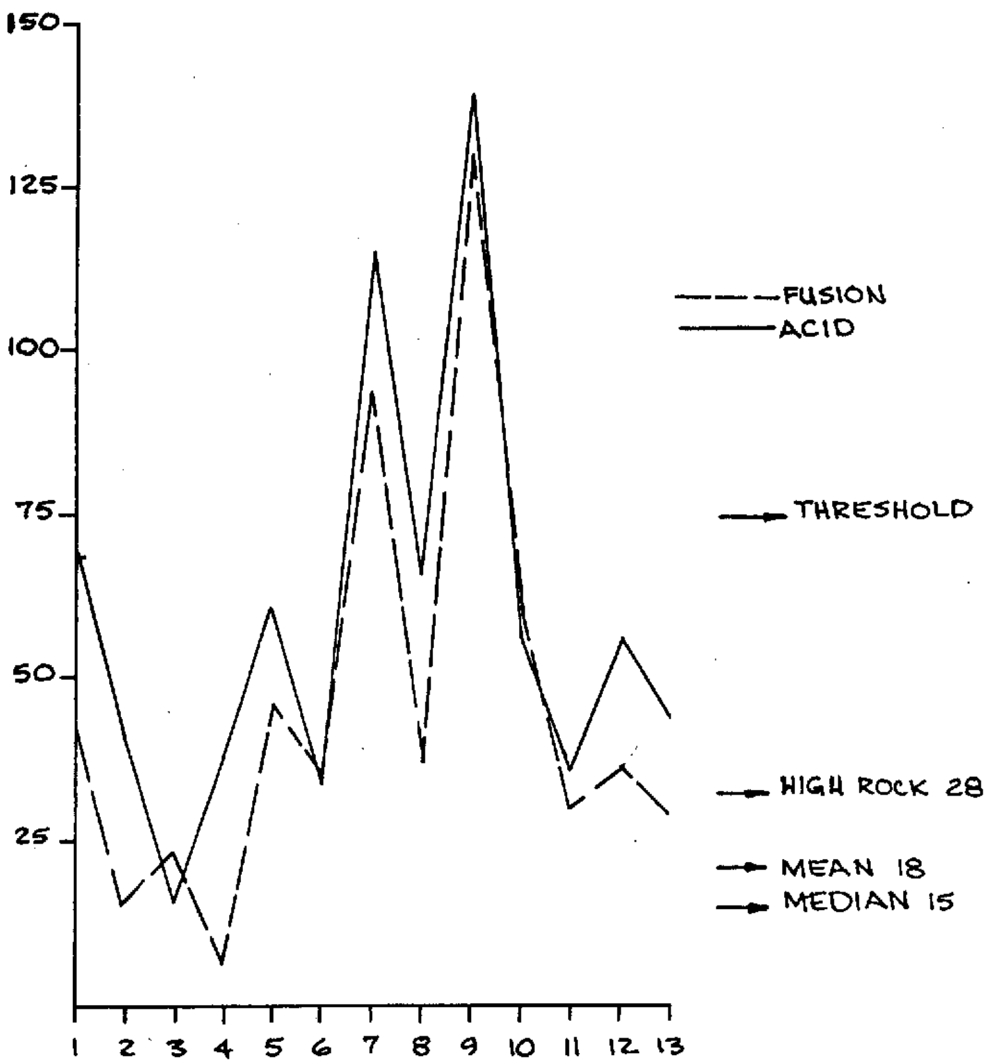


FIG. 39
HARPERSVILLE TRAVERSE 4
Pb CONCENTRATION

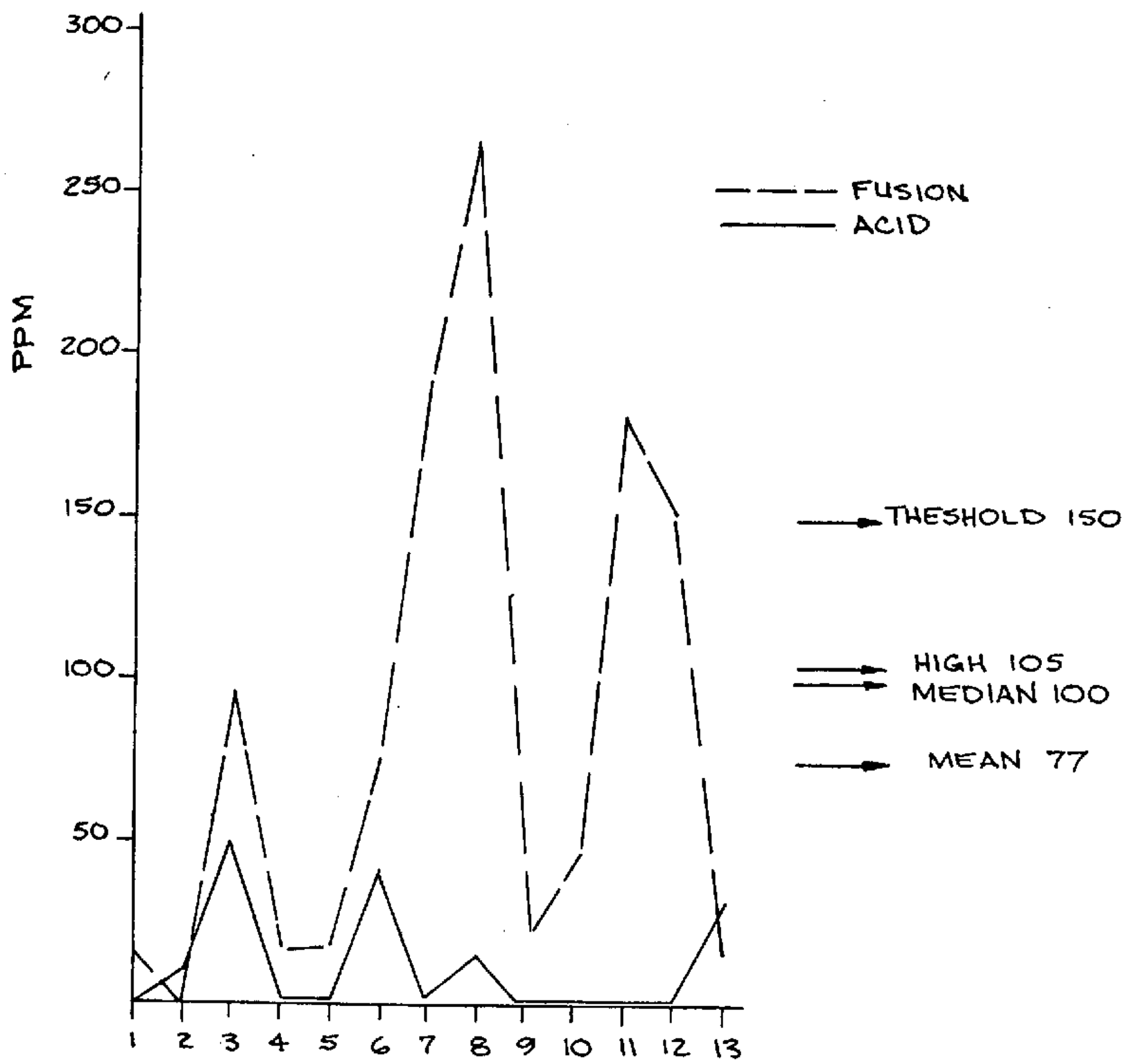


FIG. 40
TOTAL METAL CONCENTRATION
HARPERSVILLE TRAVERSE 4

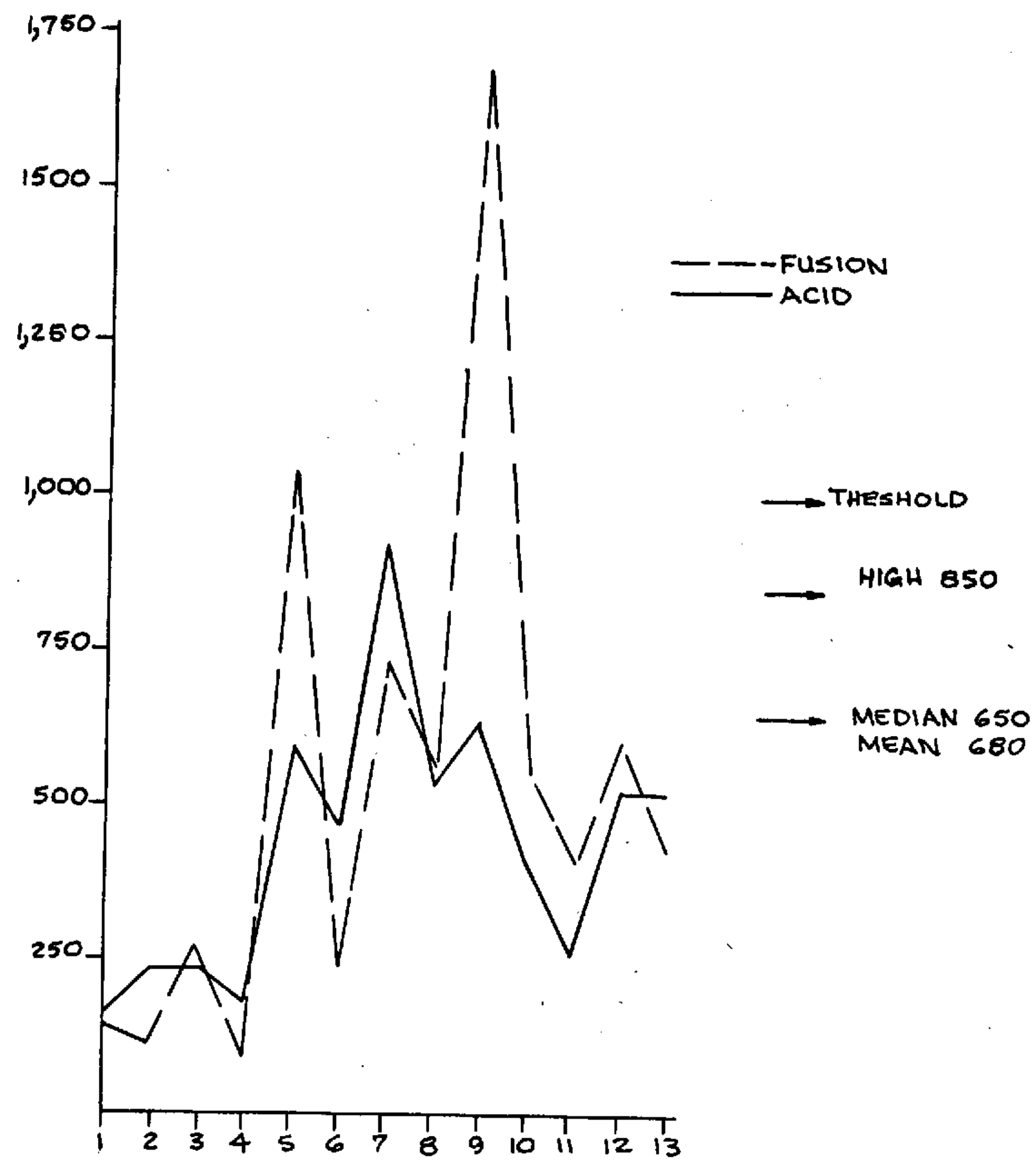


FIG. 41
HARPERSVILLE TRAVERSE 5
Ba CONCENTRATION

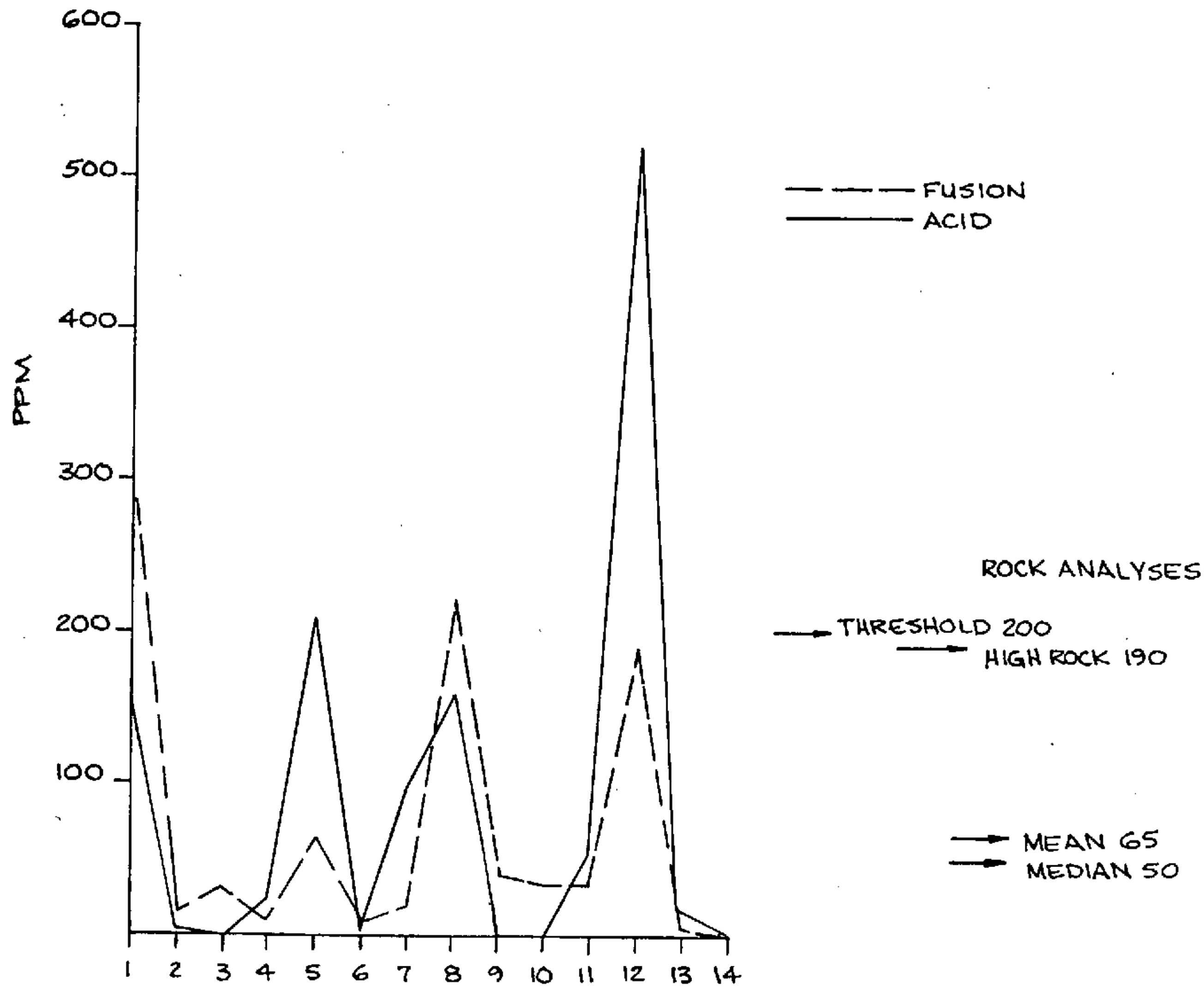


FIG. 42
Mn CONCENTRATION
HARPERSVILLE TRAVERSE 5

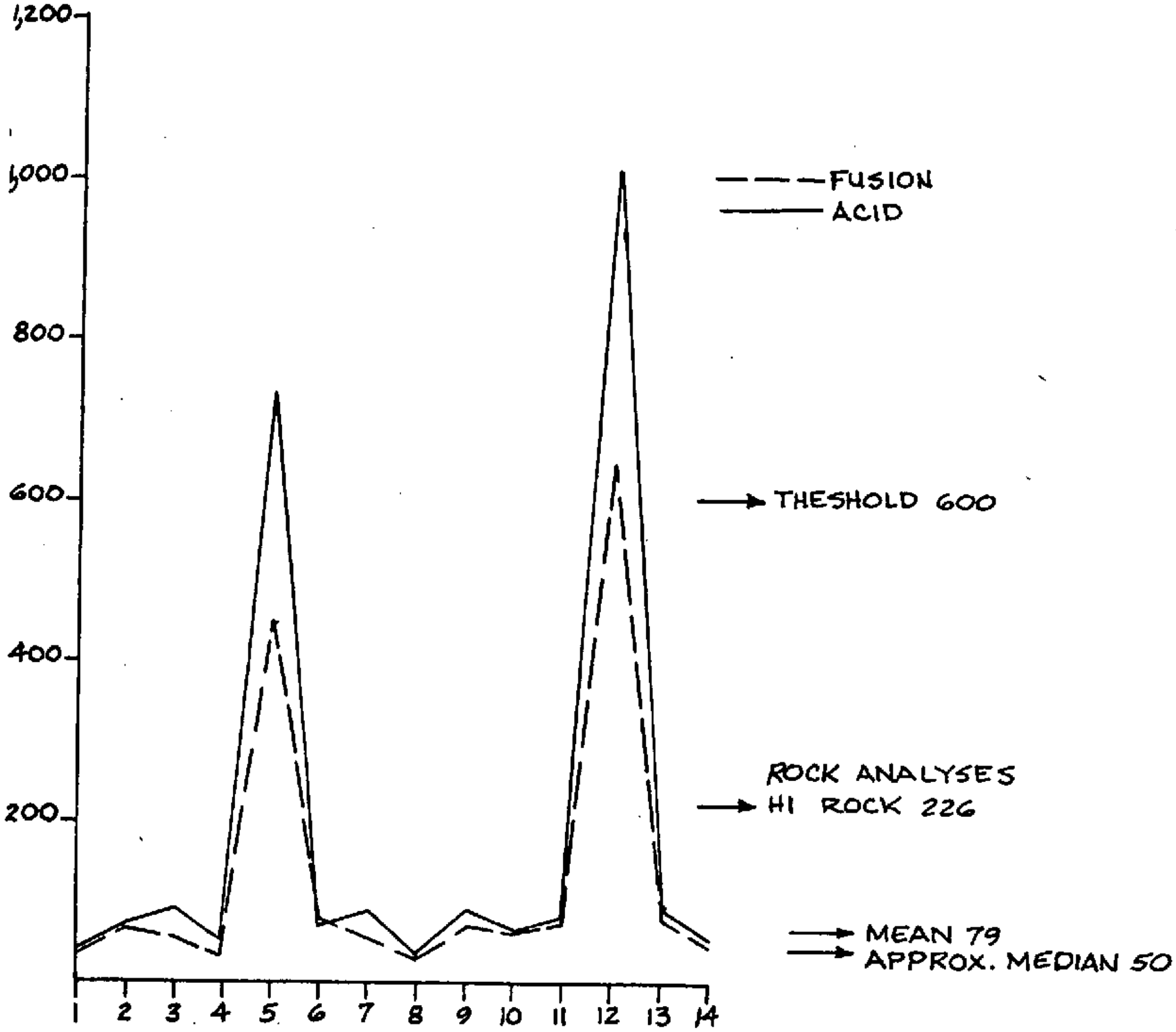


FIG. 43
HARPERSVILLE TRAVERSE 5
Sr CONCENTRATION

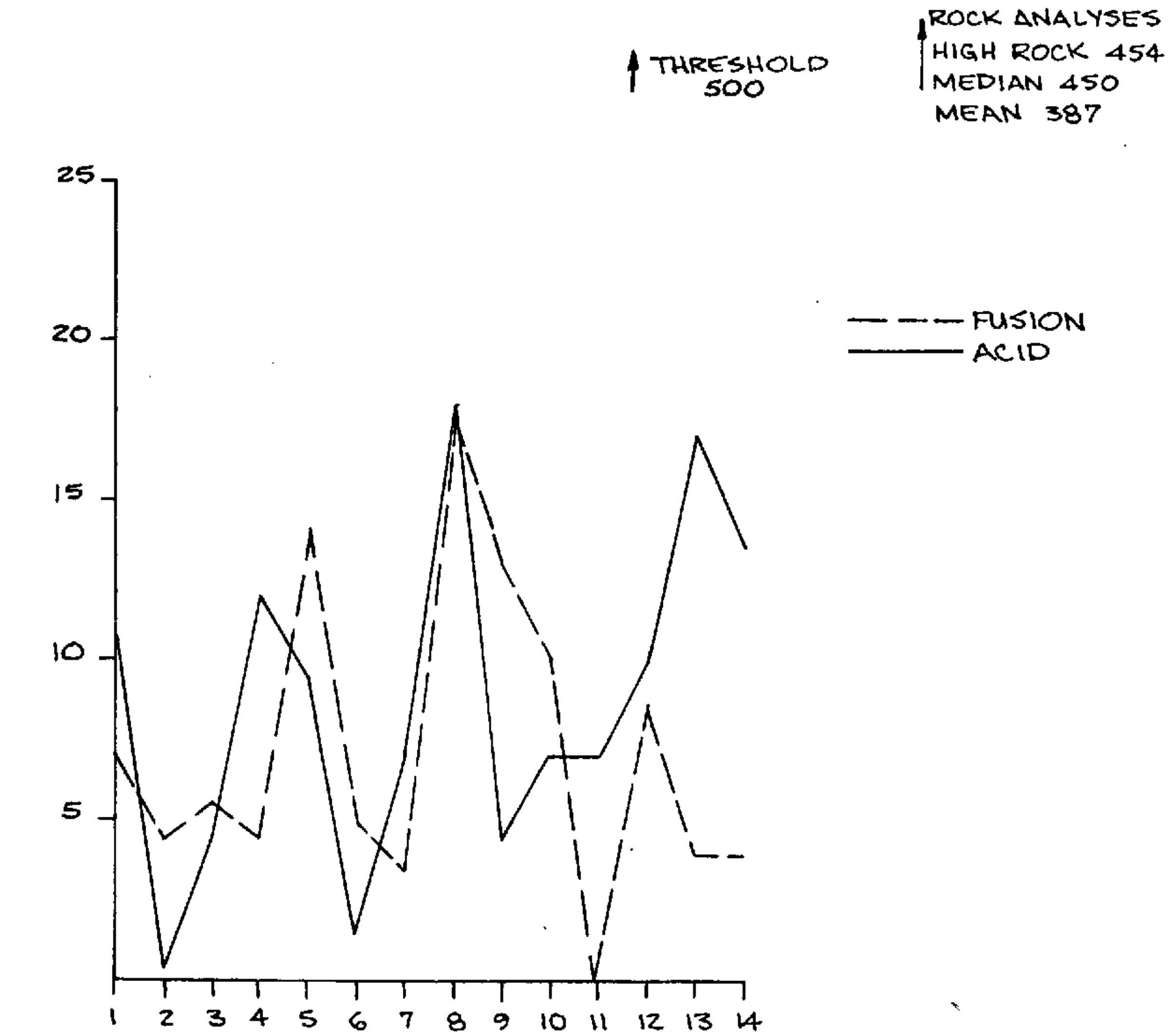


FIG. 44
HARPERSVILLE TRAVERSE 5
Cu CONCENTRATION

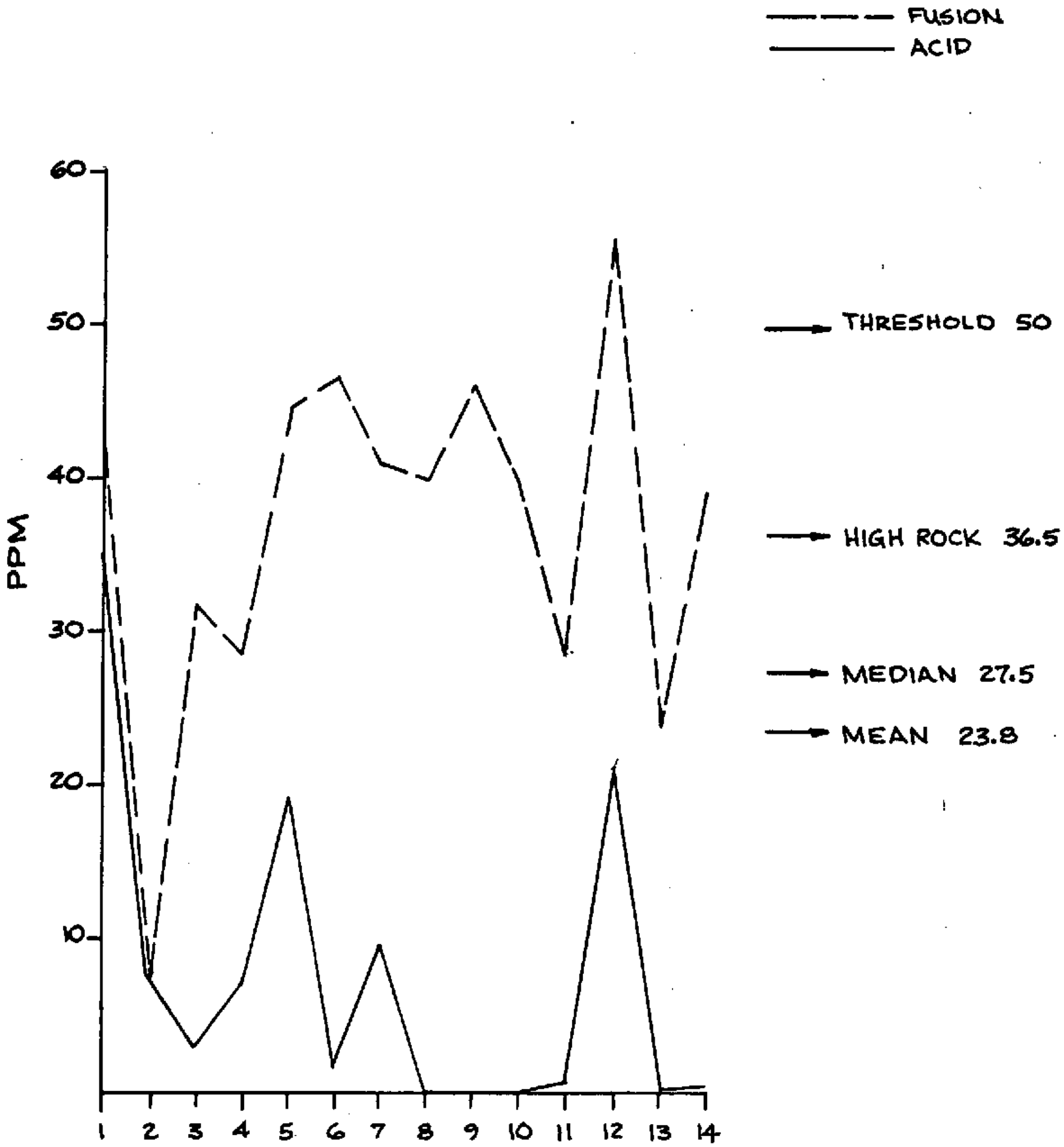


FIG. 45

HARPERSVILLE TRAVERSE 5
Zn CONCENTRATION

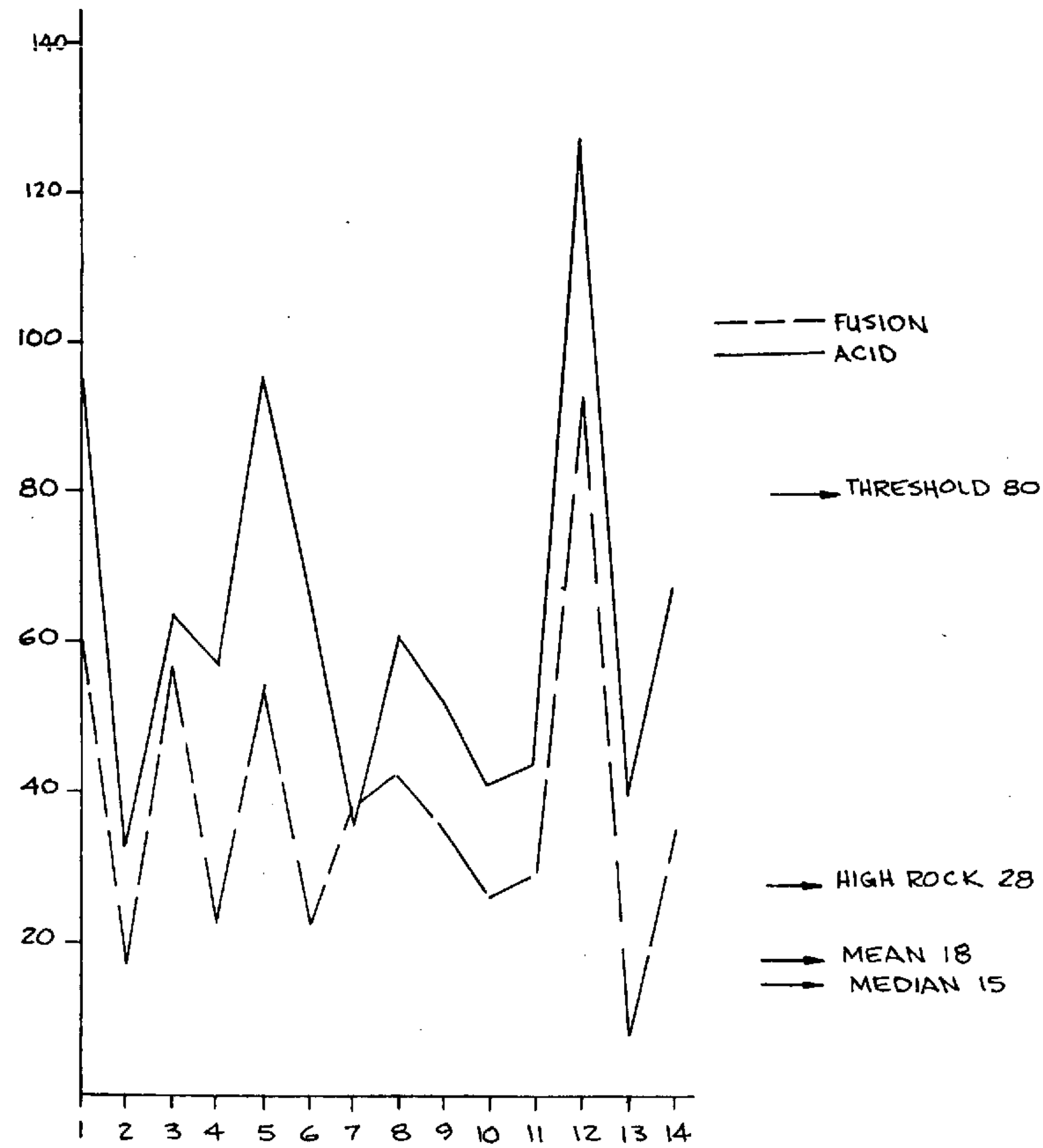


FIG. 46
HARPERSVILLE TRAVERSE 5
Pb CONCENTRATION

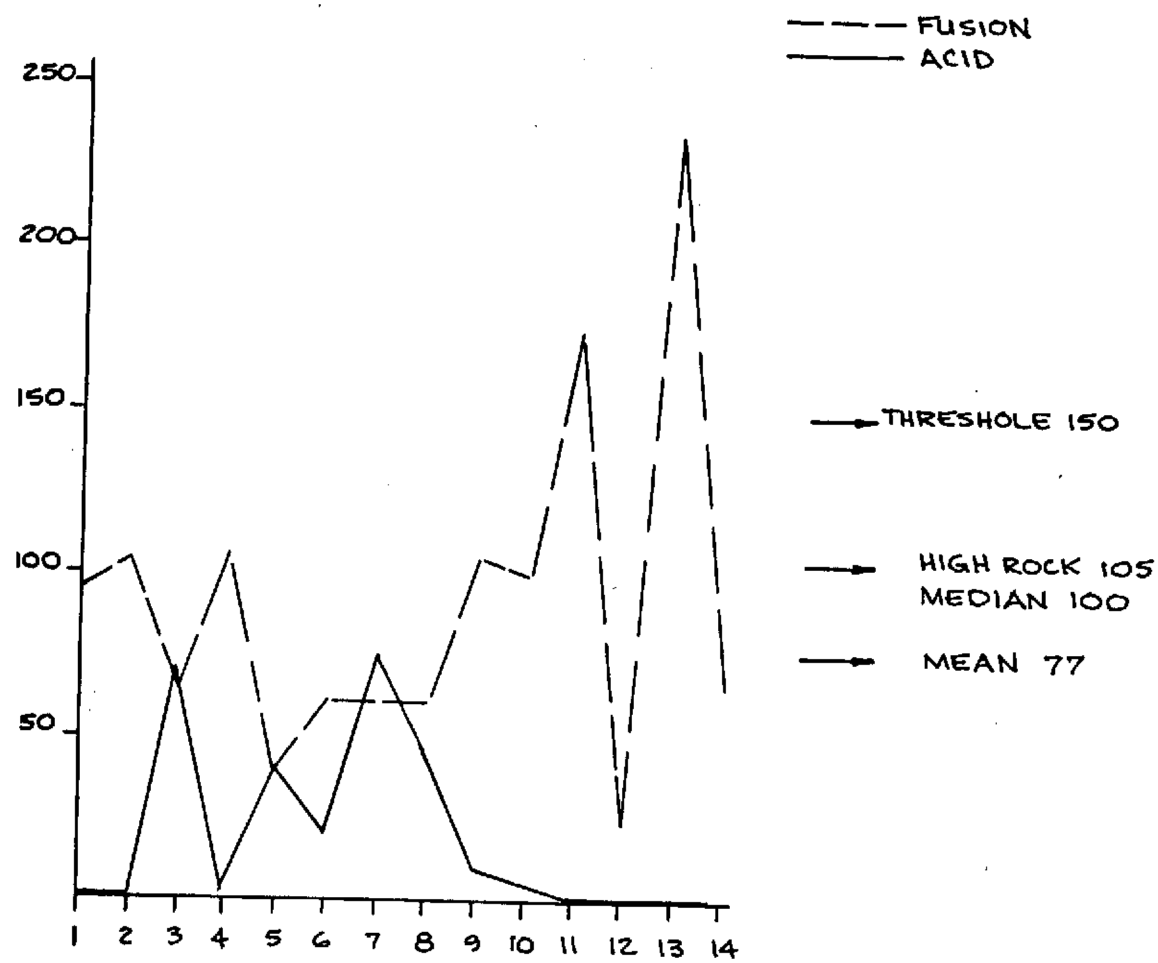
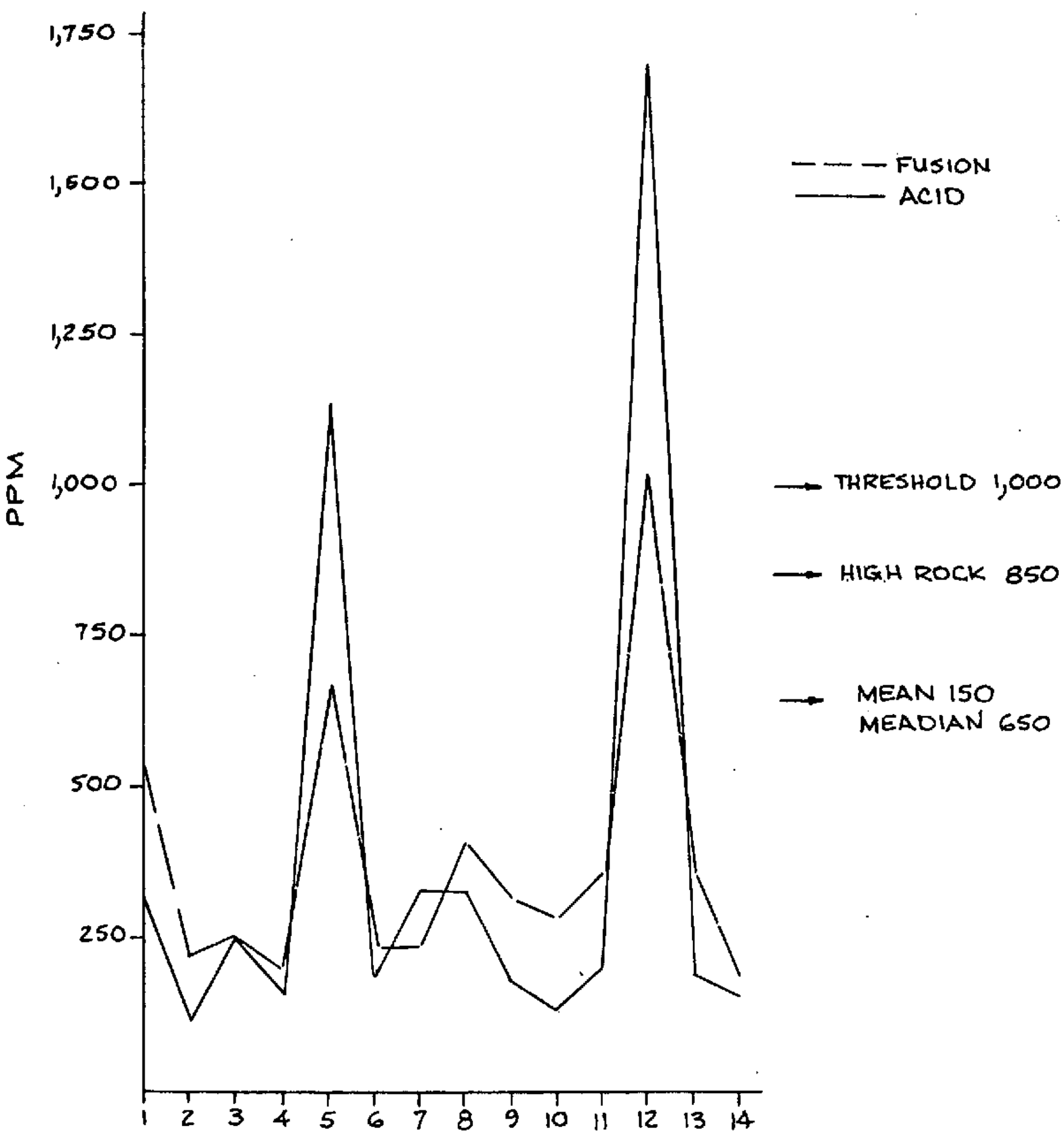


FIG. 47
TOTAL METAL CONCENTRATION
HARPERSVILLE TRAVERSE 5



3-2, 3-7, 3-8, 5-5, 5-12. Copper highs occur at 1-8, 1-9, 1-13, 2-1, 2-3, 3-4, 4-5, 4-7, 4-9, 5-12. Zinc highs occur at 1-8, 1-9, 1-12, 1-14, 3-4, 4-7, 4-9, 5-1, 5-5, 5-12. Lead highs occur at 1-6, 1-15, 2-2, 3-6, 3-10, 4-7, 4-8, 4-11, 4-12, 5-11, 5-13. Total metal highs occur at 1-8, 1-9, 1-12, 2-1, 3-2, 3-4, 3-7, 3-8, 4-5, 4-9, 5-5, 5-12.

If the locations of these highs are plotted on a series of maps (figures 48-54), several linear arrangements become apparent. These linear arrangements appear to be nearly parallel to the members of the Harpersville lineament complex (major lineaments) in the area although not exactly on their traces (Drahovzal, 1974). Barium and copper highs occur at nearly the same points, thus showing nearly identical linear arrangements. Manganese and zinc are likewide coupled and lead is variable. The reason for these relationships is unclear but may have to do with the mobilities of the various elements, or some geochemical affinity.

The fact that few highs plot precisely on traces of lineaments is not a serious drawback if the scale of the original imagery is considered. Thus, it is difficult to locate lineament traces more accurately than $\pm$ 0.5 mile. The data are too few to state whether the lineament traces are inaccurately plotted or whether geochemical enrichments actually occur parallel to but never on lineaments.

It seems probable, however, that in this area, the locations of major lineaments give visual clues to the locations of geochemical enrichment and possible mineralization. Insufficient data exists to assess the effect of minor lineaments.

The nature of the lineaments in the Harpersville area also cannot be

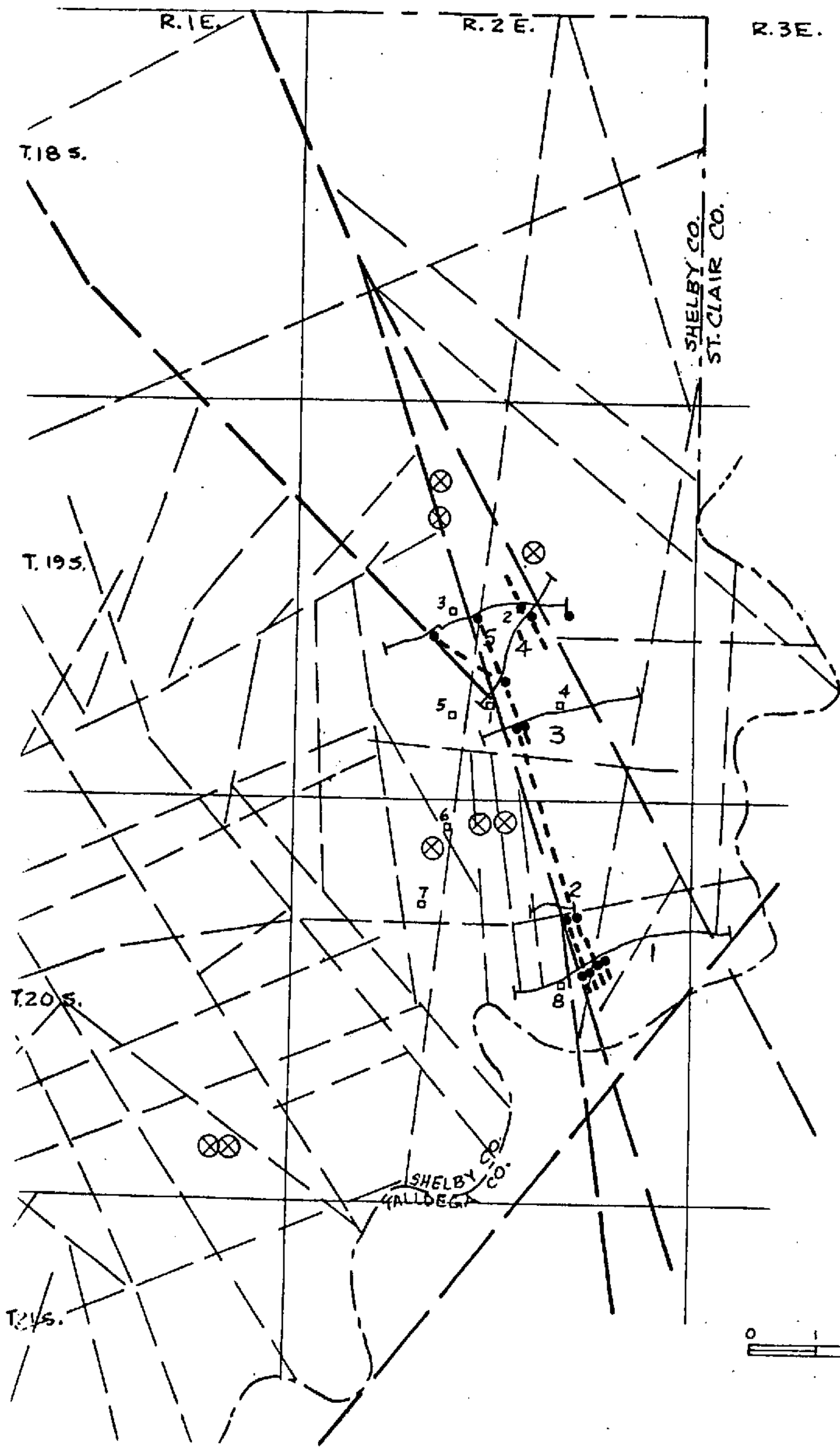


FIG. 48
LOCATION OF BARIUM ANOMALIES IN NORTHEAST SHELBY CO.

EXPLANATION
TRAVERSE
BARITE LOCALITIES
LINEAMENTS (MAJOR LINEAMENTS IN DARKER LINES)
ROCK SAMPLES
TREND OF ANOMALIES
ANOMALY

0 1 2 3 4 MILES

N

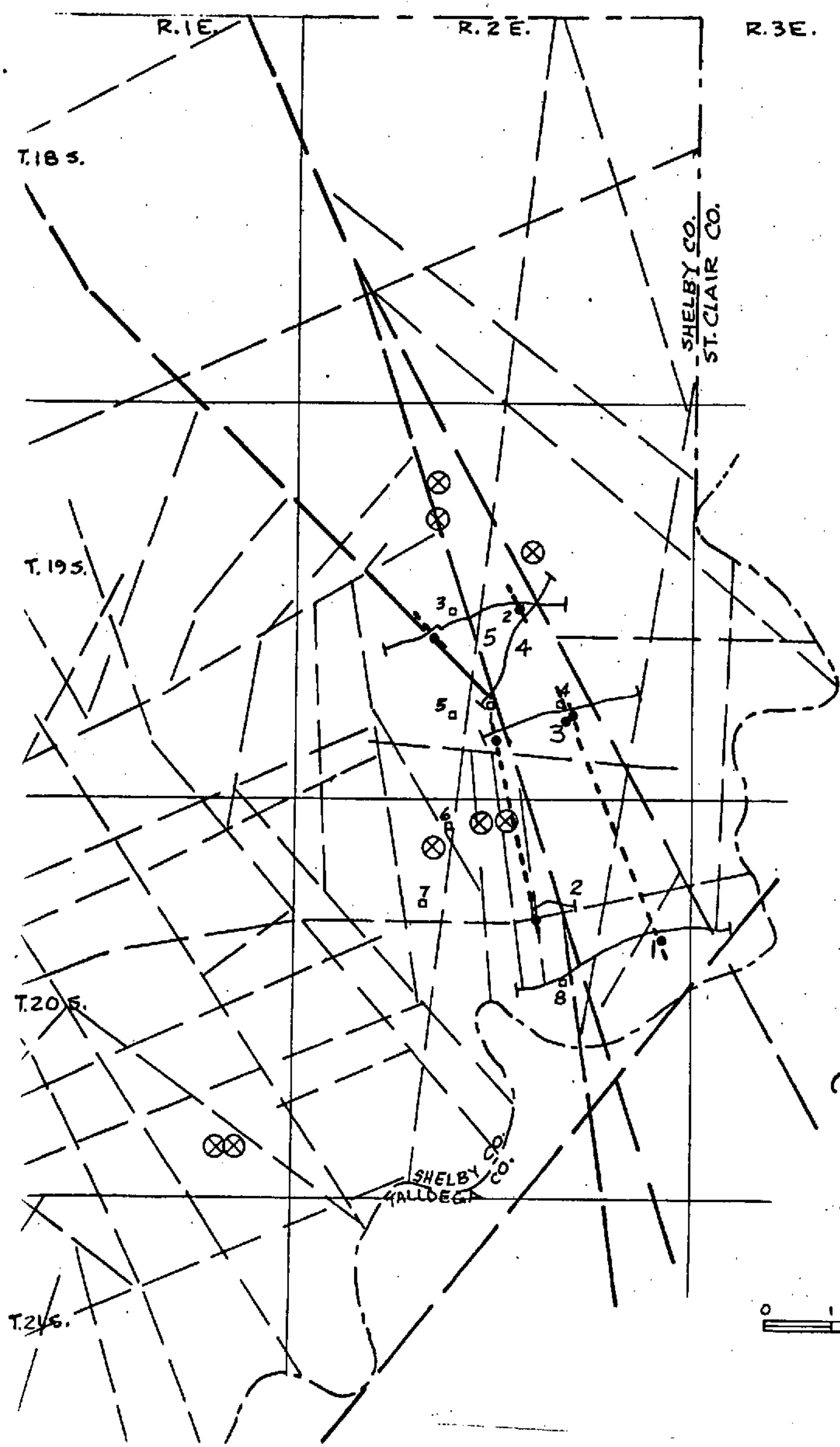


FIG. 49
LOCATION
OF
MANGANESE
ANOMALIES
IN NORTHEAST
SHELBY CO.

EXPLANATION

TRAVERSE

BARITE LOCALITIES

LINEAMENTS
(MAJOR LINEAMENTS
IN DARKER LINES)

ROCK SAMPLES

TREND OF ANOMALIES

ANOMALY

0 1 2 3 4 MILES

N

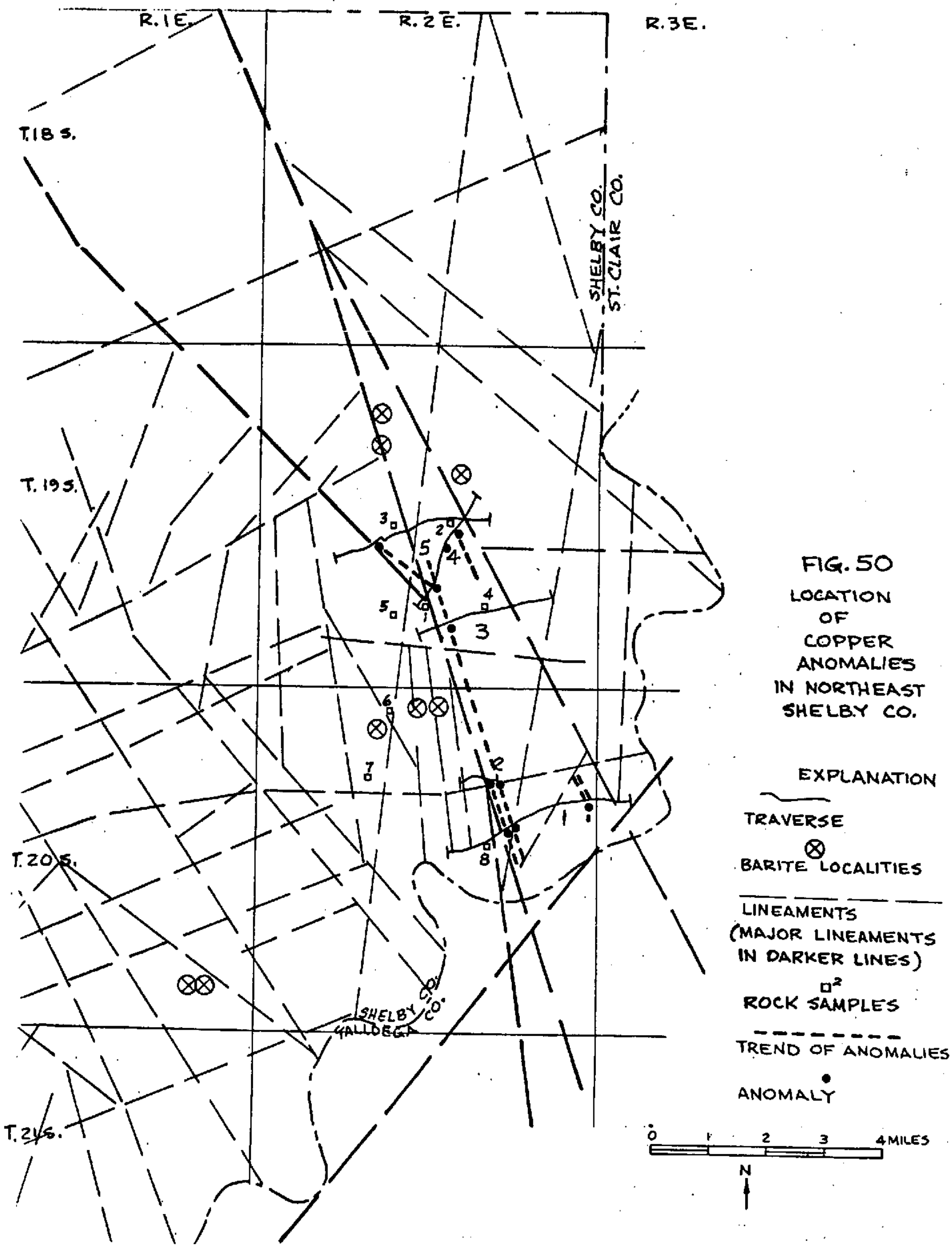


FIG. 50
LOCATION OF COPPER ANOMALIES IN NORTHEAST SHELBY CO.

EXPLANATION

TRAVERSE

BARITE LOCALITIES

LINEAMENTS (MAJOR LINEAMENTS IN DARKER LINES)

ROCK SAMPLES

TREND OF ANOMALIES

ANOMALY

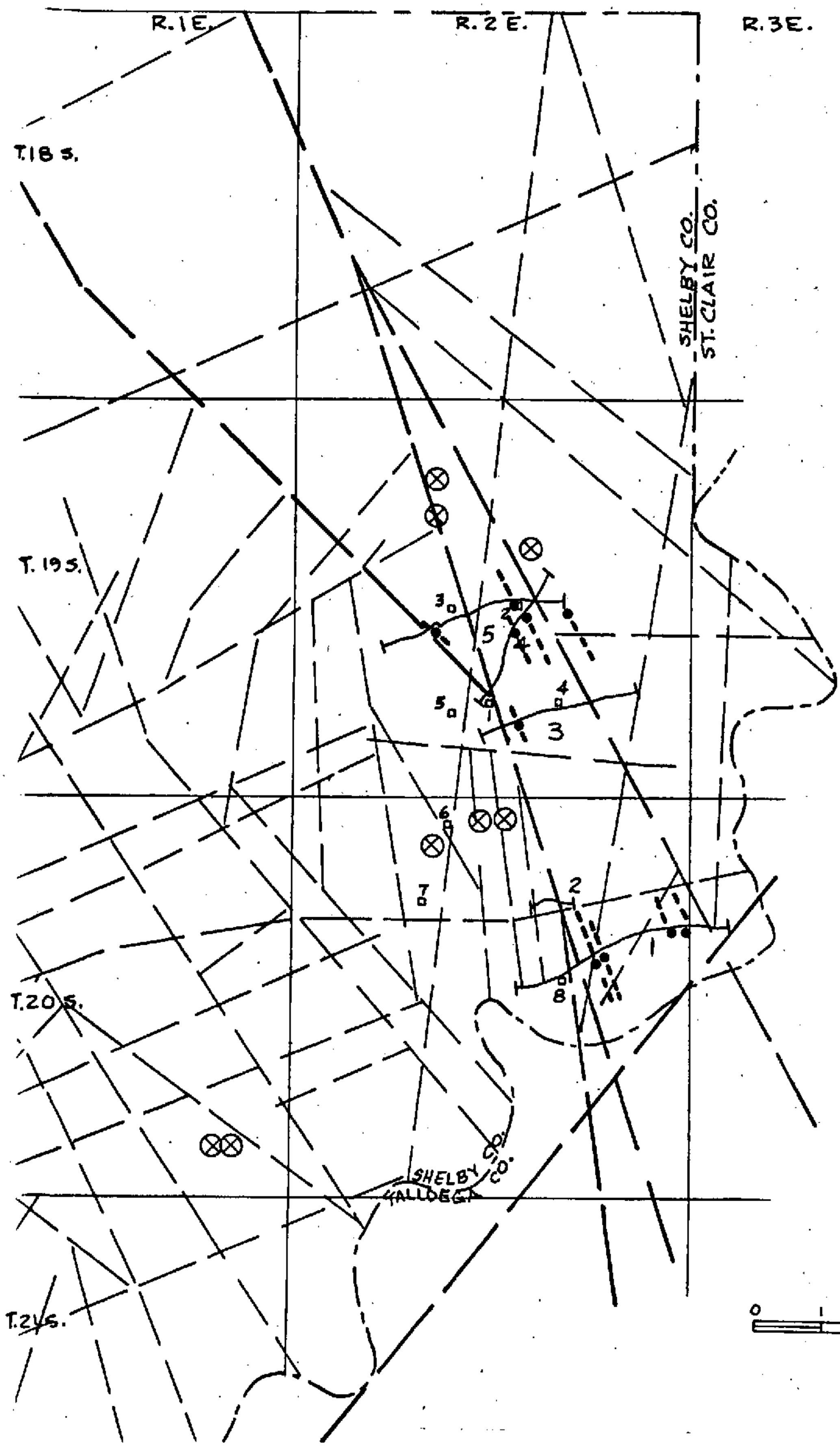


FIG. 51
LOCATION OF ZINC ANOMALIES IN NORTHEAST SHELBY CO.

EXPLANATION

TRAVERSE

BARITE LOCALITIES

LINEAMENTS (MAJOR LINEAMENTS IN DARKER LINES)

ROCK SAMPLES

TREND OF ANOMALIES

ANOMALY

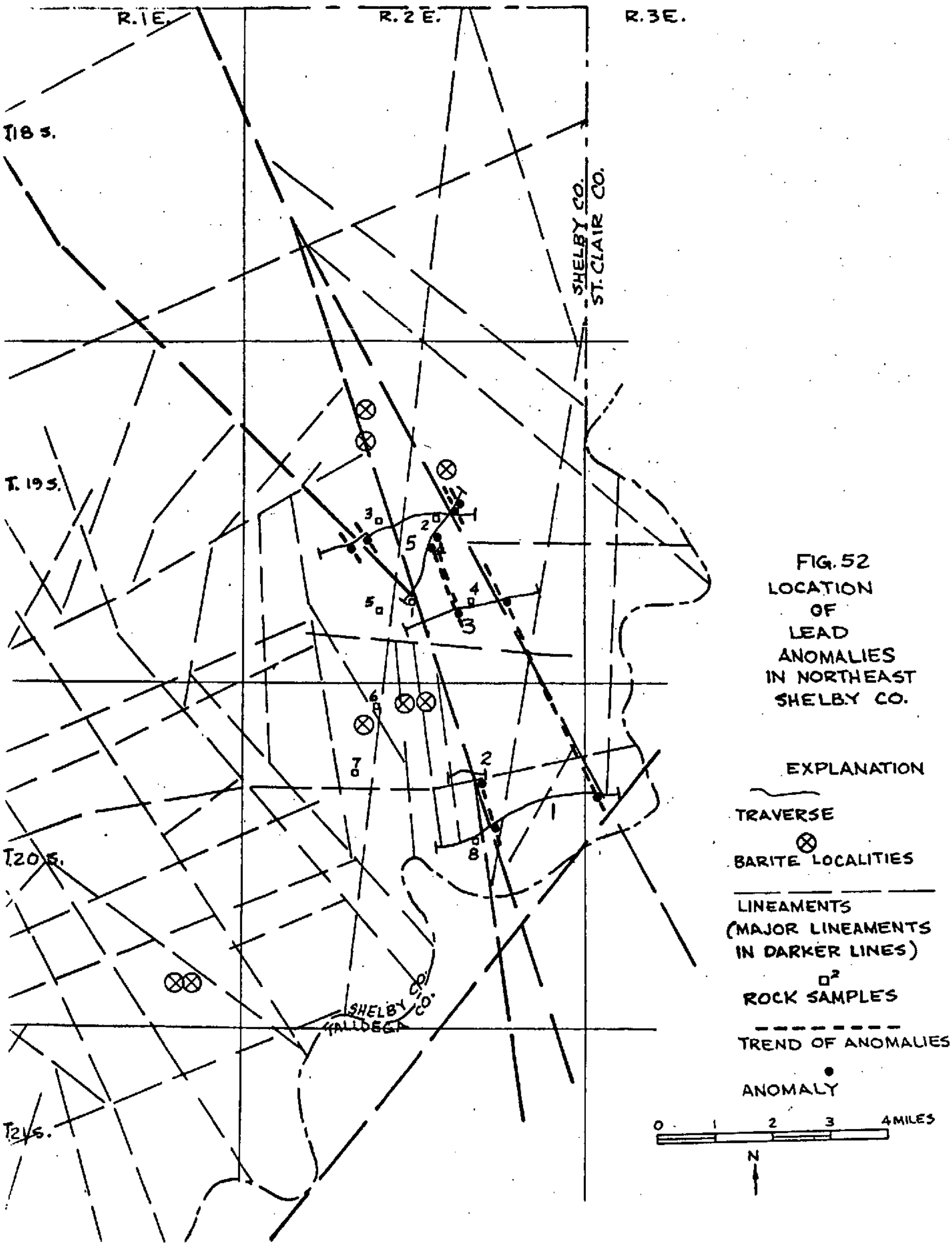


FIG. 52
LOCATION OF LEAD ANOMALIES IN NORTHEAST SHELBY CO.

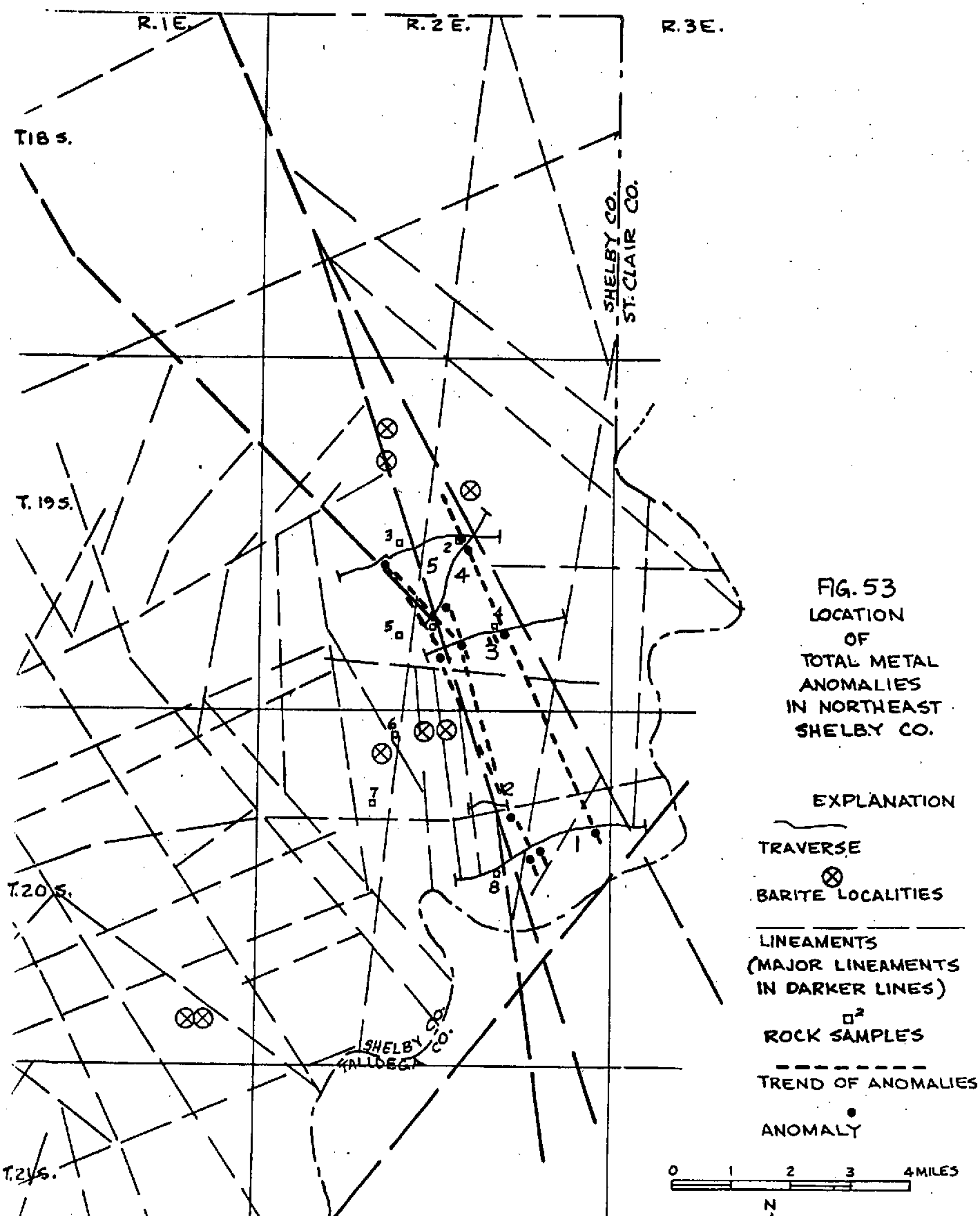


FIG. 53
LOCATION OF TOTAL METAL ANOMALIES IN NORTHEAST SHELBY CO.

EXPLANATION

TRAVERSE

BARITE LOCALITIES

LINEAMENTS (MAJOR LINEAMENTS IN DARKER LINES)

ROCK SAMPLES

TREND OF ANOMALIES

ANOMALY

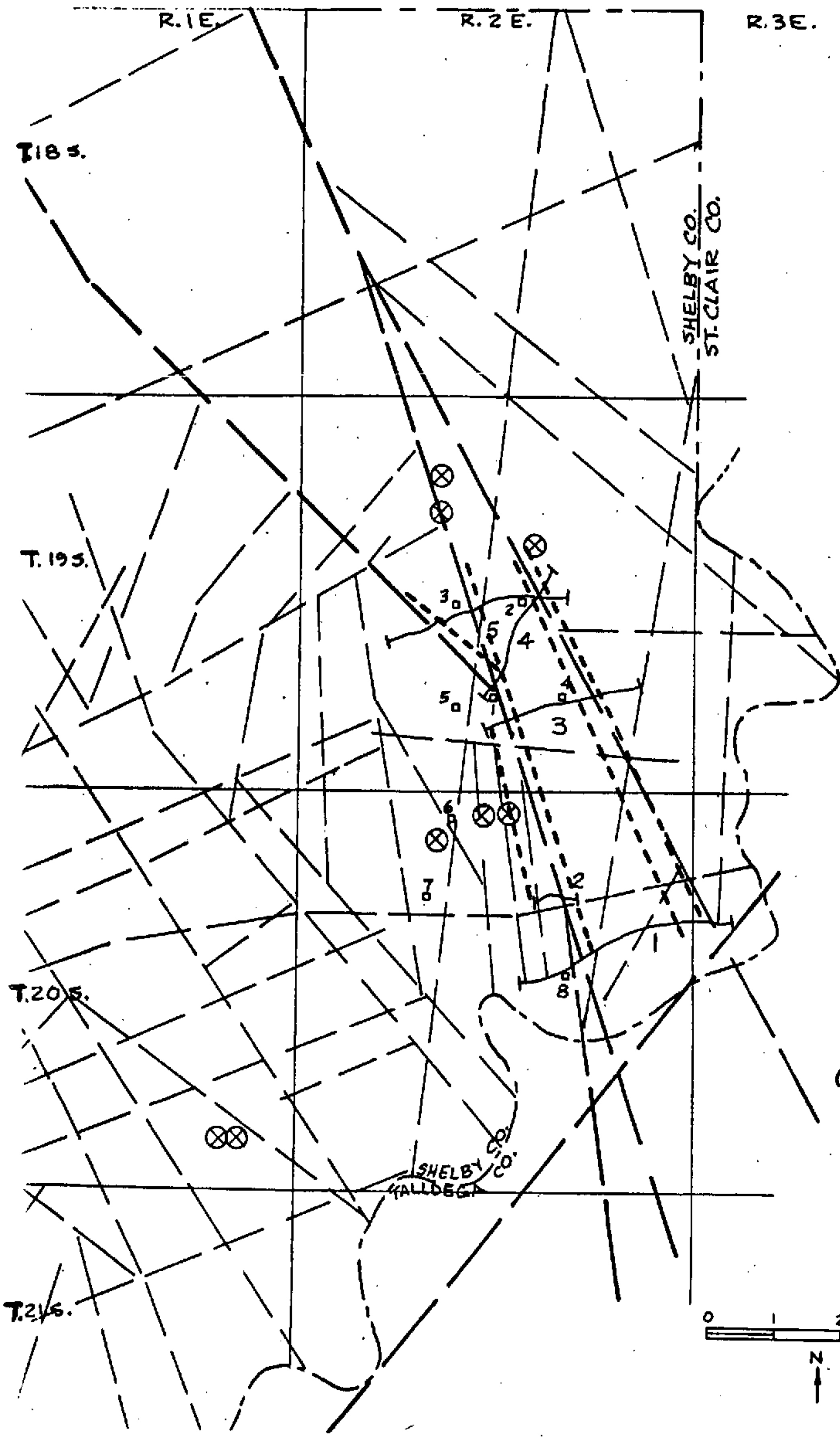


FIG. 54
LOCATION OF INFERRED TRENDS OF GEOCHEMICAL ANOMALIES IN NORTHEAST SHELBY CO.

EXPLANATION

TRAVERSE

BARITE LOCALITIES

LINEAMENTS (MAJOR LINEAMENTS IN DARKER LINES)

ROCK SAMPLES

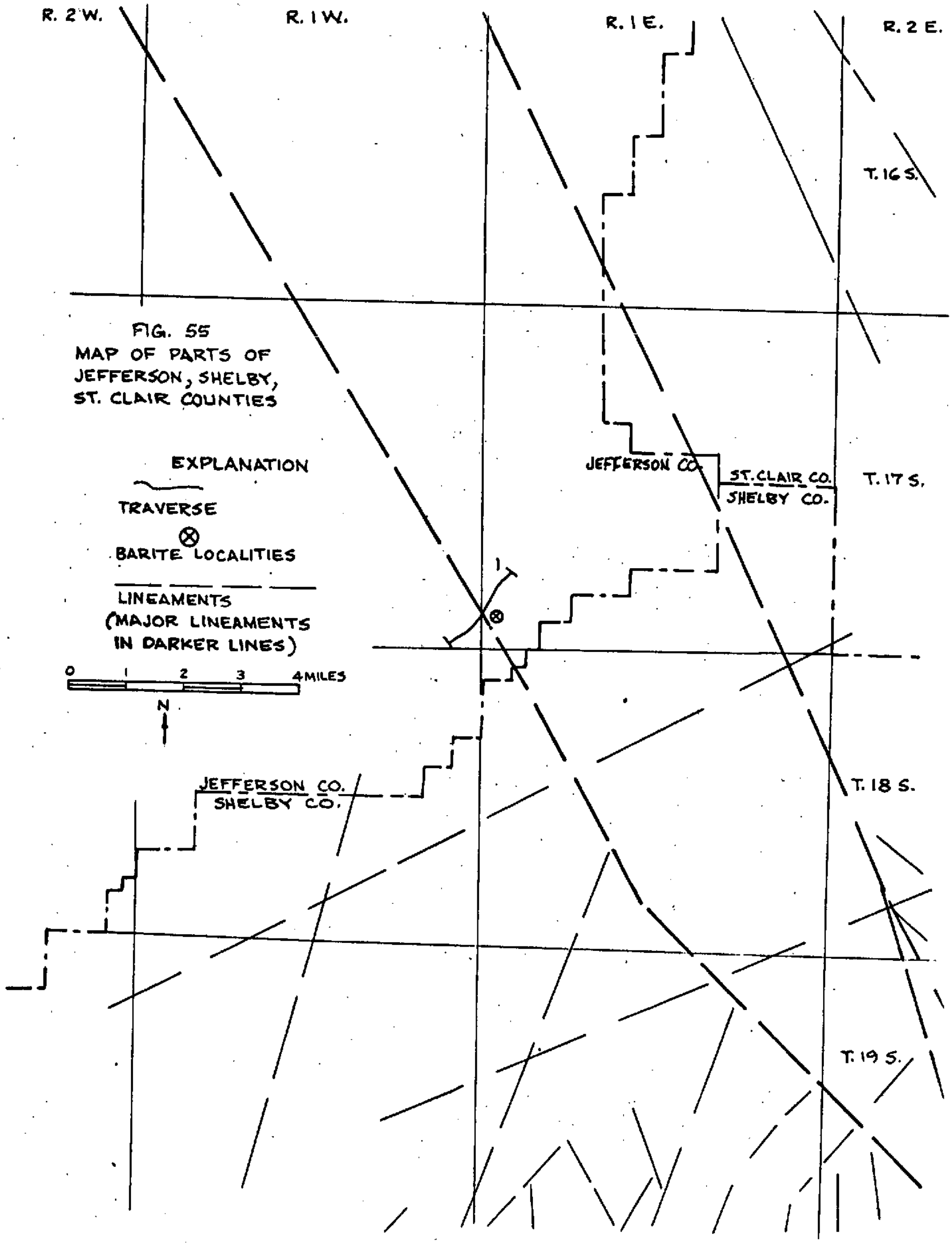
TREND OF ANOMALIES

accurately described by the present data. Drahovzal (J. A., 1974, personal communication) points out that the area is geologically and structurally complex, being underlain by a variety of rocks and many thrust faults. Whether the lineaments are faults or are fault controlled, or whether the lineaments in some way control the character and location of the faults is a question that must go unanswered by this investigation. However, it has been shown that the area exhibits geochemical anomalies and that these anomalies exhibit a linear geometrical pattern that is apparently spatially related to the lineaments. Thus, the lineaments or the faults may be channelways for mineralizing fluids. For this reason, it is suggested that this area is of prime interest and should be the object of detailed geological and geochemical study.

Area 2: Leeds

The Leeds locality of Jefferson County is shown on figure 1. Locations of lineaments, barite occurrences and traverses are shown on figure 55. One traverse was made consisting of nine soil samples. No rock samples were collected. The Leeds locality is underlain by limestones and dolomites of Cambrian and Ordovician age (Butts, 1926). Because the area is far from other locales of mineralization and apparently contains no complicated structure, it was thought that the barite occurrence was a small and extremely localized phonemenon. Thus only a rapid reconnaissance was made.

Because the rocks and mineralization appear similar to those in the Harpersville district of Shelby County, the elements analyzed were also Ba, Mn, Sr,


R. 2 W.
R. 1 W.
R. 1 E.
R. 2 E.
T. 16 S.
T. 17 S.
T. 18 S.
T. 19 S.
FIG. 55
MAP OF PARTS OF
JEFFERSON, SHELBY,
ST. CLAIR COUNTIES
EXPLANATION
TRAVERSE
BARITE LOCALITIES
LINEAMENTS
(MAJOR LINEAMENTS
IN DARKER LINES)
0 1 2 3 4 MILES
N
1
JEFFERSON CO.
ST. CLAIR CO.
SHELBY CO.
JEFFERSON CO.
SHELBY CO.

Cu, Zn, and Pb, employing acid digestion as well as fusion. The reasons for this decision are the same as those for Shelby County. Analyses are given in table 7. No analyses of barren rock from this locality are available. However, analyses of rock from the barite occurrence (Hughs and Lynch, 1973) are given in table 8.

Comparison of the two tables indicates that the rocks from the barite prospect are enriched in Cu, Zn, and Pb, compared to the soil of the traverse. Thus, Cu, Zn, and Pb appear to be relatively immobile. Manganese values are about the same in the barite prospect rocks and soil of the traverse except near the soil highs. Manganese may thus have been mobile during barite formation, but during subsequent weathering, it may be less mobile because of the presence of these highs.

By anology with Shelby County, strontium is apparently leached from the soil. However, there is a strontium high near the center of the traverse. Thus, the highs in the immobile elements cannot be the result of differential leaching because they occur in the same places. This can be seen more clearly when the chemical analyses are plotted on maps (figures 56 to 62) and graphs (figures 63 to 69).

Examination of these figures indicates a Ba high at 4; a broad Mn high at 5 and especially 6; a Pb high at 5; and a broad total metal high at 4, 5, and 6. These highs are directly adjacent to or on the plotted lineament and adjacent to the barite occurrences. Even strontium, though its value is suspect, exhibits a high at point 4.

Although the effect of possible aluminum interference is clearly visible in the graphs (see Shelby County discussion), and although no clearly discernible

Table 7
Chemical Analyses of Soils (in parts per million)

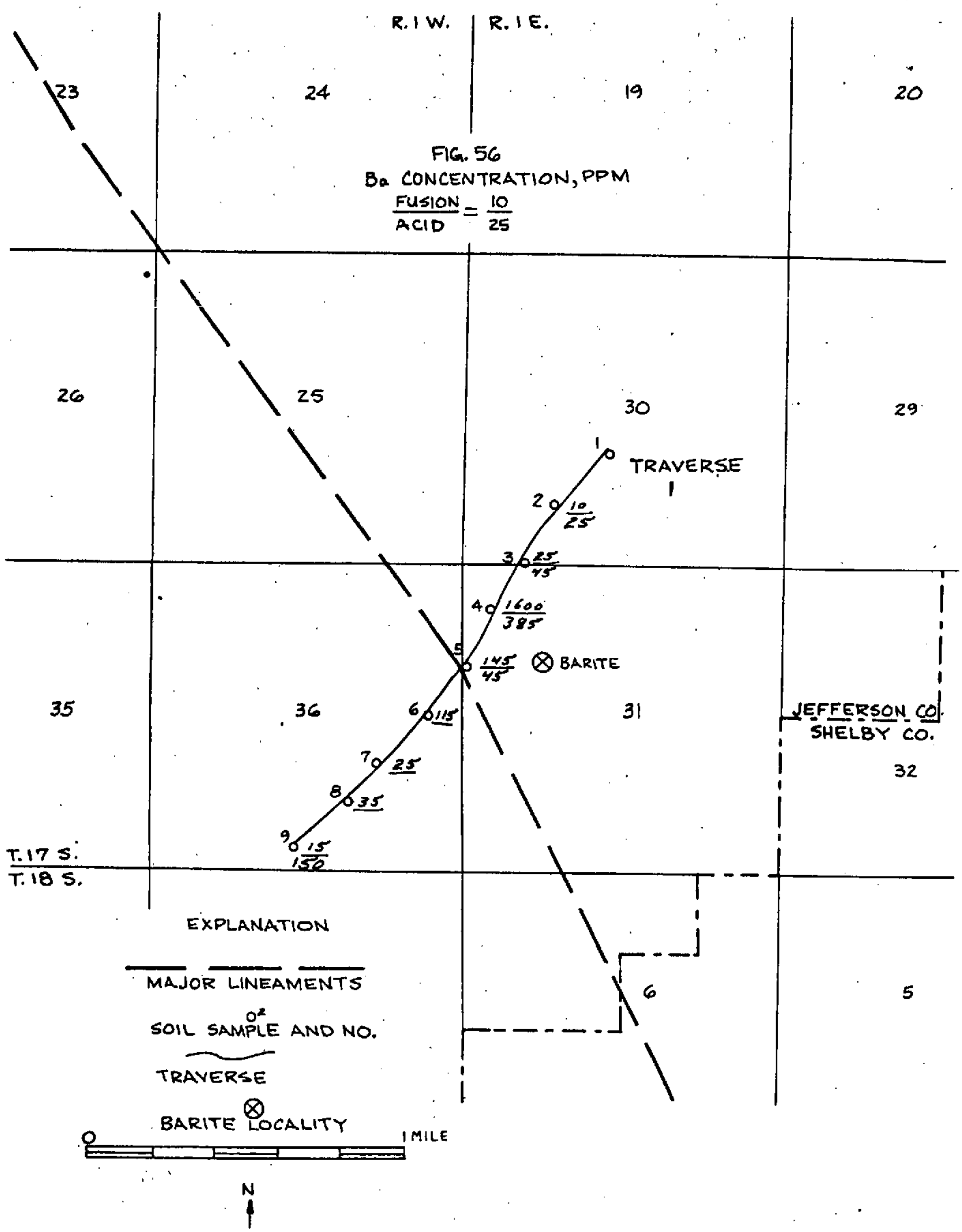
Leeds Traverse 1	Ba		Mn		Sr		Zn		Cu		Pb	
	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid	Fusion	Acid
1-1	ND	ND	121.5	147.0	2.5	7.0	34.0	43.5	50.0	10.5	90	5
1-2	10	25	299.5	59.0	2.5	5.0	36.5	59.0	43.5	ND	55	ND
1-3	25	45	122.0	173.0	6.5	24.0	31.0	84.5	37.5	26.0	35	50
1-4	1,600	385	452.0	607.5	38.5	42.0	42.5	64.5	26.5	4.5	75	30
1-5	145	45	535.0	794.0	18.0	19.5	42.0	59.0	40.0	ND	120	10
1-6	115	ND	1,088.0	1,552.5	4.0	19.0	41.0	67.0	32.0	ND	10	20
1-7	25	ND	37.0	24.5	ND	8.0	16.5	33.0	26.5	1.5	ND	65
1-8	35	ND	65.5	110.0	8.0	10.5	49.0	89.0	24.5	ND	25	35
1-9	15	150	517.0	780.0	5.5	9.0	41.5	78.5	30.0	10.5	60	ND

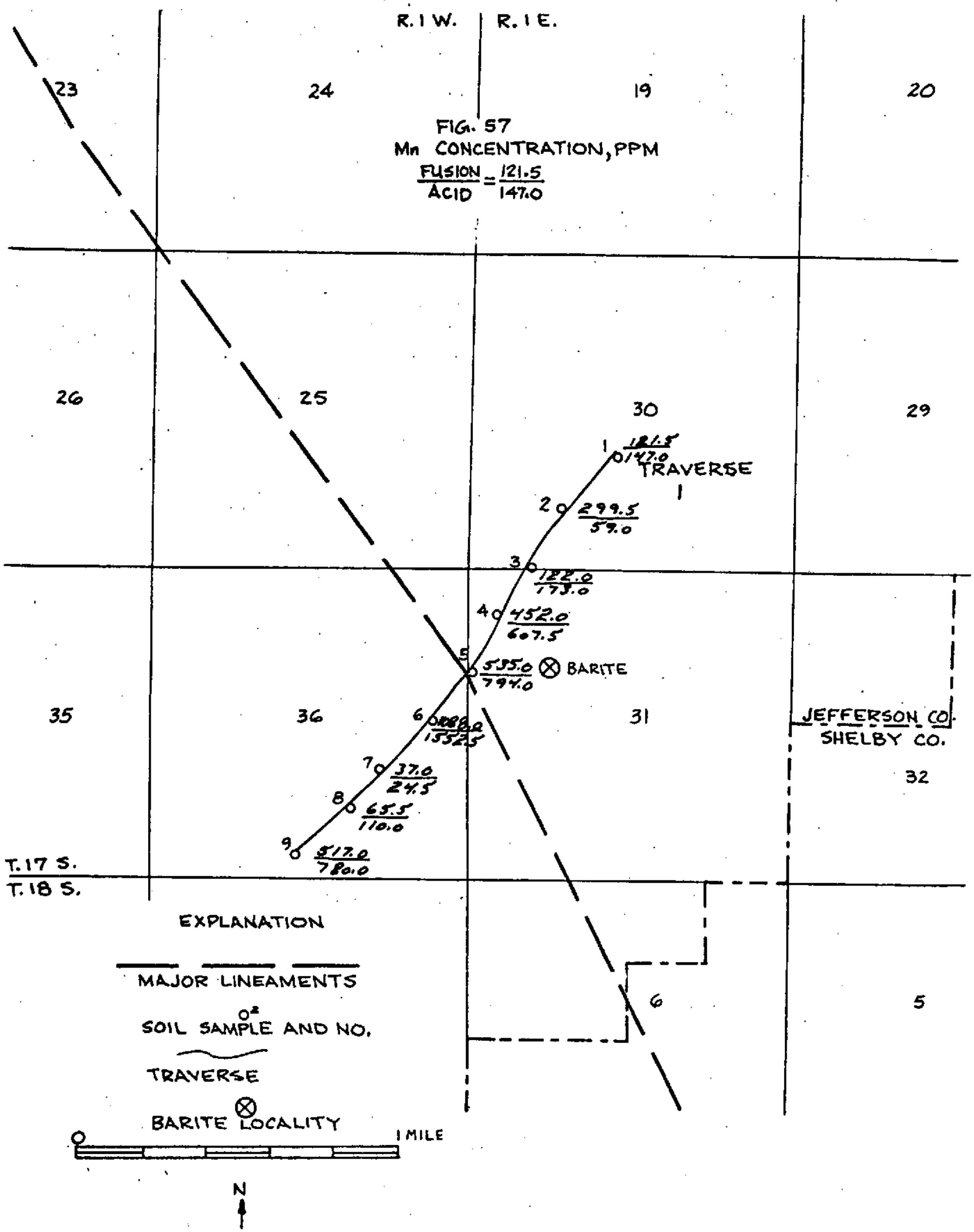
Analyst: G. Thomas, Geological Survey of Alabama

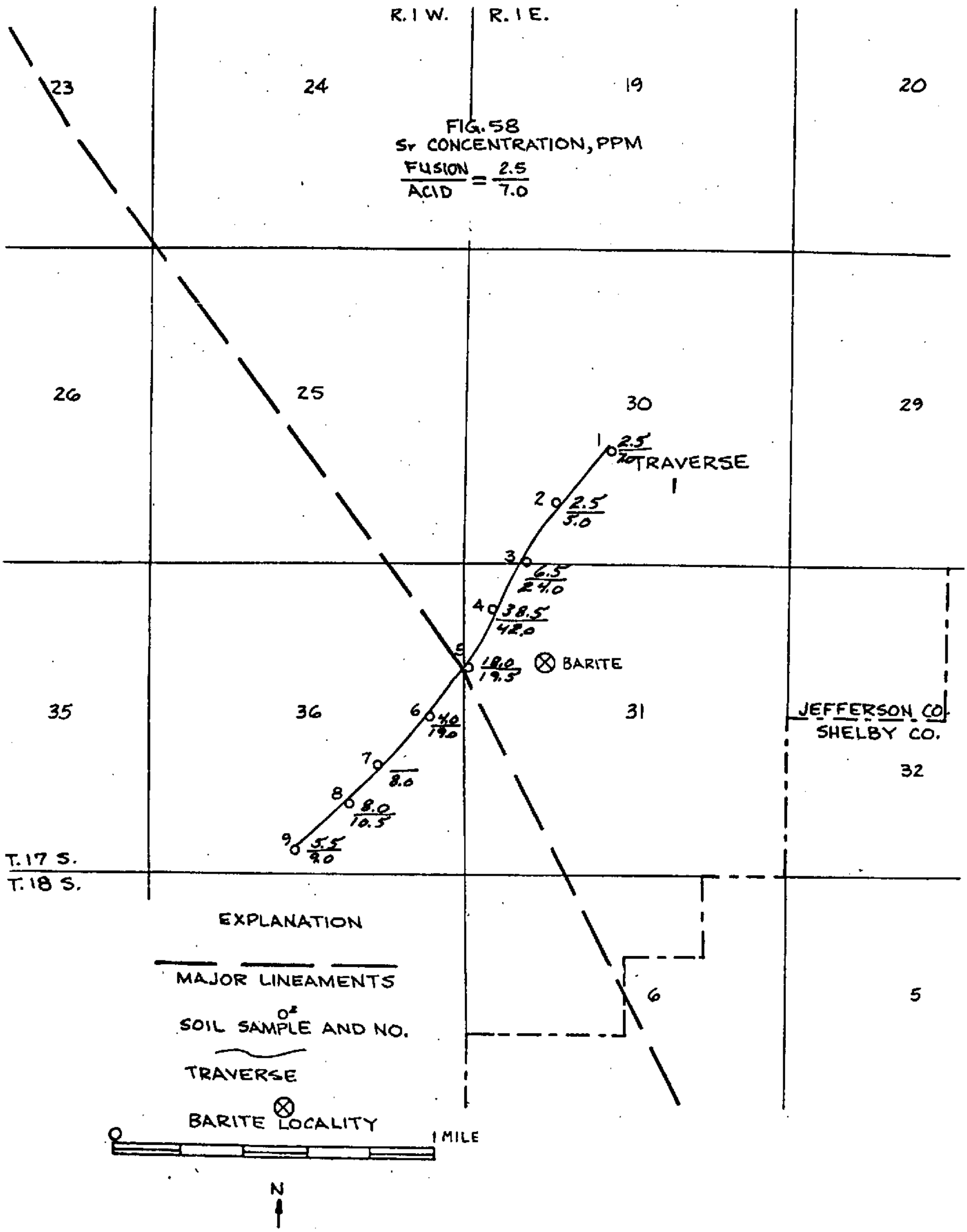
Table 8
Chemical Analyses of Rocks (in parts per million)

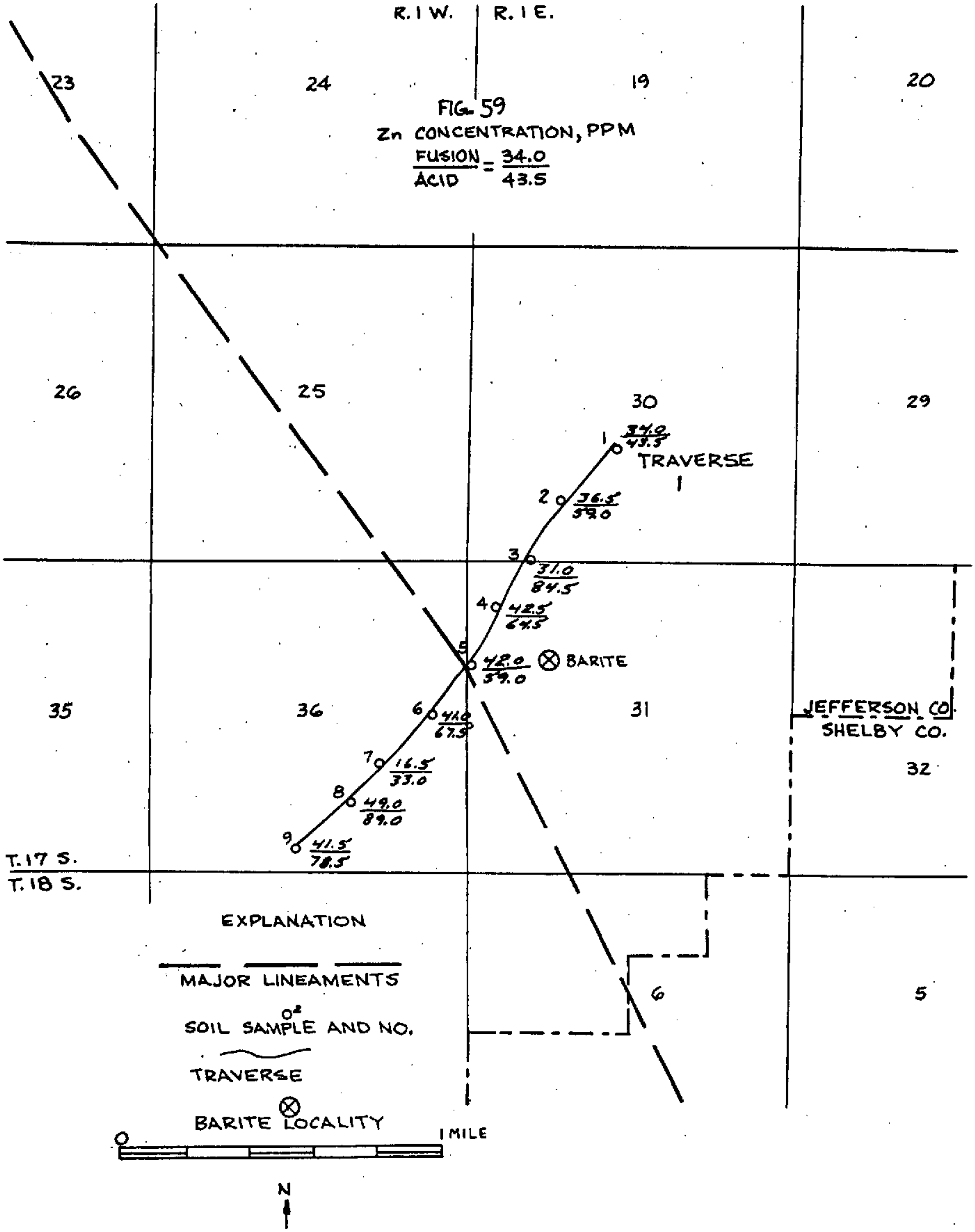
Leeds Barite Prospect	Mn	Zn	Cu	Pb	Remarks
JL-1	240	380	220	1,580	Dolomite
JL-2	280	220	250	1,740	Dolomite
JL-3	120	280	230	1,850	Limestone

Data from Hughes and Lynch (1973)

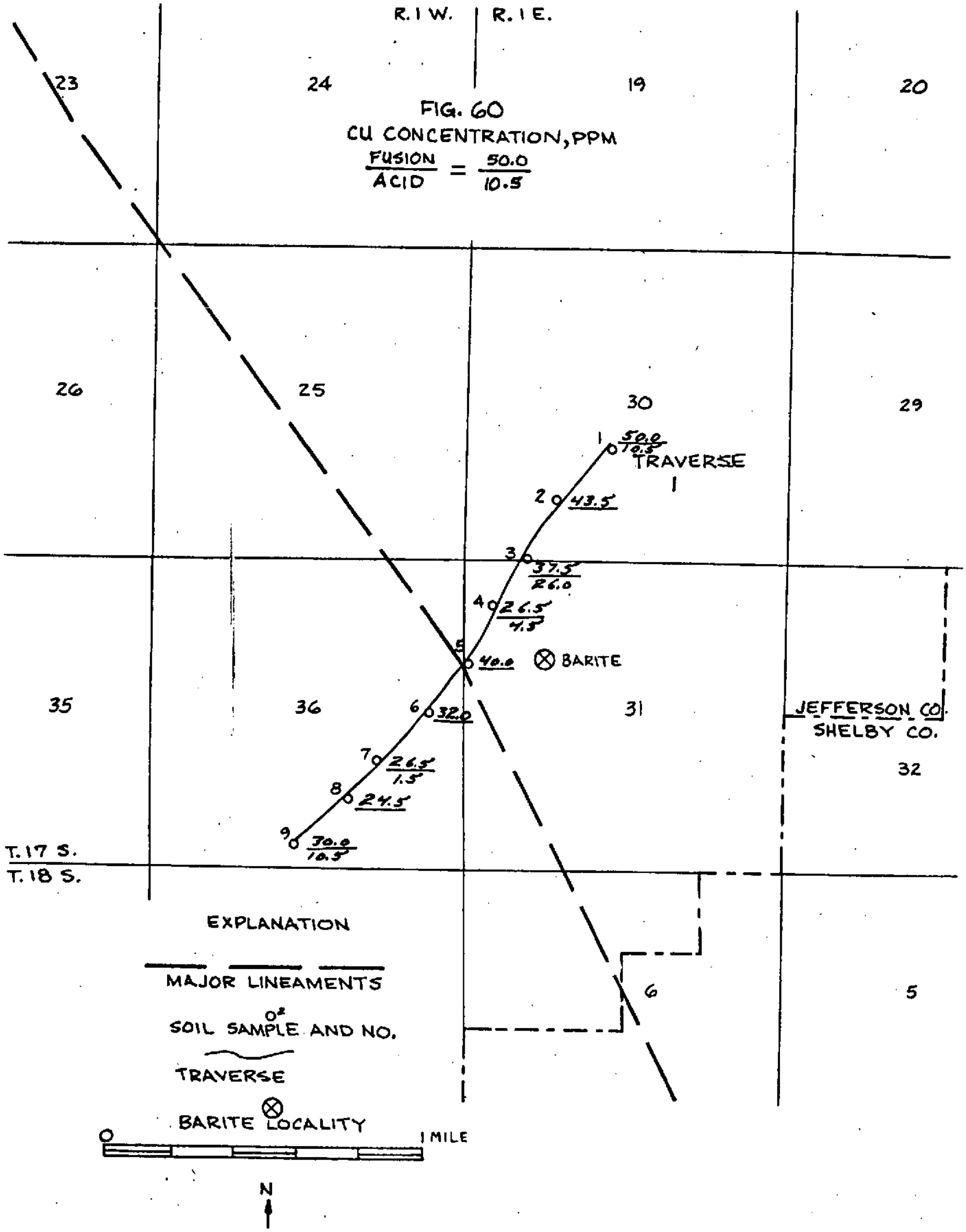

R.1 W.
R.1 E.
23
24
19
20
FIG. 56
Ba CONCENTRATION, PPM
FUSION / ACID = 10 / 25
26
25
30
29
1
TRAVERSE
1
2 10/25
3 25/45
4 1600/385
5 145/45
BARITE
35
36
31
6 115
JEFFERSON CO.
SHELBY CO.
32
7 25
8 35
9 15/150
T.17 S.
T.18 S.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
6
5
0
1 MILE
N

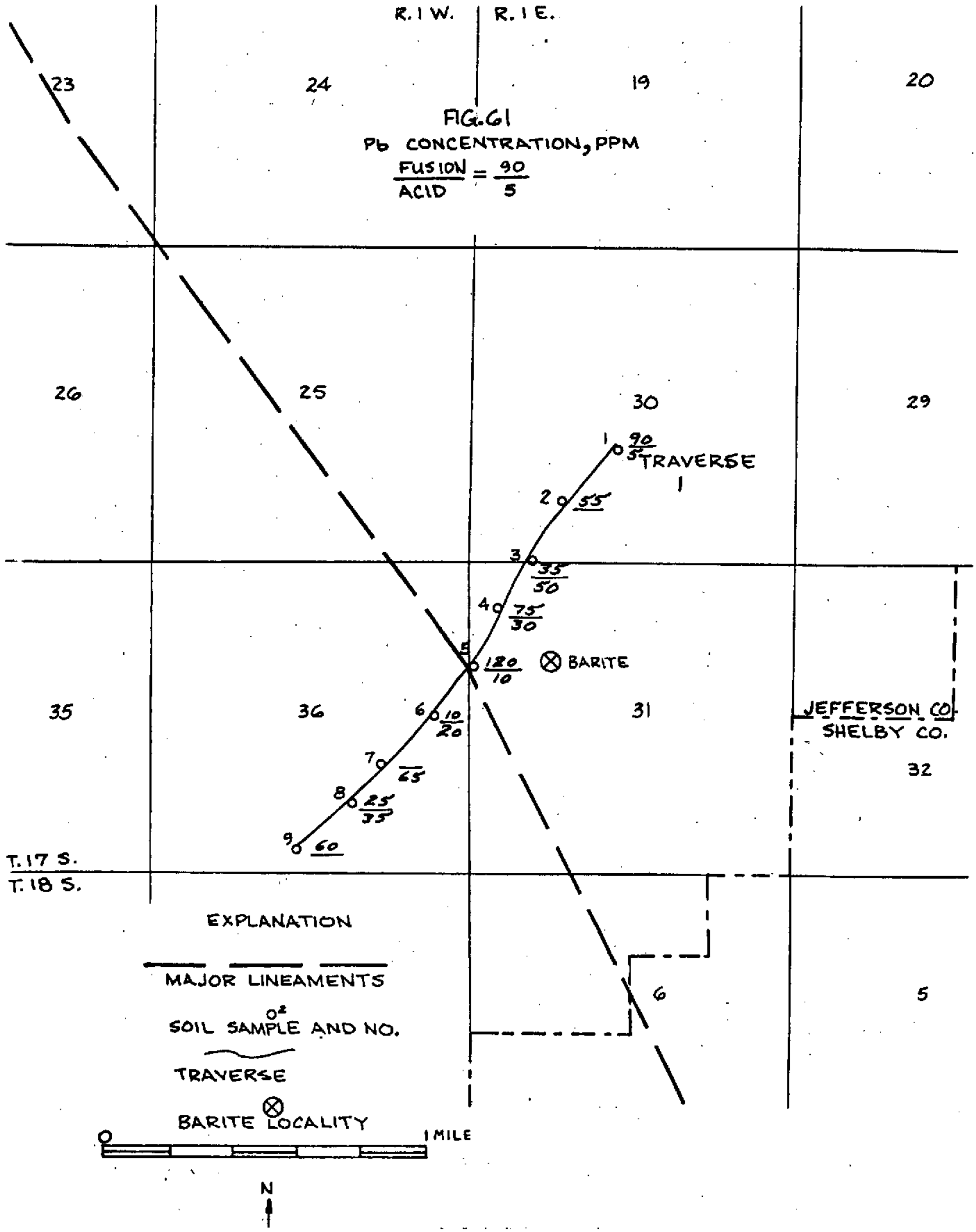

R.1 W.
R.1 E.
23
24
19
20
FIG. 57
Mn CONCENTRATION, PPM
FUSION / ACID = 121.5 / 147.0
26
25
30
29
TRAVERSE 1
35
36
31
32
BARITE
JEFFERSON CO.
SHELBY CO.
T.17 S.
T.18 S.
6
5
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
0
1 MILE
N


R.1 W.
R.1 E.
23
24
19
20
FIG. 58
Sr CONCENTRATION, PPM
FUSION / ACID = 2.5 / 7.0
26
25
30
29
TRAVERSE 1
1 2.5/2.0
2 2.5/3.0
3 6.5/24.0
4 38.5/42.0
5 18.0/19.5
BARITE
35
36
31
6 4.0/19.0
7 8.0
8 8.0/10.5
9 5.5/9.0
JEFFERSON CO.
SHELBY CO.
32
T.17 S.
T.18 S.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
6
5
0
1 MILE
N



R.1 W.
R.1 E.
FIG. 59
Zn CONCENTRATION, PPM
FUSION / ACID = 34.0 / 43.5
23
24
19
20
26
25
30
29
35
36
31
32
6
5
1 34.0/43.5
2 36.5/59.0
3 31.0/84.5
4 42.5/64.5
5 42.0/59.0
6 41.0/67.5
7 16.5/33.0
8 49.0/89.0
9 41.5/78.5
TRAVERSE 1
BARITE
JEFFERSON CO.
SHELBY CO.
T.17 S.
T.18 S.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
0
1 MILE
N


R.1 W.
R.1 E.
23
24
19
20
FIG. 60
CU CONCENTRATION, PPM
FUSION / ACID = 50.0 / 10.5
26
25
30
29
1 50.0/10.5
TRAVERSE 1
2 43.5
3 37.5/26.0
4 26.5/4.5
5 40.0
BARITE
35
36
31
6 32.0
JEFFERSON CO.
SHELBY CO.
32
7 26.5/1.5
8 24.5
9 30.0/10.5
T.17 S.
T.18 S.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
6
5
0
1 MILE
N


R. I W.
R. I E.
23
24
19
20
FIG. 61
Pb CONCENTRATION, PPM
FUSION / ACID = 90 / 5
26
25
30
29
1 90/5
TRAVERSE 1
2 55
3 35/50
4 75/30
5 120/10
BARITE
35
36
31
6 10/20
JEFFERSON CO.
SHELBY CO.
32
7 65
8 25/35
9 60
T. 17 S.
T. 18 S.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
6
5
0
1 MILE
N

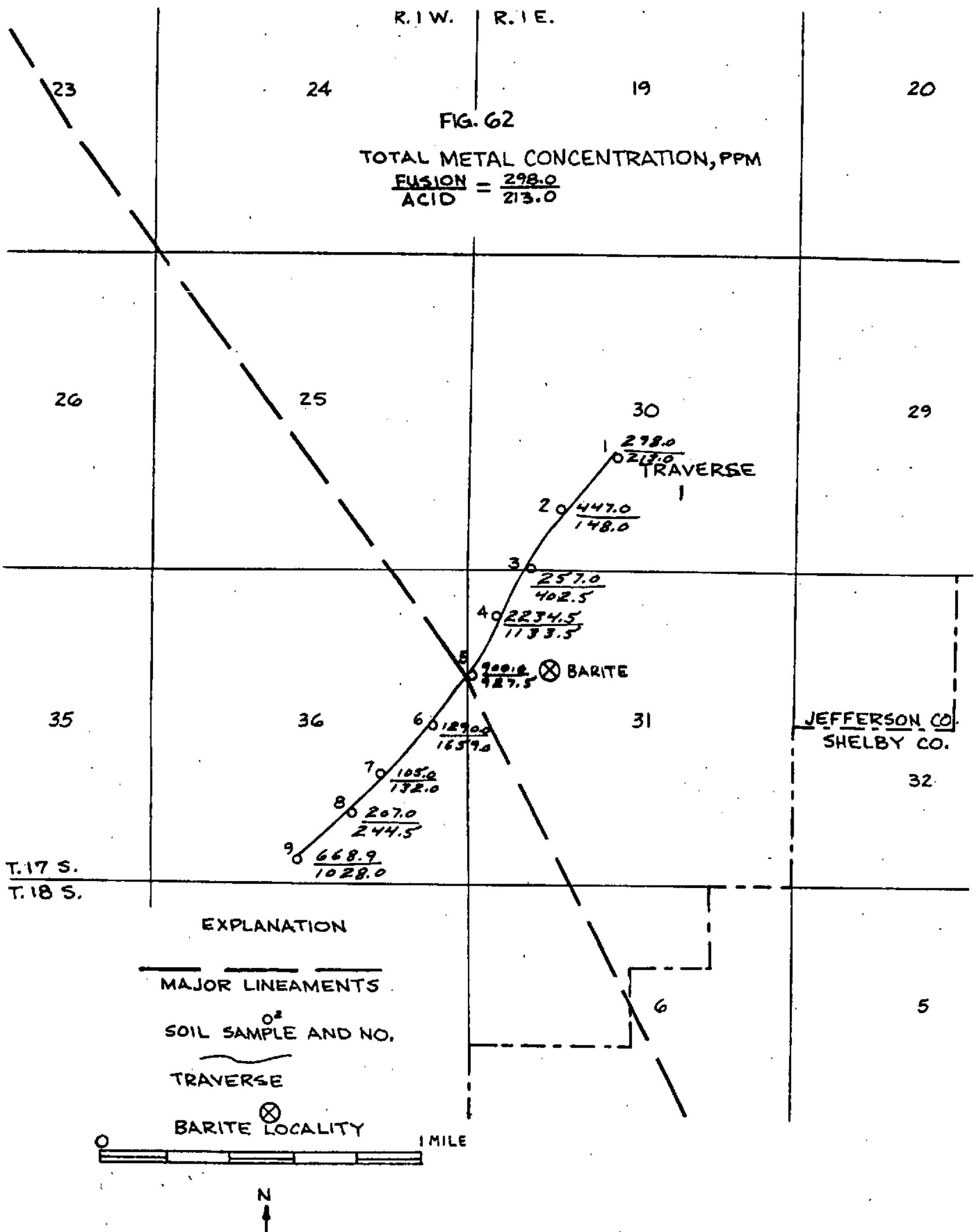

R. I W.
R. I E.
23
24
19
20
FIG. 62
TOTAL METAL CONCENTRATION, PPM
FUSION / ACID = 298.0 / 213.0
26
25
30
29
1
298.0
213.0
TRAVERSE
1
2
447.0
148.0
3
257.0
402.5
4
2234.5
1133.5
5
BARITE
35
36
31
6
1290.0
1659.0
JEFFERSON CO.
SHELBY CO.
7
105.0
172.0
32
8
207.0
244.5
9
668.9
1028.0
T. 17 S.
T. 18 S.
EXPLANATION
MAJOR LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
BARITE LOCALITY
6
5
0
1 MILE
N

FIG. 63

Ba CONCENTRATION
LEEDS TRAVERSE 1

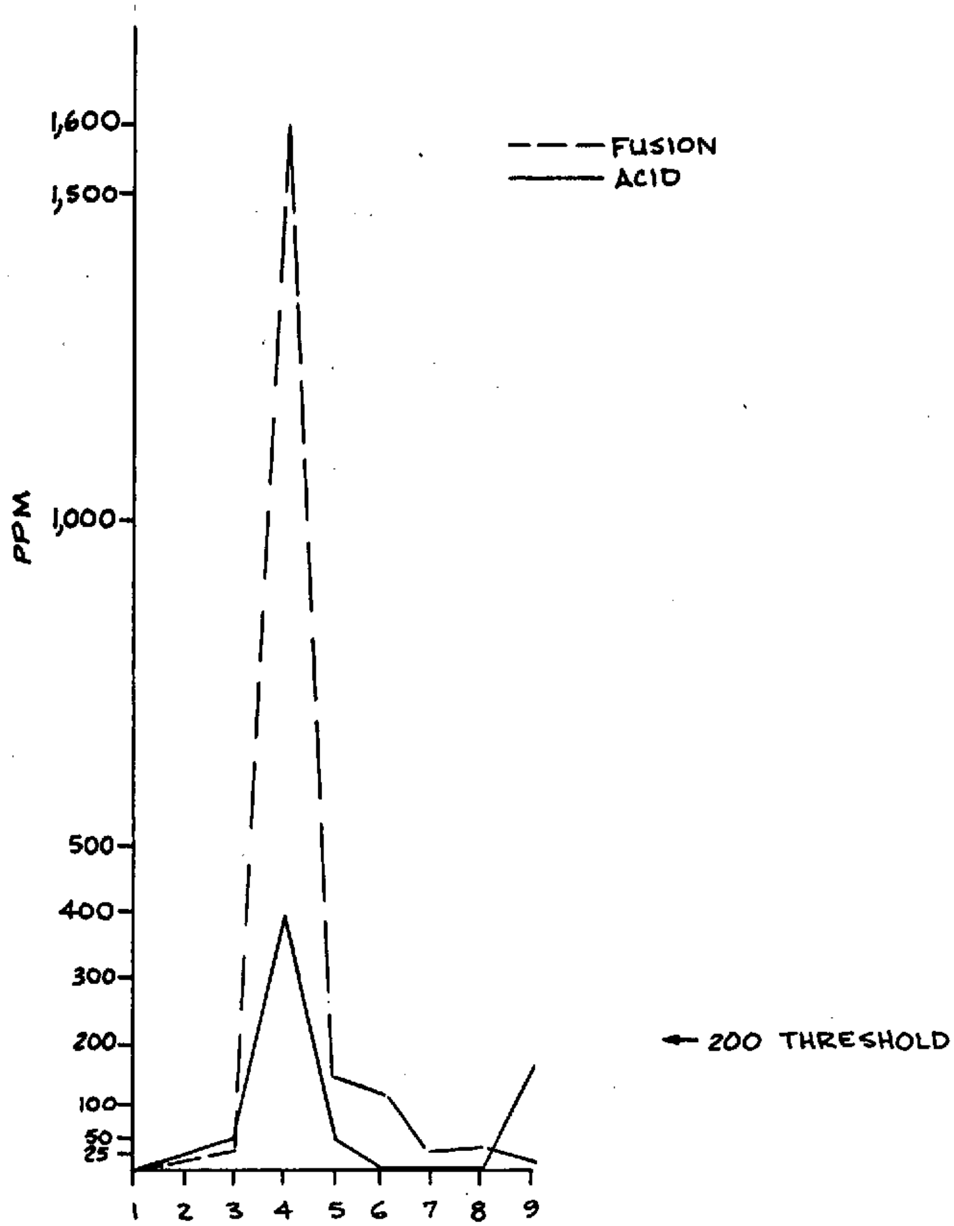


FIG. 64

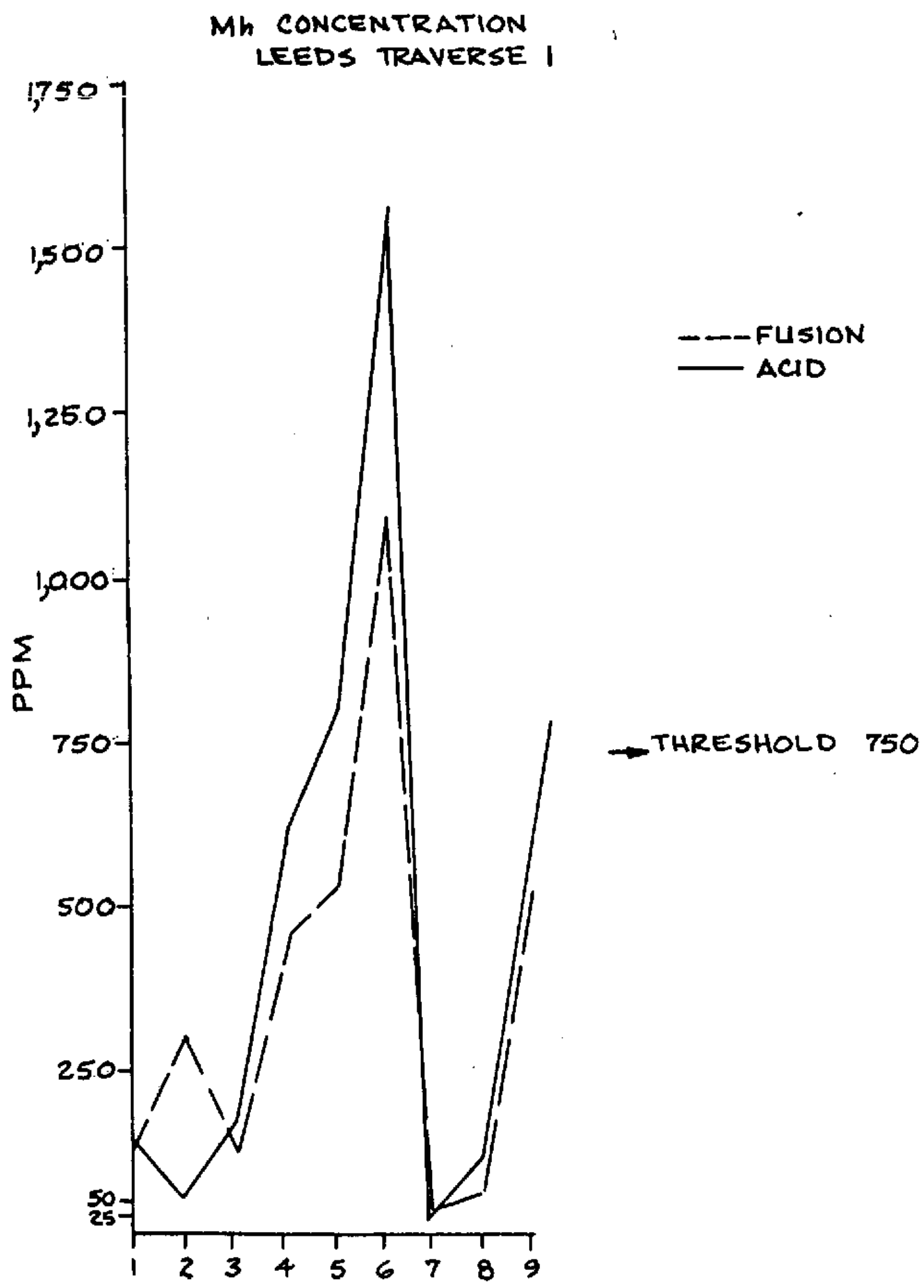

Mn CONCENTRATION
LEEDS TRAVERSE I
1,750
1,500
1,250
1,000
750
500
250
50
25
PPM
1
2
3
4
5
6
7
8
9
---- FUSION
—— ACID
THRESHOLD 750

FIG. 65
LEEDS TRAVERSE I
Sr CONCENTRATION

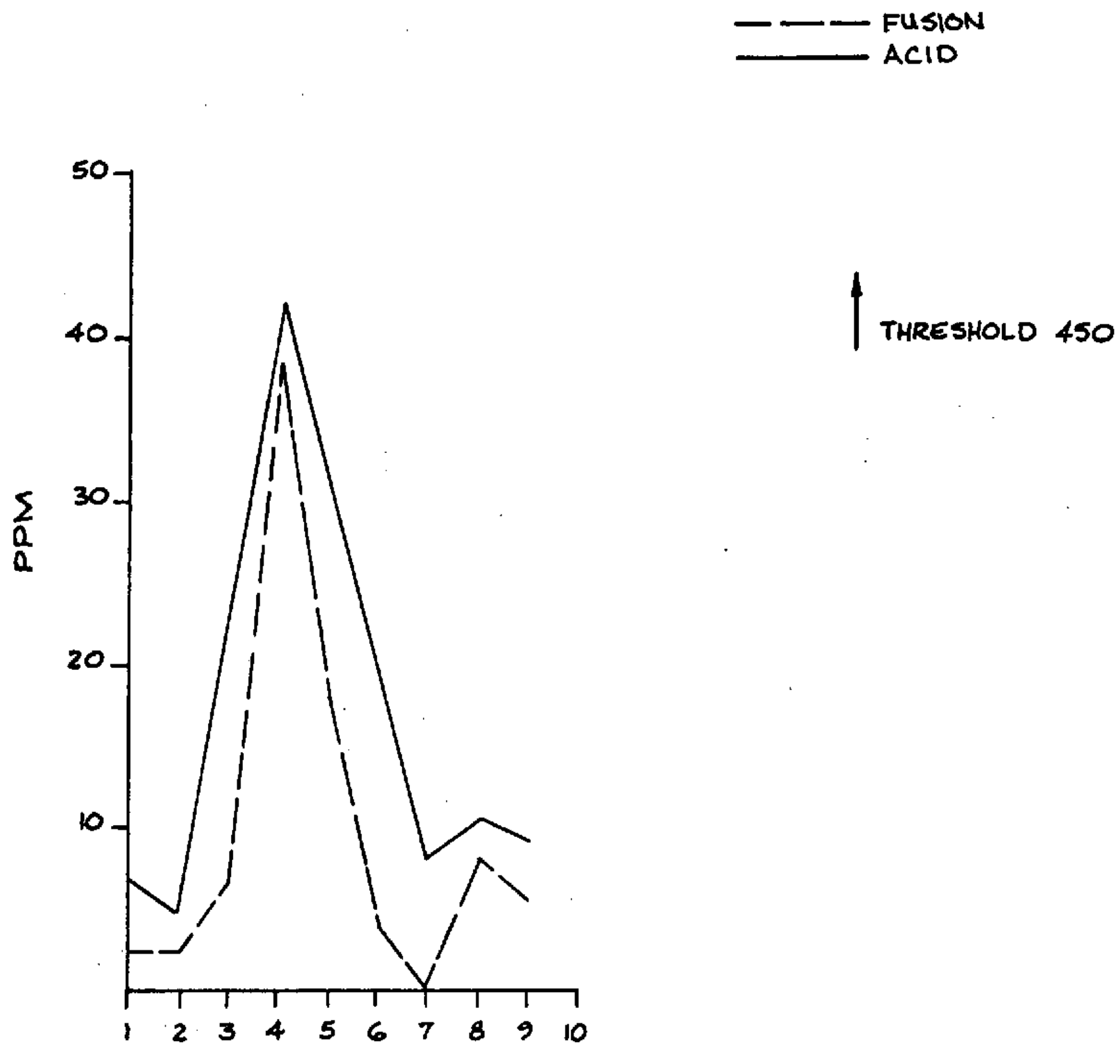


FIG. 66
LEEDS TRAVERSE I
Cu CONCENTRATION

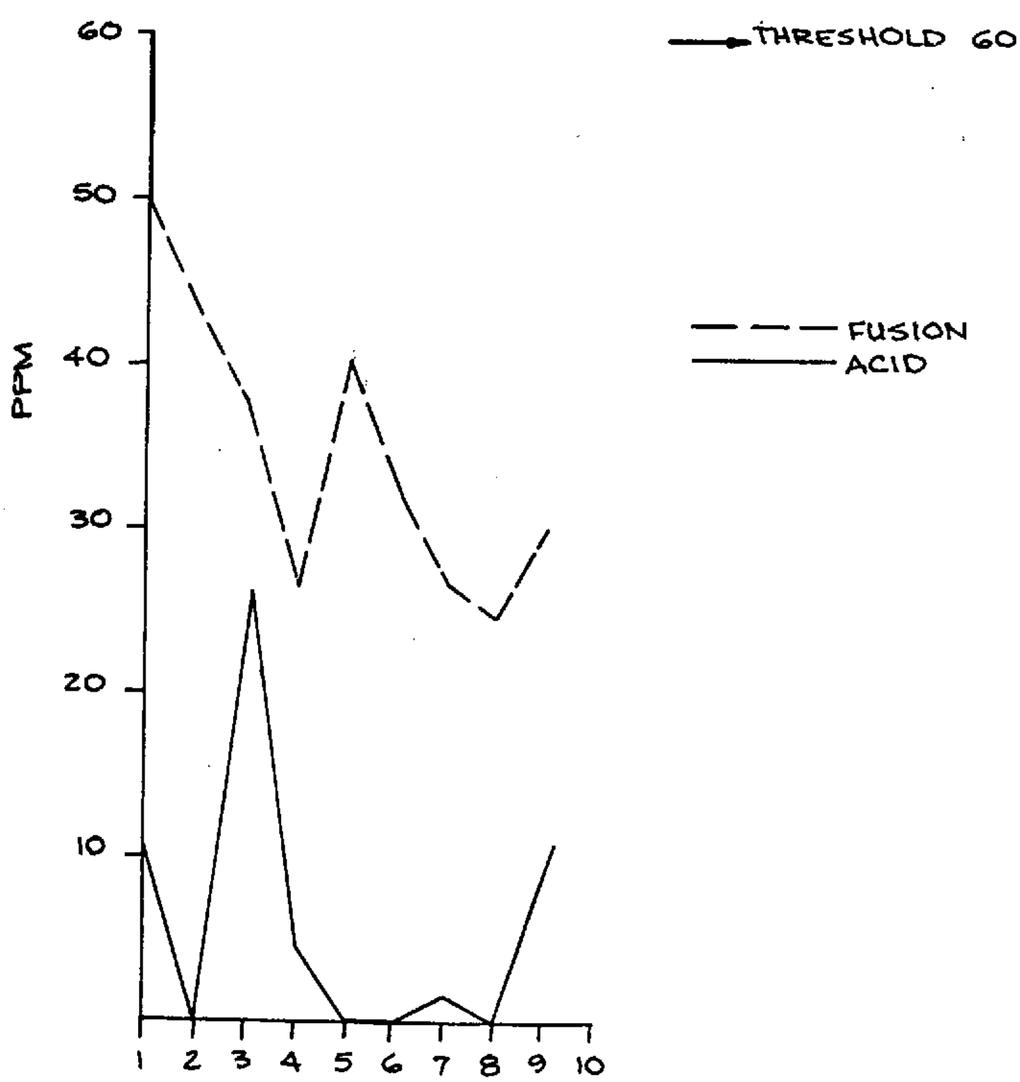


FIG. 67
LEEDS TRAVERSE I
Zn CONCENTRATION

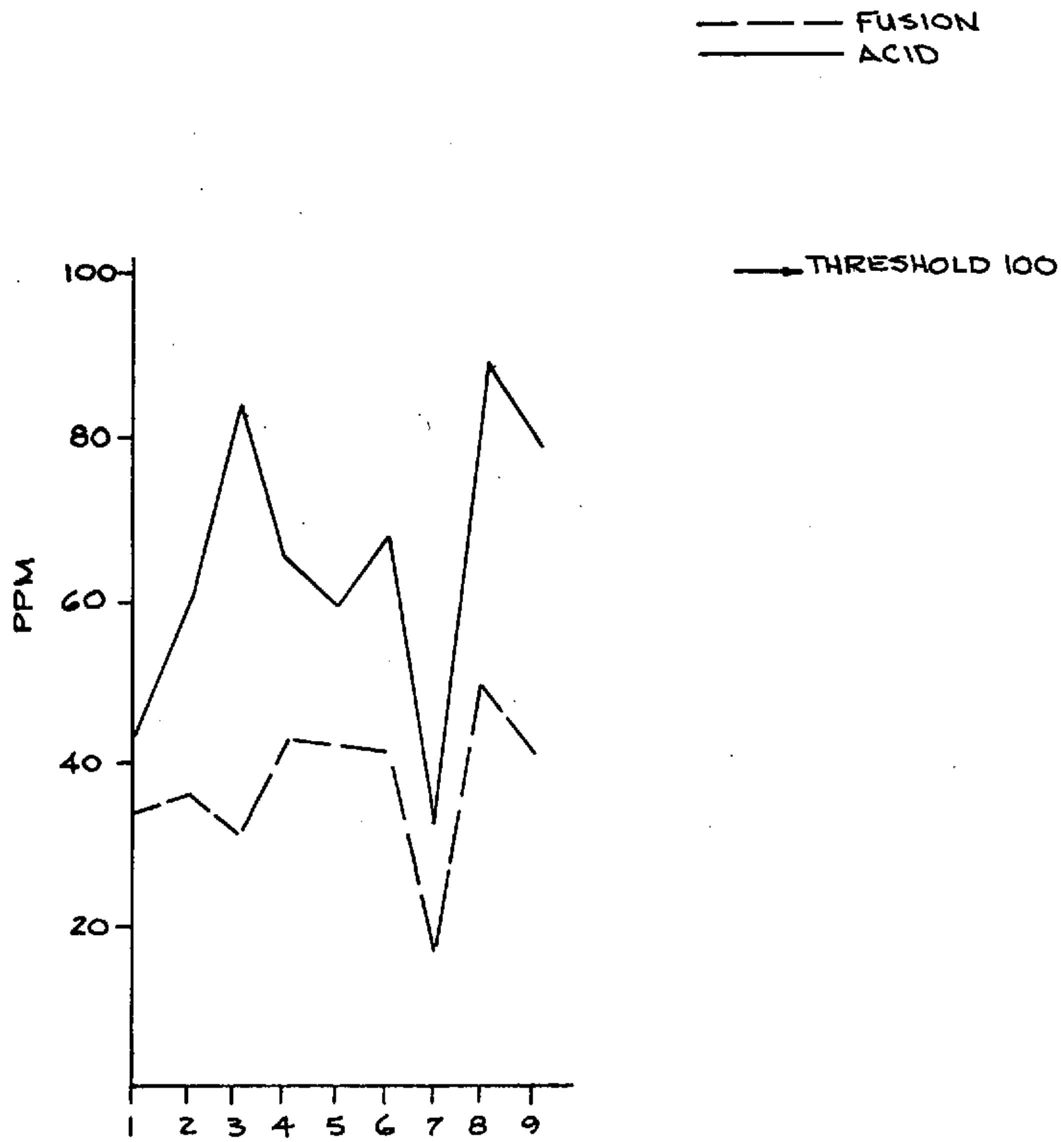


FIG. 68
LEEDS TRAVERSE 1
Pb CONCENTRATION

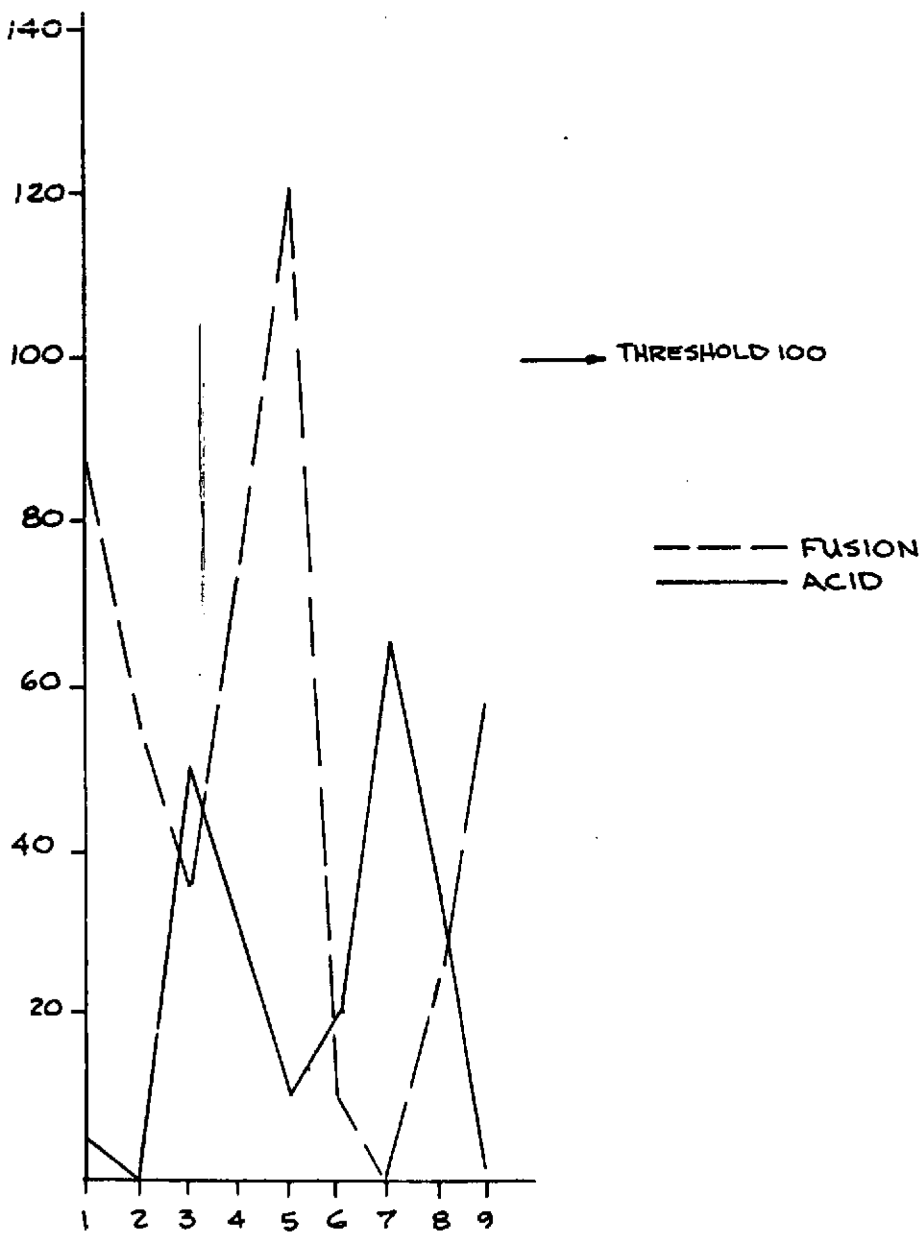
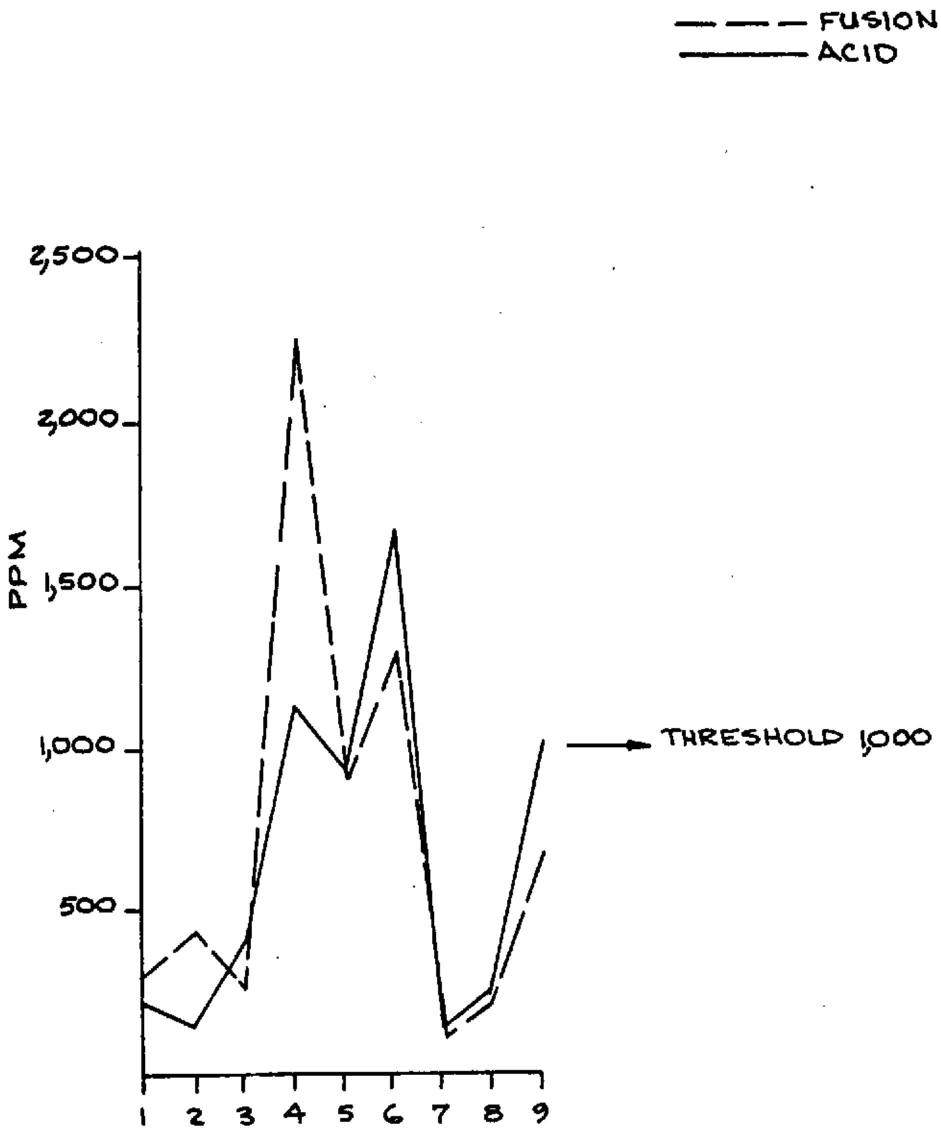


FIG. 69

LEEDS TRAVERSE 1
TOTAL METAL CONCENTRATION



copper or zinc highs are shown, there is apparently some interdependence between the lineament, the barite occurrence, and the geochemical anomalies in the area. The lineament is the northward extension of one of the major lineaments at Harpersville. This may be a significant datum. The fact that the mineralization occurs only in limestones and dolomites of Cambrian and Ordovician age may also be significant. The present data are too few, however, to offer any hypotheses.

Because of the data presented above, this area should also be studied in more detail.

Area 3: Odenville

The Odenville district of St. Clair County is located on figure 1. Locations of lineaments, copper occurrences, and traverses are shown on figure 70. Two traverses were made, consisting of 27 samples. In addition, 4 rock samples were collected.

The Odenville district is underlain by limestones and dolomites of Cambrian and Ordovician age. These rocks are the same stratigraphic units as those at Leeds. Copper is known to occur in the district and lineament traces can be seen near these occurrences. Therefore, traverses were planned to intersect the lineament traces and pass near the copper occurrences.

Samples were prepared by HF-H_2SO_4 digestion. Copper was analyzed since it is known to occur in the area. Copper is often associated with lead and zinc (Ginzburg, 1960) as well as manganese and antimony (Hawkes and Webb, 1962). Zinc is also associated with cadmium (Hawkes and Webb, 1962). Thus, elements analyzed

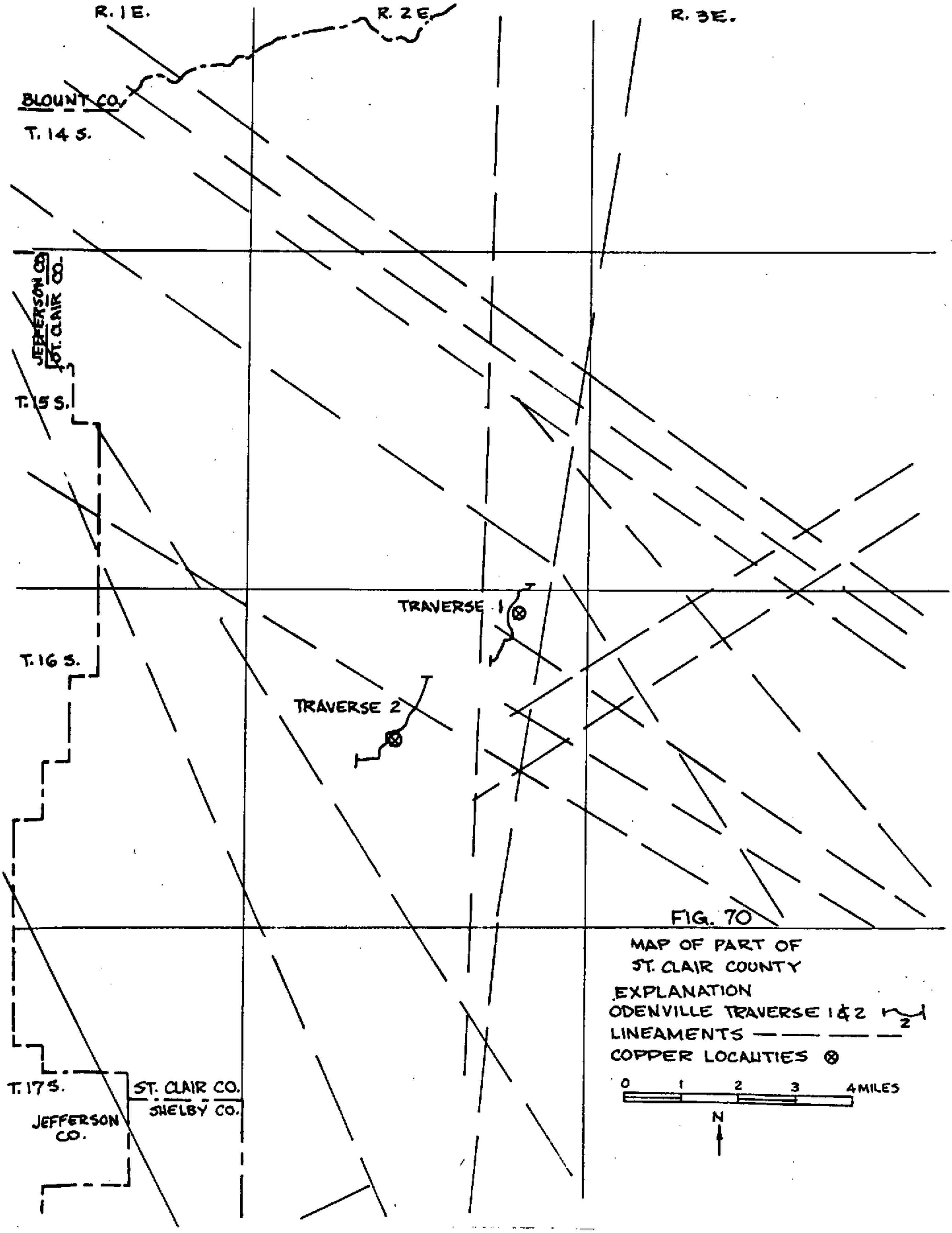


FIG. 70
MAP OF PART OF ST. CLAIR COUNTY

were Cu, Zn, Pb, Mn, Sb, and Cd. Analyses are shown in tables 9 to 11.

These values, used in conjunction with threshold values at Leeds, give an indication of threshold values in the soil at Odenville.

Chemical analyses are plotted as maps on figures 71 to 77 and as graphs on figures 78 to 91. Also plotted on figures 78 to 91 are mean, median, and high rock analyses, as well as indicated threshold values for each element. Traverse 1 exhibits manganese highs at points 3 and 8; antimony highs at points 6, 13, 14 and 15; a lead high at point 13; and total metal highs at points 3, 7, and 8. The highs at points 6, 7, and 8 may be a result of the nearby copper mineralization. The highs at points 13, 14 and 15 may be a result of the lineament. The location of the lineament was plotted near but not at these points although at the scale of the original imagery, an error of $\pm$ 0.5 is not unreasonable. The manganese high at point three may be a result of contamination. It cannot be related to any geologic features or any lineament.

Traverse 2 exhibits antimony highs at points, 1, 2, 5, 6, 7, and 8 and lead highs at points 7 and 9. The highs at 7, 8, and 9 may be a result of the nearby copper mineralization. The highs at 1 and 2 or, alternatively, the highs at 5 and 6 may result from the lineament which is plotted between these locations.

The geochemical data at Odenville are not nearly as straightforward as at Harpersville or Leeds. In particular, no copper highs appeared in the traverses although copper was seen at the located occurrences. Moreover, one rock sample taken approximately 20 meters from one of the copper occurrence contained

Table 9

Chemical Analyses of Rocks (in parts per million)

Odenville	Cd	Mn	Sb	Zn	Cu	Pb	Remarks
1	7.0	29.0	ND	14.0	ND	15	Limestone
2	8.5	471.0	ND	33.0	1.0	25	Limestone
3	7.5	92.5	ND	24.0	1.5	ND	Dolomite
4	6.5	92.0	ND	30.0	1.0	ND	Dolomite
							Total Metal
Mean	7.4	171	ND	25	0.9	10	215
Median	7.2	92	ND	28	1.0	7.5	215
High	8.5	471	ND	33	1.5	25	538

Analyst: G. Thomas, Geological Survey of Alabama

N. B. Same stratigraphic units as at Leeds.

Table 10
Chemical Analyses of Soils (in parts per million)

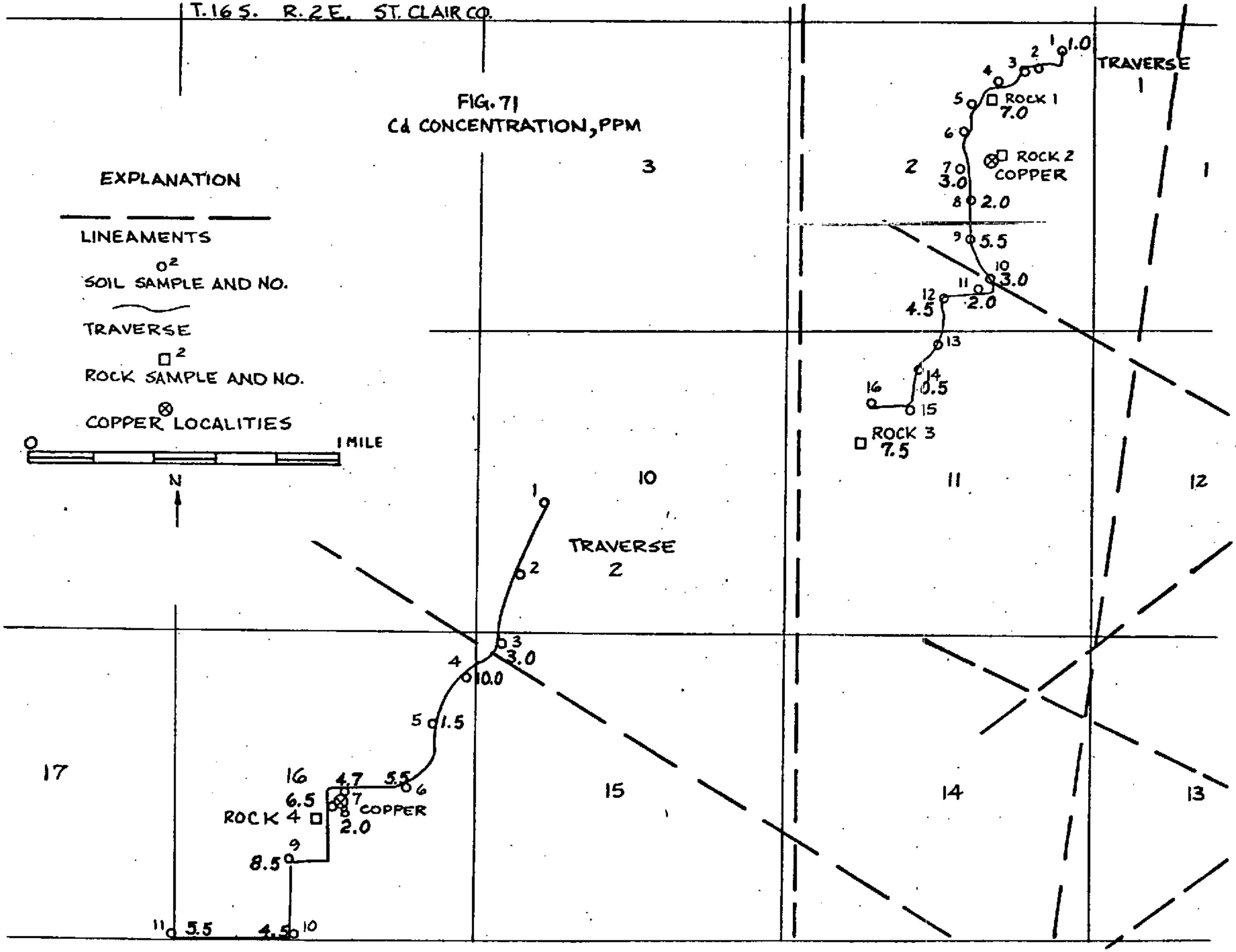
Glenville Traverse 1	Cd	Mn	Sb	Zn	Cu	Pb
1-1	1.0	506.0	60	61.5	16.0	ND
1-2	ND	91.0	ND	47.0	19.5	ND
1-3	ND	2,720.5	ND	51.0	17.0	ND
1-4	ND	318.0	ND	65.5	21.0	ND
1-5	ND	57.5	45	36.5	10.5	ND
1-6	ND	86.0	140	40.0	8.0	ND
1-7	3.0	914.5	ND	76.5	13.0	25
1-8	2.0	1,171.0	ND	40.0	0.5	20
1-9	5.5	432.5	5	44.5	12.0	ND
1-10	3.0	43.5	50	68.5	13.0	ND
1-11	2.0	237.0	80	43.0	9.5	5
1-12	4.5	94.5	60	99.0	21.0	ND
1-13	ND	188.0	250	74.0	8.5	45
1-14	0.5	99.0	165	45.5	4.5	5
1-15	ND	483.5	220	64.0	15.5	10
1-16	ND	820.0	15	55.5	5.5	10

Analyst: G. Thomas, Geological Survey of Alabama

Table 11
Chemical Analyses of Soils (in parts per million)

Odenville Traverse 2	Cd	Mn	Sb	Zn	Cu	Pb
2-1	ND	91.0	150	30.0	10.0	15
2-2	ND	145.0	155	40.5	6.0	5
2-3	3.0	319.5	ND	35.0	4.5	20
2-4	10.0	166.0	ND	22.5	ND	ND
2-5	1.5	65.5	115	38.5	7.5	15
2-6	5.5	408.0	150	23.0	7.5	15
2-7	4.0	75.5	165	25.0	6.0	40
2-8	2.0	218.0	250	30.5	2.5	ND
2-9	8.5	230.5	ND	45.0	0.5	35
2-10	4.5	54.5	ND	30.0	3.0	ND
2-11	5.5	250.5	ND	42.5	4.5	ND

Analyst: G. Thomas, Geological Survey of Alabama


T.16 S. R.2E. ST. CLAIR CO.
FIG. 71
Cd CONCENTRATION, PPM
EXPLANATION
LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
COPPER LOCALITIES
0
1 MILE
N
TRAVERSE 1
ROCK 1
7.0
ROCK 2
COPPER
ROCK 3
7.5
TRAVERSE 2
ROCK 4
COPPER
3
2
1
10
11
12
17
16
15
14
13
12-320

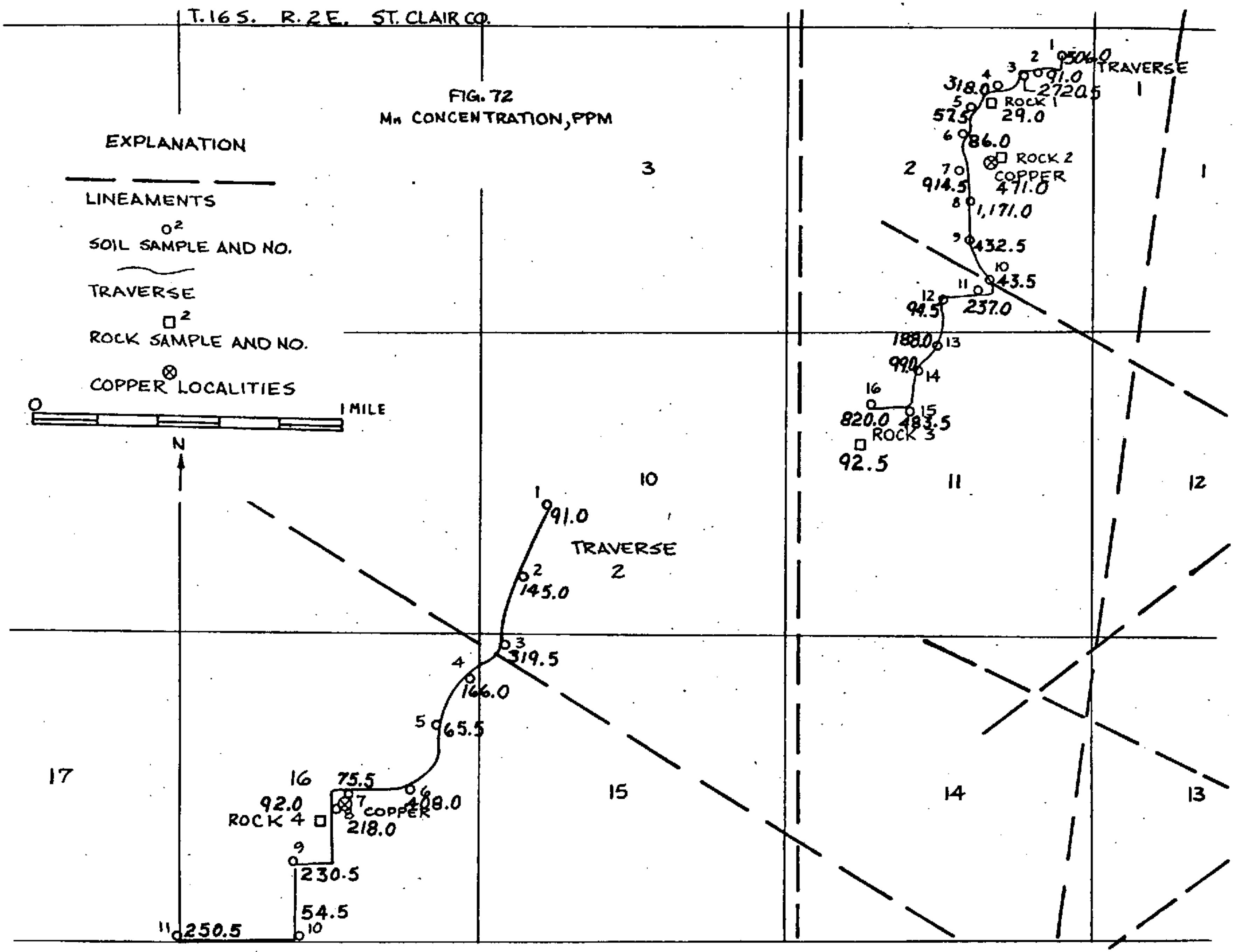
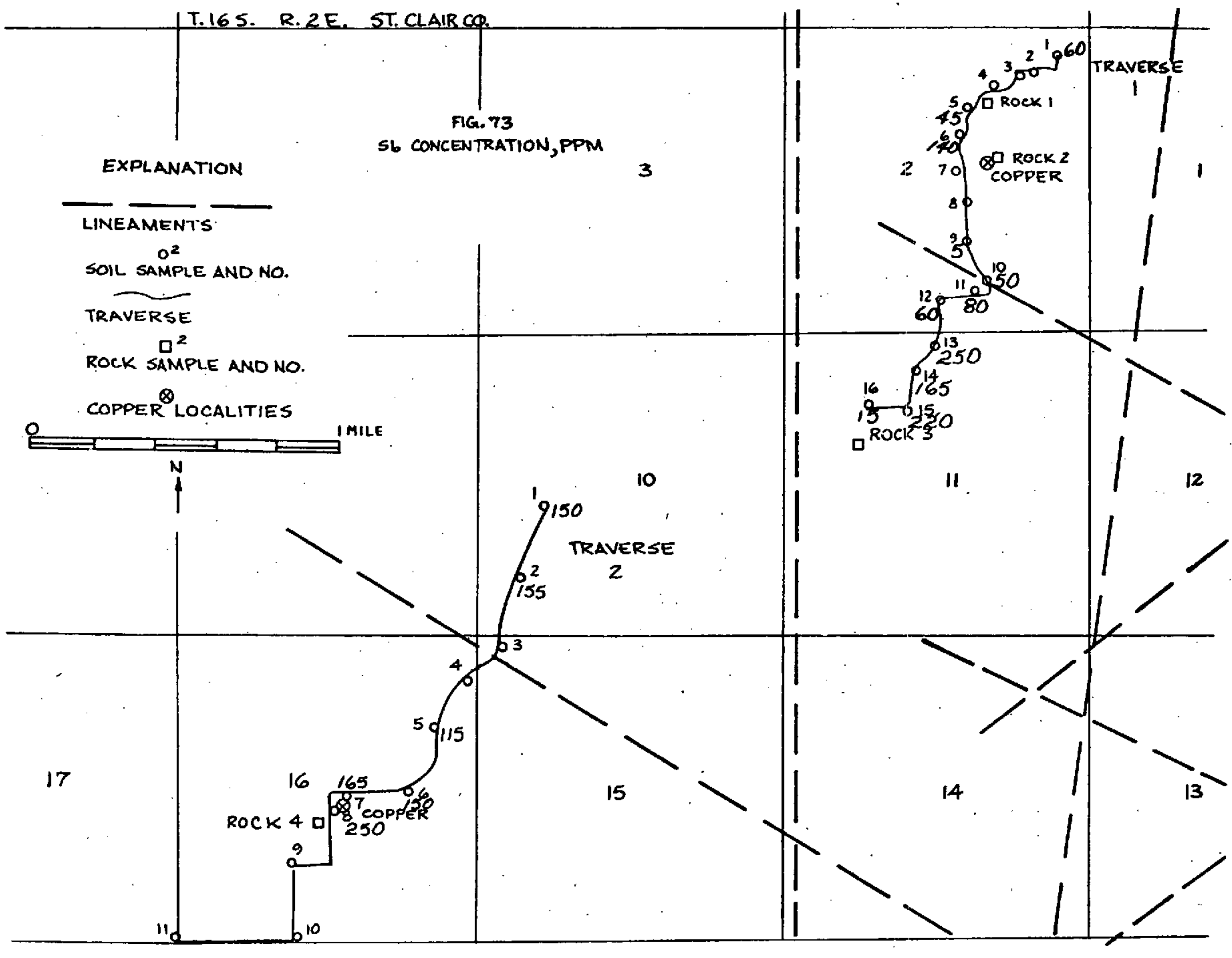


FIG. 72
Mn CONCENTRATION, PPM


T.16S. R.2E. ST. CLAIR CO.
FIG. 73
Sb CONCENTRATION, PPM
EXPLANATION
LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
COPPER LOCALITIES
1 MILE
N
TRAVERSE 1
ROCK 1
ROCK 2
COPPER
ROCK 3
TRAVERSE 2
ROCK 4
COPPER

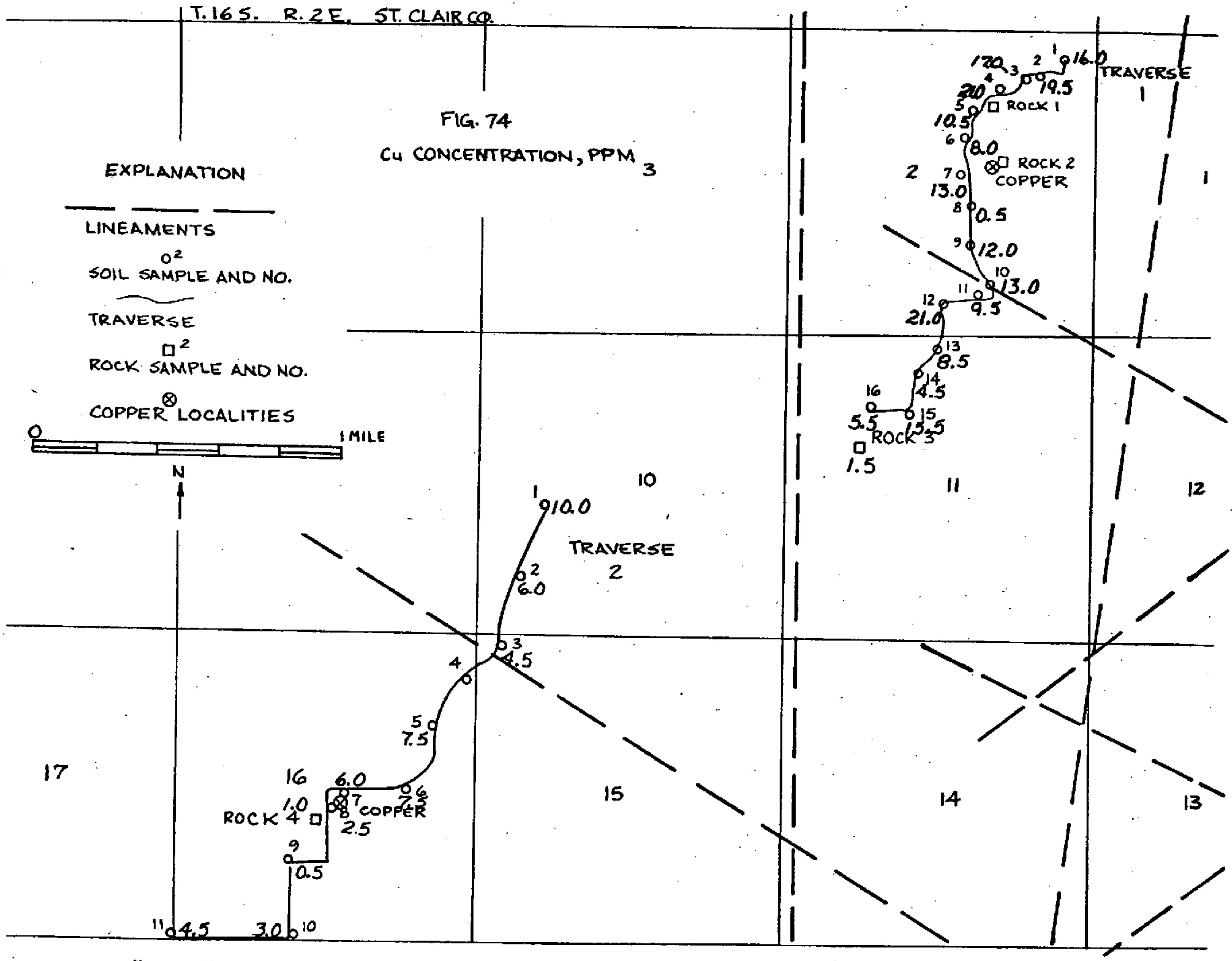


FIG. 74

Cu CONCENTRATION, PPM

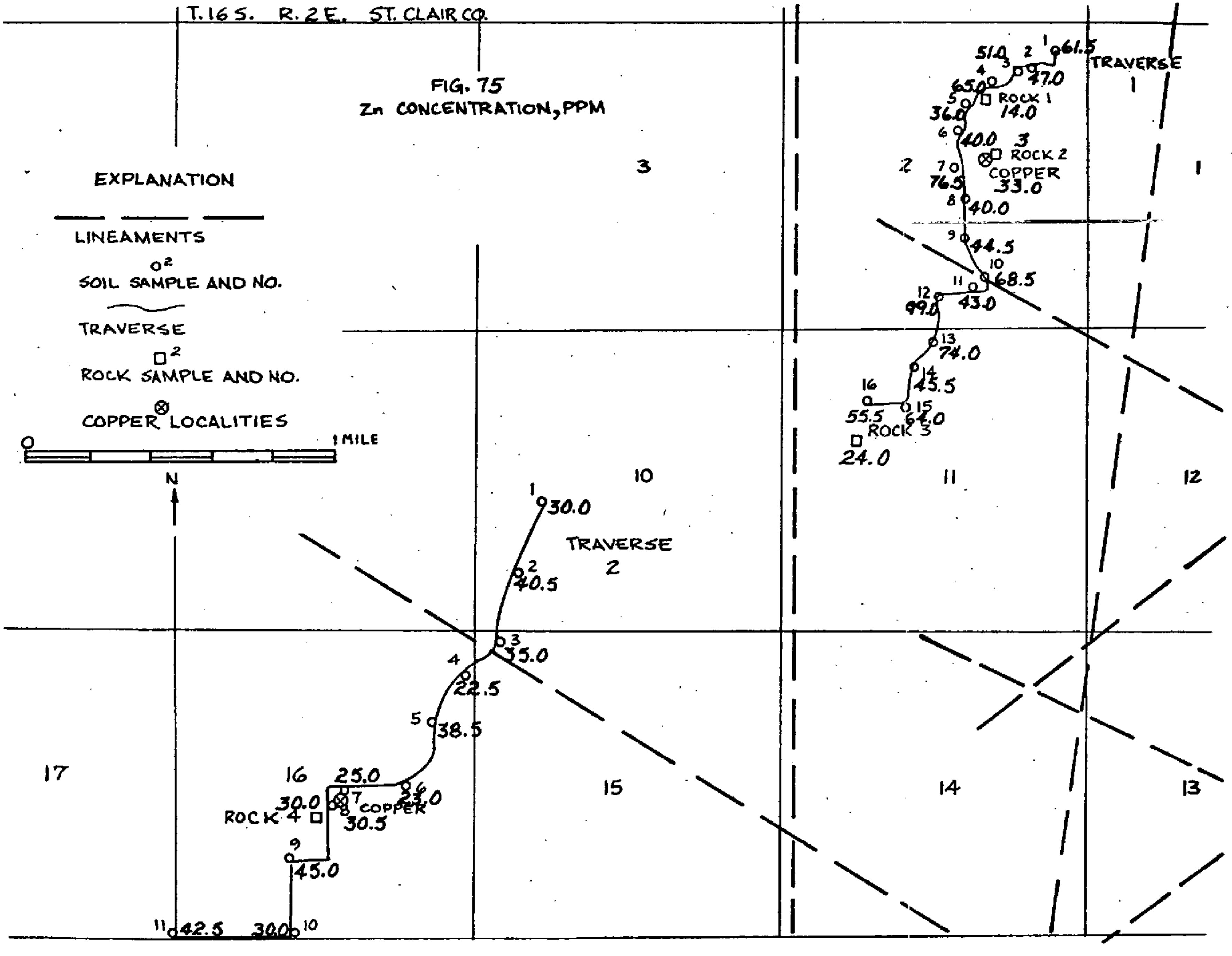
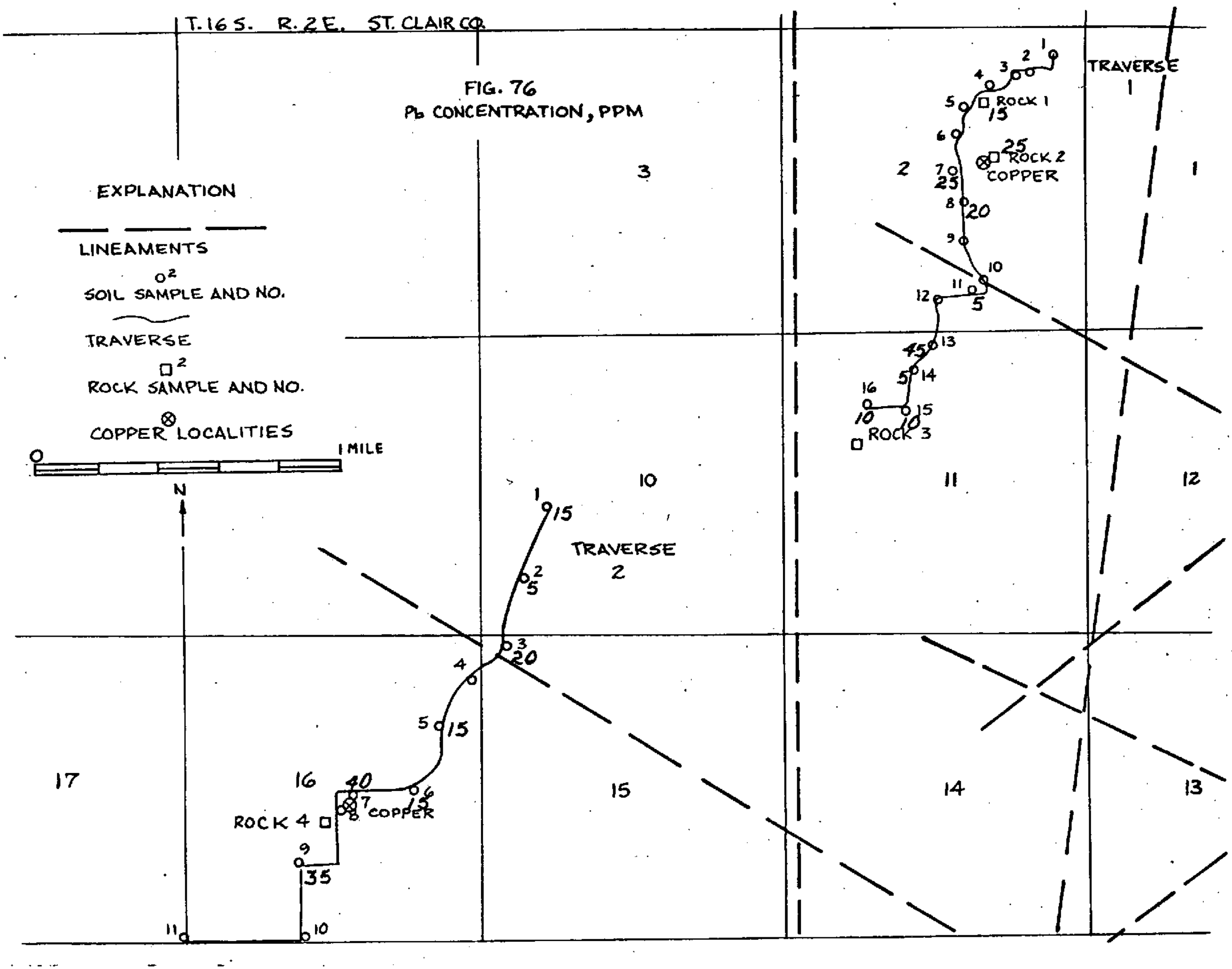


FIG. 75
Zn CONCENTRATION, PPM


T.16 S. R.2E. ST. CLAIR CO.
FIG. 76
Pb CONCENTRATION, PPM
EXPLANATION
LINEAMENTS
SOIL SAMPLE AND NO.
TRAVERSE
ROCK SAMPLE AND NO.
COPPER LOCALITIES
0
1 MILE
N
TRAVERSE 1
TRAVERSE 2
ROCK 1
ROCK 2
COPPER
ROCK 3
ROCK 4
COPPER
3
2
1
10
11
12
17
16
15
14
13

12-325

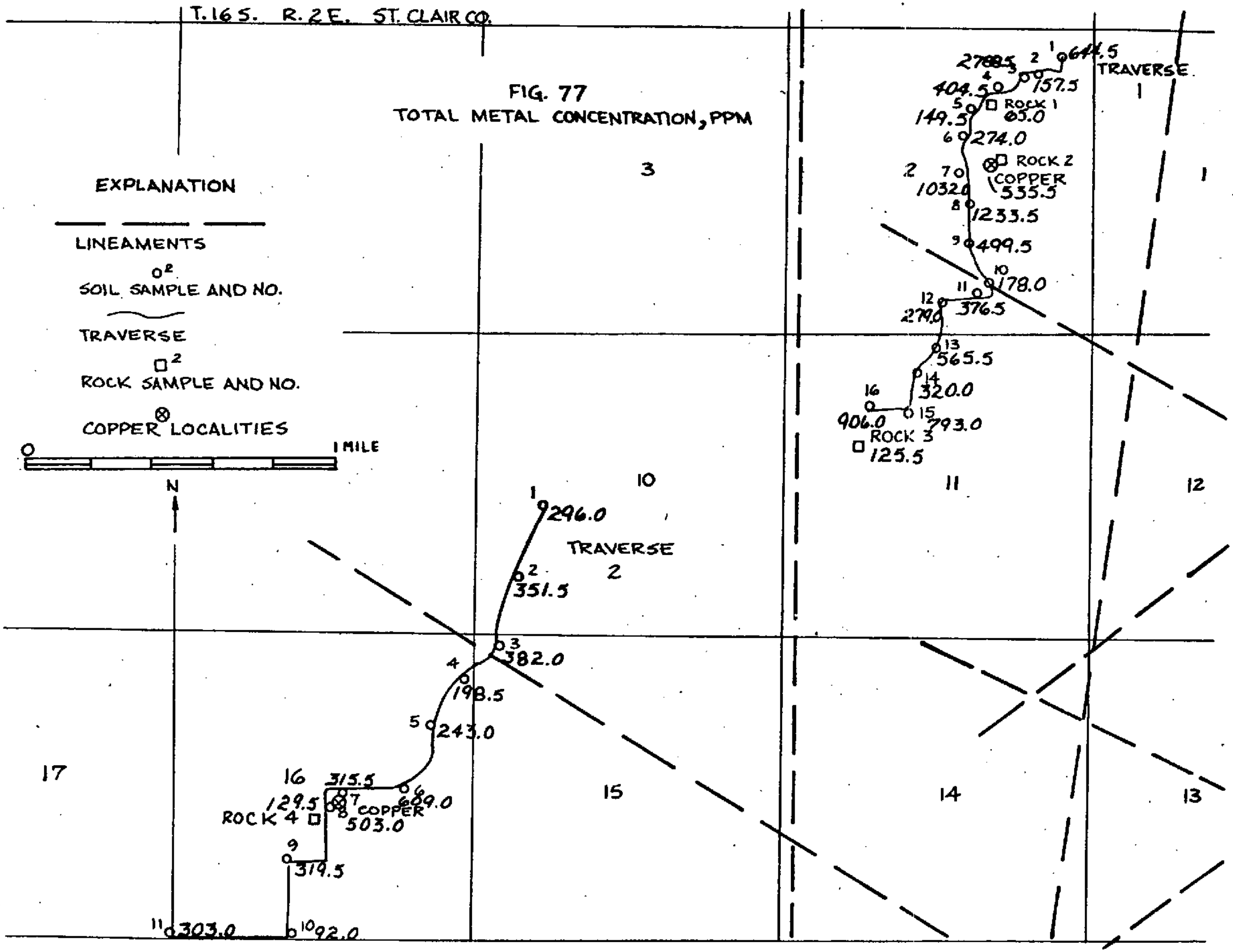


FIG. 77
TOTAL METAL CONCENTRATION, PPM

FIG. 78
ODENVILLE TRAVERSE I
Cd CONCENTRATION

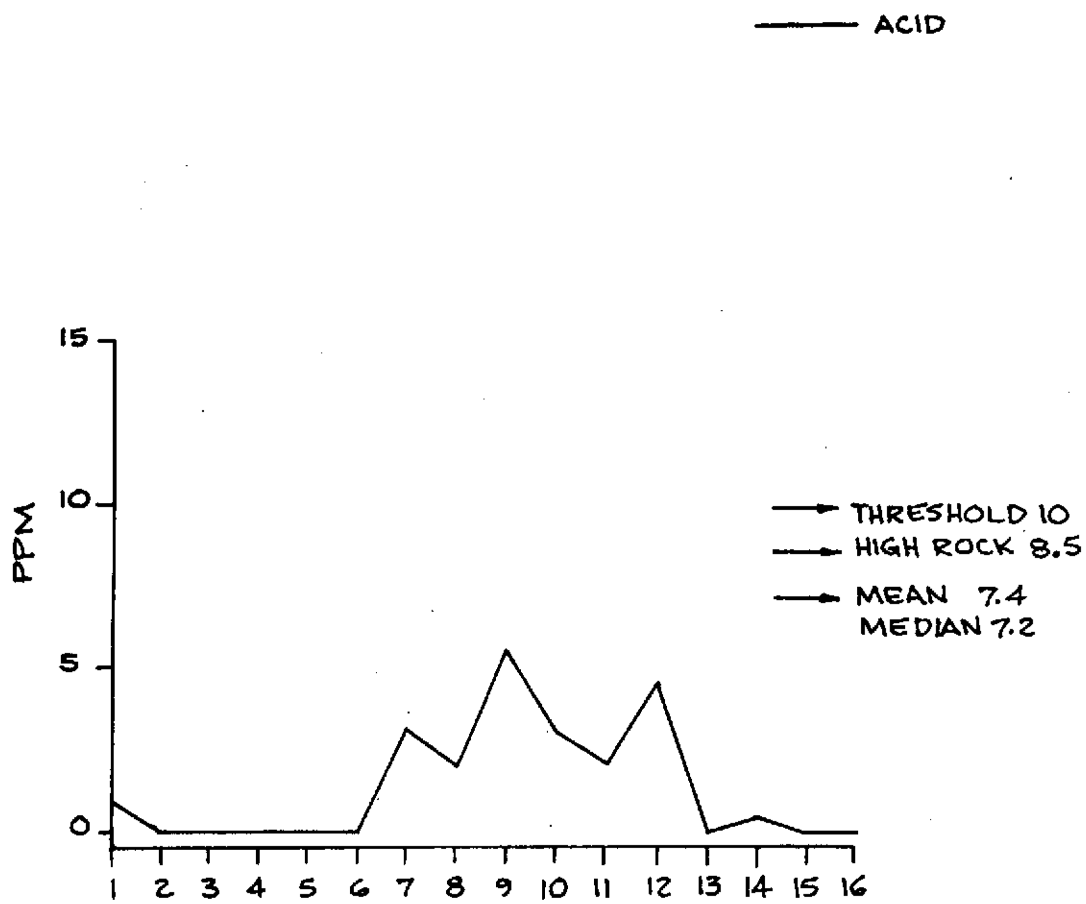


FIG. 79
ODENVILLE TRAVERSE 1
Mn CONCENTRATION

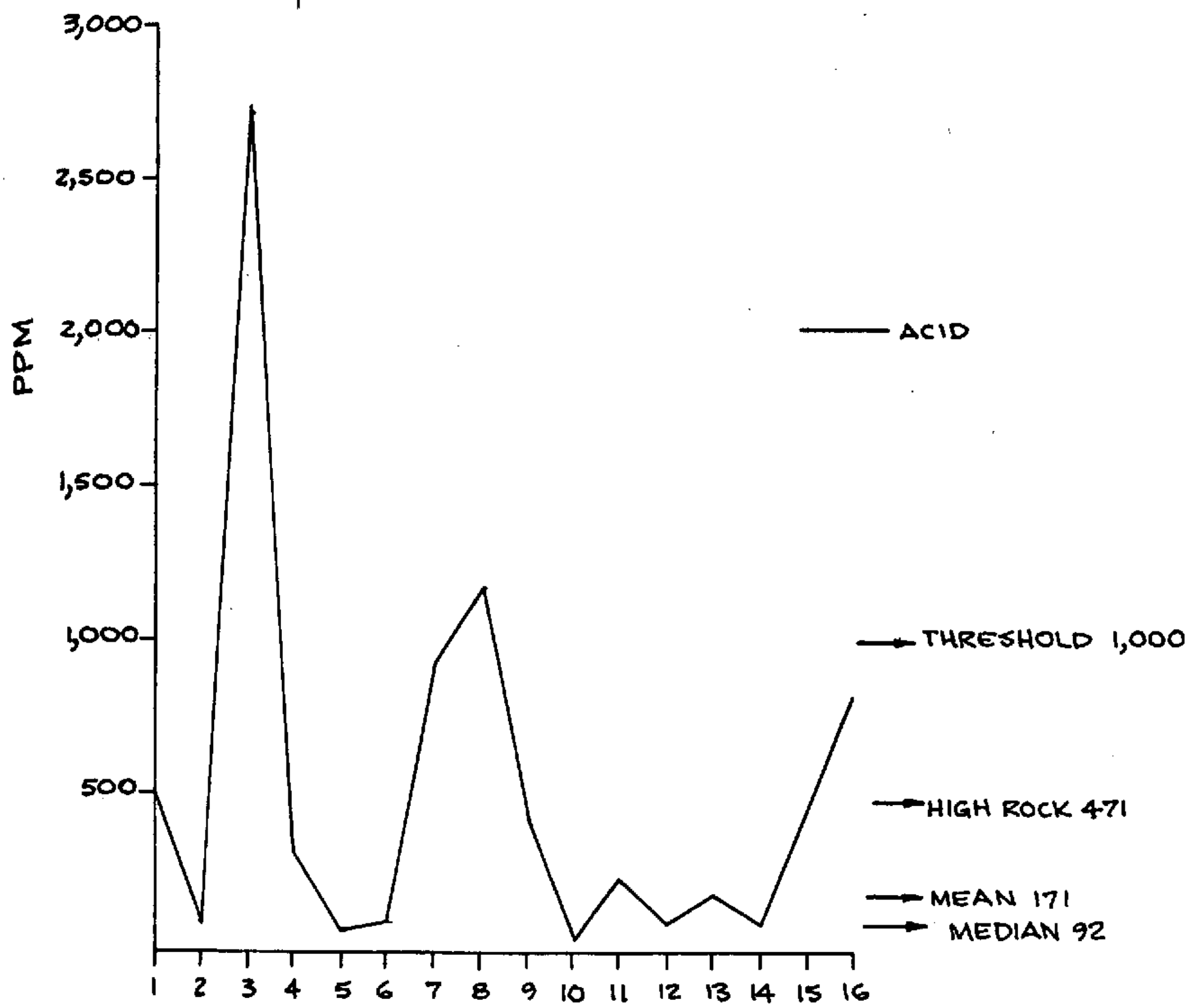


FIG. 80
ODENVILLE TRAVERSE I
Sb CONCENTRATION

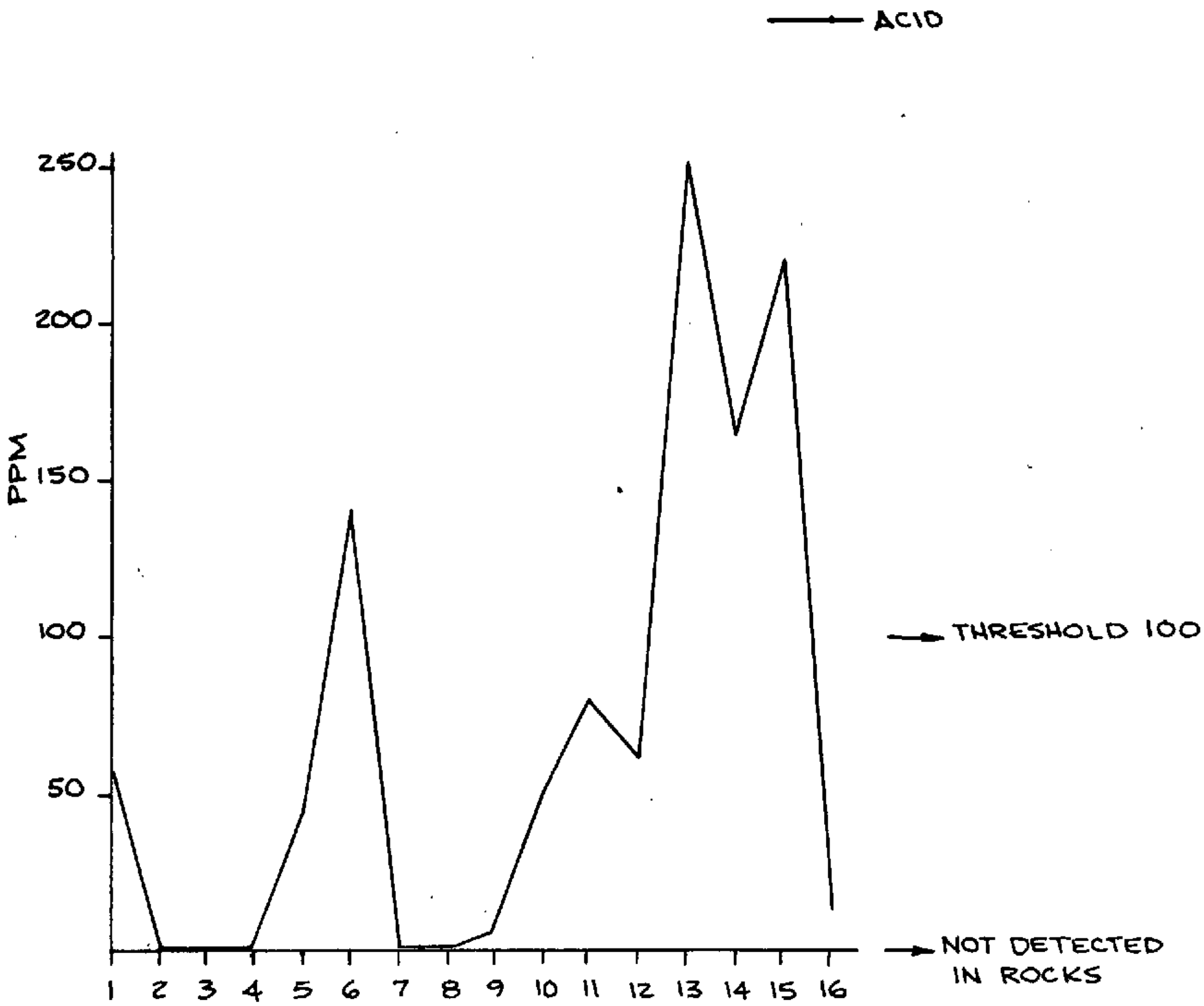


FIG. 81
ODENVILLE TRAVERSE I
Cu CONCENTRATION

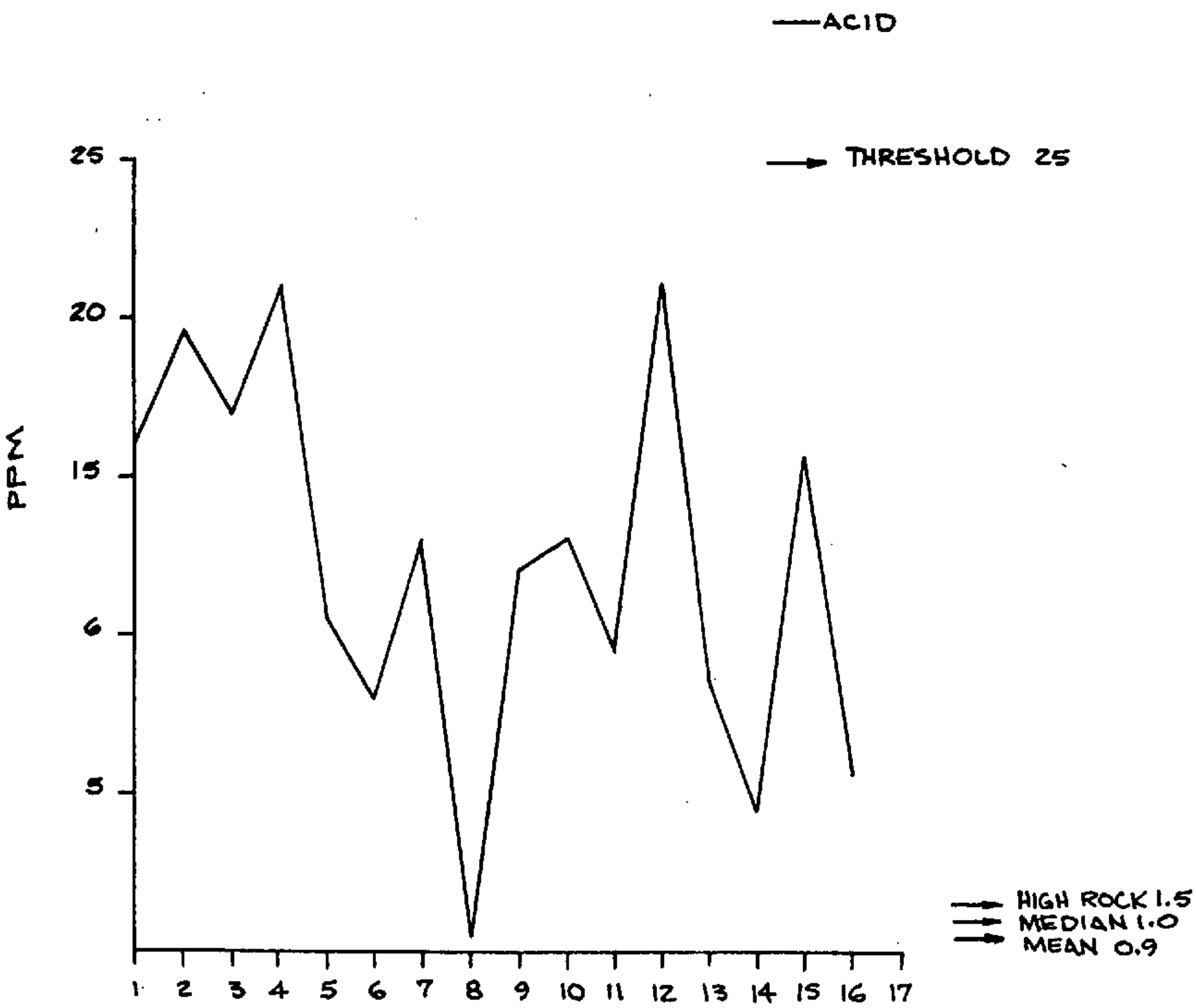


FIG. 82

ODENVILLE TRAVERSE I
Zn CONCENTRATION

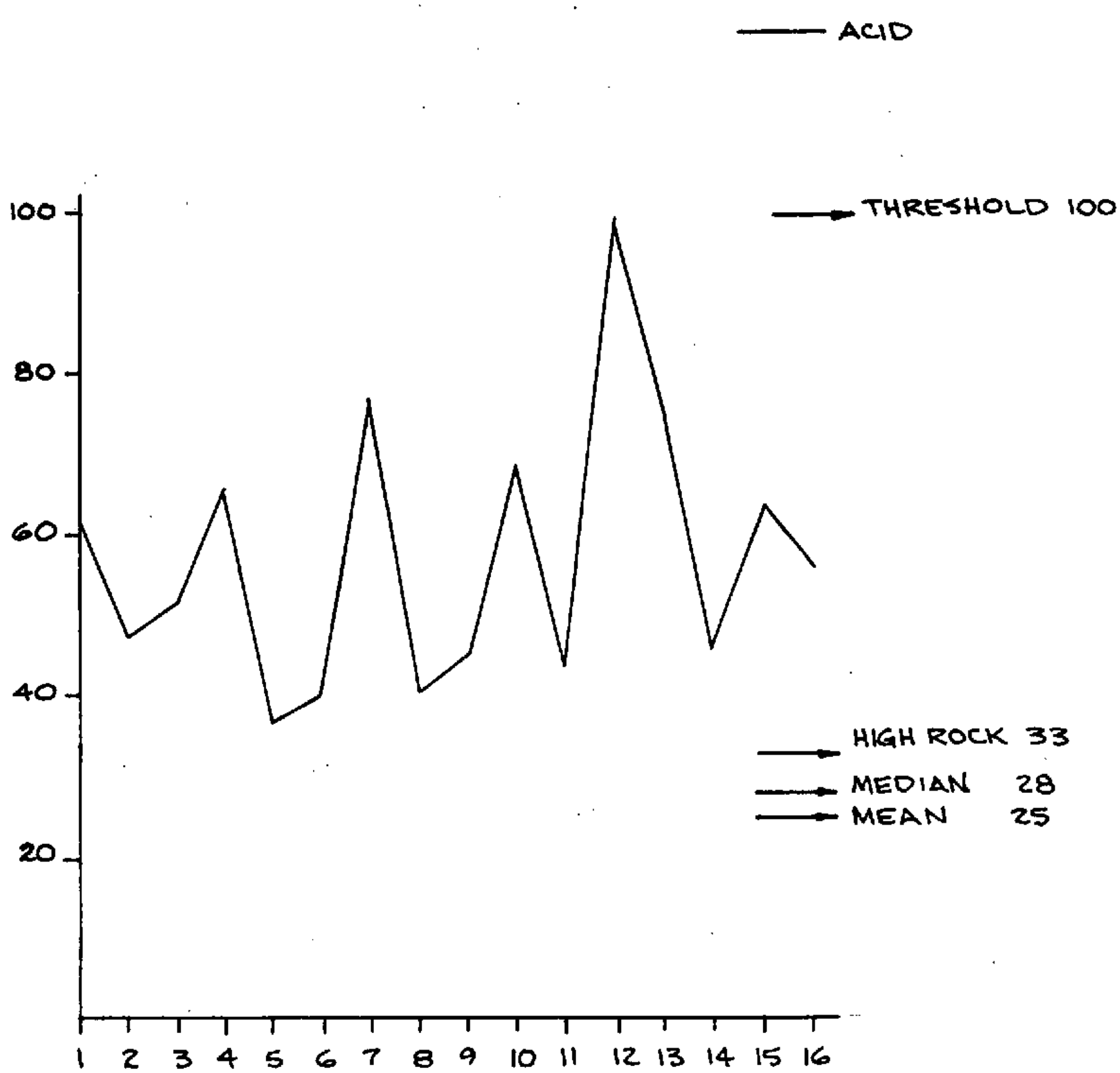


FIG. 83
ODENVILLE TRAVERSE 1
Pb CONCENTRATION

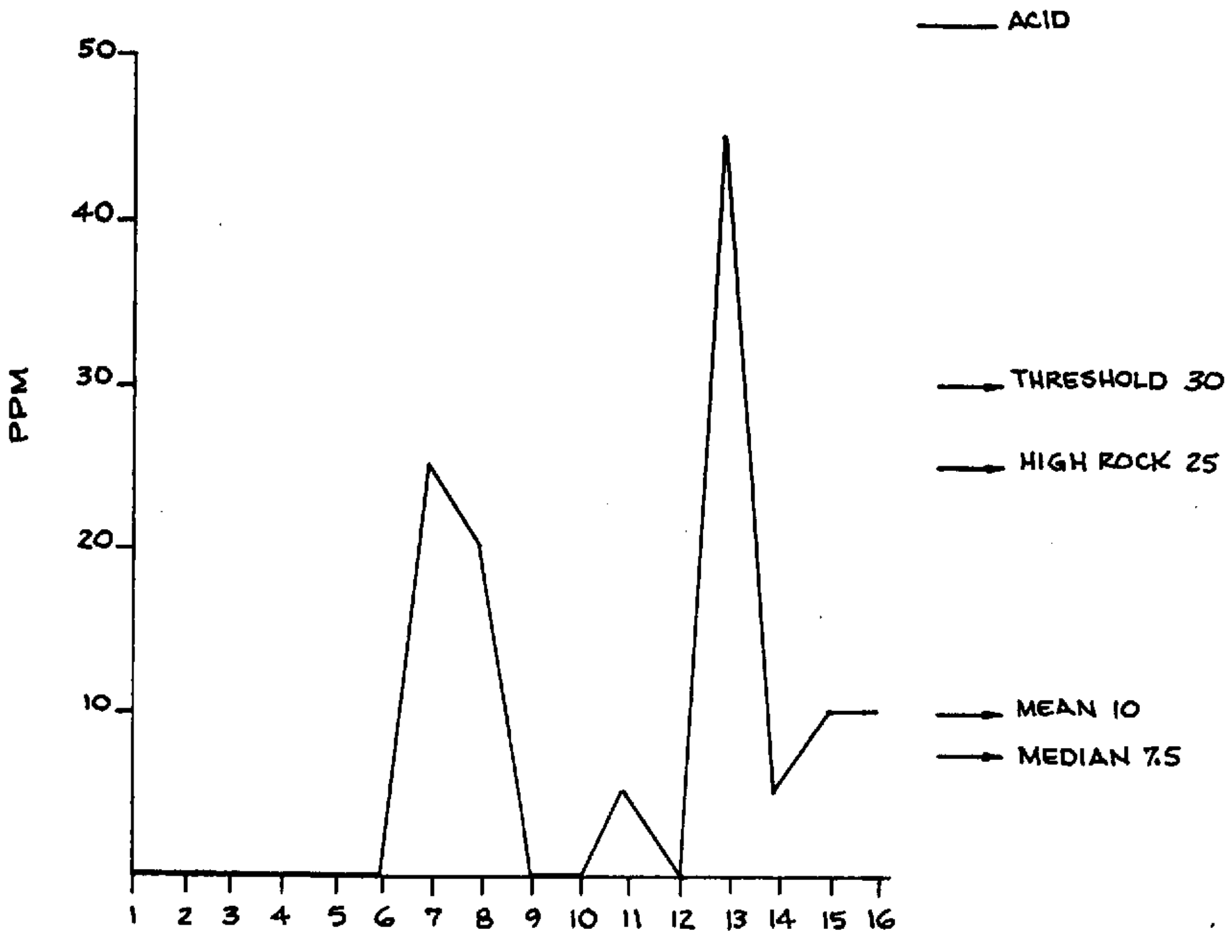


FIG. 84
ODENVILLE TRAVERSE I
TOTAL METAL CONCENTRATION

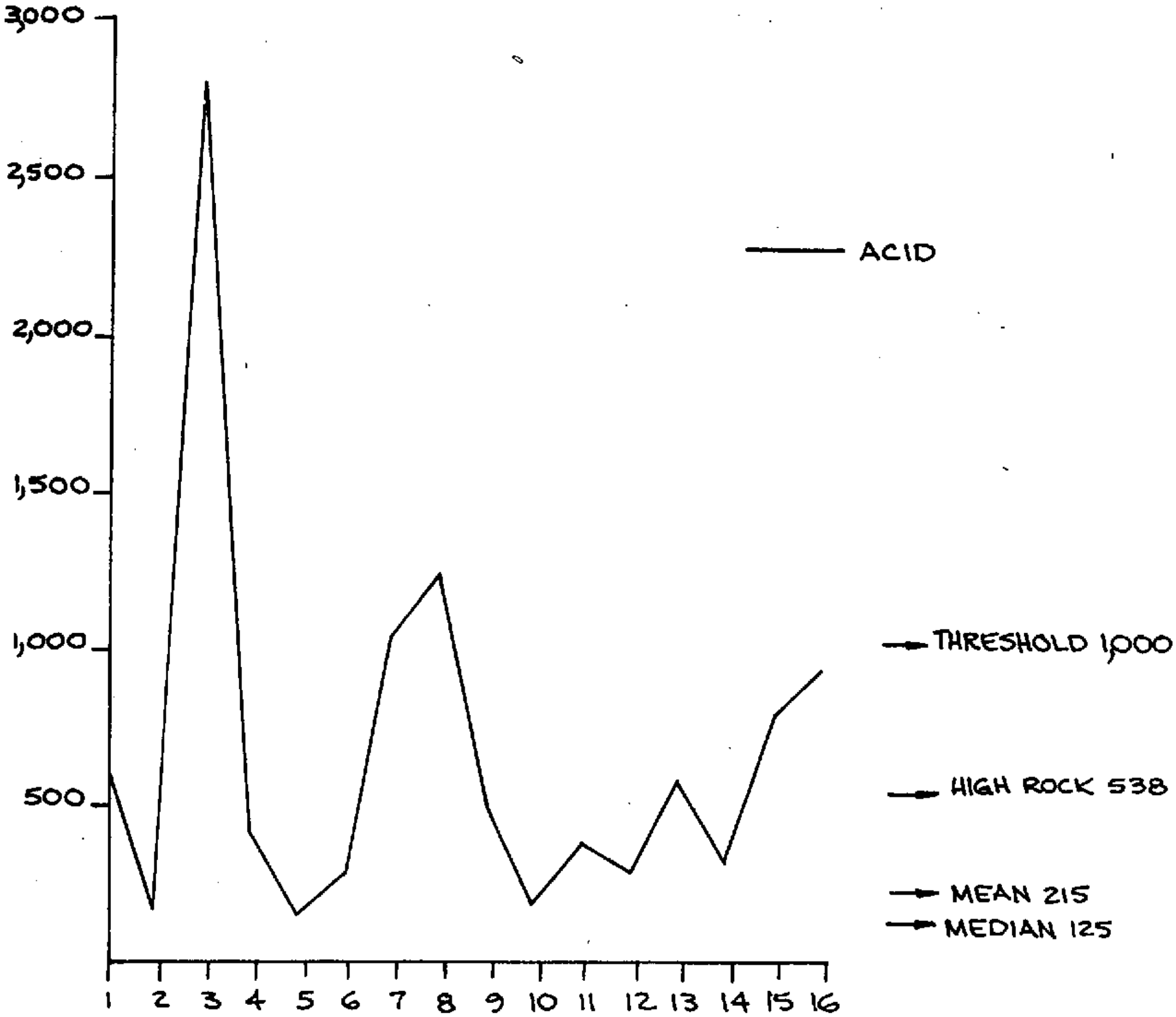


FIG. 85
ODENVILLE TRAVERSE 2
Cd CONCENTRATION

——— ACID

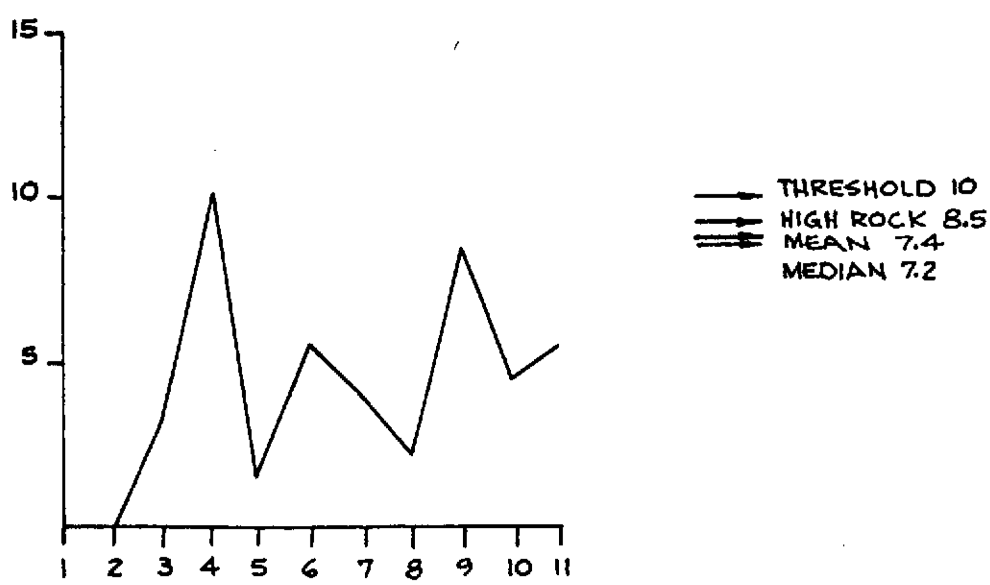


FIG. 86
ODENVILLE TRAVERSE 2
Mn CONCENTRATION

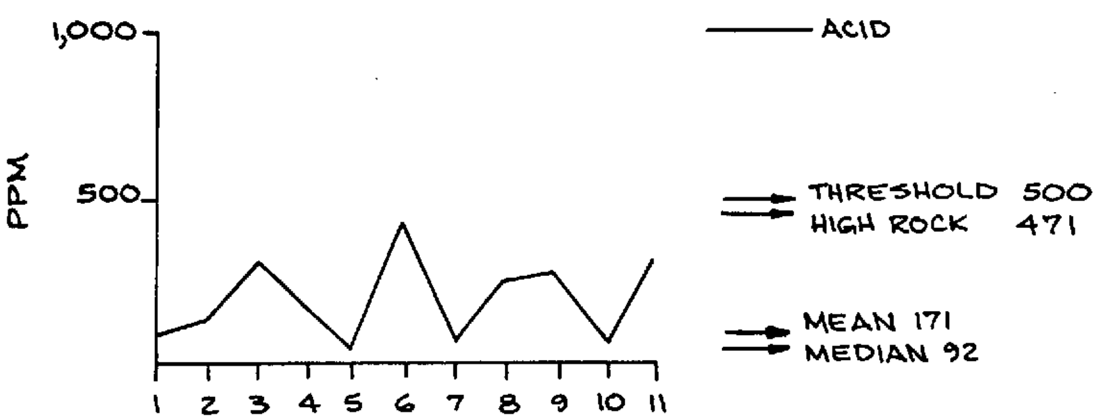


FIG. 87
ODENVILLE TRAVERSE 2
Sb CONCENTRATION

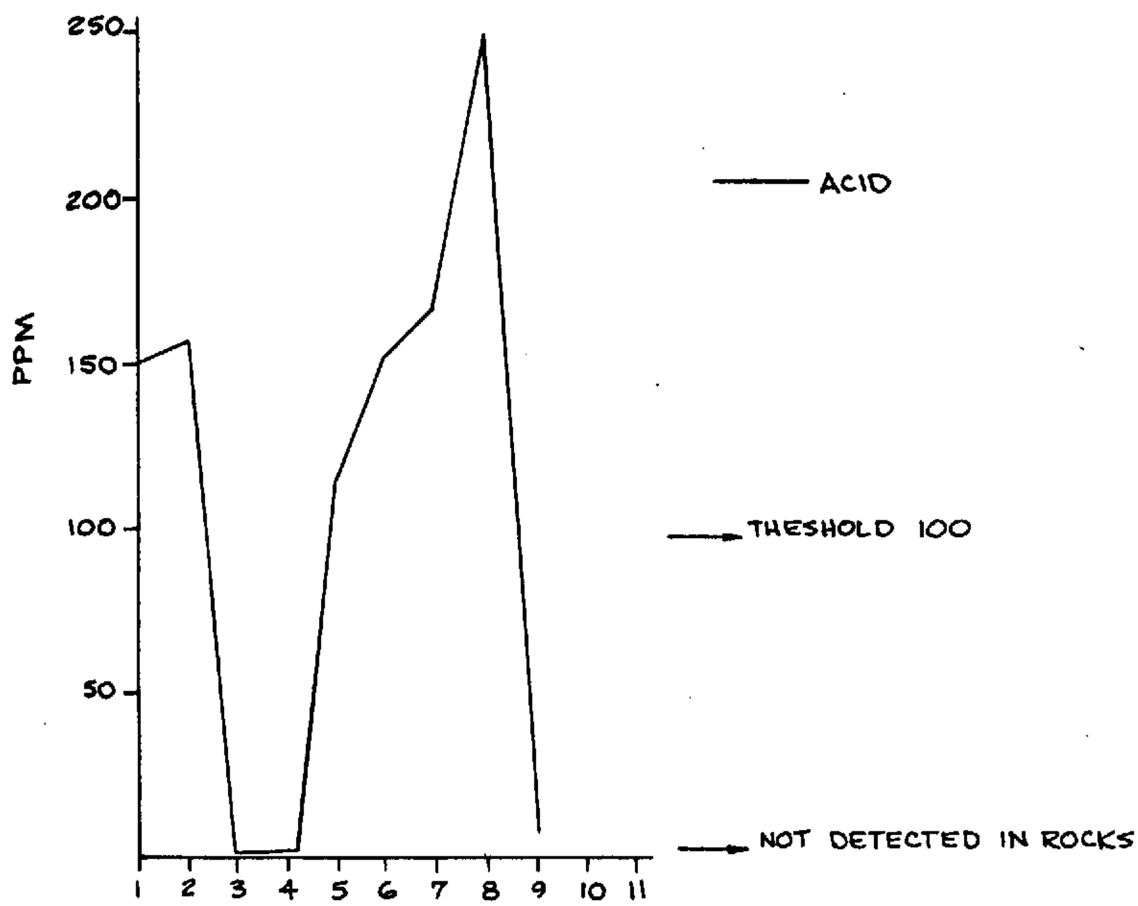


FIG. 88
ODENVILLE TRAVERSE 2
Cu. CONCENTRATION

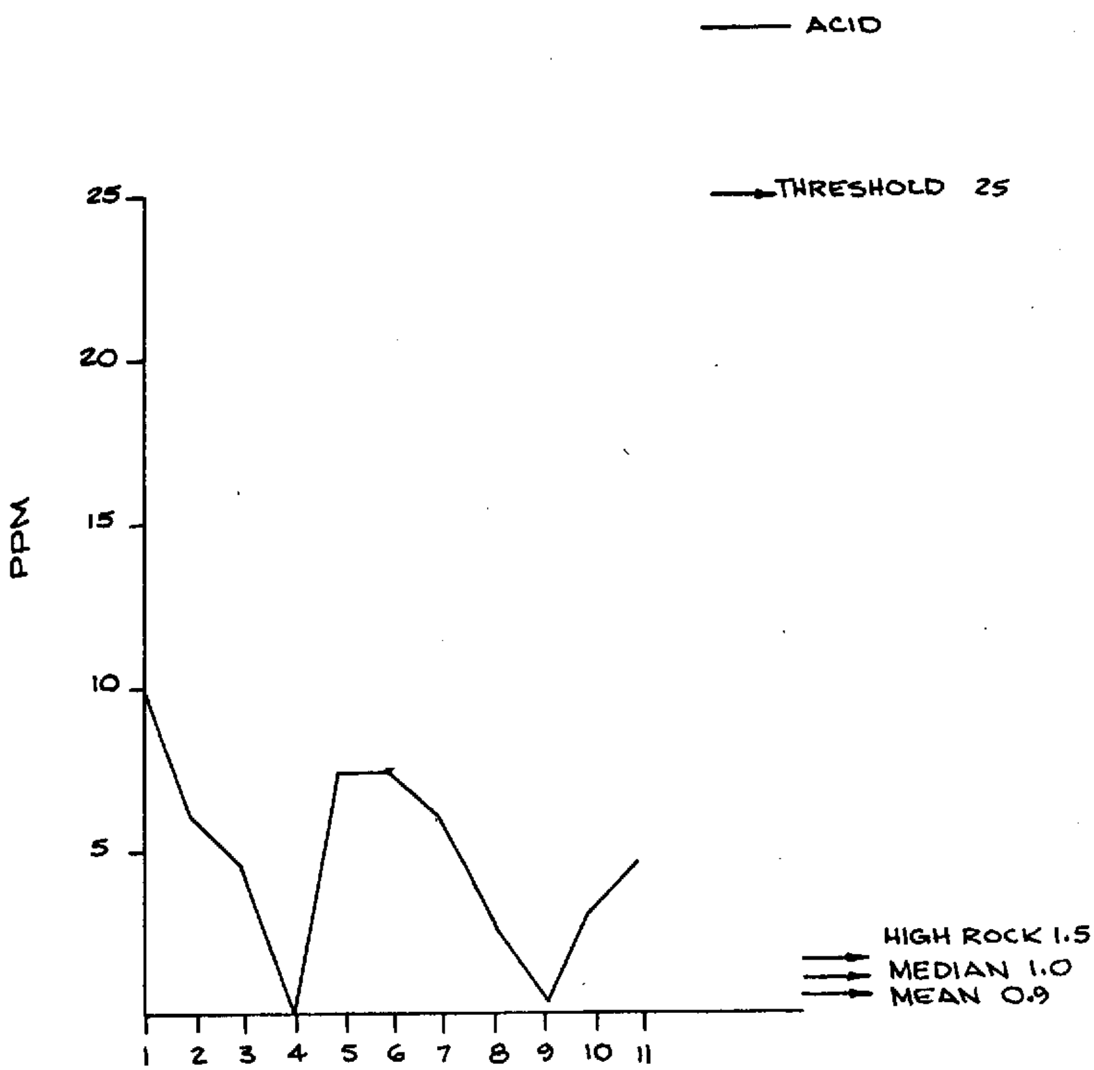


FIG. 89
ODENVILLE TRAVERSE 2
Zn CONCENTRATION

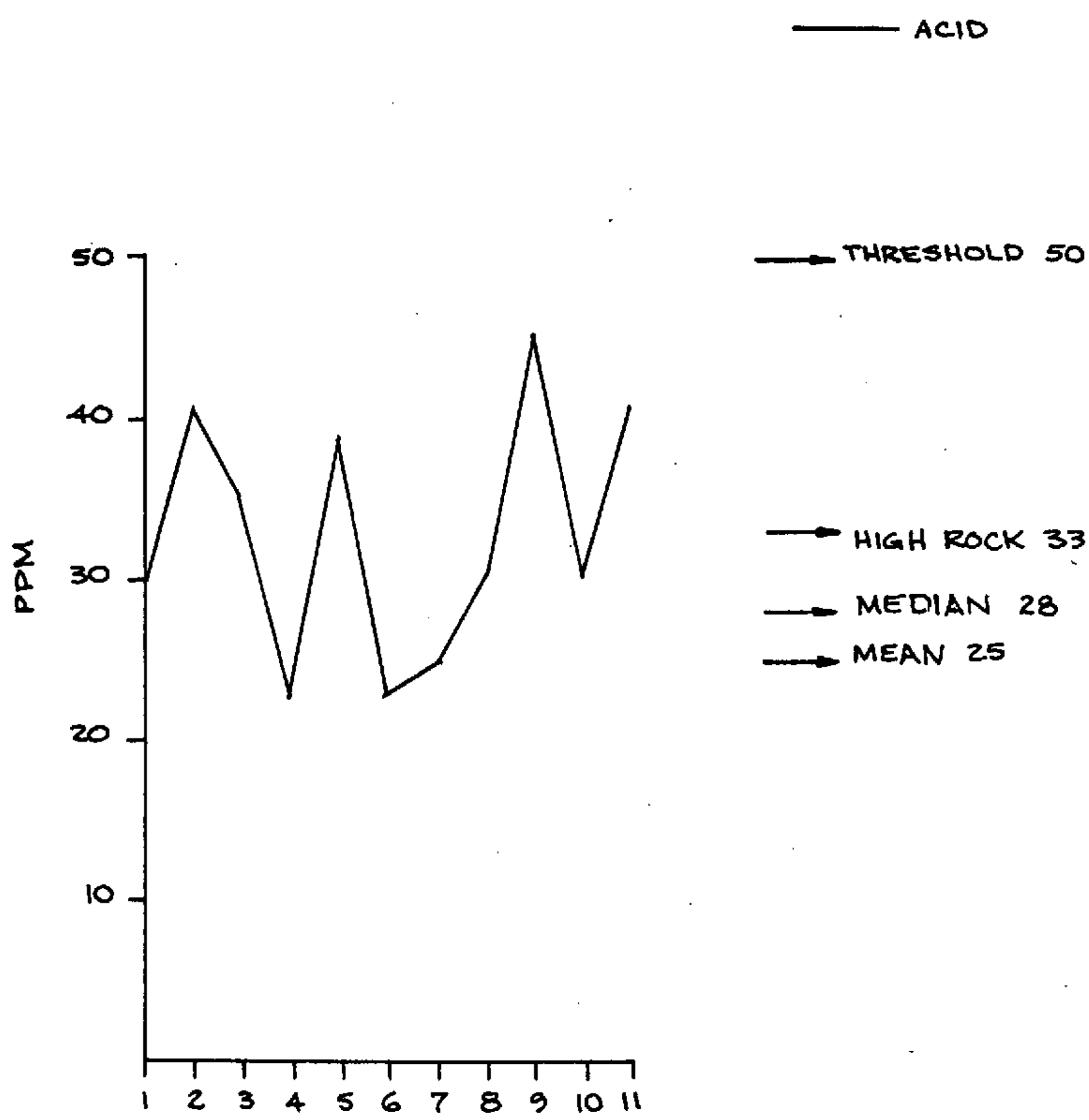


FIG. 90
ODENVILLE TRAVERSE 2
Pb CONCENTRATION

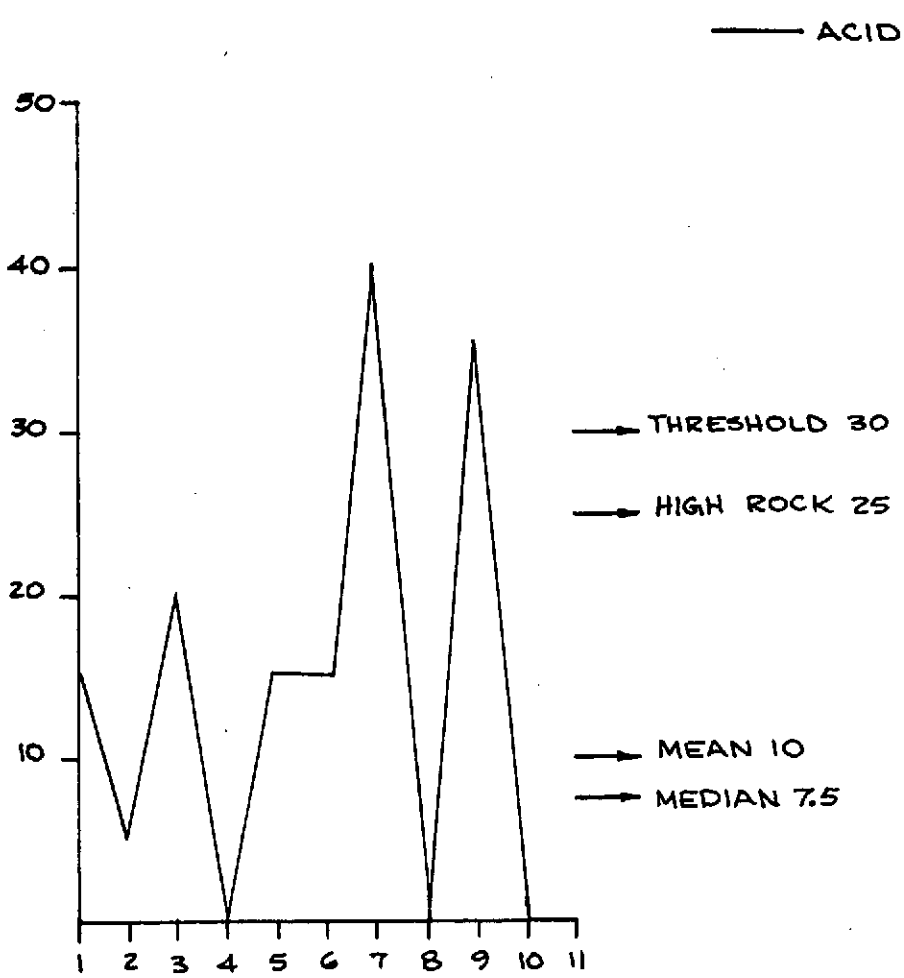
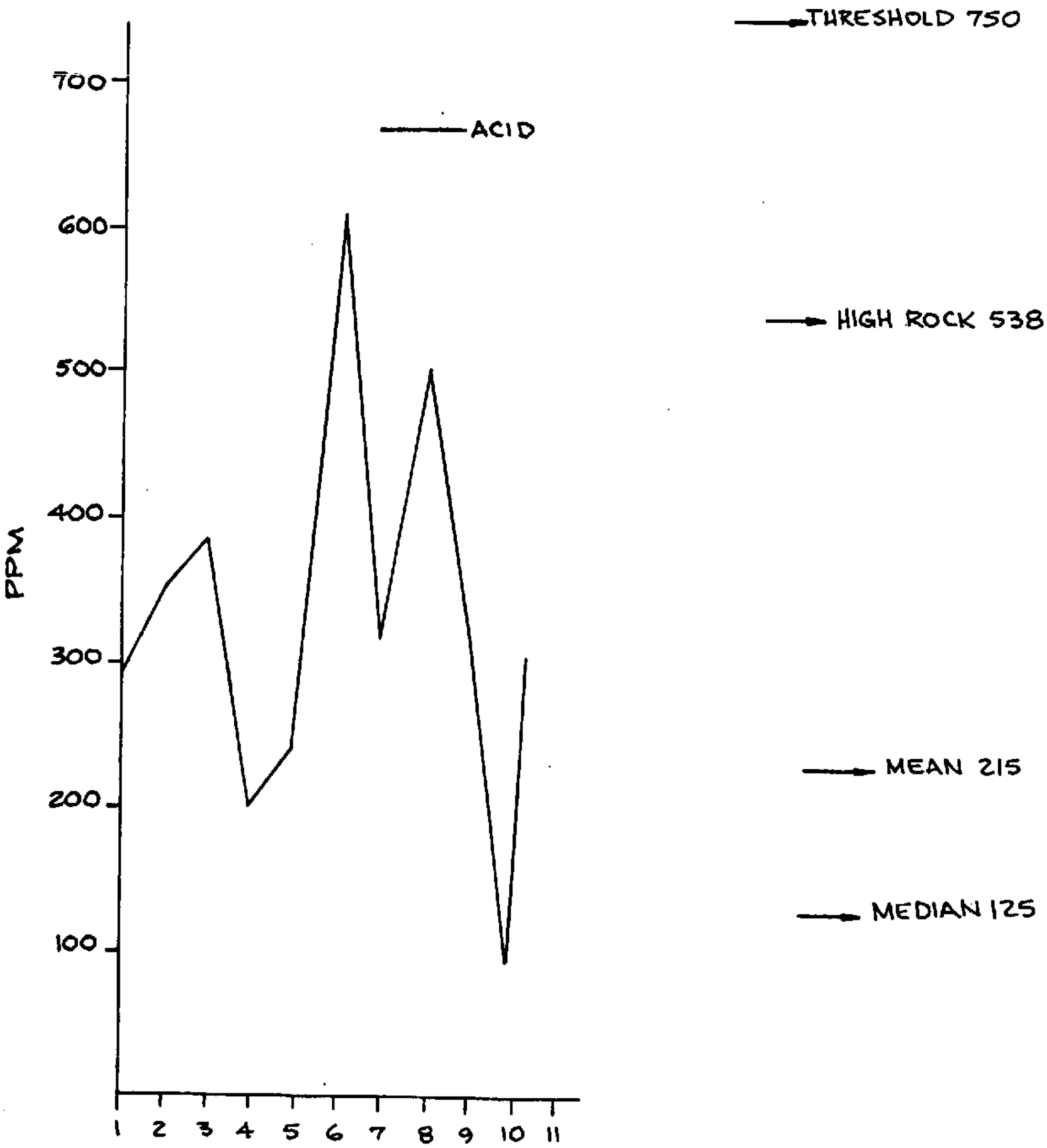


FIG. 91

ODENVILLE TRAVERSE 2
TOTAL METAL CONCENTRATION



only 1 ppm copper. This suggests that the copper occurs in limited quantities or is extremely localized. A further complication is the fact that soil samples contained up to 250 ppm antimony, whereas none was detected in the rocks. This may be the result of concentration of immobile antimony in the soil by leaching of mobile components Ca, Mg, Sr, and others from the rocks. Furthermore, the copper occurrences are not as closely related in space to lineaments as they are at Leeds or Harpersville. Thus, while there may be geochemical highs at Odenville, it is by no means certain that they are caused by the mineralization or the lineaments.

Area 4: Talladega

This area lies in sections 5, 6, 7 and 8 of T. 19 S., R. 6 E., approximately 5 miles southeast of Talladega in Talladega County (fig. 1).

The rocks present are the cherty dolomites of the Cambrian Copper Ridge Dolomite and the Ordovician Chepultepec Dolomite. To the south of the area across the Talladega Fault lies the Devonian Lay Dam Formation (O. E. Gilbert, Jr. personal communication, 1974).

Traverses were run on all roads near the lineament intersection. Soil samples were taken at approximately 0.1 mile intervals (fig. 92).

Carbonate rocks do not crop out within the study area, however, two samples of chert were collected from stations 5 and 18. Geochemical data for the carbonates were obtained from sampling done in the Harpersville district of Shelby County (area 1 of this report). These data are presented in table 12 and the soil analysis data are presented in table 13.

Table 12

Chemical Analyses of Rocks (in parts per million)

Sample No.	Cu	Mo	Pb	Zn	Cd
Chert					
Talladega 5	3.0	ND	ND	15.0	ND
Talladega 18	1.0	ND	5	31.5	ND
Shelby County 1	18.0	ND	125	13.0	ND
Shelby County 8	28.0	ND	100	4.0	ND
Limestone					
Shelby County 2	32.0	ND	95	28.0	ND
Shelby County 3	29.0	ND	105	22.5	ND
Shelby County 6	0.5	ND	35	15.0	ND
Shelby County 7	36.5	ND	100	13.5	ND
Dolomite					
Shelby County 4	24.0	ND	90	16.0	ND
Shelby County 5	20.5	ND	35	15.0	ND
Detection limit	0.5	10	15	0 5	0.5
Average	19	0	69	17	0

Analyst: G. Thomas, Geological Survey of Alabama

Table 13
Chemical Analaysis of Soils (in parts per million)
Talladega Area

Station no.	Cu	Mo	Pb	Zn	Cd	Total metal
1	42.0	ND	45	164.0	ND	251
2	21.0	ND	5	58.0	ND	84
3	26.5	ND	5	136.5	2.5	170
4	27.5	ND	15	78.0	1.5	122
5	18.5	ND	ND	83.0	1.0	102
6	22.5	5	10	70.5	2.0	110
7	19.0	ND	10	45.5	2.5	77
8	6.0	ND	45	49.0	3.0	103
9	22.0	ND	ND	45.5	1.0	68
10	41.0	ND	10	75.0	4.5	130
11	13.0	ND	10	55.5	ND	78
12	36.0	ND	5	40.0	3.0	84
13	11.0	ND	25	72.5	ND	108
14	ND	ND	ND	46.0	4.5	50
15	9.0	ND	ND	50.5	11.5	71
16	19.0	ND	15	49.0	ND	83
17	26.5	30	40	65.5	ND	162
18	18.0	10	ND	64.0	0.5	92
19	9.0	ND	20	47.5	2.5	79
20	31.5	ND	50	75.0	2.0	158

Station no.	Cu	Mo	Pb	Zn	Cd	Total metal
21	40.0	10	60	126.0	3.0	239
22	18.0	ND	15	56.0	5.0	94
23	10.5	ND	20	58.5	3.0	92
24	15.0	ND	ND	74.0	2.0	91
25	21.0	ND	30	117.0	3.0	171
26	16.5	ND	25	71.5	1.5	114
27	5.0	ND	30	57.5	ND	92
28	15.0	ND	25	79.0	ND	119
29	20.5	ND	30	60.0	1.5	112
30	26.5	ND	10	94.5	6.0	137
31	25.0	ND	ND	97.0	5.5	128
32	27.5	ND	15	98.0	2.5	143
33	38.0	ND	25	74.0	5.5	142
34	35.0	ND	15	78.0	6.5	134
35	42.5	ND	25	99.0	3.5	170
36	51.0	55	20	86.0	5.5	218
37	29.5	ND	ND	72.5	3.5	106
38	6.5	75	20	55.5	6.5	164
39	16.5	10	5	73.5	3.0	108
40	46.5	ND	5	135.5	3.5	190

Analyst: G. Thomas, Geological Survey of Alabama

Copper

Copper values in the soil range from none detected to 51 ppm (fig. 93). The threshold value was estimated at 40 ppm. Six values exceed threshold and four of these are close to the lineament. Sample number 1 was collected from a pelite unit, probably the Lay Dam and hence represents a false anomaly. The distribution of values suggests the possibility of a slight enrichment of copper near the lineaments.

Molybdenum

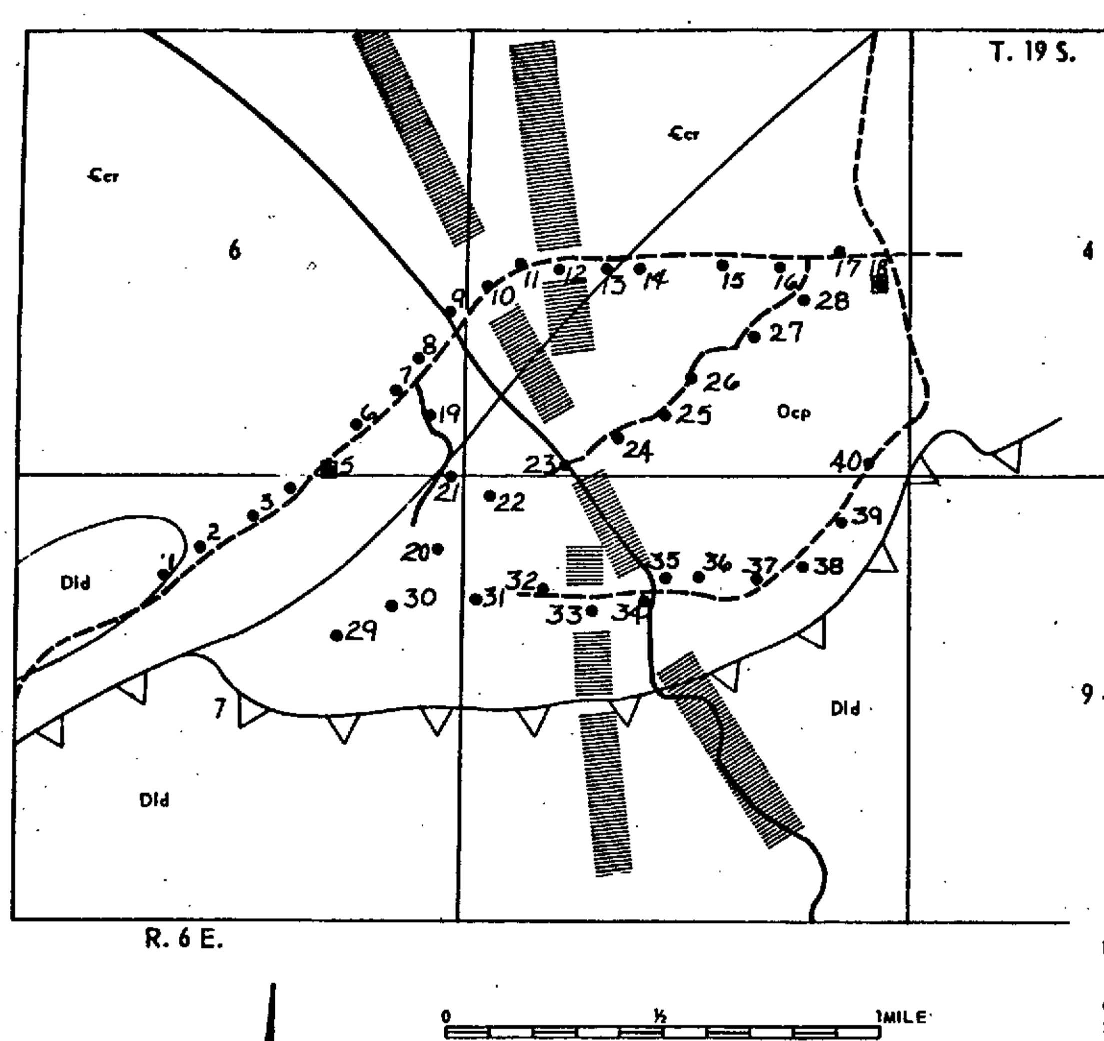
Molybdenum was detected in 7 of 40 samples in amount ranging up to 75 ppm (fig. 94). Three samples exceed the threshold value of 15 ppm. While one of the anomalous values coincides with a copper anomaly, no significance can be suggested for the distribution.

Lead

Lead values range from none detected to 60 ppm (fig. 95). Threshold was estimated to be 40 ppm and five values exceed this. Three of these are near the lineaments and one represents the false anomaly from the Lay Dam Formation.

Zinc

Zinc values range from 40 ppm to 164 ppm (fig. 96). Threshold has been estimated at 90 ppm and nine values exceed it. Most of the high values are in the Chepultepec Dolomite, whereas most of the low values are in the Copper Ridge Dolomite. This distribution suggest a slight stratigraphic control in the distribution



EXPLANATION

- Lineament trace
- Paved road
- Dirt road
- Contact
- Sample station
- Anomalous value
- Rock sample
- Talladega Fault

Figure 92. Area 4, Talladega.
Sample station numbers.

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally contains fine- to medium-grained orthoquartzites in lower part of formation. Outcrops characterized by fragile, cavernous, gray or with chert.

Єcr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.

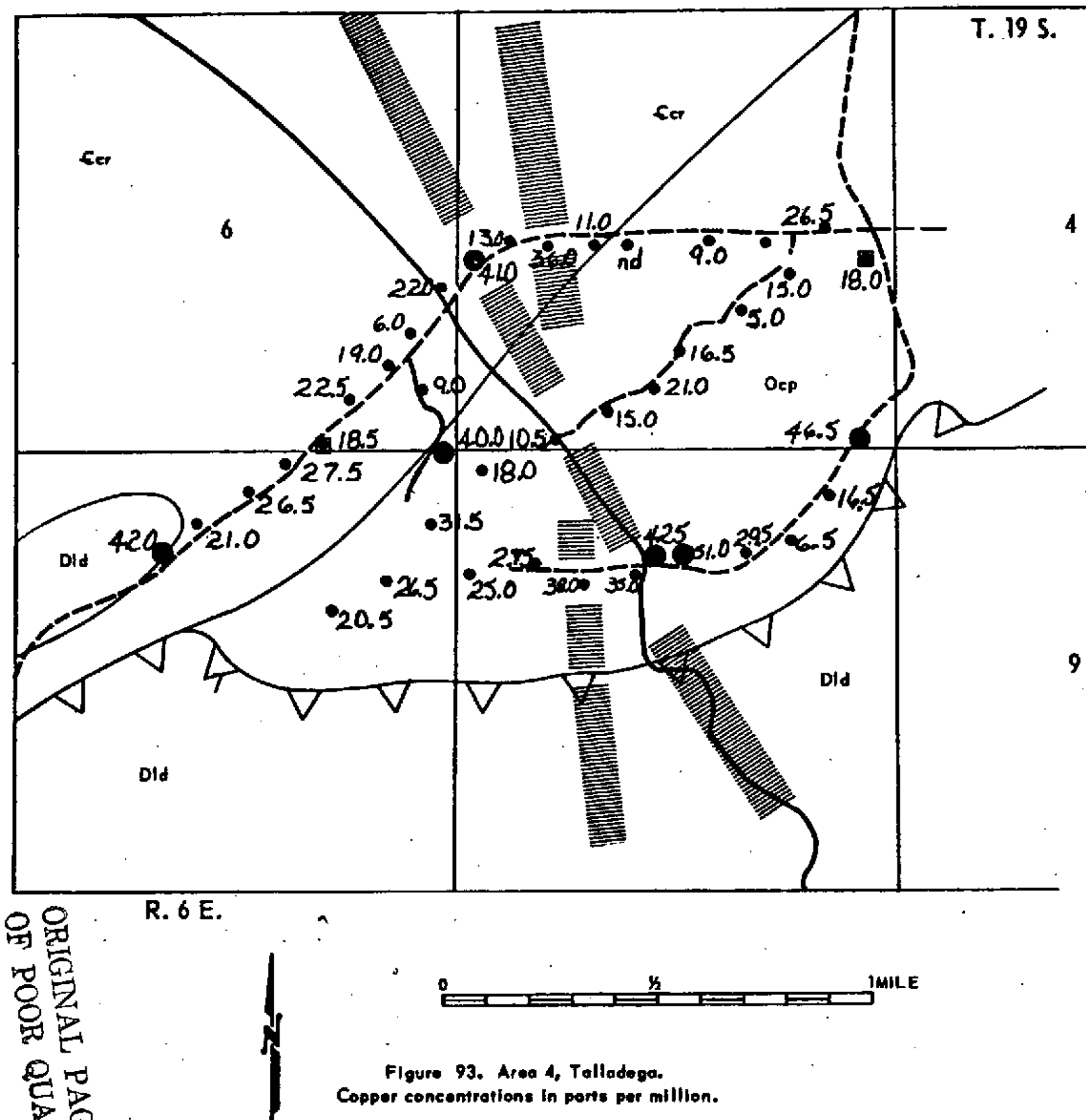


Figure 93. Area 4, Talladega.
Copper concentrations in parts per million.

EXPLANATION

- Lineament trace
- Paved road
- Dirt road
- Contact
- Sample station
- Anomalous value
- Rock sample
- Talladega Fault

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally contains fine- to medium-grained orthoquartzites in lower part of formation. Outcrops characterized by fragile, cavernous, gray or with chert.

Ccr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.

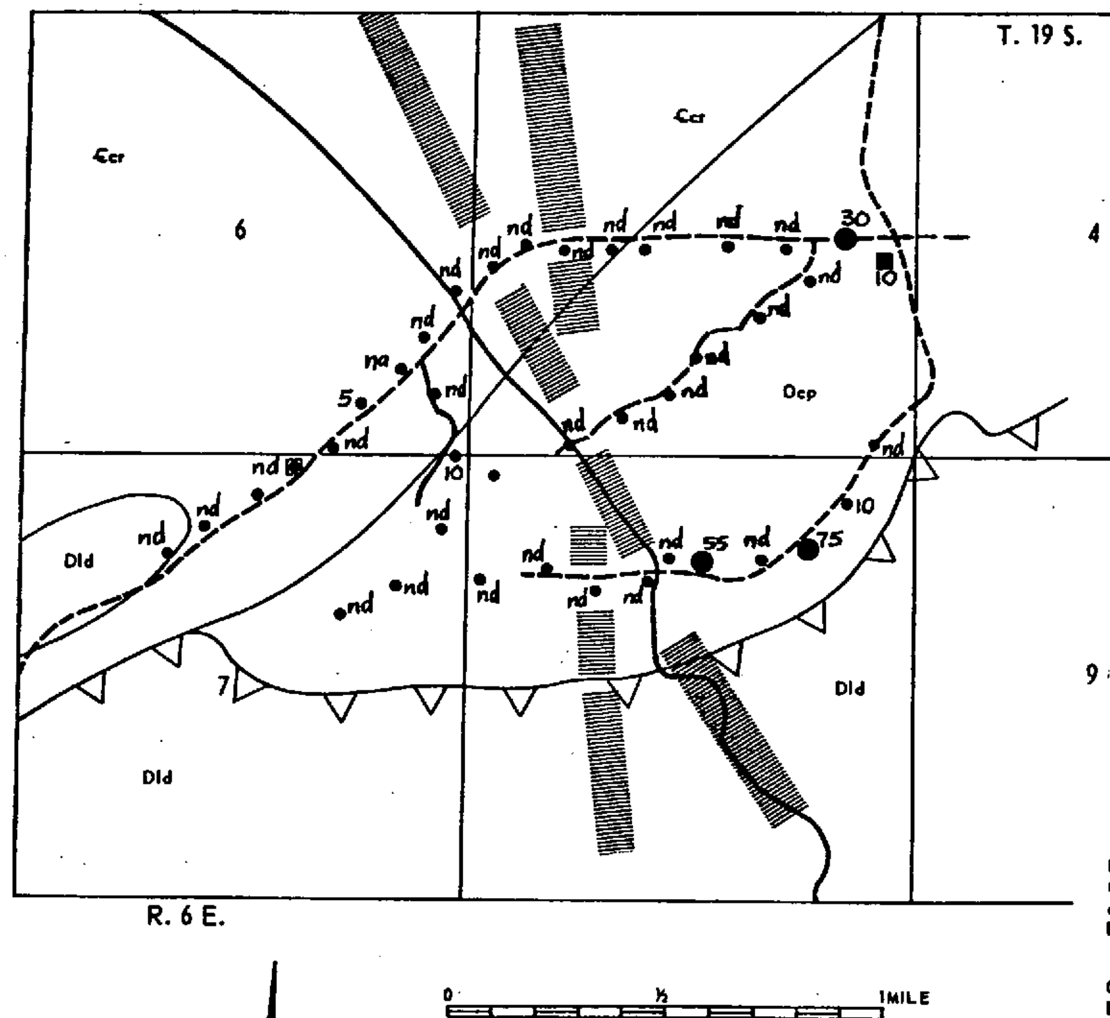


Figure 94. Area 4, Talladega.
Molybdenum concentrations in parts per million.

EXPLANATION

Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value
Rock sample
Talladega Fault

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally contains fine- to medium-grained orthoquartzites in lower part of formation. Outcrops characterized by fragile, cavernous, gray or with chert.

Ccr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.

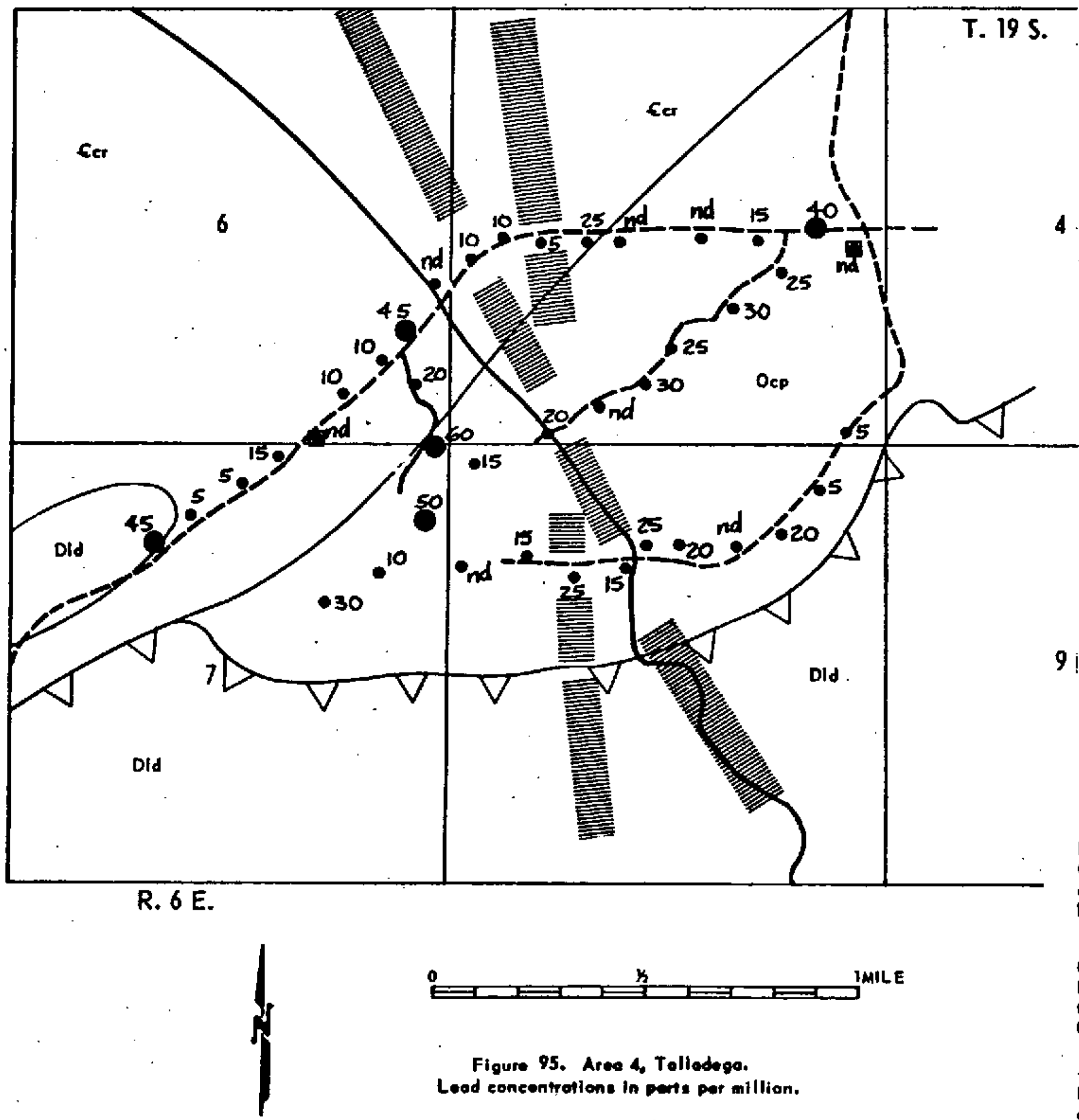


Figure 95. Area 4, Talladega.
Lead concentrations in parts per million.

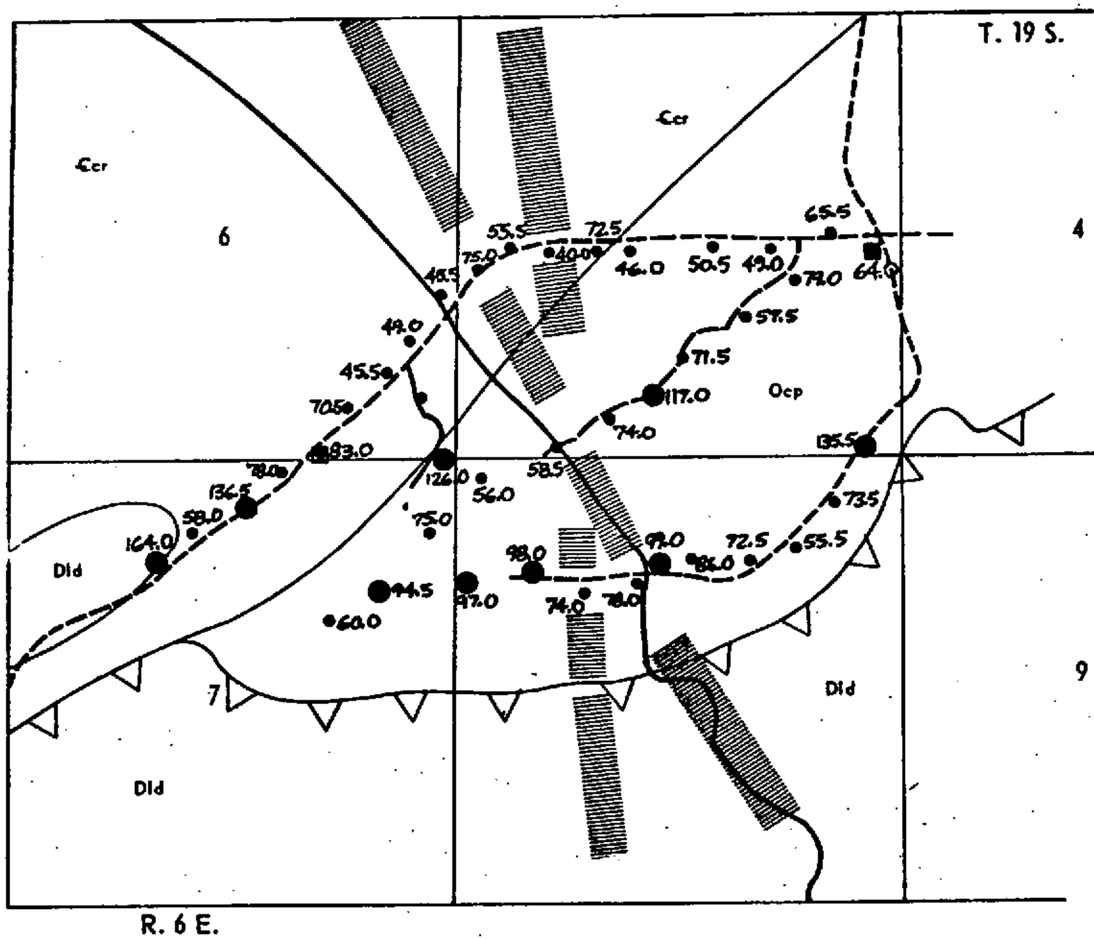
EXPLANATION

- Lineament trace
- Paved road
- Dirt road
- Contact
- Sample station
- Anomalous value
- Rock sample
- Talladega Fault

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally co: tains fine- to medium-grained orthoquartzites in lower part of formatior Outcrops characterized by fragile, cavernous, gray or with chert.

Ꞓcr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.



EXPLANATION

Lineament trace	
Paved road	
Dirt road	
Contact	
Sample station	
Anomalous value	
Rock sample	
Talladega Fault	

0 ½ 1 MILE

Figure 96. Area 4, Talladega.
Zinc concentrations in parts per million.

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally contains fine- to medium-grained orthoquartzites in lower part of formation. Outcrops characterized by fragile, cavernous, gray or with chert.

Ꞓcr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.

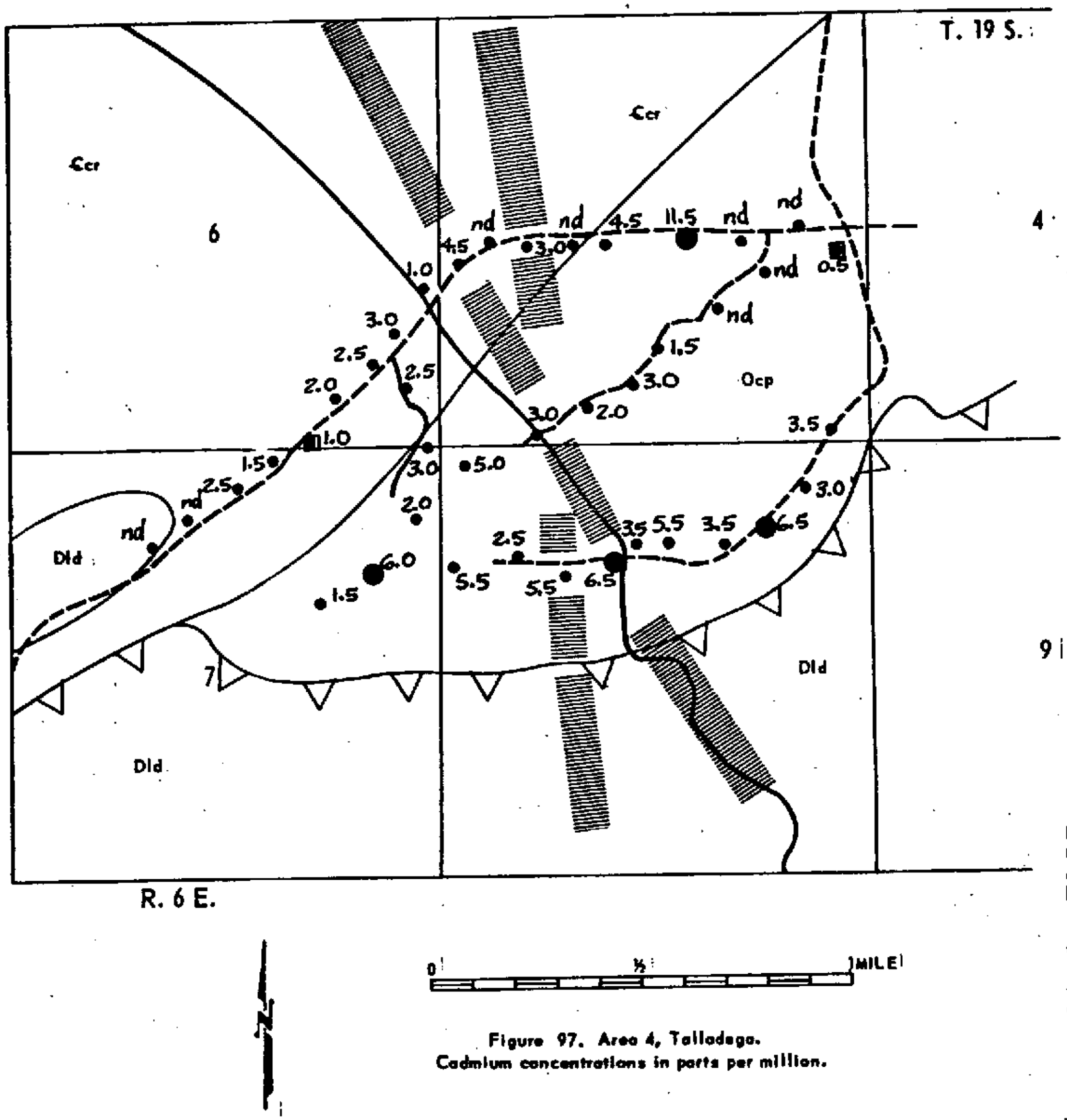


Figure 97. Area 4, Talladega.
Cadmium concentrations in parts per million.

EXPLANATION

- Lineament trace
- Paved road
- Dirt road
- Contact
- Sample station
- Anomalous value
- Rock sample
- Talladega Fault

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally co-tains fine- to medium-grained orthoquartzites in lower part of formatior. Outcrops characterized by fragile, cavernous, gray or with chert.

Ccr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.

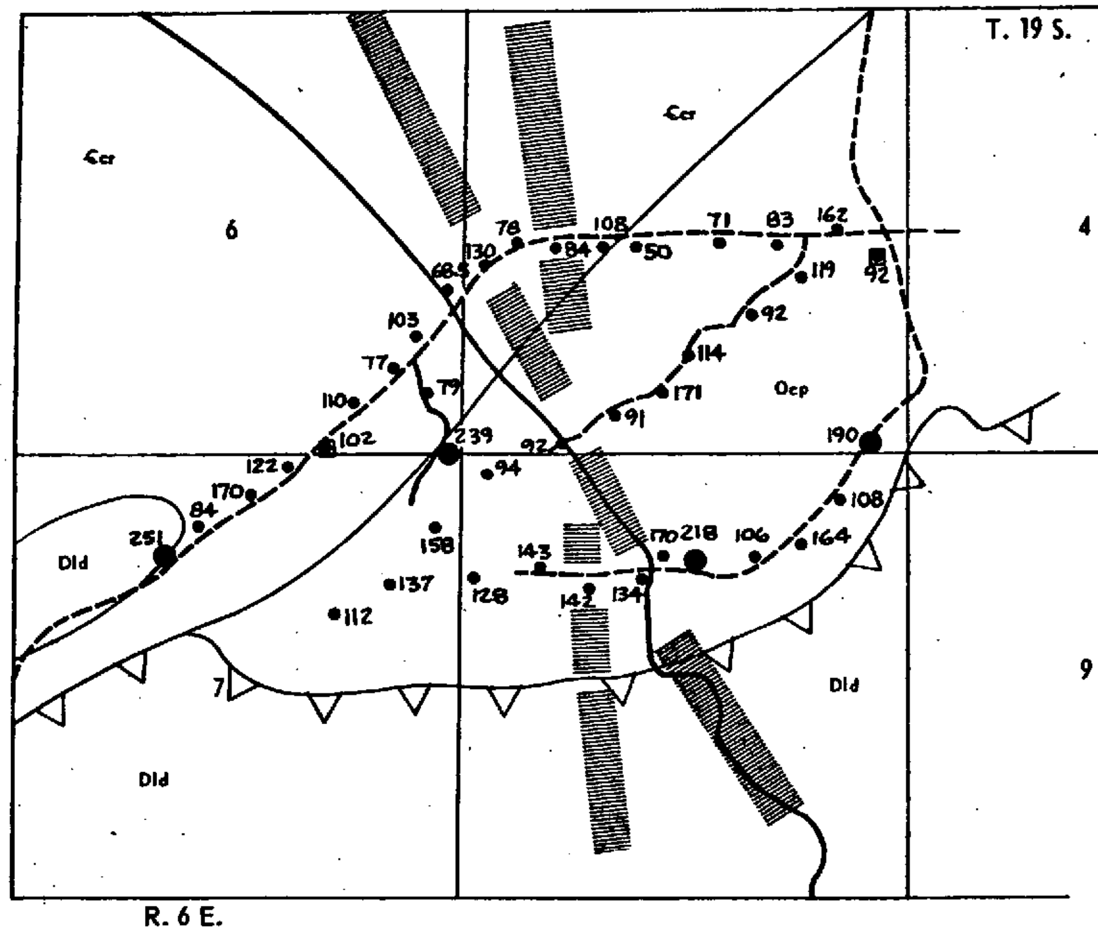


Figure 98. Area 4, Talladega.
Total metal concentrations in parts per million.

EXPLANATION

- Lineament trace
- Paved road
- Dirt road
- Contact
- Sample station
- Anomalous value
- Rock sample
- Talladega Fault

Dld - Lay Dam Formation
Gray to green, locally calcareous slate and chlorite phyllite; green calcareous arkose and quartzite; dark gray, thin-bedded fine grained limestone.

Ocp - Chepultepec Dolomite
Light gray, thick-bedded, fine- to medium-grained dolomite; locally co- tains fine- to medium-grained orthoquartzites in lower part of formatior Outcrops characterized by fragile, cavernous, gray or with chert.

Єcr - Copper Ridge Dolomite
Light gray, thick-bedded, fine- to coarse-grained dolomite. Outcrops characterized by massive blocky chert.

of zinc.

Cadmium

Cadmium values range from none detected to 11.5 ppm (fig. 97). Four values exceed the estimated threshold of 6 ppm. The distribution of values is similar to that of zinc and again suggests a slight stratigraphic control in the distribution of cadmium.

Total Metals

The sums of the values obtained from each sample range from 50 ppm to 251 ppm and the sum of the thresholds is 190 ppm. Four samples exceed this combined threshold value. Disregarding the false anomalies from the Lay Dam Formation at station 1, two of the remaining three lie near the lineaments (fig. 98).

Summary

Concentrations of each element do not vary greatly beyond the expected range. Copper seems to show a weak association with the lineaments. Molybdenum shows no apparent correlation with lineaments or stratigraphy. Three lead anomalies parallel the lineaments at a distance of approximately 1,000 feet. This may indicate some control in the distribution of lead. Distribution of zinc and cadmium values seems to suggest a stratigraphic control with the Chepultepec Dolomite having higher concentrations than the Copper Ridge Dolomite.

Area 5: Cragford

Eight lineaments were investigated in the Cragford area. Several of these had been found by Smith, Drahovzal and Lloyd (1973) to contain anomalously high metal concentrations. The present study examined five of these lineaments several miles to the south and north as well as in the main mineralized area.

Three rock samples of the Cragford Phyllite from the central area were analyzed for trace element content. The results are presented as follows in parts per million.

	Cu	Mo	Pb	Zn	Cd	Sb	Total Metal
Station No. 49	29.5	ND	ND	113.5	1.0	315	459
34	19.0	ND	15	54.0	ND	305	393
9	32.0	ND	ND	135.0	3.0	330	500
Detection Limit	0.5	10	15	0.5	0.5	30	
Ave.	27	—	5	100	1	317	450

South Cragford Area

Two traverses were run in the southern area using a sampling interval of 0.2 miles (fig. 99). Traverse 1 is located in sections 15 and 17 of T. 21 S., R. 10 E. Traverse 2 is located in sections 5 and 8 of T. 21 S., R. 10 E. Country rock in this area is the Cragford Phyllite of the Wedowee Group (Neathery and Reynolds, 1974). Results of the soil analyses are presented in table 14.

Copper

Copper values in the soil range from 20.0 ppm to 101.5 ppm. Six values exceed the threshold value estimated to be 60 ppm for this area. In traverse 1 all three anomalies, including the strongest in this area lie near the lineament. In traverse 2 two of the three anomalies lie near to the lineaments (fig. 100).

Table 14
Chemical Analyses of Soils (in parts per million)
South Cragford Area

Station no.	Cu	Mo	Pb	Zn	Cd	Sb	Total metal
T1- 1	56.0	ND	125	70.0	6.5	120	378
2	43.5	ND	30	76.5	5.0	280	435
3	39.5	ND	55	65.5	5.5	ND	165
4	101.5	ND	60	100.5	5.5	ND	268
5	60.0	ND	90	98.0	7.5	5	260
6	47.5	ND	30	134.5	4.5	190	406
7	46.0	ND	10	85.0	7.5	60	208
8	46.5	ND	5	83.5	1.0	285	421
9	69.0	ND	ND	136.5	2.0	80	283
10	42.5	5	5	106.5	4.0	190	353
11	35.0	15	25	104.5	4.0	105	288
12	54.5	5	5	85.5	5.0	300	455
T2- 13	63.5	ND	15	87.5	6.5	540	712
14	20.0	ND	ND	38.5	8.0	395	462
15	39.5	45	ND	52.5	4.0	395	536
16	20.0	ND	ND	41.0	ND	480	541
17	35.0	ND	ND	52.5	2.5	360	450
18	73.5	15	10	160.5	7.0	365	631
19	63.0	ND	35	67.0	0.5	95	260
20	22.5	ND	45	49.5	4.0	ND	121

Molybdenum

Molybdenum values range from none detected up to 45 ppm. Threshold was estimated to be 15 ppm and is exceeded by three values. The largest of these is near the intersection of the lineaments on traverse. One of the smaller anomalies is near a single lineament on traverse 2 while the third is located away from the lineaments in traverse 1 (fig. 101).

Lead

Lead values range from none detected up to 125 ppm. Three of the four values which exceed the estimated threshold of 50 ppm bracket the lineament in traverse 1 (fig. 102).

Zinc

Zinc values range from 38.5 ppm to 160.5 ppm. Threshold was estimated to be 100 ppm. Three of the six values exceeding threshold lie within 1000 feet of the lineament traces (fig. 103).

Cadmium

Cadmium values range from none detected to 8.0 ppm. Threshold was estimated to be 7.5 ppm and is exceeded by three values. None of the anomalies from traverse 1 show a close spatial relationship to the lineaments, however, the single anomalous value in traverse 2 lies near a lineament (fig. 104).

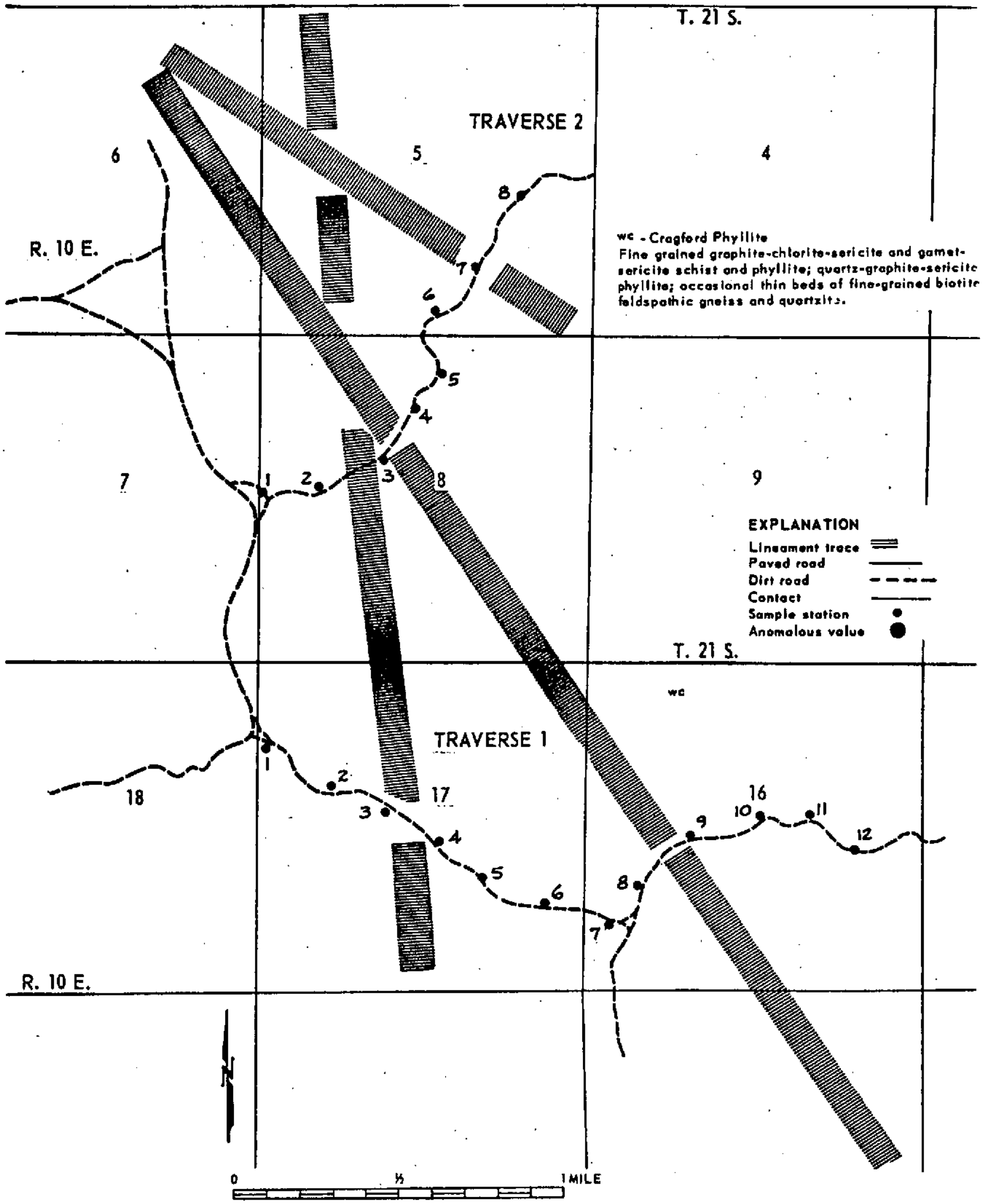


Figure 99. Area 5, south Cragford.
Sample station numbers.

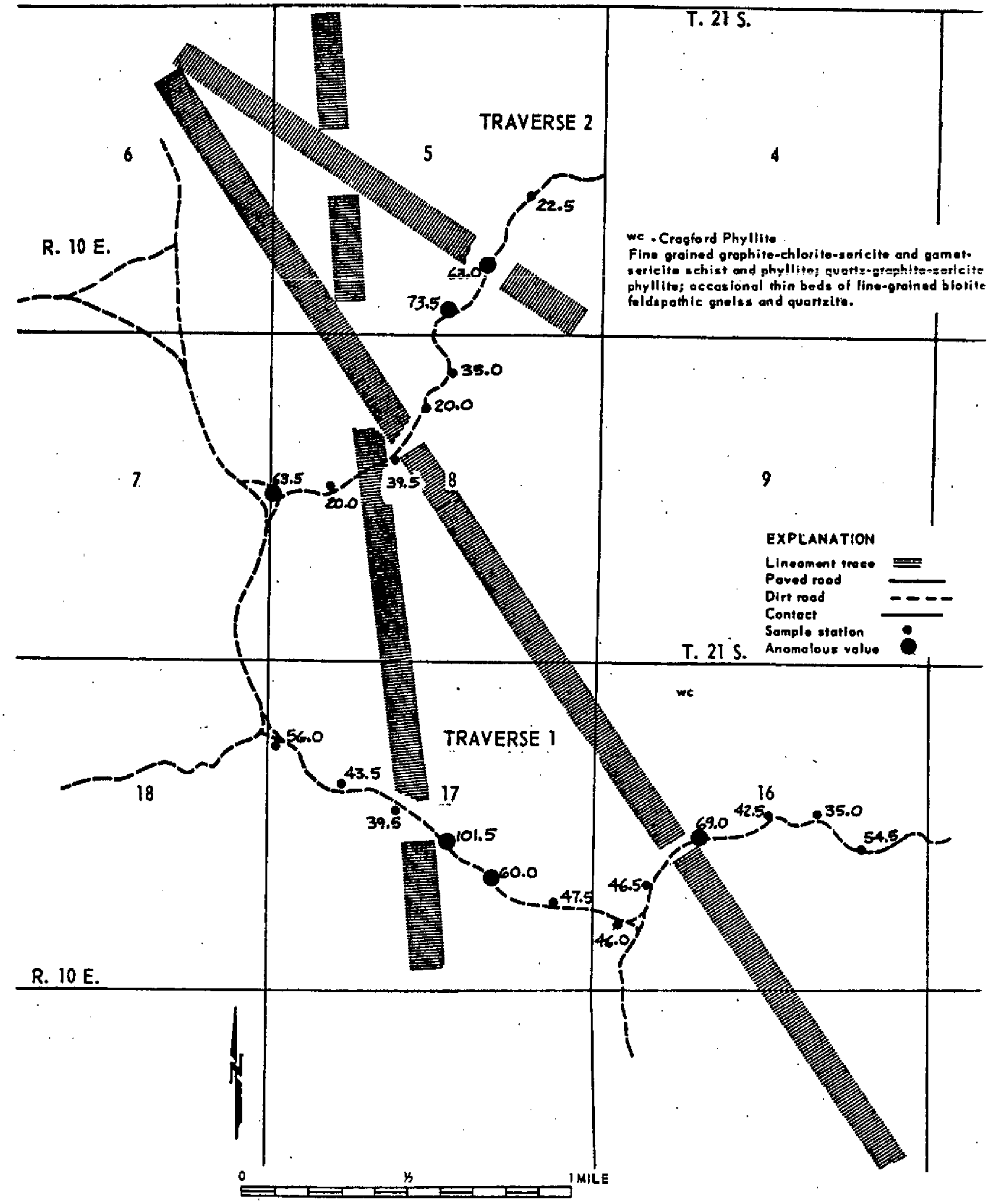


Figure 100. Area 5, south Cragford.

Copper concentrations in parts per million.

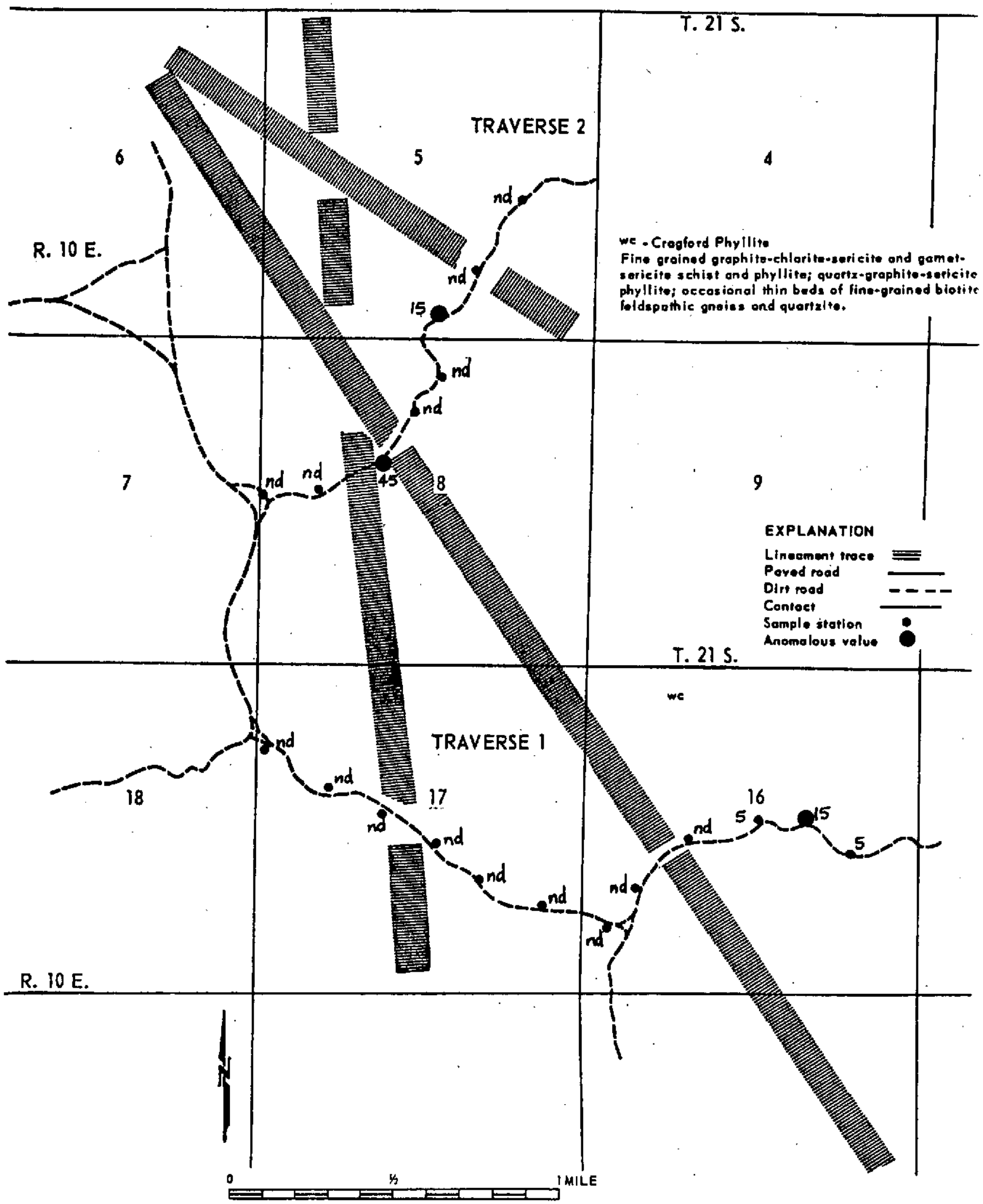


Figure 101. Area 5, south Cragford.
Molybdenum concentrations in parts per million.

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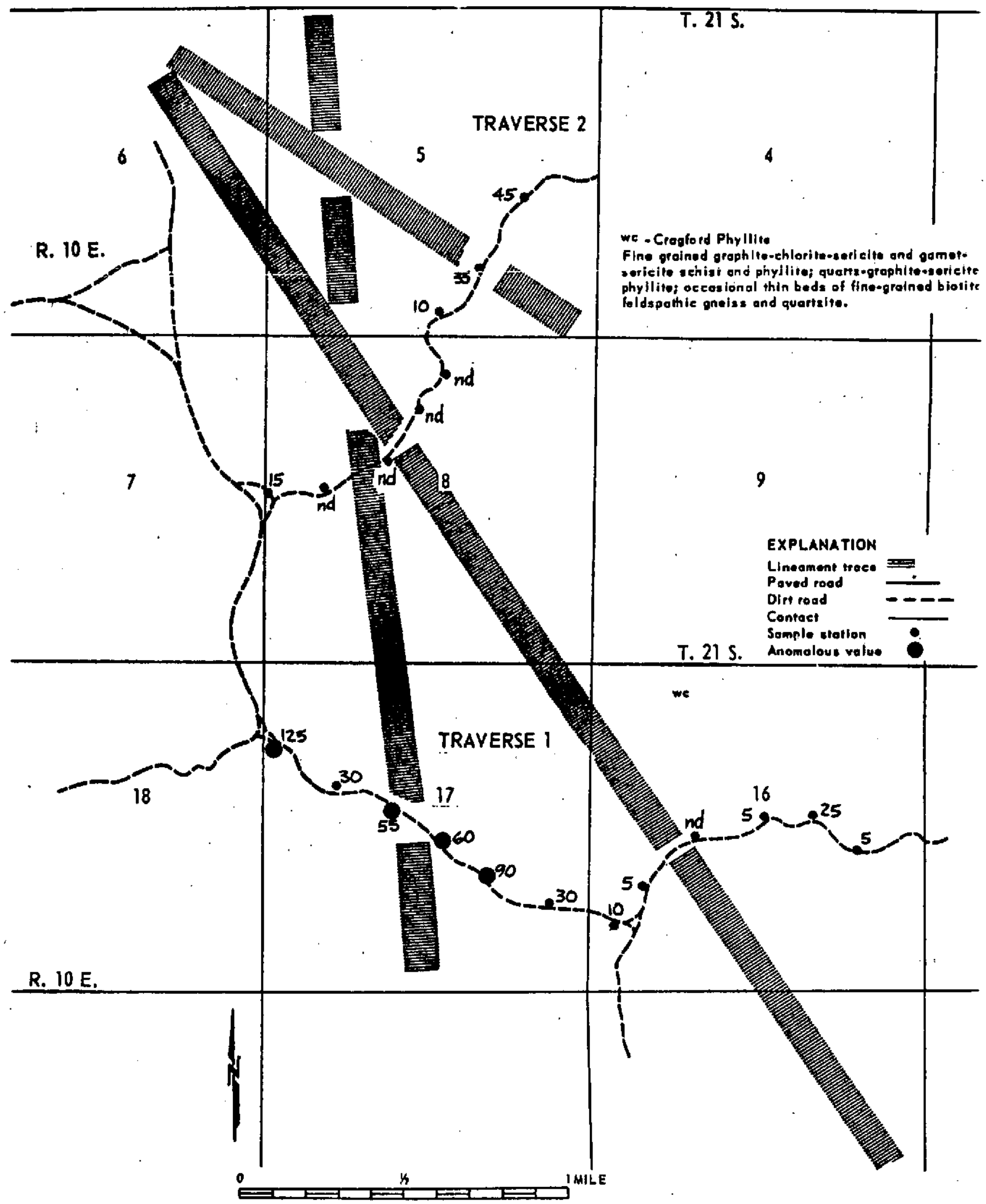


Figure 102. Area 5, south Cragford.
Lead concentrations in parts per million.

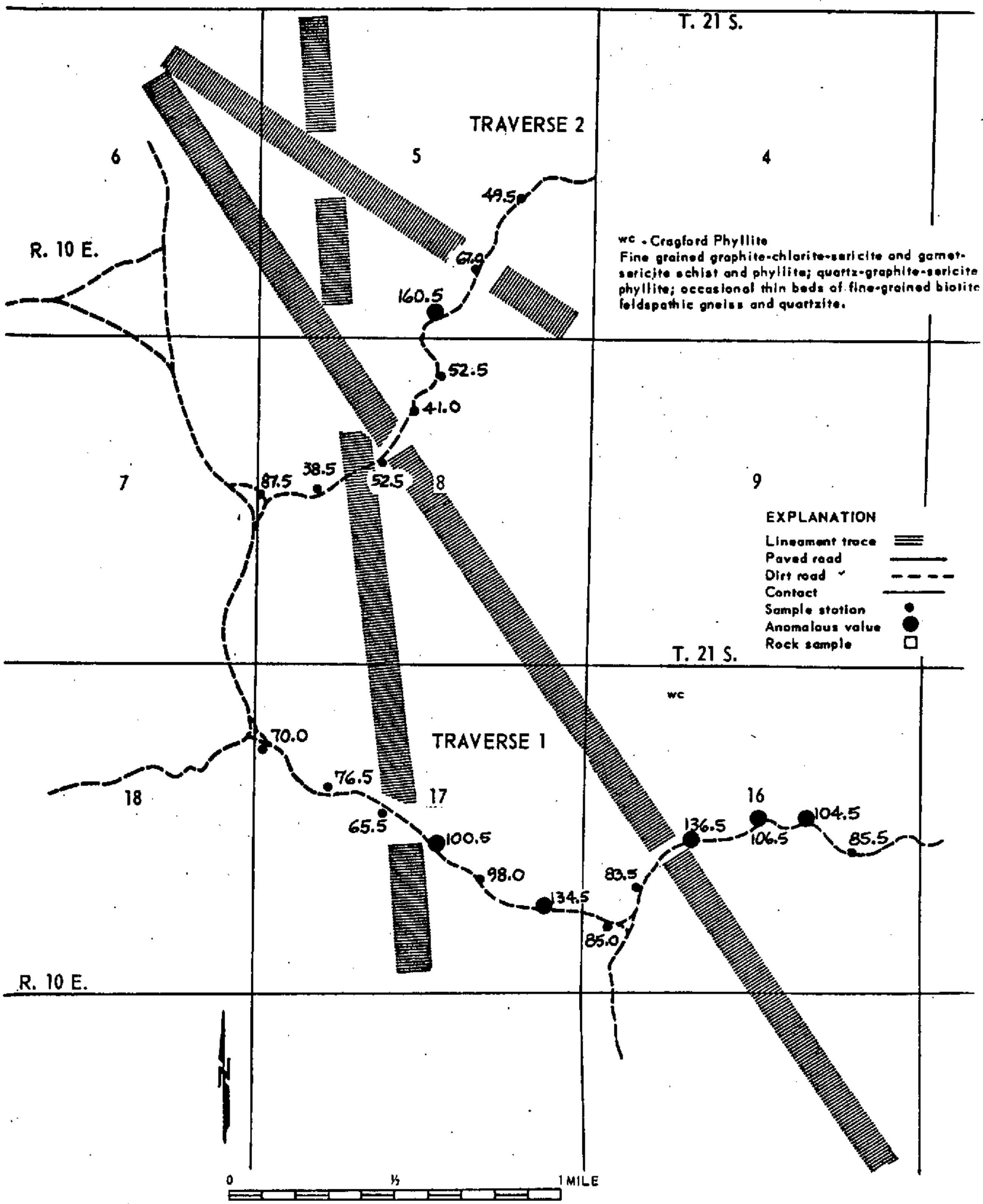


Figure 103. Area 5, south Cragford.
Zinc concentrations in parts per million.

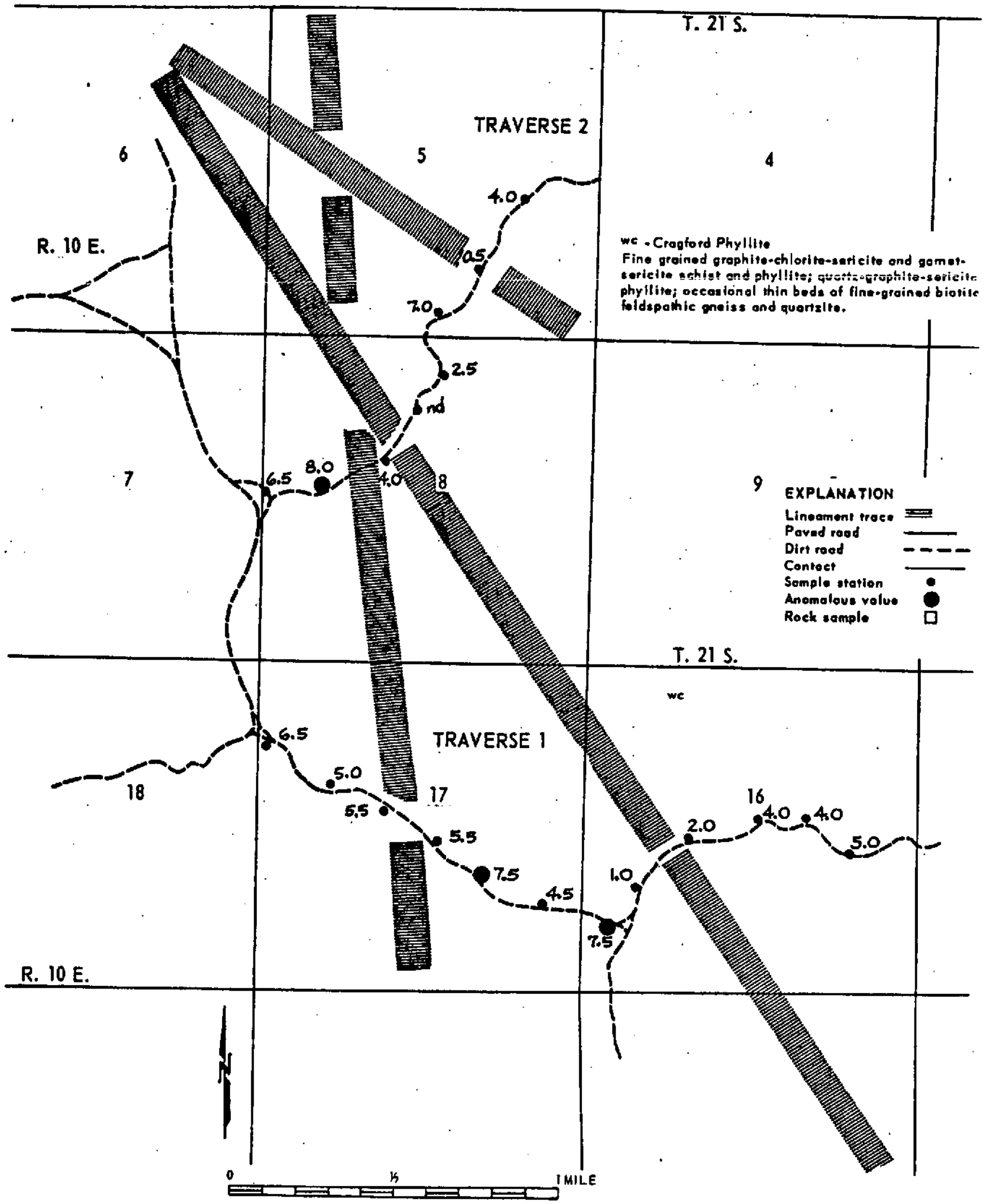


Figure 104. Area 5, south Cragford.
Cadmium concentrations in parts per million.

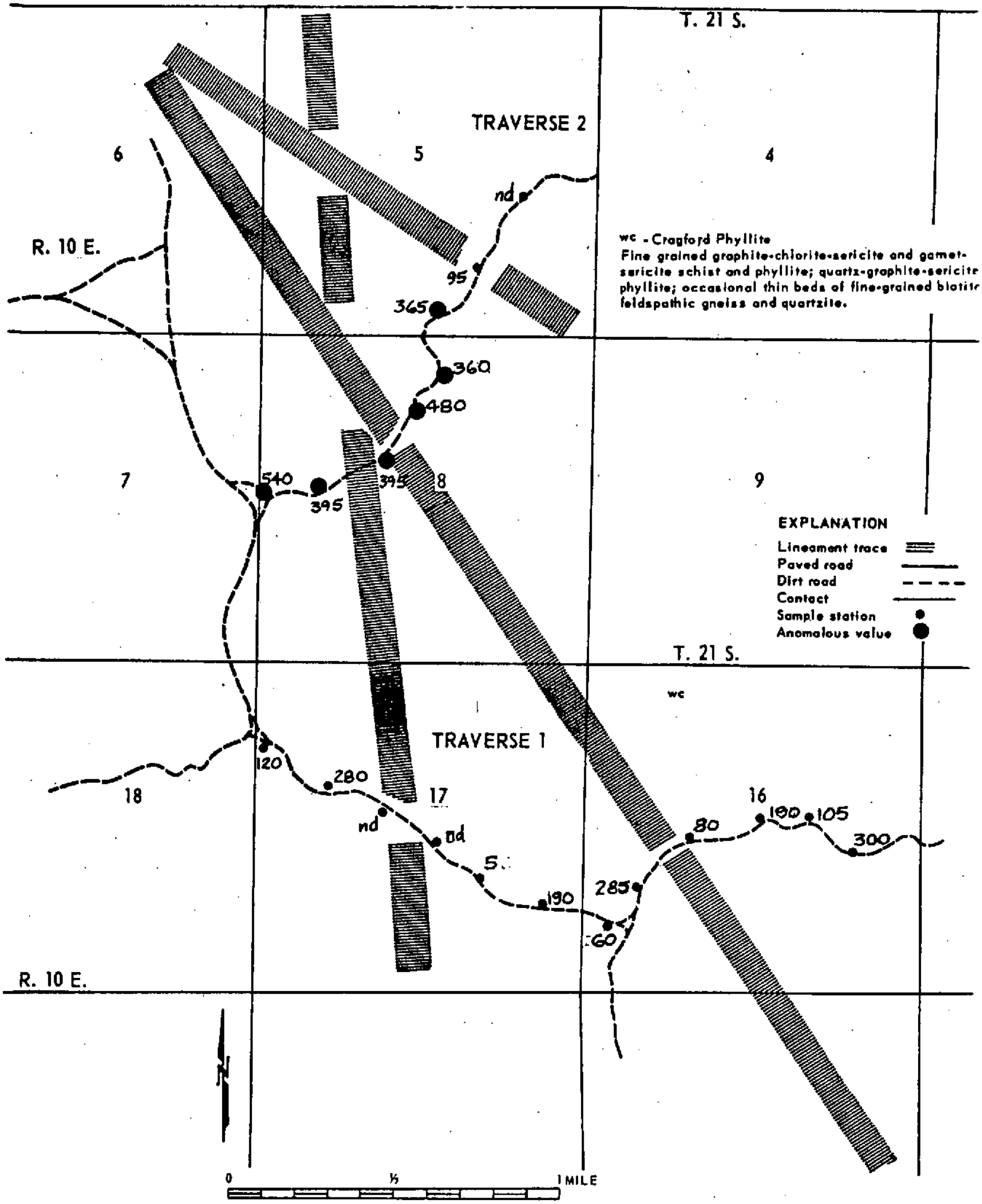


Figure 105. Area 5, south Cragford.
Antimony concentrations in parts per million.

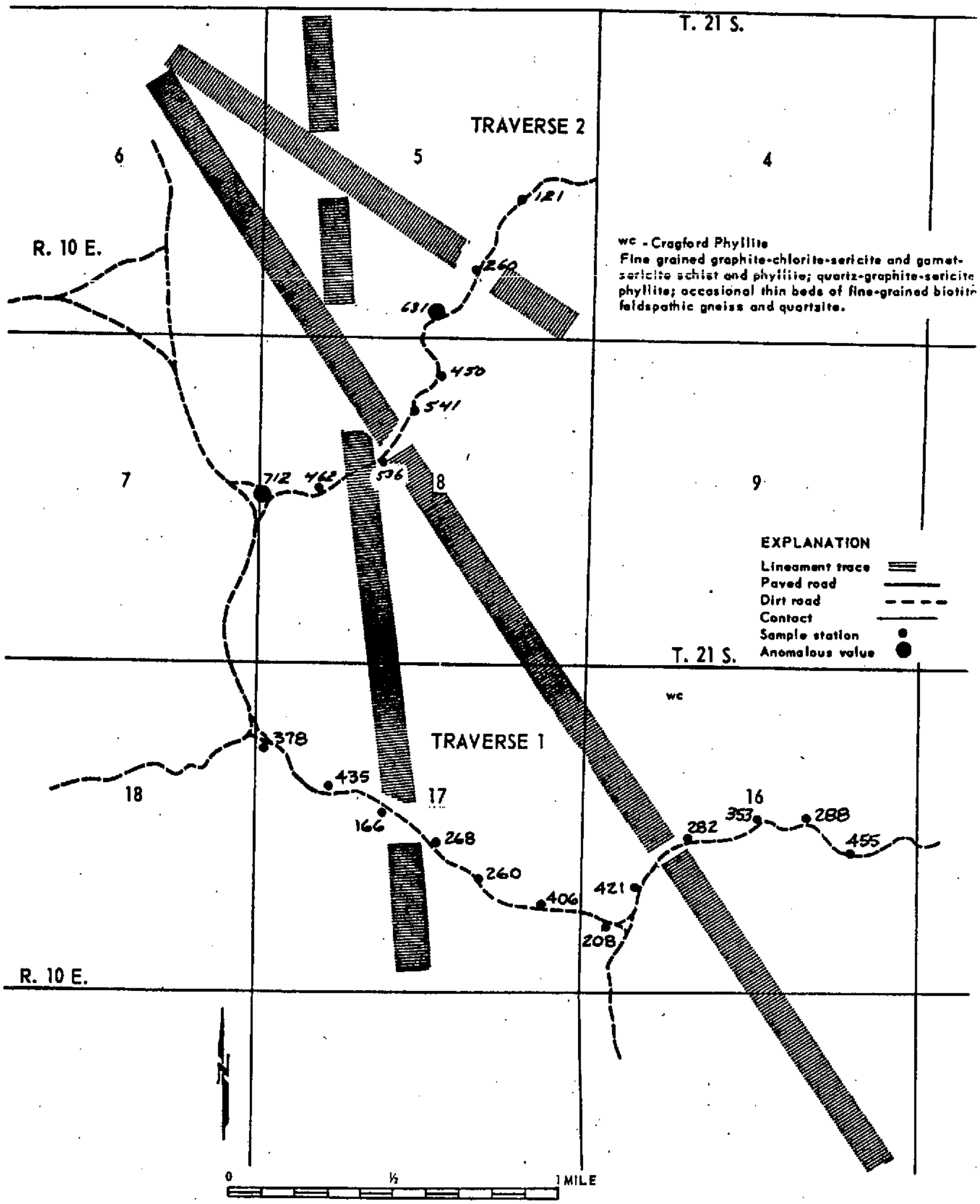


Figure 106. Area 5, south Cragford.
Total metal concentrations in parts per million.

Antimony

Antimony values range from none detected to 540 ppm. Threshold value was estimated to be 350 ppm based largely on the uniform concentration of the three rock analyses. The extreme and erratic distribution of values is believed to be the result of differential leaching of antimony from the soil. Values exceeding 400 ppm may represent primary concentration. Six values exceeding threshold are located on traverse 2 bracketing the intersection of the two lineaments (fig. 105).

Total Metals

Total metal values range from 121 ppm to 712 ppm. Threshold was determined to be the sum of thresholds of each element and is 582 ppm. Two values exceed this, however, no significance is attached to this because the values are so greatly influenced by the leaching of antimony (fig. 106).

Summary

A weak positive correlation seems to exist between higher copper concentration in soils and positions of lineaments. Molybdenum, lead, zinc, and antimony exhibit slight increases in some places near lineaments or the intersection. The distribution of cadmium values shows no apparent relationship to lineaments.

Central Cragford Area

The central Cragford area lies just over a mile to the east and north of Cragford in sections 18, 19, 20, 29, 30, and 31 of T. 20 S., R. 10 E. and section 25 of T. 20 S., R. 9 E. Most of the rock in this area is the Cragford Phyllite of the

Wedowee Group and a minor amount of Almond Trondhjemite also occurs (Neathery and Reynolds, 1974). Traverses were run on most passable roads in the mineralized area in an effort to obtain the closest possible control. Samples were collected at intervals of 0.1 and 0.2 miles (fig. 107) and the results of these analyses are presented in table 15.

Copper

Copper values in the phyllite range from 21 ppm to 131 ppm. Threshold is estimated to be 90 ppm and is exceeded by 6 values. Two of these show a close spatial relationship to the lineaments (fig. 108).

Five samples were collected from the granitic rocks. These are too few to permit any definite conclusions to be drawn, however, the two highest values bracket the trace of the lineament.

Molybdenum

Molybdenum values in the phyllite range from none detected to 20 ppm. One value exceeds the estimated threshold of 15 ppm. This is too few to permit any conclusions to be drawn (fig. 109).

Three of the 5 samples collected from the granitic rocks contain detectable amounts of molybdenum. However, no pattern is apparent and no conclusions are warranted due to the limited number of samples.

Lead

Lead values in the phyllite range from none detected to 140 ppm. Threshold is estimated to be 50 ppm and is exceeded by none values. One anomaly

Table 15
Chemical Analyses of Soils (in parts per million)
Central Cragford Area

Station No.	Cu	Mo	Pb	Zn	Cd	Sb	Total
T-3 1	92.5	ND	ND	107.0	2.0	ND	220
2	131.0	ND	75	82.0	5.5	ND	294
3	77.5	ND	ND	75.0	4.0	ND	156
4	58.0	ND	75	53.0	8.5	ND	194
5	44.5	ND	20	71.5	3.5	80	202
6	41.0	ND	15	69.5	2.5	ND	128
7	66.0	ND	ND	100.5	1.5	ND	168
8	31.0	10	15	53.0	1.5	265	376
9	47.5	ND	20	91.5	ND	145	304
10	59.5	20	20	80.5	ND	265	445
11	61.0	10	30	61.0	2.5	170	334
12	36.5	ND	15	64.5	3.0	230	349
13	23.5	ND	30	77.5	9.0	ND	140
14	30.0	ND	25	56.5	9.0	165	286
15	23.0	ND	ND	105.0	6.0	ND	128
16	65.5	ND	25	101.5	ND	90	282
17	45.0	ND	10	71.0	0.5	190	316
18	60.0	5	ND	70.5	ND	205	340
19	115.5	ND	15	68.0	3.0	185	386
20	79.5	ND	5	74.5	8.0	315	482

Station No.	Cu	Mo	Pb	Zn	Cd	Sb	Total
T-3 21	55.0	ND	25	57.5	ND	360	498
22	57.5	ND	80	63.5	4.5	180	385
23	63.5	ND	ND	61.0	2.0	ND	126
24	65.0	ND	ND	59.5	0.5	115	240
25	52.0	ND	10	76.5	2.0	85	226
26	46.5	ND	ND	64.0	ND	10	120
27	39.5	ND	ND	70.5	ND	5	115
28	54.5	ND	15	84.0	0.5	40	194
29	68.0	ND	140	71.5	0.5	ND	280
30	90.0	ND	65	74.5	5.0	ND	234
31	39.5	ND	40	84.0	1.0	55	220
32	33.5	ND	ND	58.5	3.5	ND	96
33	74.5	ND	25	74.0	3.0	ND	176
34	52.0	ND	15	62.5	8.0	ND	138
35	73.5	ND	30	97.5	9.0	240	450
36	50.5	ND	20	108.5	7.0	35	221
37	31.5	ND	40	61.5	4.0	ND	137
38	59.0	ND	15	85.5	1.5	60	221
39	86.5	ND	100	64.5	4.0	ND	255
40	57.0	ND	ND	63.5	ND	165	286

Station No.	Cu	Mo	Pb	Zn	Cd	Sb	Total
T-3 41	91.5		100	73.0	1.5	105	371
42	73.5	10	40	78.5	ND	ND	202
43	48.5	ND	20	82.5	2.0	ND	153
44	49.5	ND	40	51.0	ND	160	300
45	64.5	5	ND	70.5	ND	45	185
46	21.0	ND	ND	59.0	ND	ND	80
47	42.0	ND	ND	72.5	ND	ND	114
48	36.5	ND	15	66.0	7.0	160	284
49	108.5	ND	30	85.5	3.5	ND	228
50	76.5	ND	40	70.5	6.5	180	374
51	82.5	ND	ND	75.0	ND	260	418
52	68.0	ND	40	72.5	4.5	105	290
53	86.5	ND	10	80.5	7.0	ND	175
54	66.5	ND	25	72.0	6.5	ND	170
55	45.5	ND	5	82.5	4.0	5	142
56	35.5	ND	30	44.5	6.5	125	242
57	56.0	ND	105	77.0	6.0	140	384
58	55.5	ND	60	56.0	1.5	65	238
59	39.0	ND	20	61.0	11.0	20	151
60	77.0	ND	95	70.5	8.5	50	301

Station No.	Cu	Mo	Pb	Zn	Cd	Sb	Total
T-3 61	36.0	ND	45	51.0	4.0	70	206
T-4 1	47.0	ND	10	68.5	3.0	100	256
2	2.5	15	ND	52.5	6.5	175	252
3	26.0	ND	15	78.5	8.0	176	304
4	28.0	25	ND	65.5	3.5	265	387
5	7.5	15	ND	126.0	3.5	265	417
6	1.0	ND	25	87.5	3.0	170	286

Analyst: G. Thomas, Geological Survey of Alabama

lies near a lineament (fig. 10).

Lead was detected in two of the five samples collected from the granitic rock. No conclusion is believed warranted from these few samples.

The distribution of lead in the soils suggests no positive correlation with lineaments.

Zinc

Zinc content of soils collected over phyllite ranges from 44.5 ppm to 108.5 ppm. Threshold is estimated to be 100 ppm and is exceeded by five values. Four of these samples lie near to lineaments, however, the low magnitude of the anomalies and the overall distribution pattern of values do not suggest an association with lineaments (fig. 111).

One of the five samples collected from the granitic rock contains an anomalous quantity of zinc, but lies far from the lineaments.

Cadmium

Cadmium from the phyllite ranges from none detected to 11.0 ppm. Eight values exceed the threshold value estimated to be 7.5 ppm. Four of the anomalous samples occur near lineaments (fig. 112).

One of the five samples from the granitic rocks contains an anomalous concentration of cadmium. This sample is adjacent to the trace of the lineament.

The distribution of cadmium values seems to suggest an increase in cadmium near some lineaments in some places.

Antimony

Antimony content of the soil samples from the phyllite ranges from

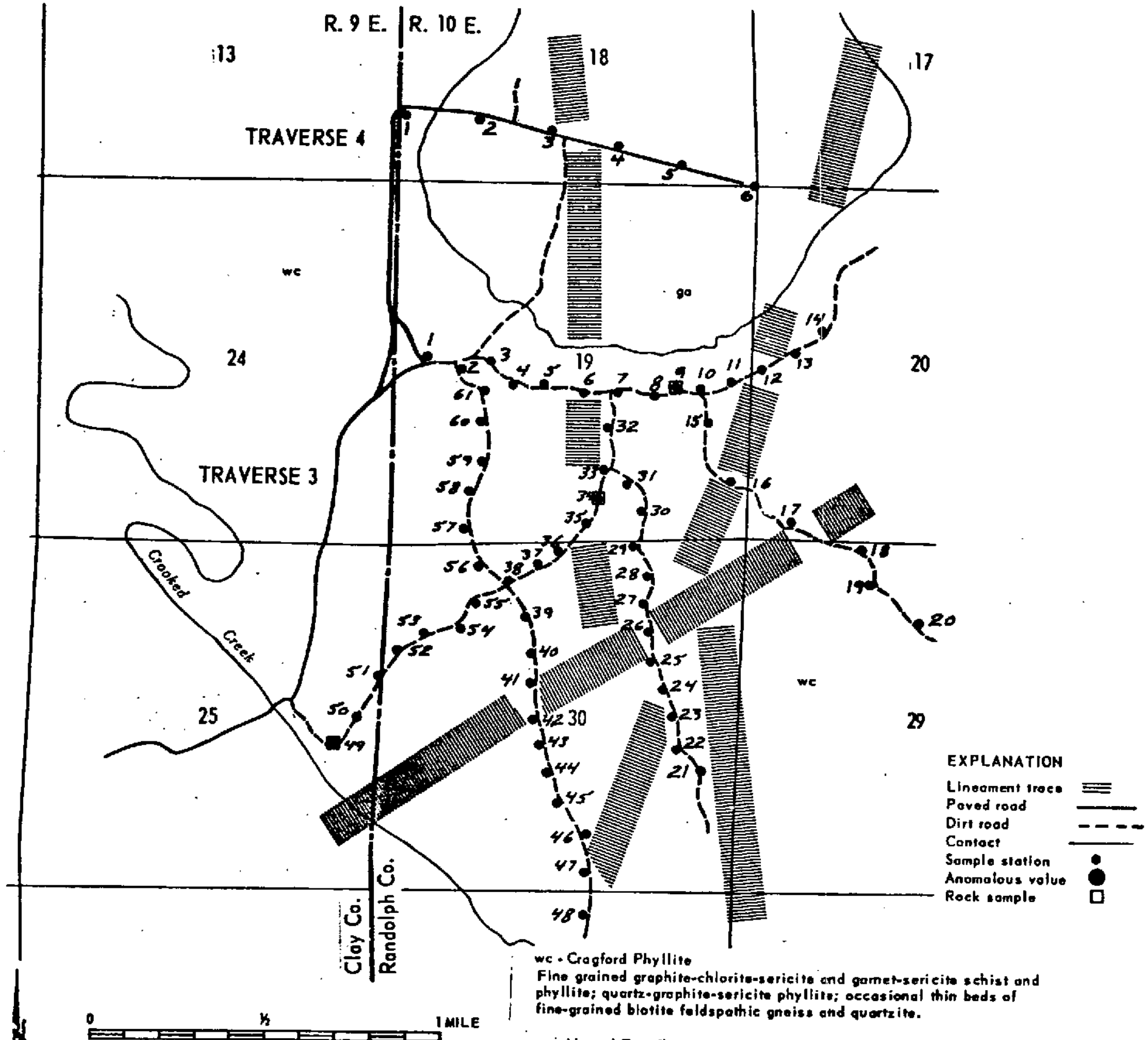


Figure 107. Area 5, central Cragford. Sample station numbers.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.

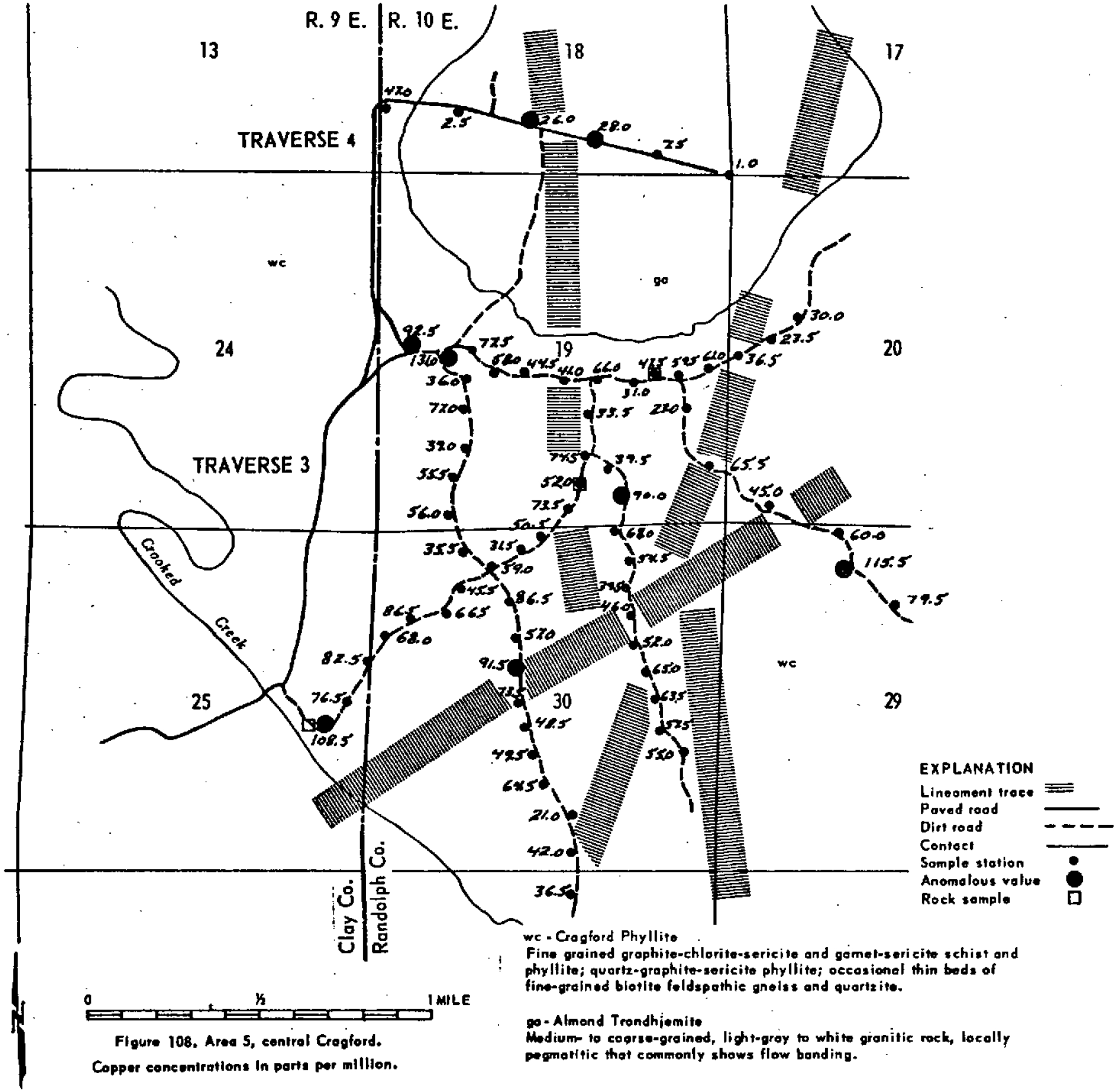
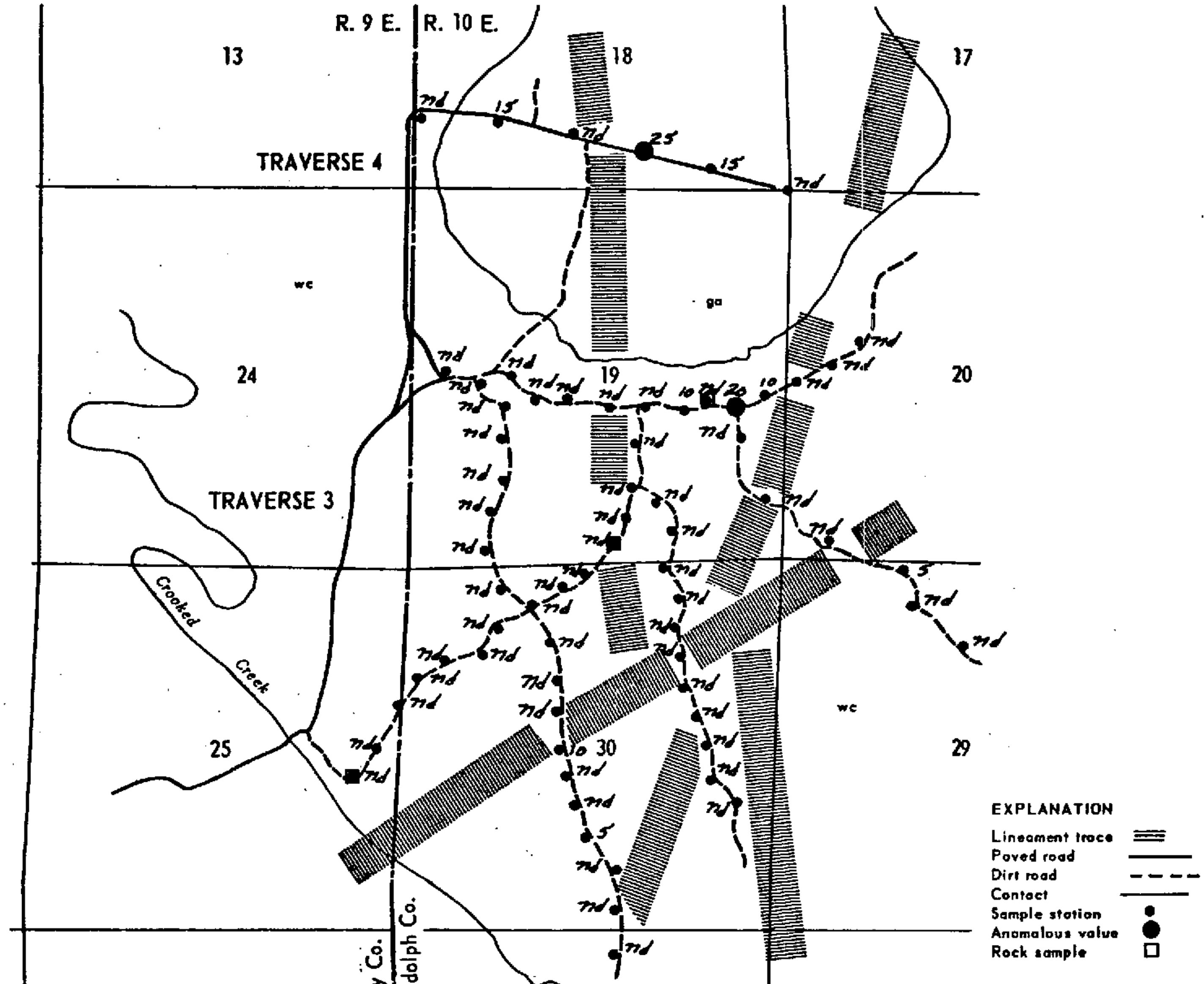


Figure 108. Area 5, central Cragford.
Copper concentrations in parts per million.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.



0 ½ 1 MILE

Figure 109. Area 5, central Cragford.
Molybdenum concentrations in parts per million.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.

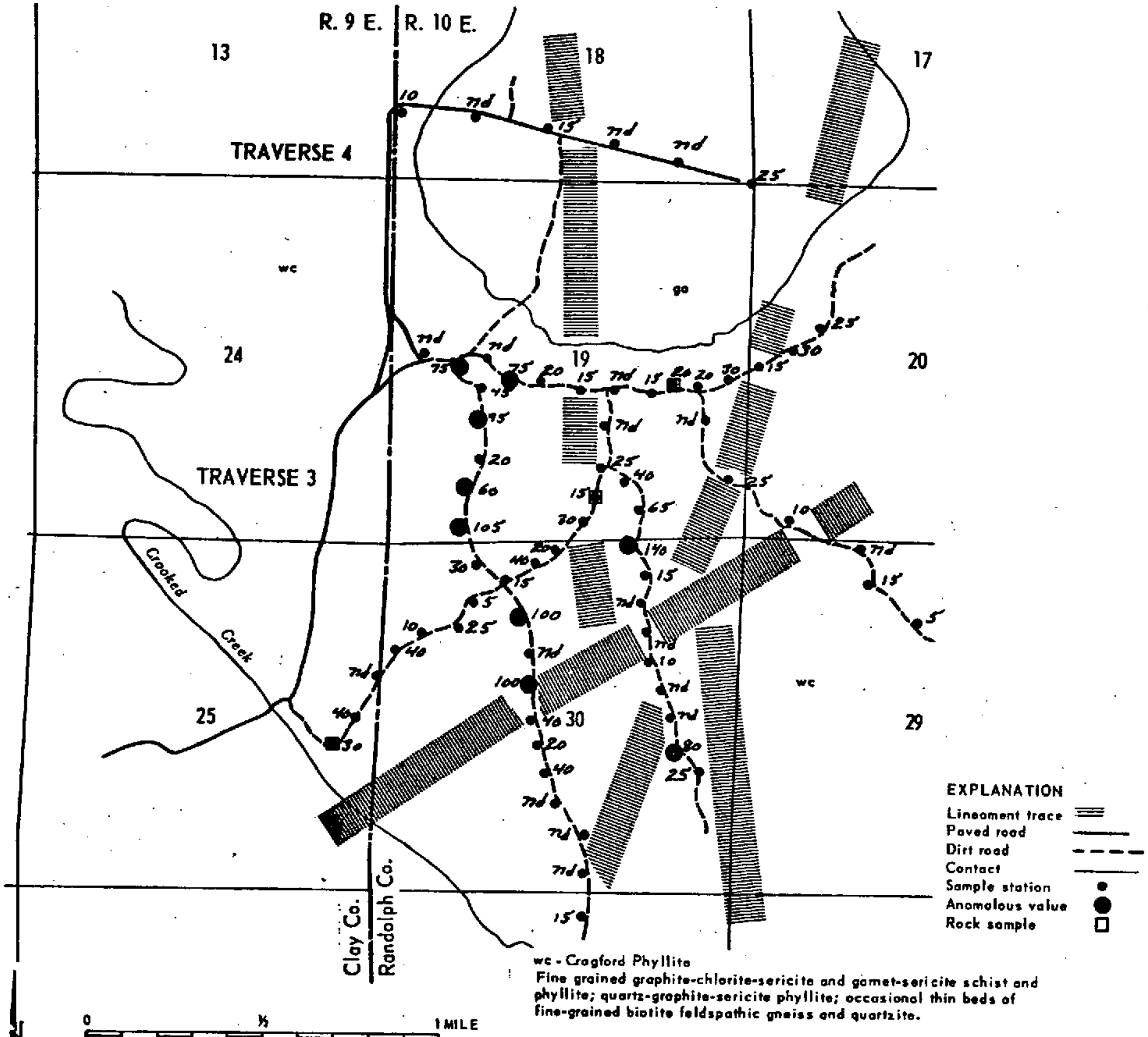


Figure 110. Area 5, central Cragford.
Lead concentrations in parts per million.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.

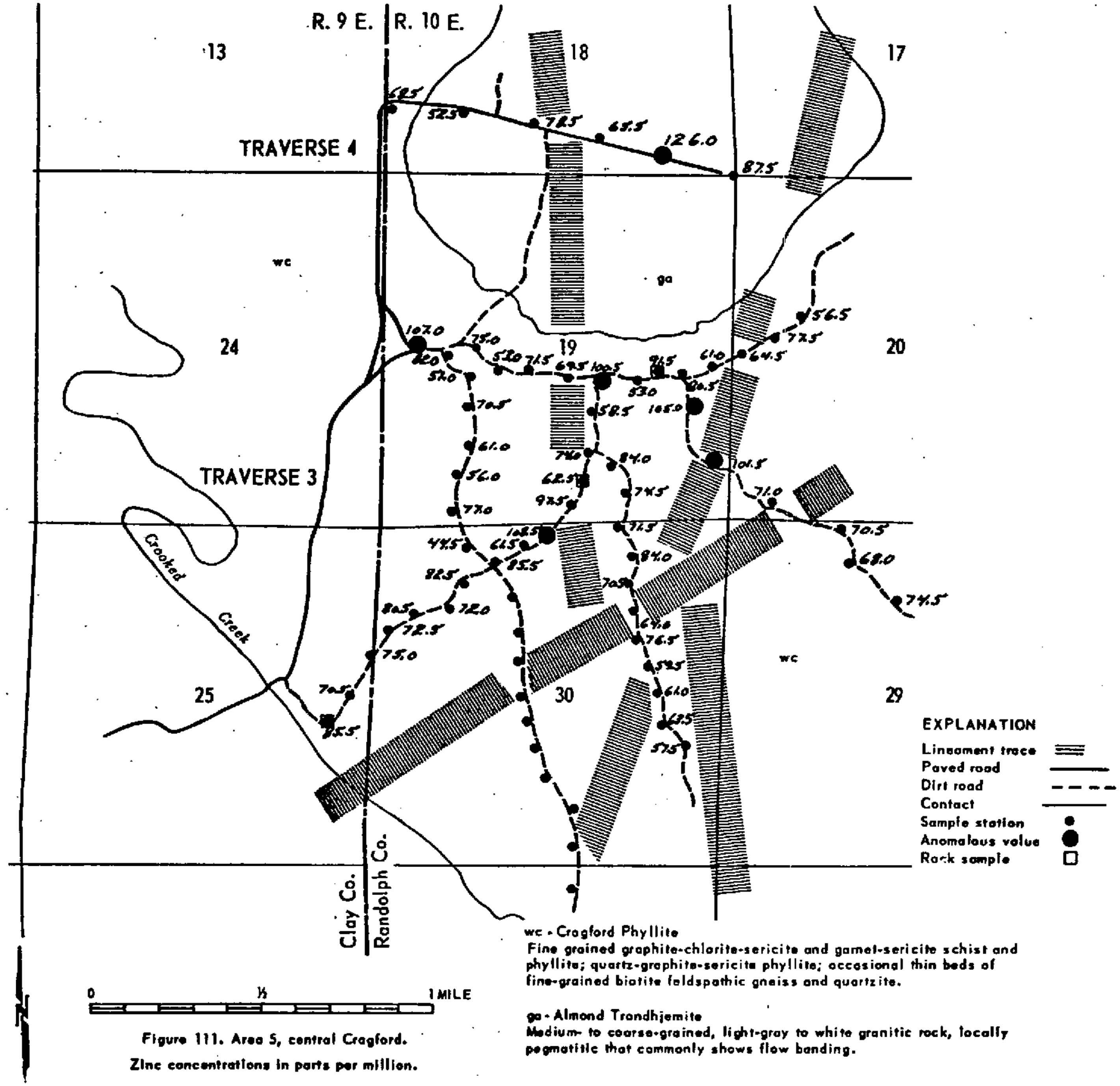


Figure 111. Area 5, central Cragford.
Zinc concentrations in parts per million.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.

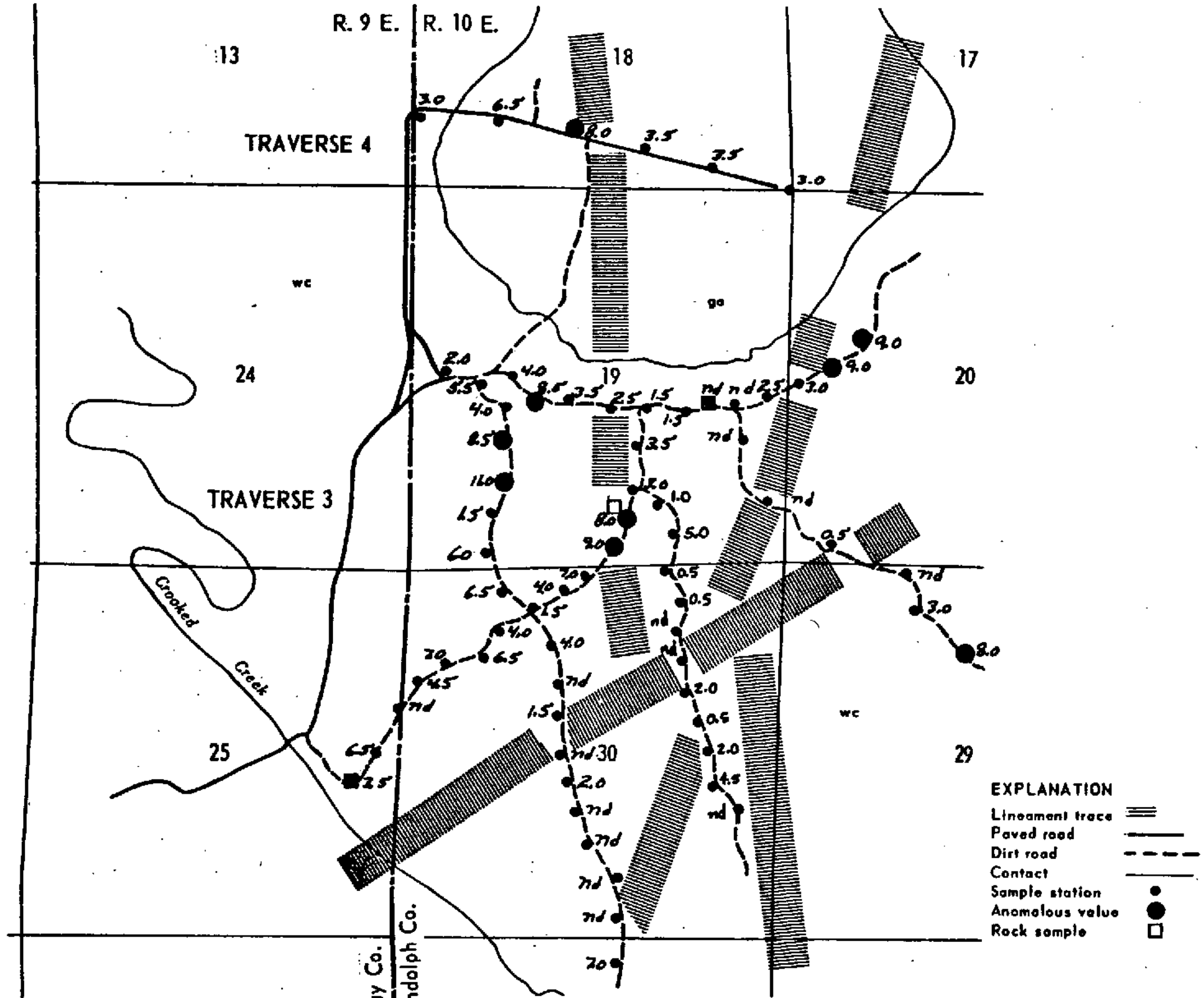


Figure 112. Area 5, central Cragford. Cadmium concentrations in parts per million.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.

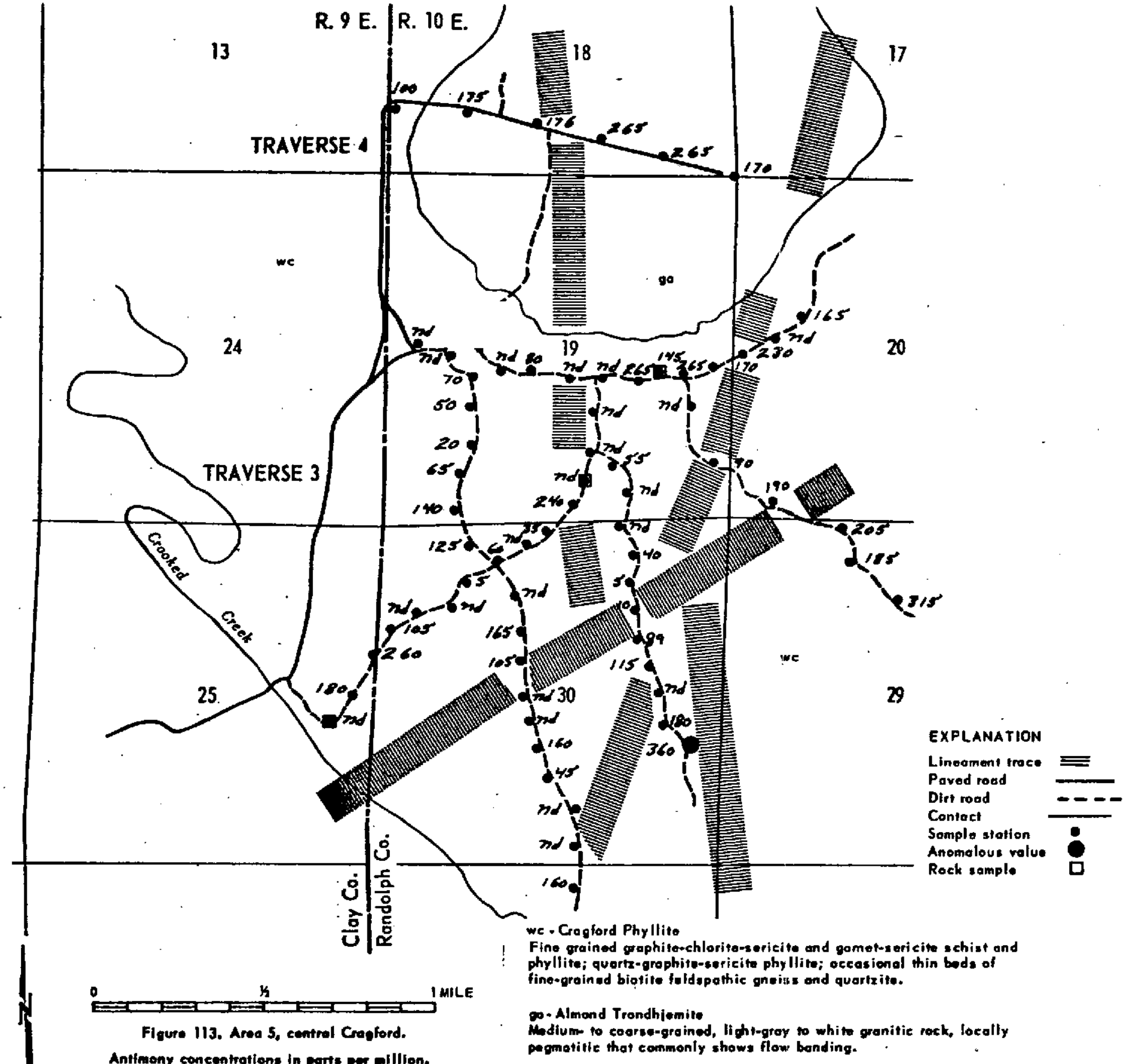


Figure 113. Area 5, central Cragford.
Antimony concentrations in parts per million.

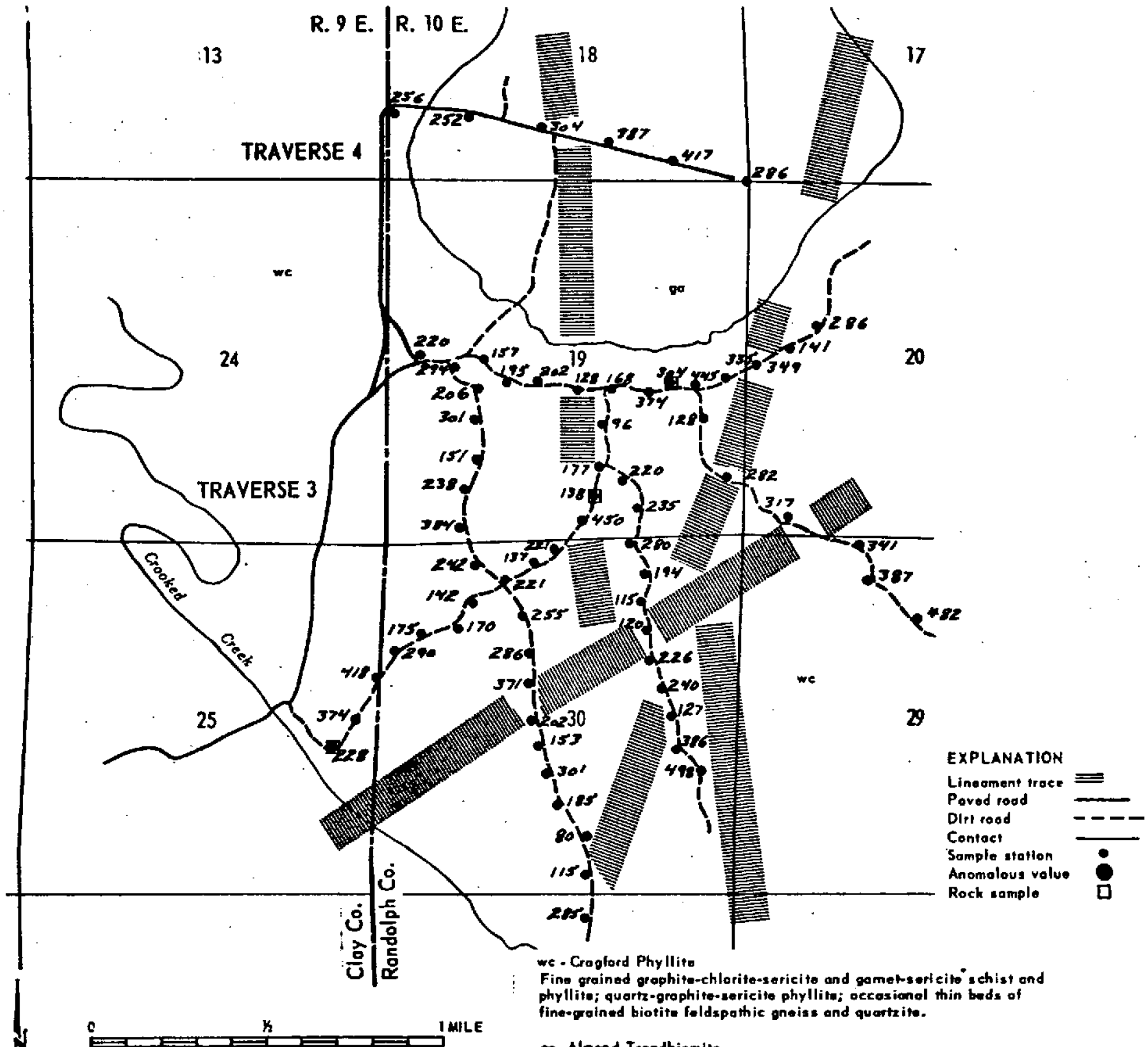


Figure 114. Area 5, central Cragford.

Total metal concentrations in parts per million.

wc - Cragford Phyllite
Fine grained graphite-chlorite-sericite and garnet-sericite schist and phyllite; quartz-graphite-sericite phyllite; occasional thin beds of fine-grained biotite feldspathic gneiss and quartzite.

ga - Almond Trondhjemite
Medium- to coarse-grained, light-gray to white granitic rock, locally pegmatitic that commonly shows flow banding.

none detected to 360 ppm. Threshold was placed at 350 ppm largely because of the uniform concentration of antimony in the three rock samples. The variation is believed to reflect differential leaching of antimony from the soils. No relationship with lineaments is apparent (fig. 113).

Total Metals

Total metal values range from 80 ppm to 498 ppm in the phyllites and from 252 ppm to 417 ppm in the granitic rocks. The sum of thresholds is 612 ppm and is not exceeded at any station. Again this distribution is thought to be of little value because of the great influence of antimony leaching (fig. 114).

Summary

Copper and cadmium contents of the soil exhibit a slight increase in the vicinities of some lineaments in some places. Molybdenum, lead, zinc and antimony distributions show no apparent relationships to the lineaments.

North Cragford Area

The northern traverse in the Cragford area was run as a reconnaissance examination of one of the lineaments extending north from the central Cragford area at its intersection with two other lineaments. The traverse is in section 6 of T. 20 S., R. 10 E. and section 1 of T. 20 S., R. 9 E. (fig. 115).

Rocks underlying this area are the Hackneyville Schist of the Wedowee Group with minor amounts of Bluff Springs Granite (Neathery and Reynolds, 1974).

Samples were collected along Alabama State Highway 48 at intervals of 0.2 miles. Seven soil samples were analyzed and the results are presented in table 16. No fresh rock samples were collected from this area.

Seven soil samples are insufficient to establish background and threshold values, consequently only general trends of the distribution of values will be pointed out.

Copper

Copper values range from 2.0 ppm to 54.5 ppm. Higher values are generally located near the lineament intersection in the schist and the two samples from the granite suggest a low background (fig. 116).

Molybdenum

Molybdenum was detected in one sample which lies on the trace of a lineament (fig. 117).

Lead

Lead values range from none detected to 70 ppm. No pattern is discernible from this distribution (fig. 118).

Zinc

Zinc values range from 60.5 ppm to 71.0 ppm and as such are nearly constant across the traverse (fig. 119).

Cadmium

Cadmium values range from none detected to 5.5 ppm. No pattern is discernible from this distribution (fig. 120).

Antimony

Antimony values range from none detected to 200 ppm. The higher

Table 16
Chemical Analyses of Soils (in parts per million)
North Cragford Area

Station No.	Cu	Mo	Pb	Zn	Cd	Sb	Total Metal
1	2.0	ND	45	71.0	4.0	40	162
2	7.0	ND	ND	61.5	ND	5	74
3	36.5	15	40	60.5	5.5	180	338
4	40.5	ND	20	69.0	ND	200	330
5	22.5	ND	70	68.5	ND	ND	161
6	23.0	ND	ND	67.0	5.0	ND	95
7	54.5	ND	65	62.5	5.5	ND	188

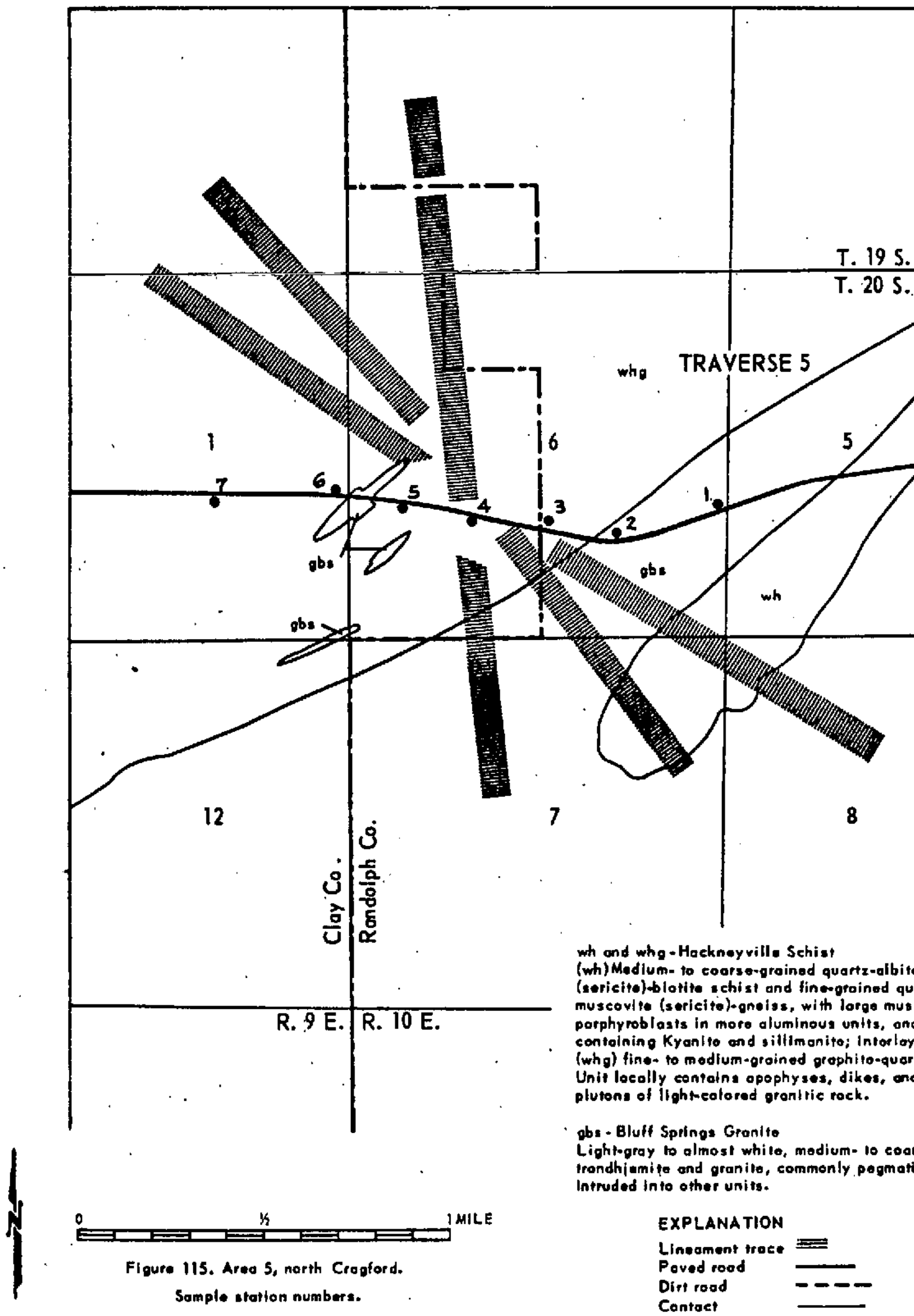
values occur near the intersection of the lineaments (fig. 121).

Total Metals

Totals range from 74 ppm to 338 ppm. Higher values are near the lineament intersection as result of the high antimony values and to a lesser extent copper (fig. 122).

Summary

Copper and antimony contents of the soils are highest in the vicinity of the lineament intersections. Molybdenum, lead, zinc and cadmium in the soils show no apparent spatial relationships to the lineaments.



wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitice where intruded into other units.

EXPLANATION
Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value

Figure 115. Area 5, north Cragford.
Sample station numbers.

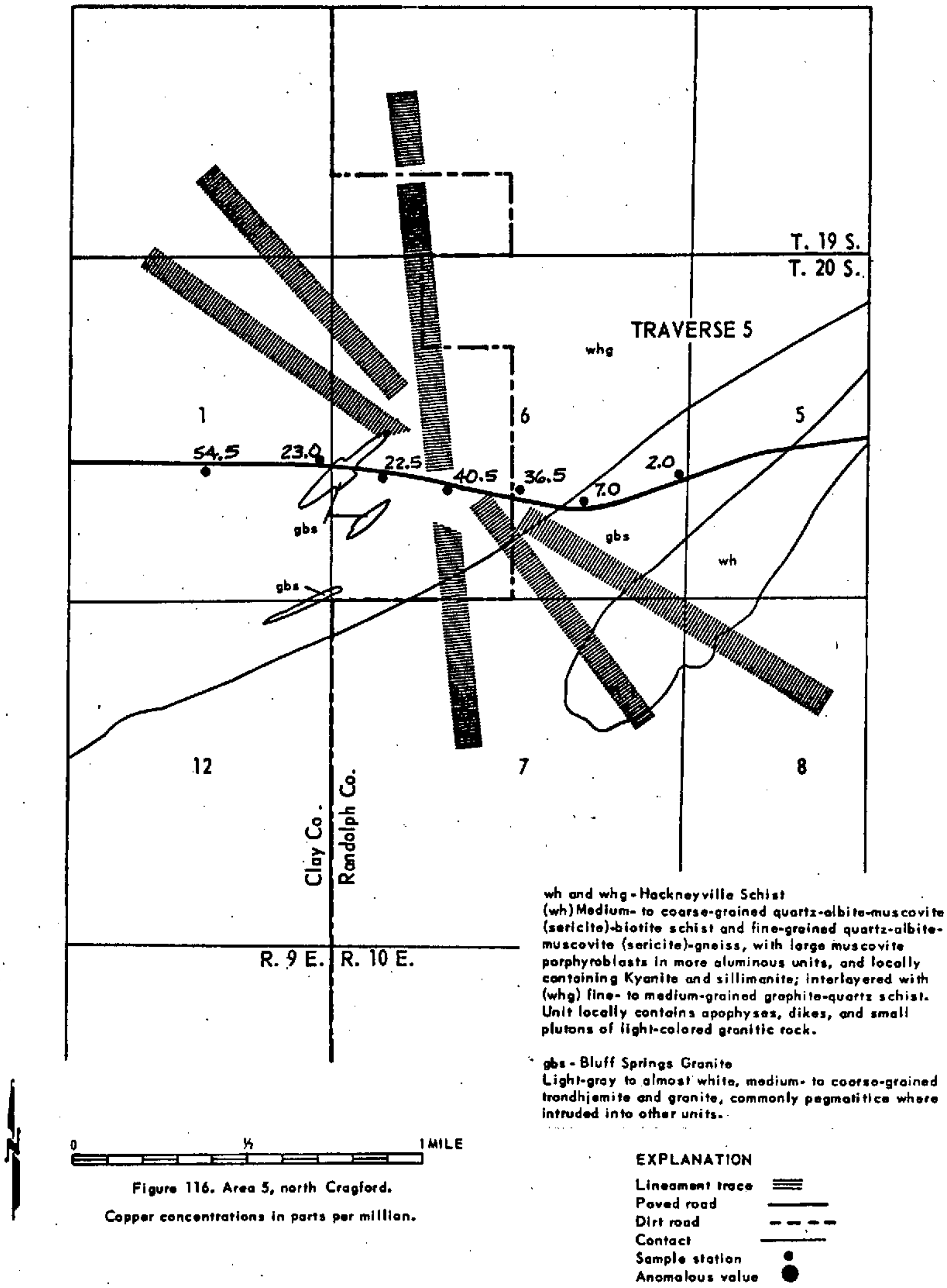
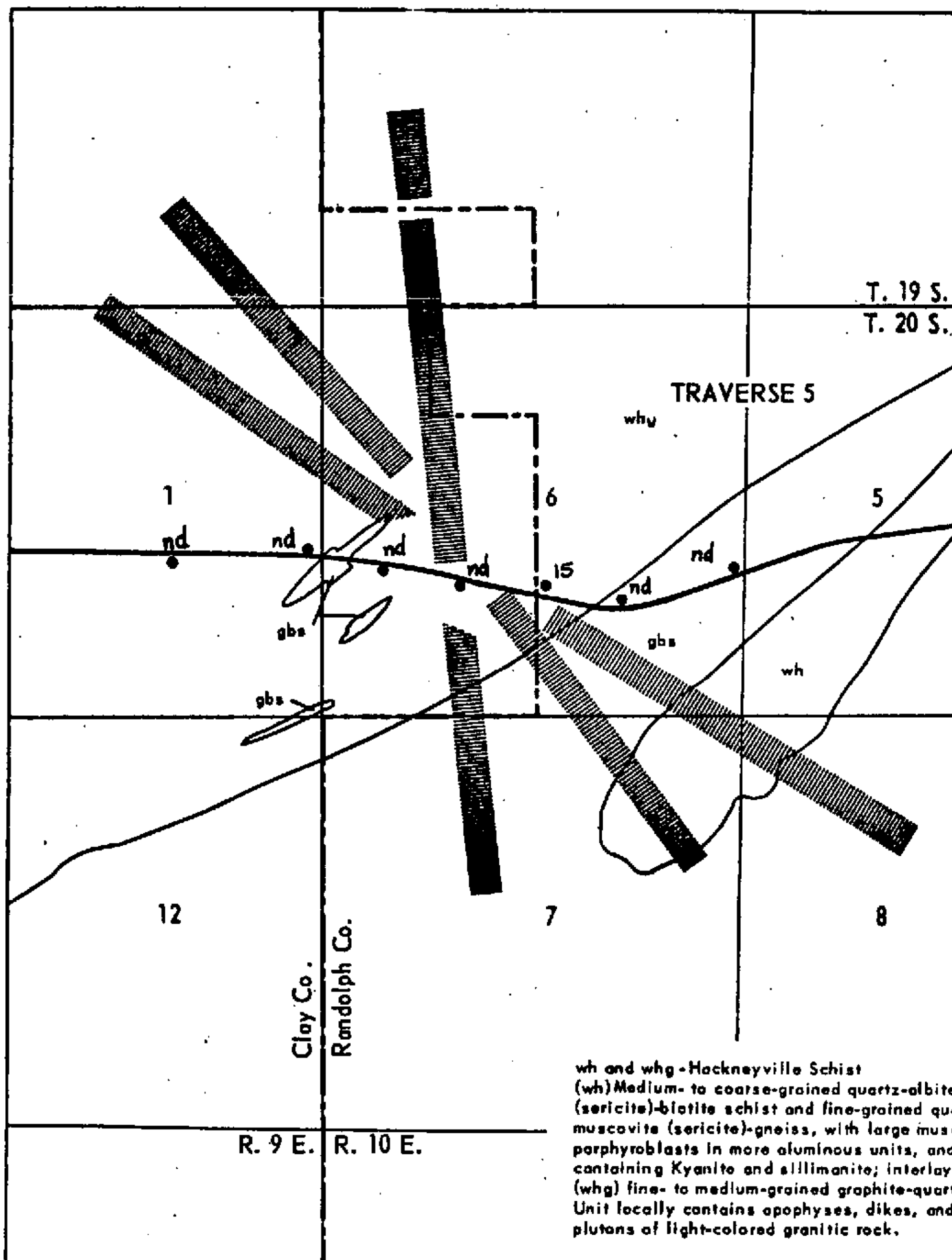


Figure 116. Area 5, north Cragford.

Copper concentrations in parts per million.



wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitice where intruded into other units.

0 ½ 1 MILE

Figure 117. Area 5, north Cragford.
Molybdenum concentrations in parts per million.

EXPLANATION

Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value

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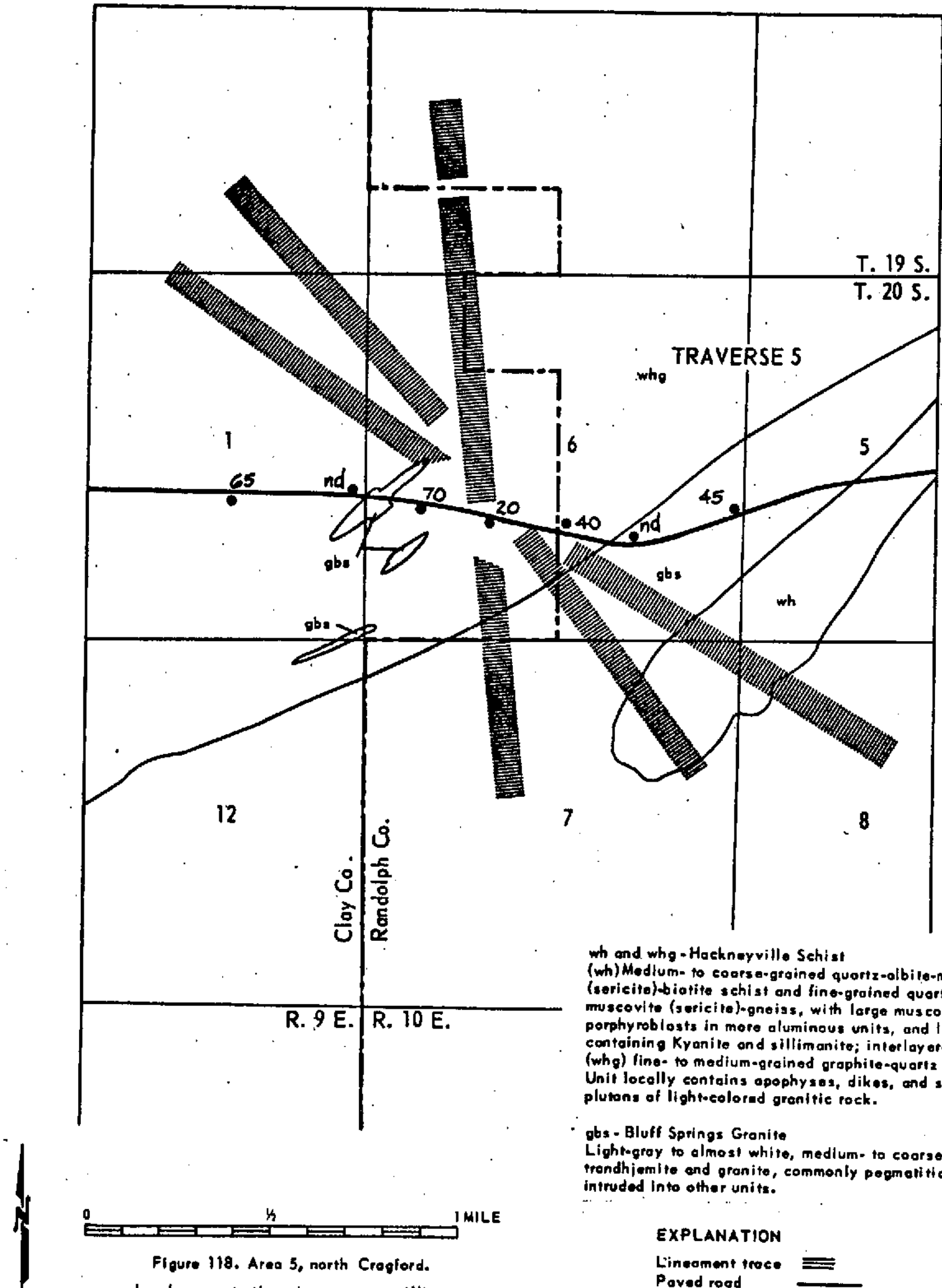
OF POOR QUALITY



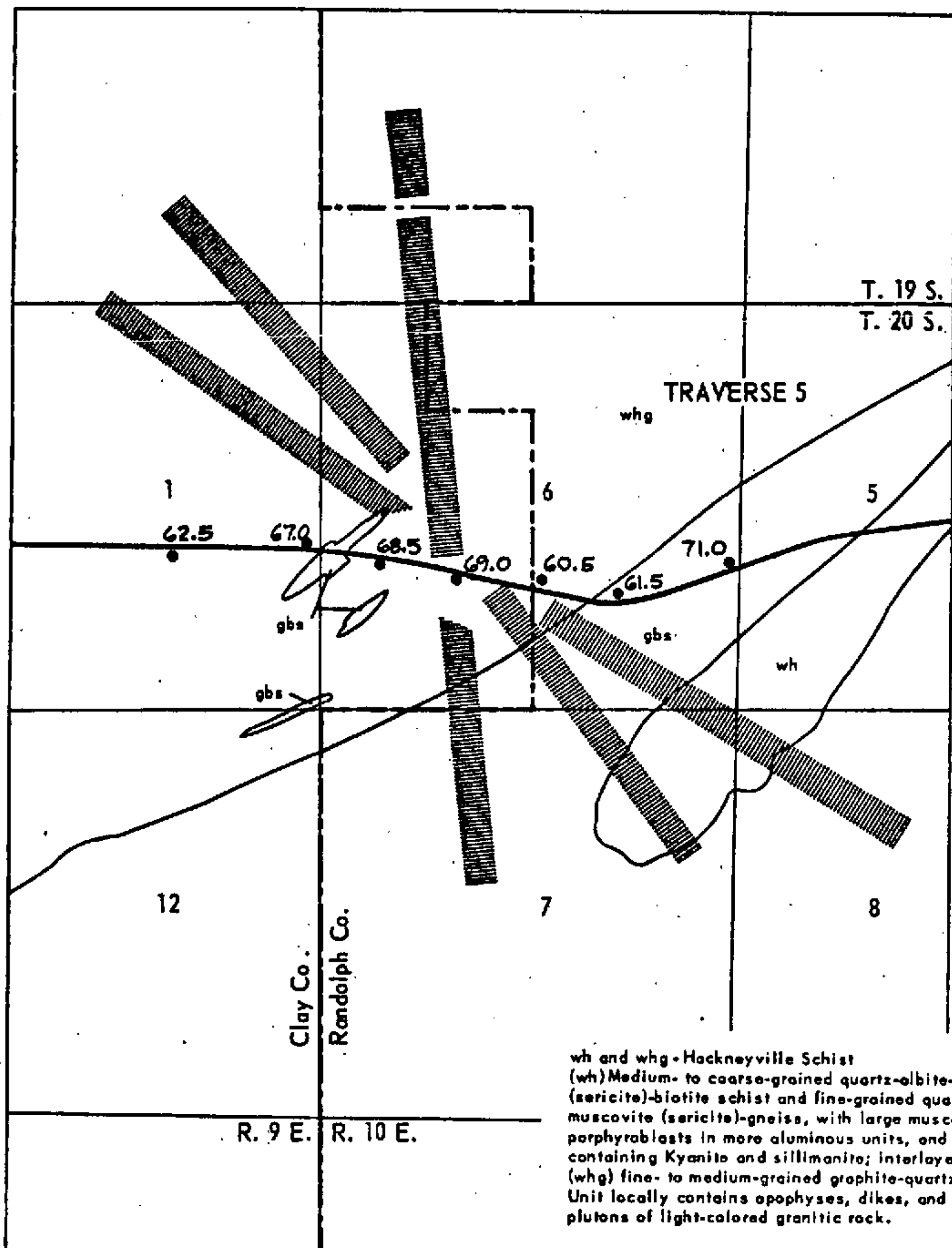
wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitice where intruded into other units.

Figure 118. Area 5, north Cragford.
Lead concentrations in parts per million.

EXPLANATION

Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value



wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitice where intruded into other units.

0 ½ 1 MILE

Figure 119. Area 5, north Cragford.
Zinc concentrations in parts per million.

EXPLANATION

Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value

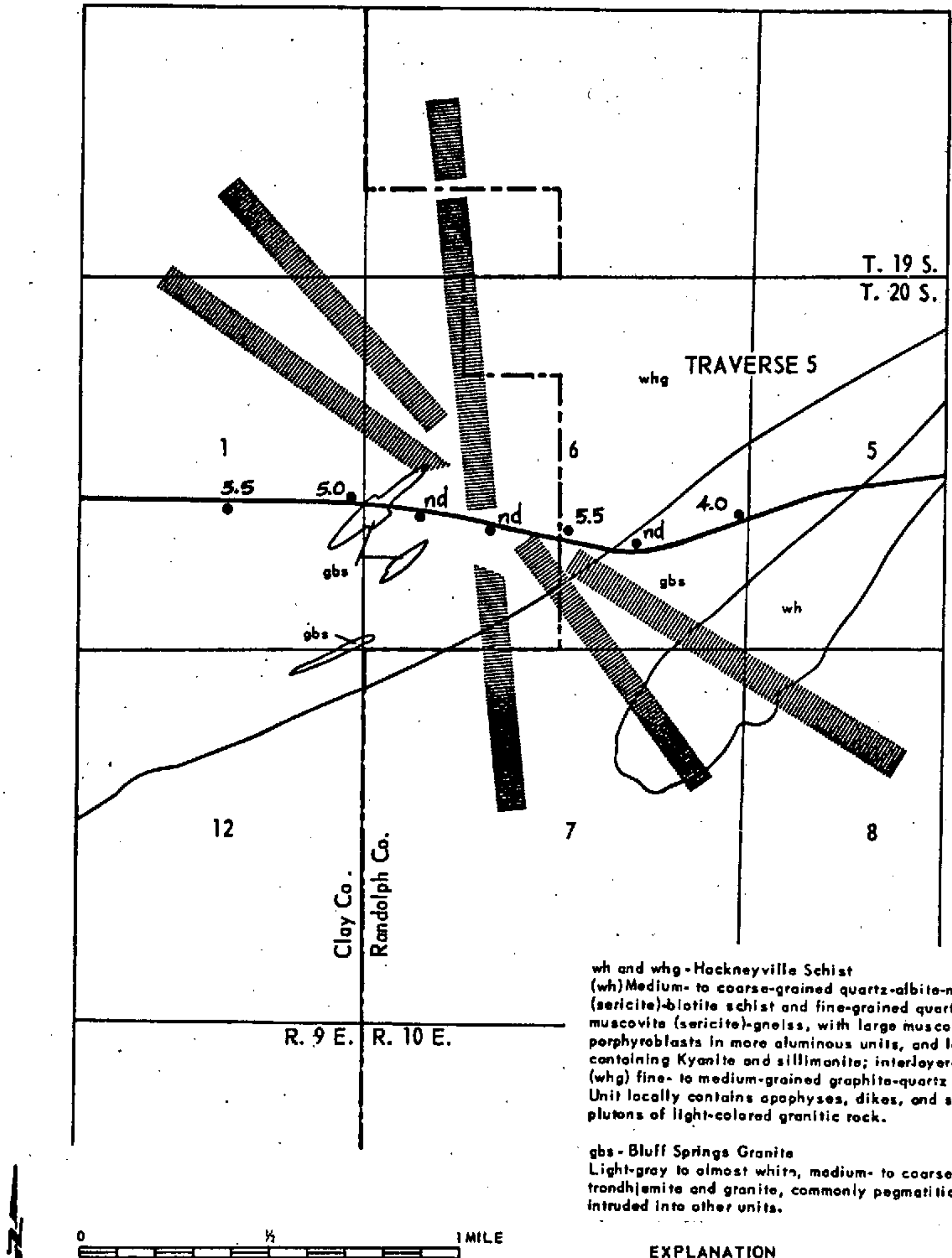


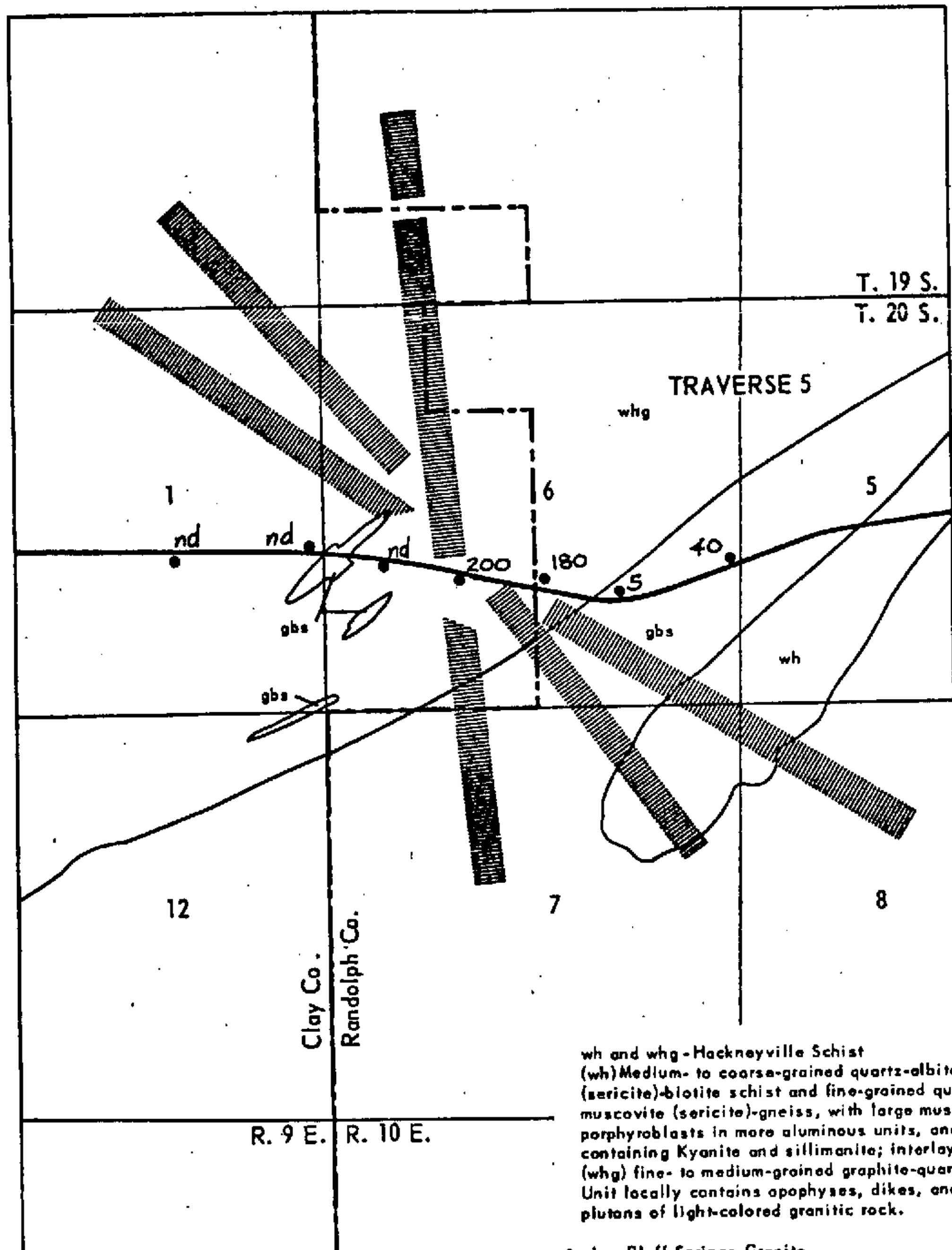
Figure 120. Area 5, north Cragford.
Cadmium concentrations in parts per million.

wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitice where intruded into other units.

EXPLANATION

Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value



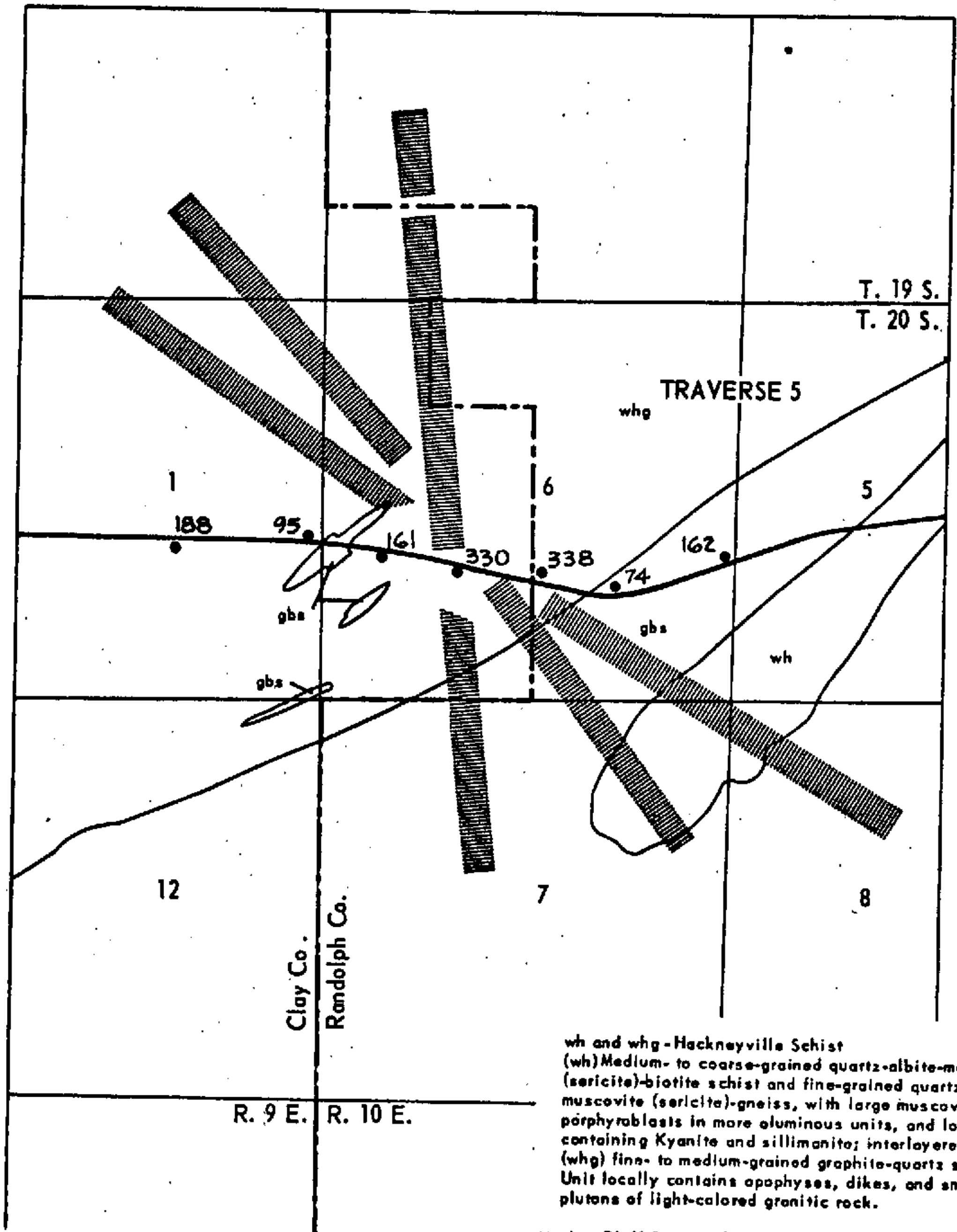
wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitice where intruded into other units.

0 ½ 1 MILE

Figure 121. Area 5, north Cragford.
Antimony concentrations in parts per million.

EXPLANATION
Lineament trace
Paved road
Dirt road
Contact
Sample station
Anomalous value
Rock sample



wh and whg - Hackneyville Schist
(wh) Medium- to coarse-grained quartz-albite-muscovite (sericite)-biotite schist and fine-grained quartz-albite-muscovite (sericite)-gneiss, with large muscovite porphyroblasts in more aluminous units, and locally containing Kyanite and sillimanite; interlayered with (whg) fine- to medium-grained graphite-quartz schist. Unit locally contains apophyses, dikes, and small plutons of light-colored granitic rock.

gbs - Bluff Springs Granite
Light-gray to almost white, medium- to coarse-grained trondhjemite and granite, commonly pegmatitic where intruded into other units.

0 ½ 1 MILE

Figure 122. Area 5, north Cragford.
Total metal concentrations in parts per million.

EXPLANATION

Lineament trace	
Paved road	
Dirt road	
Contact	
Sample station	•
Anomalous value	●
Rock sample	□

Area 6: Shoals Creek Area, Lauderdale County

Soil sampling in the Shoals Creek sampling area was done in a zone of intersection of two apparent lineaments (figure 123). A NW trending lineament appears on ERTS imagery as a relatively narrow zone which intersects a wider lineament zone approximately $1\frac{1}{2}$ miles north of the confluence of Shoals Creek and the Tennessee River.

Analysis of soil samples from this area did not include determination of cadmium or antimony. Lead concentrations were not determined for 19 of the samples.

Most samples from the Shoals Creek drainage valley (along the trace of the wide lineament) show relatively high concentration of zinc (Table 17). Such concentration might be normal for the highly residual soils of the drainage valley.

Samples 14-30 represent a traverse across the relatively narrow north-west trending lineament in T. 1 S., R. 10 W. Of these samples, samples 15-19, and 24 show relatively high values for zinc. Samples 31-38 represent a traverse across the narrow lineament in T. 2 S., R. 9 W. Sample 38 from this traverse shows a relatively high zinc concentration.

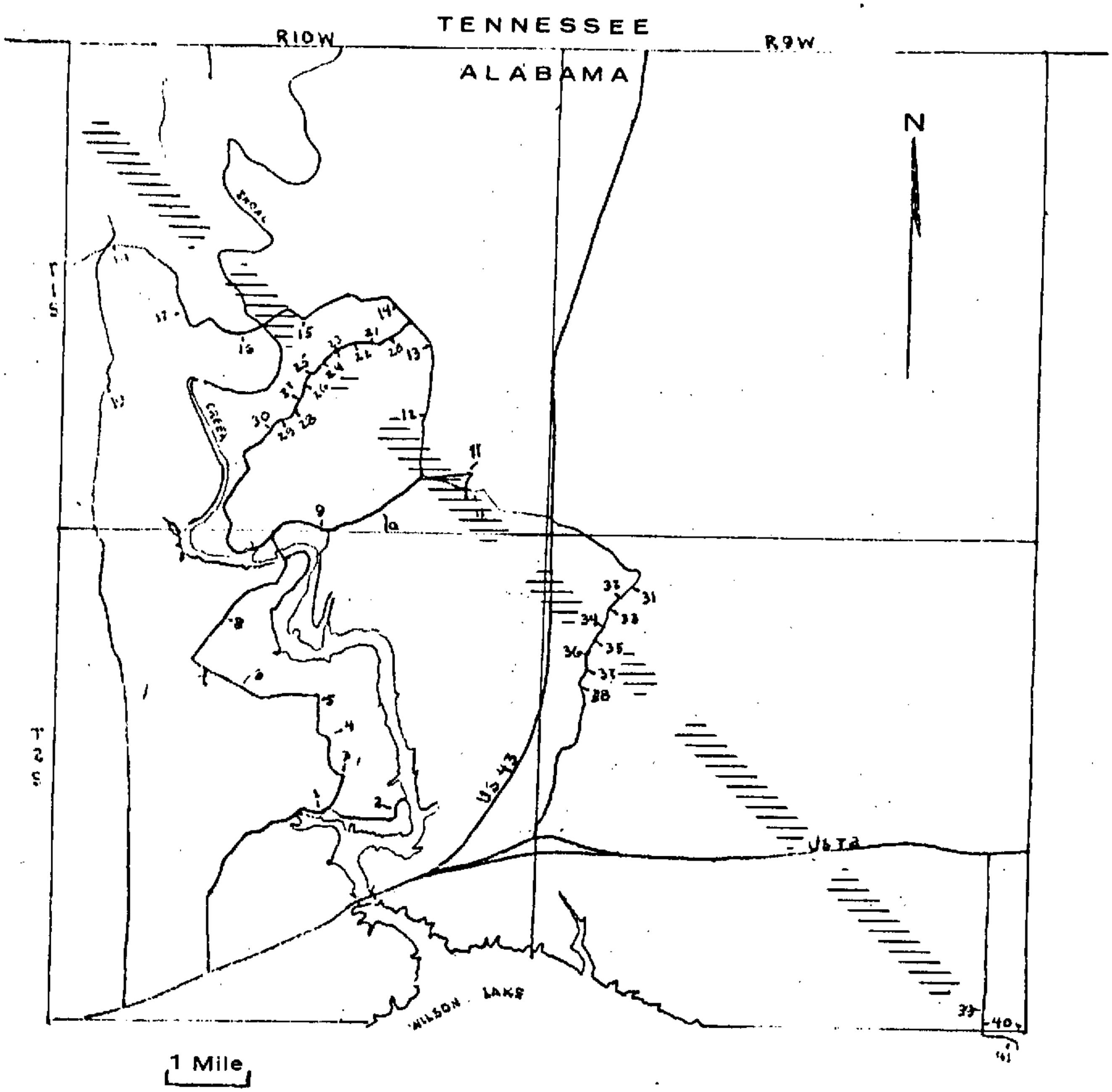


Figure 123. Area 6, Shoals Creek, Lauderdale County, Alabama

Table 17

Chemical Analyses of Soils (in parts per million)
Shoals Creek Area

Station No.	Cu	Mo	Pb	Zn
1	50	ND [1/]	--- [2/]	148
2	45	ND	---	133
3	60	ND	---	216
4	55	ND	---	129
5	50	ND	---	133
6	45	ND	---	122
7	50	ND	---	132
8	55	ND	---	198
9	55	ND	---	145
10	55	ND	---	249
11	60	ND	---	188
12	55	ND	---	148
13	55	ND	---	109
14	40	ND	---	82
15	40	ND	---	110
16	45	ND	---	101
17	45	ND	---	130
18	50	ND	---	120

1/ Not detected.

2/ Lead values not determined for samples 1-19.

Table 17 (Cont'd)

Station No.	Cu	Mo	Pb	Zn
19	60	ND	---	355
20	10	ND	35	26
21	15	ND	40	76
22	15	ND	40	34
23	10	ND	ND	37
24	25	ND	30	159
25	15	ND	70	55
26	30	ND	45	48
27	15	ND	ND	36
28	15	ND	15	88
29	15	ND	50	49
30	20	ND	35	52
31	25	ND	25	58
32	10	ND	50	7
33	15	ND	25	56
34	10	ND	25	36
35	ND	ND	25	27
36	10	ND	45	64
37	10	10	60	50
38	20	ND	60	186

Table 17 (Cont'd)

Station No.	Cu	Mo	Pb	Zn
39	10	ND	ND	150
40	10	ND	5	134
41	5	65	5	55

Area 7: Elk River Area, Limestone County

The area is traversed by a wide zone of northwest trending tonal alignments (Figure 124). Samples from across this lineament zone in vicinity of Elk River, Limestone County, generally show no amonalous metal concentration (Table 18). Sample 44 from this traverse shows zinc value of 148 ppm.

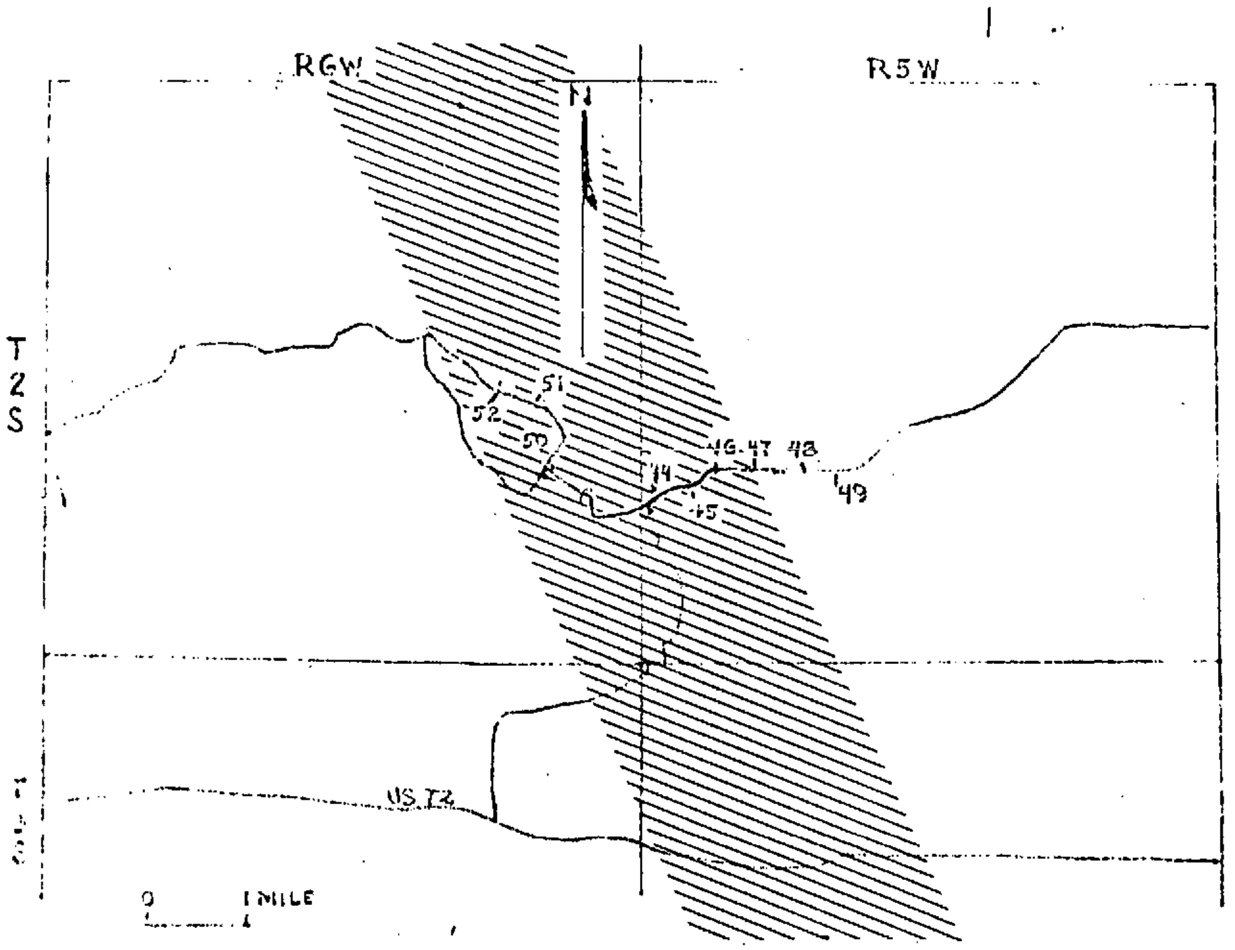


Figure 124. Area 7, Elk River Area, Limestone County, Alabama

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Table 18

Chemical Analyses of Soils (in parts per million)
Elk River Area

Station No.	Cu	Mo	Pb	Zn
44	20	ND	5	148
45	5	20	25	61
46	15	ND	25	82
47	15	45	55	47
48	15	ND	15	17
49	5	20	15	56
50	15	5	10	48
51	10	25	5	49
52	ND	40	10	42

CONCLUSIONS AND RECOMMENDATIONS

Most of the hydrothermal mineral deposits in the Valley and Ridge and the Piedmont Provinces of Alabama occur either along lineaments or near lineament intersections. In two of the areas of study, Harpersville and Leeds, lineaments appear to have exerted an influence over the type, localization and concentration of mineralization. Lesser influences were noted in the other areas. The lineaments investigated do not exhibit uniform metal concentrations along their strike but may exhibit locally high concentrations. This variation may be caused by lineaments passing through different or variable rock units. Whereas the type of host rock appears to be a factor in localization of mineralization, the type of lineament appears to be more important. Specifically, some lineaments appear to be "hot" and some "cold" in regard to mineralization or geochemical anomalies. The reasons for this are not clear. In order to resolve this problem it is recommended that geological and geophysical investigations be undertaken to discern the nature and character of the lineaments and that a more detailed geochemical investigation be made of the Harpersville and Leeds area as well as areas surrounding anomalies located by Smith, Lloyd, and Drahovzal (1973) employing a closely spaced grid sampling technique to more accurately delineate anomalies and their relationship to lineaments. In summary, whereas space acquired imagery cannot be used to directly locate mineralized zones, it is an important tool in defining areas of interest for earth-based investigation.

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HYDROLOGIC EVALUATION AND APPLICATION OF ERTS DATA

By

George F. Moravec
and
James D. Moore

Geological Survey of Alabama

INTRODUCTION

ERTS images have for the first time provided the hydrologist and hydrogeologist with a comprehensive regional look at the earth's surface. Hydrologic applications of ERTS images appear innumerable. The small scale broad coverage provides a regional and first look capability that is unexcelled. Large-scale drainage basins and whole systems of smaller-scale basins are contained on the image. The effects of geology, structure and geomorphology on development of drainage basins and the interaction of basins on one another are evident and real.

Many possible hydrologic applications of ERTS images were evaluated including: the quantitative inventory of surface water resources, mapping flood-prone areas, the attenuation of a flood crest by a drainage basin, and methods for evaluating ground-water resources. As with all scientific approaches certain conditions must be met to successfully evaluate a new technique, method, or application of a revolutionary data collecting tool. Most of the applications of ERTS data mentioned met with varying success not because the data failed to produce, but because of interference from other factors. In the case of one experiment designed by the author to evaluate flood-prone areas and to predict the attenuation of a flood crest by a drainage basin, poor weather conditions at the critical moment the satellite was overhead caused the necessary detail to be lost on the image. Within the time limits of this study the experiment could not be repeated; therefore, the study was unsuccessful. However, another study involving flood-prone area mapping was successfully carried out and is presented in this volume (Wielchowsky, 1974). As for the quantitative inventorying of surface water bodies, other investigators superseded the authors efforts. The evaluation of ground-water resources proved most promising and fruitful.

After evaluating many possible techniques and methods of applying ERTS data to ground-water resources evaluation, large-scale lineaments evident on ERTS images appeared to be the most significant with respect to ground-water occurrence. In some areas water is in short supply or exceedingly difficult to locate such as in limestone terranes and crystalline rock areas. Large-scale lineaments have been noted on ERTS images in many of these areas. By proving that a relationship between large-scale lineaments and ground-water occurrence exists, the hydrologist and geohydrologist would have a new and valuable tool with which to locate promising areas of high-yield water wells. Therefore, this investigation is directed at establishing this relationship using ERTS data.

THE RELATIONSHIP BETWEEN LARGE-SCALE LINEAMENTS AND GROUND-WATER HYDROLOGY USING ERTS IMAGES

Introduction

Lineaments on the earth's surface have been recognized as early as 1911 (Hobbs, 1911), and with the introduction of space-acquired imagery, much emphasis has been directed toward the study of linear features on the earth's surface. Lineaments are those long, narrow, relatively straight vegetation, soil tonal and drainage alignments visible on aerial photographs, mosaics and space-acquired images. Apparently the term lineament has been used to describe linear features ranging from a few miles long to continental dimensions. The origin of these features has been attributed to faults, fractures and major relief forms (Lattman and Nickelsen, 1958). If lineaments are the result of faulting and fracturing, then they may represent areas or zones of increased porosity and permeability in consolidated rock. Such zones have great significance in the accumulation and movement of fluids such as oil and water. It is the purpose of this study to evaluate the relationship between large-scale lineaments noted on ERTS-acquired imagery and ground-water hydrology. Previous work in Alabama evaluating hydrology and linear features include Sonderegger, 1970; Powell and others, 1970; Powell and LaMoreaux, 1971; Alverson, 1970; and Spigner, 1969.

The area selected for study was the Tennessee Valley and the Cumberland Plateau escarpment in Madison and Morgan Counties, Alabama (fig. 1). These areas are underlain by a thick sequence of carbonate rocks with clastic rocks capping the

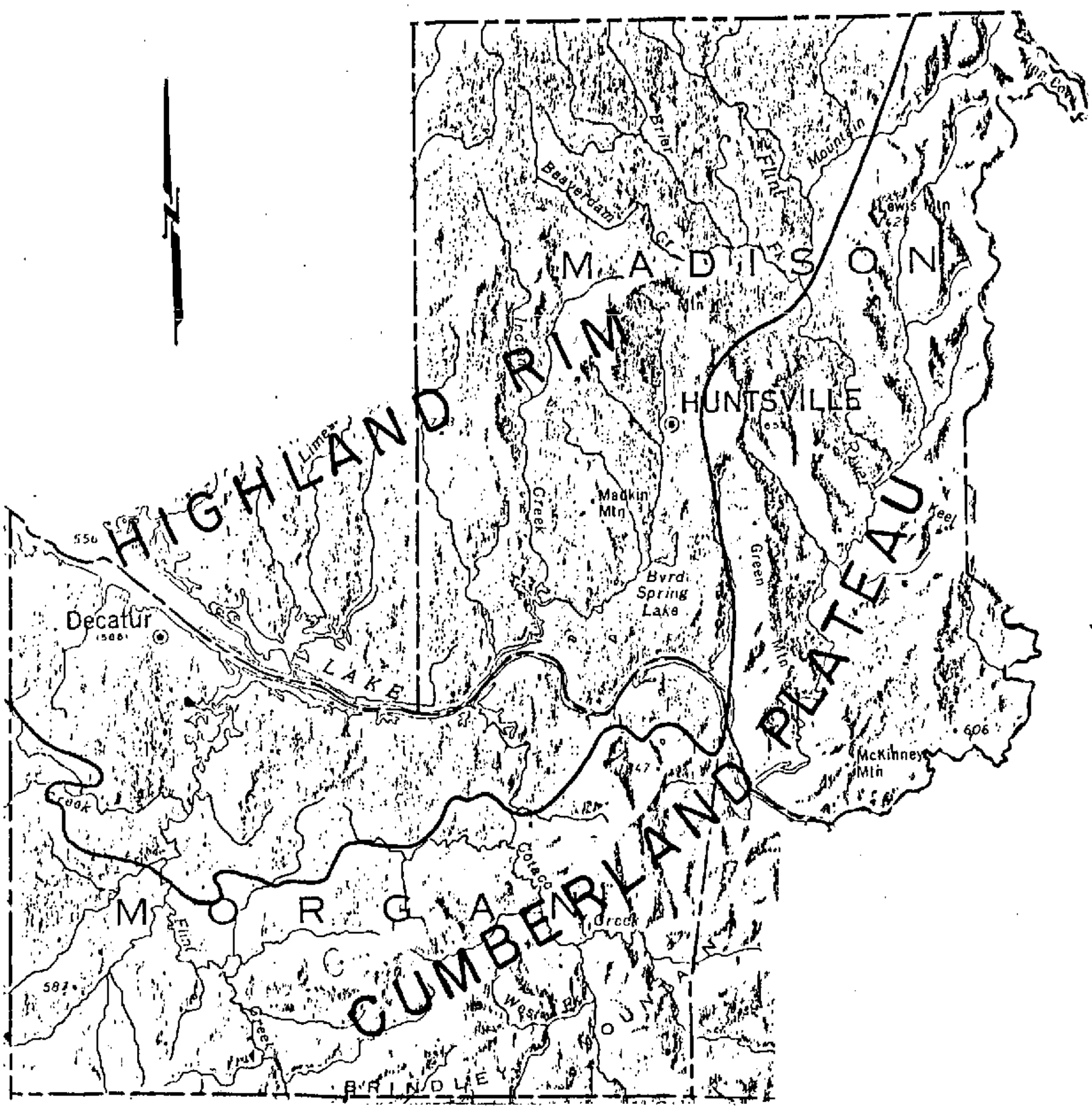


Figure 1.—Location map of study area showing physiographic subdivisions.

Cumberland Plateau region and outlier hills in the Tennessee Valley. A limestone terrane was selected for study because carbonate rocks are soluble, and solution in many cases will enhance faulting and fracture zones through topographic expression and hydrologic anomalies. Caves in limestones add a third dimension to the study of large-scale lineaments where they coincide with straight line valley segments and lineaments as in Newsome Sinks, Morgan County. Limestone terranes are of great concern hydrologically, because they are one of the most difficult areas to locate large ground-water supplies, thus, hendering regional development.

In addition to geomorphic and geologic advantages of the study area, a great amount of hydrologic data is available. The U. S. Geological Survey has information on over 3,000 water wells and numerous stream-flow measurements in Madison County. A number of water availability reports have been written for the county (Malmberg and Downing, 1957; LaMoreaux and Swindel, 1950; Sanford, 1955; Sanford, 1957; Sanford and West, 1960; and LaMoreaux and Powell, 1963). A ground-water availability report for Morgan County was written by Dodson and Harris (1965). Reports with locations and detailed maps of caves in the state (Varnedoe, 1973) and in Madison County (Jones and Varnedoe, 1973) have been published. With this mass of hydrologic information available, a detailed study of the relationships between hydrology and lineaments is possible.

In evaluating the relationship between large-scale lineaments and hydrology, four hydrologic parameters were considered: occurrence of high-yield water wells, occurrence of large springs, regional trends in development of caves, and morphologic development of straight valley segments along the Cumberland Plateau. The working premise employed to relate lineaments to ground-water hydrology follows - if lineaments have an effect on ground-water hydrology, then hydrologic anomalies such as concentration of high-yield wells, numerous large natural springs, or the development of caves, should be located on or aligned with lineaments. Anomalous trends and associations between ground-water hydrology and lineaments were evaluated through field investigations to determine their origin and relationships to lineaments.

METHODS

The methods employed consisted of plotting large-scale lineaments on 1:250,000 scale ERTS images, which were then transferred to a 1:125,000 scale base map of the study area. Lineament delineation of the ERTS images was carried out by another worker (Drahovzal, 1974, pl. 1) who worked independently of the author. The locations of high-yield wells and large springs from U.S.G.S. records were plotted separately on a similar scale map, and then the two maps were superimposed. Hydrologically anomalous areas could be correlated and compared to the lineaments. A similar procedure has been followed with caves mapped in the study area. When anomalous areas were identified by this method, they were checked to determine if they were indeed anomalies, and the factors responsible for their development were evaluated.

RESULTS

Relationship Between High-Yield Wells and Large-Scale Lineaments

In Madison County, from over 3,000 water wells inventoried by the U.S.G.S. and the Geological Survey of Alabama, 194 were found to be high-yield wells (fig. 2). For this report a well capable of producing 50 gpm (gallons per minute) is considered to have a high yield. The well with the highest yield in Madison County is the Williams well, T. 4 S., R. 2 W., sec. 34, which has been tested at over 5,000 gpm.

There are a number of factors important to the development of high-yield wells that must be considered in addition to the presence of large-scale lineaments, namely stratigraphy, structure, soil thickness, topography, climate, and surface drainage (LaMoreaux and Powell, 1963).

LaMoreaux and Powell effectively demonstrate that the high-yield wells and big springs are controlled by stratigraphy and structure in the Huntsville area. "In the Huntsville area, the downward movement of water in limestone is arrested by the relatively impermeable underlying Chattanooga Shale. The general mass movement of water in the limestone is to the southeast, under the control and direction of the regional dip of the beds in the area. . ." The influence of regional as well as minor

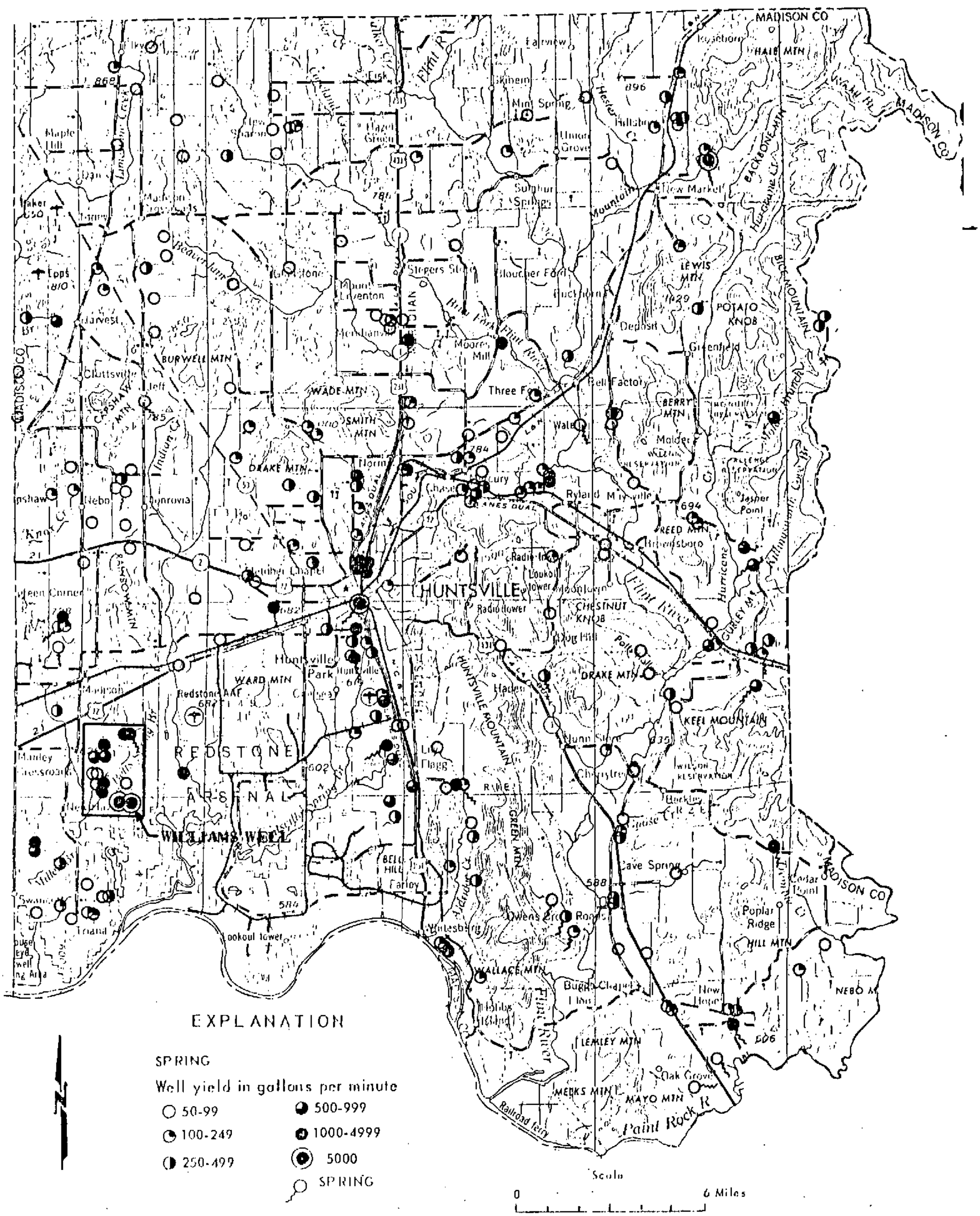
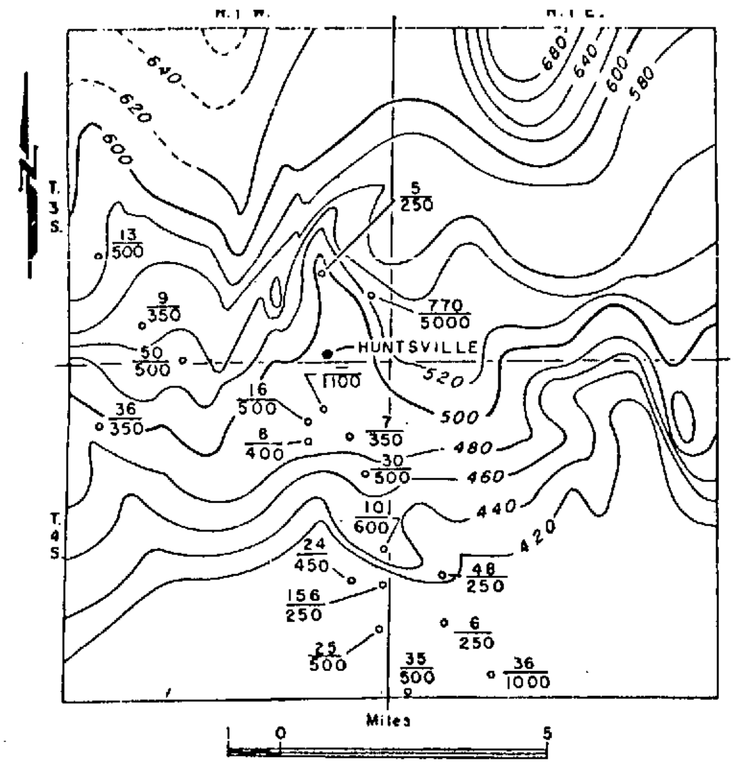


Figure 2.—Map of high yield well and spring location in Madison County.

structure on the movement of water is very evident from a comparison of the water level map with the structural map (fig. 3). The influence of structure on the availability of water in the area can be observed also by noting that all the big springs (Huntsville, Merrimack, Byrd, Harris, and Blue Springs) discharge along synclinal axes, and that the wells of large discharge in the area are along or near synclinal axes." (LaMoreaux and Powell, 1963, p. 371).

Located in an area approximately seven miles southwest of Huntsville is a grouping of high-yield wells; one of which is the largest in the area - the Williams well (fig. 2). Of this cluster there are two wells with yields greater than 5,000 gpm; two wells with yields greater than 1,000 gpm and two springs with yields greater than 1,000 gpm. There is a total of 13 high-yield wells and two large springs located within an area of six square miles. When compared to the average well yield of approximately 20 gpm for water wells completed in limestone areas of the county, this grouping of high-yield wells indicates an anomalous hydrologic condition.

The geology and stratigraphy is similar to that described by LaMoreaux and Powell (1963) in the vicinity of Huntsville. In the area surrounding the high-yield wells, the Mississippian age, Fort Payne Chert and Tuscumbia Limestone compose the principal aquifer system, and the Chattanooga Shale of Devonian age is an aquiclude retarding and deflecting the downward movement of ground water.



HUNTSVILLE AREA, ALABAMA

EXPLANATION

—— 420 - - - -

Contours on top of Chattanooga shale

Contour interval 20 feet

Dashed where inferred

Datum is mean sea level

$\circ\frac{16}{500}$

Well of large capacity

Numerator (16) indicates specific capacity, in gpm / ft. dd

Denominator (500) potential yield, in gpm

Figure 3.—Structure map showing the configuration of the contact between the Chattanooga Shale and Fort Payne Chert and the locations of wells of large capacity (from LaMoreaux and Powell, 1963).

In the area around the Williams well a structural map constructed on the top of the Chattanooga Shale (Drahovzal, Neathery and Wielchowsky, 1974) indicates a series of low undulating folds that trend northwest-southeast, subparalleling an extension of the Anniston lineament. Along with the folds a large trough has been mapped just east of the Williams well (fig. 4). This trough or low is thought to control ground-water movement locally. The origin of the trough may be due to folding of the limestone beds or faulting. There are strong indications from geophysical evidence present in this volume that the trough is due to faulting (Wilson, 1974).

If the trough is due to faulting, then we could anticipate increased fracturing of the limestone and greater solutional development. The effects on local hydrology would include an increase in the number and size of springs and increased well yields. The number and yields of wells and springs do increase along the flanks and axis of the trough, thus verifying the fact that the trough does control local ground-water movement. More than 20 high-yield wells (greater than 50 gpm) and several very large springs are located in the depression; two of the wells and two springs yield more than 1,000 gpm.

Well inventories show that well yields decrease on either side of the trough to approximately 15-20 gpm which is average for wells developed in the Fort Payne Chert and Tuscumbia Limestone aquifers in this area. High-yield wells do occur outside of the trough, but their yields are generally less than 100 gpm with the exception of the area around the Williams well.

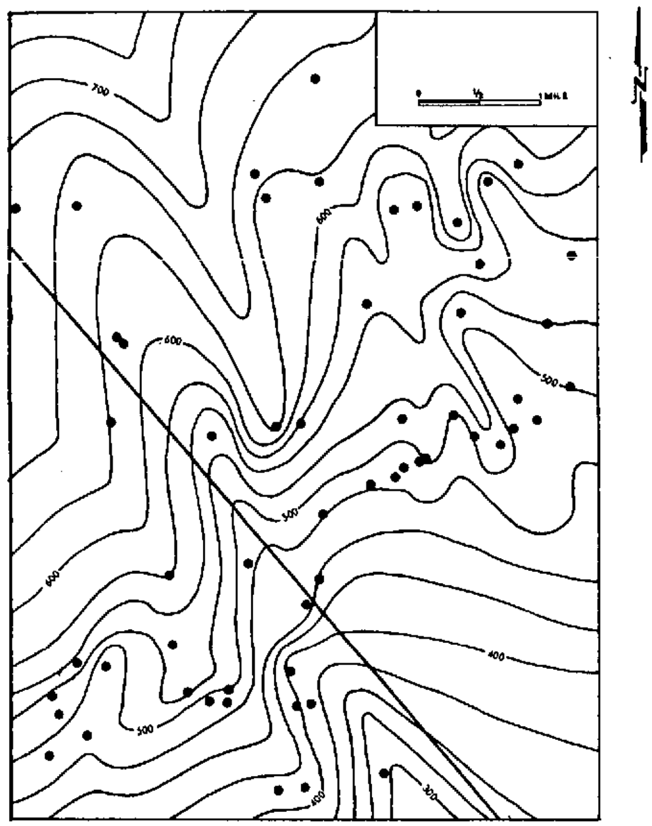


Figure 4.--Structure map on top of Chattanooga Shale in southwest Madison County, Alabama. Datum is mean sea level. Solid straight line represents one of the traces of the Anniston lineament complex. (Modified from Drahovzal, Neathery, and Wielchowsky, 1974).

The Williams well lies beyond the limits of the structural trough; therefore, to explain the hydrologically anomalous conditions, other hydrologic parameters must be considered.

Ground-water occurrence in the Fort Payne Chert and Tuscumbia Limestones is in solutionally-enlarged joints, fractures and bedding planes. According to Vanlier and Alverson (1972) a 10-foot cavity, 97 feet below land surface was encountered in the Williams well. Aquifer tests indicated that much of the water pumped was derived from storage in the overlying residuum. Aquifer tests and cavity geometry prove that the fracture system is open and hydraulically connected to the overlying residuum. Over 5,000 gpm were pumped from the well for sustained periods of time indicating that the fracture system is large and well integrated. Vanlier (personal communications, 1974) describes the hydrologic regime of the area as being compartmentalized, so that pumping of one high-capacity well drawing water from one cavity system may not affect nearby wells tapping another cavity. He also states that some of the cavities are small and tight and great difficulty has been encountered in tapping the same cavity system with wells as close as 15 feet away.

Examination of ERTS imagery clearly shows that a well defined series of parallel lineaments, constituting part of the Anniston lineament complex, traverse the study area and intersect the Williams well (Drahovzal, Neathery, and Wielchowsky, 1974) (fig. 5). Here, the concentration of high-yield wells and springs with lineaments is more than just coincidence. As

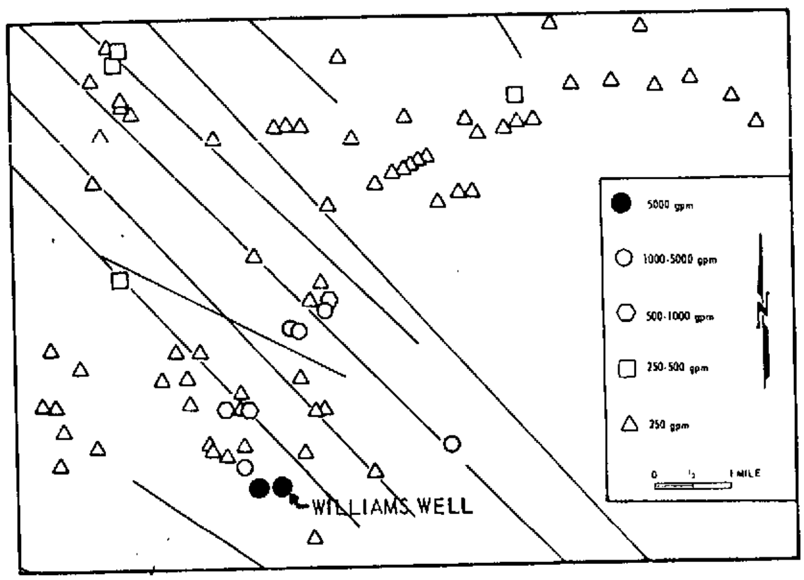


Figure 5.—Location and extent of large scale lineaments in the vicinity of the William Well (from Drahovzal, Neathery, and Wielchowsky, 1974).

shown earlier, neither stratigraphy or structure, nor the combination of the two are adequate to explain the anomalous ground-water conditions. The presence of large-scale lineaments noted on ERTS images may indicate fracture zones of higher permeability exist as suggested by other authors (Lattman and Parizek, 1964; Trainer and Ellison, 1967; Trainer, 1967; and Sondregger, 1970). Cavity geometry and aquifer tests on the Williams well support this conclusion.

EVALUATION OF HIGH-YIELD SPRINGS

Further proof that large-scale lineaments affect hydrologic conditions may be noted by the distribution of high-yield springs in Madison County (fig. 6). Of the 23 high-yield springs inventoried by the U.S.G.S. and Geological Survey of Alabama, 13 fall on or near a lineament mapped from ERTS images by another worker (Doyle, 1973); the lineament passes south of Huntsville where cultural features partially have masked it, but the lineament is believed to be continuous.

The springs fall in a band approximately three miles wide and 28 miles long. The axis of the band strikes N. 45° W. along one of the strongly developed minor lineament trends. The 14 large springs (50-1,000 gpm) within this band are: Sweatman, Blue, New Hope, Rock, Brauton, Grayson, Esslinger, Byrd, Braham, Huntsville, Boiling, Nickel, Indian, and an unnamed spring. These springs may be described as being of two types: gravity springs issuing from bedrock, and resurges in soil. Of these springs, six (Boiling, Indian, Nickel, Braham, Esslinger, New

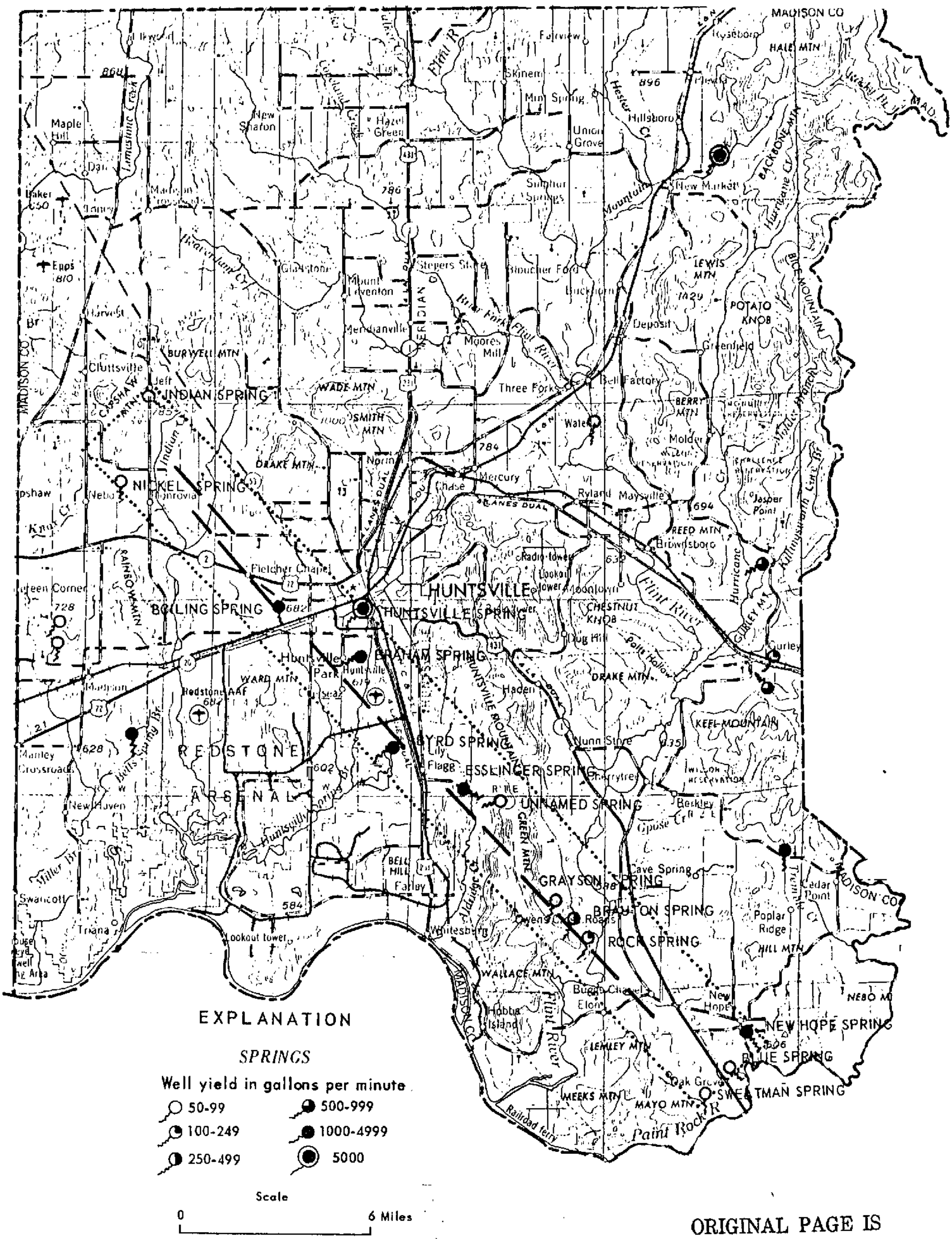


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Figure 6.—Map of high yield springs in Madison County.

Hope, and Grayson) occur as rises in a soil overlying limestone bedrock. No rock is exposed in these springs to evaluate the origin or controls responsible for their development. However, based on the springs large flow, hydraulic head, and the hydrologic characteristics of the dense Mississippian limestones, particularly the Fort Payne and Tuscumbia, we can assume that these springs are primarily controlled by jointing and fracturing. Two resurge springs were field checked (Esslinger and Grayson), each had a hydraulic head that raised the water boils up nearly to land surface indicating artesian conditions. Artesian conditions can only exist where the aquifer is confined and the point of recharge is higher than the point of discharge. In this setting, artesian conditions can result from two possible sources: one, a confining clay layer may occur on the bedrock surface and partly fill the upper cavity system; or a continuously confined cavity system in bedrock may act as a conduit. The conduit may be a solutionally enlarged bedding plane, joint, fracture, or a combination of these.

The hydraulic head on Esslinger and Grayson springs is slight and may be the result of local conditions; therefore, it is probable that these springs are the result of a combination of the mentioned factors. For example, water falling on the nearby mountains drain downward into open joints and fractures until the water table or local base level is reached, then ground water begins to move horizontally through solutionally enlarged joints, fractures, and bedding planes under the valley floors. Under the valley floors where gradients are slight, local conditions become very important, so that any confining layer such as clay overlying bedrock cavities may produce hydraulic head down gradient. The large spring flow is indicative of a large drainage basin that may originate from some distant point such as the nearby mountains and hills where the limestone outcrops.

Braeton, Rock, Byrd, Huntsville, Sweatman, and a large unnamed spring in Weatherly Cove are all gravity springs issuing from bedrock. Many of these springs are associated with caves: Byrd, Rock, Braeton, and Huntsville. All springs of this class exhibit joint, fracture and bedding plane control to some extent; however, they are dominantly joint and fracture controlled. Where water can be seen moving through caves to the spring outlets solutionally enlarged joints and fractures control water movement.

Bedding plane and joint solution cavities are very common in the walls of cliffs around spring discharge points. This one feature seems to be indicative of large springs coming from the Monteagle Limestone. The unusual degree of solution development is accompanied by excessively blocky jointing and fracturing much of it within individual beds, Braeton's spring is the only exception.

Braeton's spring is located near a cliff face and boils up from beneath a pool. The spring may come from a bedding plane, however, the outlet is not visible. The cliff face does not show a great deal of fracturing, jointing, or solution development.

From the acquired evidence, springs along the zone are primarily joint and fracture controlled with bedding-plane control a minor factor. The joint sets exhibiting the greatest solution development appear to be a minor joint set in most cases. Local structure, such as synclines, anticlines, and topography are major factors in locating springs in addition to regional gradients.

The alignment of over 50 percent of the high-yield springs in the county within a zone 3 miles by 28 miles indicates that some large scale control is being exerted in this area. The lineament noted on ERTS images passing through this zone is possibly an expression of this control. The control has not been defined, but data suggest that ground-water occurrence and movement is intimately related to an integrated system of joints and fractures exhibiting concentrated solution development as evidenced by the large bedrock springs. Solution of the limestones results in subtle topographic relief forms and tonal variations seen as a lineament on ERTS imagery, thus the lineament appears to be a definite zone where jointing and fracturing increases significantly when compared to the surrounding region.

RELATIONSHIP BETWEEN CAVES AND LINEAMENTS IN MADISON AND MORGAN COUNTIES, ALABAMA

An attempt was made to determine if unusually high concentrations of caves occur along lineaments in Madison County. A map of cave locations with superimposed lineaments delineated on ERTS imagery revealed no apparent correlation between lineament trends and cave concentrations. Areas with high concentrations of caves generally were found to correspond to areas of largest topographic relief.

Bearings on cave passages exhibiting linearity were estimated from the publication, "Caves of Madison County, Alabama" (Jones and Varnedoe, 1973). Figure 7 is a rose diagram showing cave passages orientation. The most significant trend was north-south. A second trend was east-west. Several passages have bearings ranging from approximately N. 20° W. to N. 60° W. Many of the passages having bearings within this latter range appear to be joint-controlled and have long straight passages. The two predominant lineament trends in Madison County occur within this range and have bearings of about N. 40° W. and N. 60° W. Most of the lineaments have bearings of N. 40° W. These trends occur throughout the Highland Rim section of the Interior Low Plateaus (Drahovzal, 1974, figs. 8, 16), but regionally a moderately strong north-south lineament orientation is also present. In this volume Drahovzal (1974) suggests that the very strong development of cave passages along a north-south orientation may indicate that the north-south lineaments reflect fractures with a higher degree of openness than those developed in other orientations and that the moderately strong east-west cave passage orientation is probably related to the strong east-west systematic joint pattern.

In addition to joint and fractures, the bedrock gradient and local base level exert strong influences on cave passage direction development. In Madison County, the bedrock gradient is generally to the south, and the Tennessee River is base level

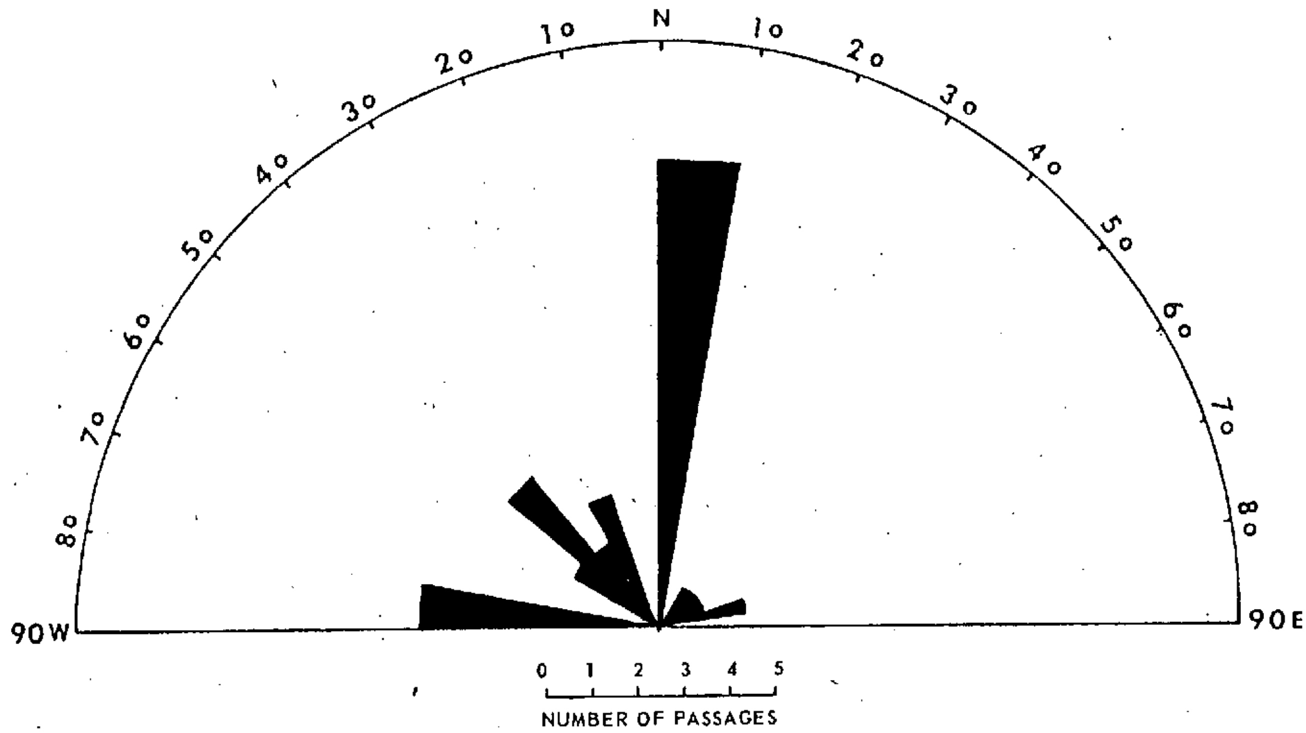


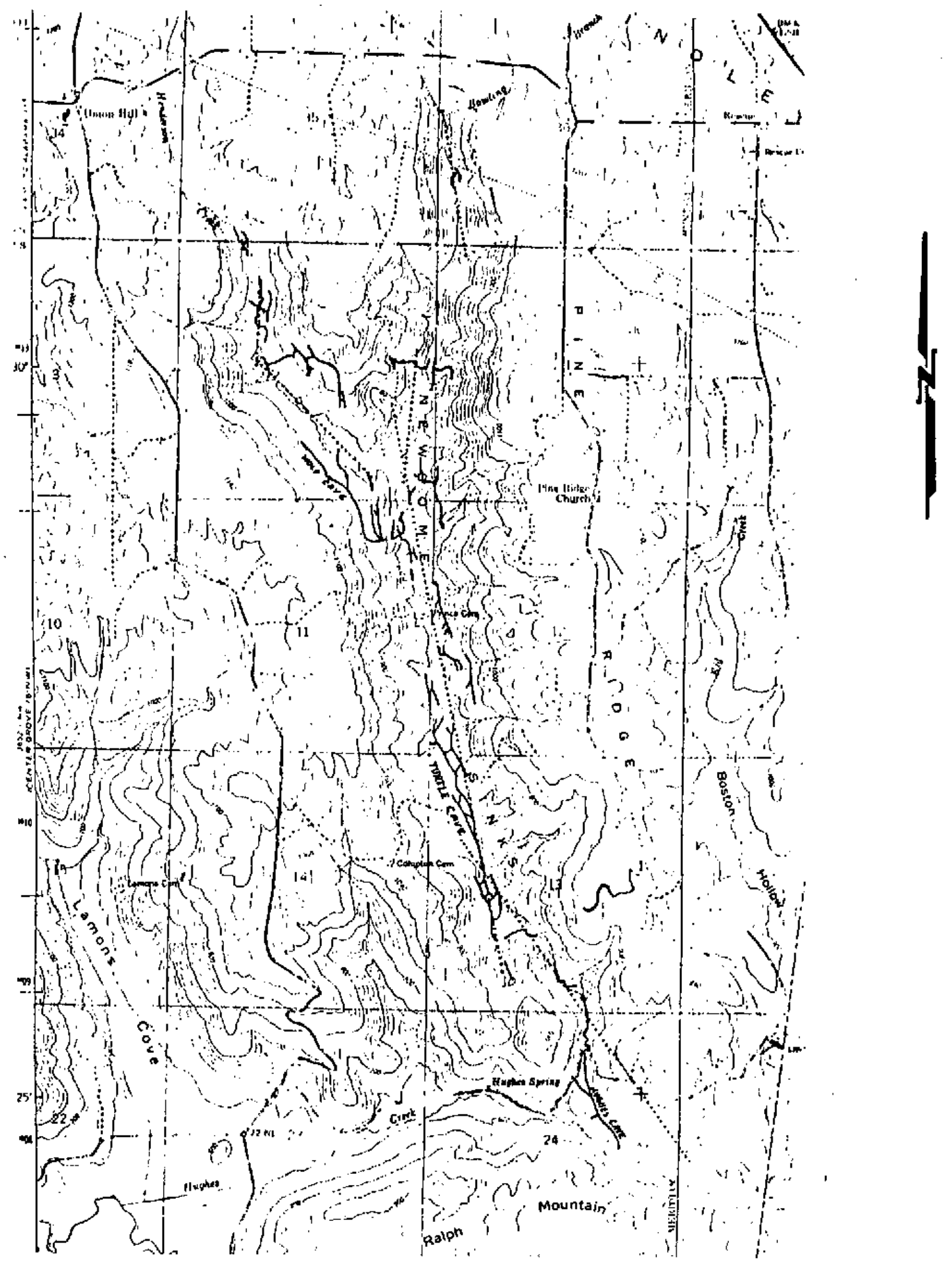
Figure 7.–Rose diagram showing orientation of cave passages in Madison County.

for much of the county. As a result, ground-water movement and cave passage directions development are to the south along open joints that parallel the bedrock gradient. These joints offer the paths of least resistance to ground-water movement from recharge areas to points of discharge near base level, in this case the Tennessee River. Where open joints parallel to the bedrock dip direction are absent, open joints striking in other directions become the conduits for ground water.

In Morgan County, Newsome Sinks presents a unique opportunity to study the relationship between cave development and large-scale lineaments, because the sinks are a prominent topographic feature and National Speological Society has accumulated a great deal of data for the caves occurring in the sinks.

Newsome Sinks is a blind karst valley of high relief (500-600 feet) characterized by sinks, caves, disappearing streams and subterranean drainage. The valley consists of a series of straight line segments ranging from ¼ mile to 2¼ miles in length. These segments were first noted on ERTS images and confirmed by sidelooking-airborne radar images (SLAR). They appear to tie into larger lineaments. Background investigation revealed that 40 caves occur in Newsome Sinks. These caves have been mapped in detail by members of the National Speological Society mainly from the Huntsville Grotto (Varnedoe, 1963).

When the lineaments observed on ERTS images are compared to the mapped caves, a profound relationship is apparent (fig. 8). Major cave passages have similar orientations as the lineaments,



Cave passage

ERTS lineament

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Figure 8.—Map of Newsome Sinks showing the relationship of known cave passages and ERTS lineament.

and they are closely associated if not coincident with each other. The lineaments noted on ERTS images correspond with straight valley segments and they are aligned with numerous large sinks along the valley floor. In this case, lineaments reflect topographic features, primarily negative ones that result from structural control. The valley, caves, and sinkholes are all intimately related (Varnedoe, 1963).

The origin of the caves in Newsome Sinks is complex and beyond the scope of this study; however, several of the major caves in the sinks were investigated. Hughes Cave, which is the southernmost cave of the system, exhibits both vadose and phreatic features such as elliptical tube passage cross-sections with entrenched stream meanders cut into some passage floors. The direction of passages appear to be primarily controlled by joints and the regional dip of limestone beds.

Varnedoe (1963) explains the present topography, cave pattern, and drainage system of Newsome Sinks through a step by step process.

> "The original drainage was a surface one running along the Newsome axis to the south where it jointed another stream heading west at a location a little to the south of the present Skidmore Cave (fig. 9). By the time the axis was established and the sandstone cap breached, underground drainage developed along this

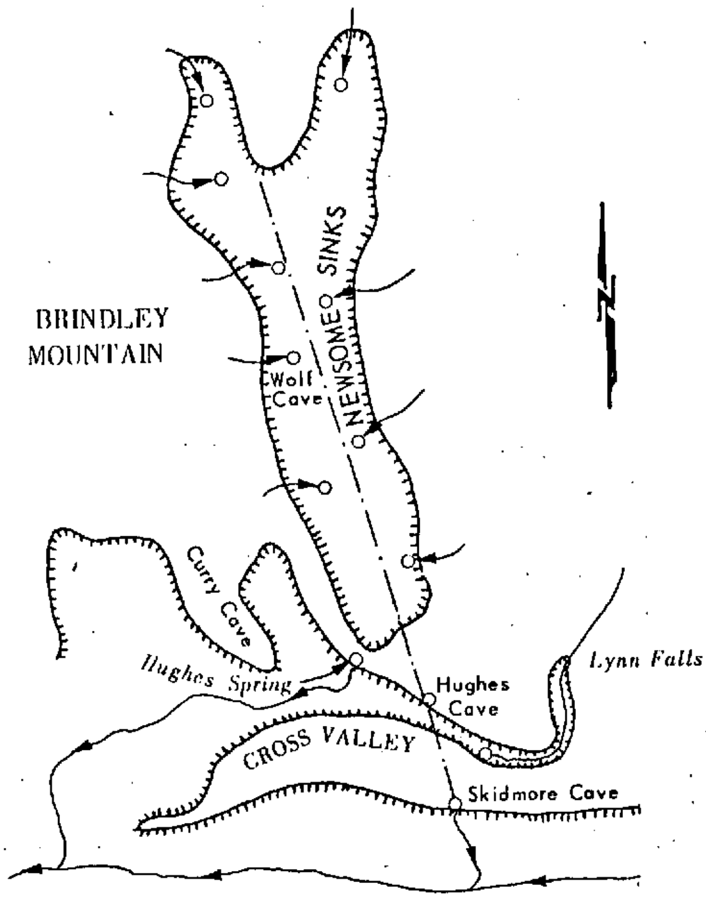

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Figure 9.—Newsome axis and its extension to Skidmore Cave (from Varnedoe, 1963).

> axis. This new drainage was instrumental in development of the later stages of most of the present caves, including Hughes Cave . . ."

This concept appears to be compatable with Hack's (1960) concept of dynamic equilibrium in landscape development.

> "As area is graded by erosional processes the differences in the bedrock from one place to another causes a differentiation of the forms on them. Landscapes that develop on intricate and actively rising fault blocks may bear a close relationship to major structural features than the underlying rock, but in a landscape like the Appalachian region in which large areas are mutually adjusted, the diversity of form is largely the result of differential erosion of rocks that yield to weathering in different ways. Such topography may be referred to as erosionally graded."

The axis or axes of Newsome Sinks appear to have structural control as well as being erosionally graded. ERTS images have shown large-scale lineaments to extend across physiographic provinces without interruptions. However, the lineaments noted along the straight segments of Newsome Sinks are not of this magnitude, but they do extend across physiographic sections cutting many formations and rock types. They also follow the same general trends as the large-scale lineaments that do cut physiographic provinces (fig. 10). For these reasons they are probably genetically similar.

In addition to large-scale lineaments, cave passages tend to be aligned with the straight valley segments. These cave passages exhibit pronounced joint and fracture control. Thus, the lineaments observed in Newsome Sinks appear to be the reflection of topographic and tonal variations on images that result from the effects of joint and fracture control on landscape development and features resulting from ground-water movement.

Jointing noted in passages in the upper level of Hughes Creek are both systematic and non-systematic. The larger systematic joints, generally cut the passages at some angle to the passages axis, while many of the smaller non-systematic joints fall directly on the axis or parallel to it. This evidence indicates that ground-water movement has been to the south down the regional gradient and along a minor joint set which closely parallels the regional gradient. In other parts of Hughes Cave and in Wolf Cave, systematic joints exert greater control on the cave passages direction.

Fifty-five joints and joint sets were measured in the Bangor Limestone at three locations on Brindley Mountain in the vicinity of Newsome Sinks (fig. 11) in addition to the joints in caves. The most persistent joint sets were N. 10°-40° E., N. 70°-80° W.,

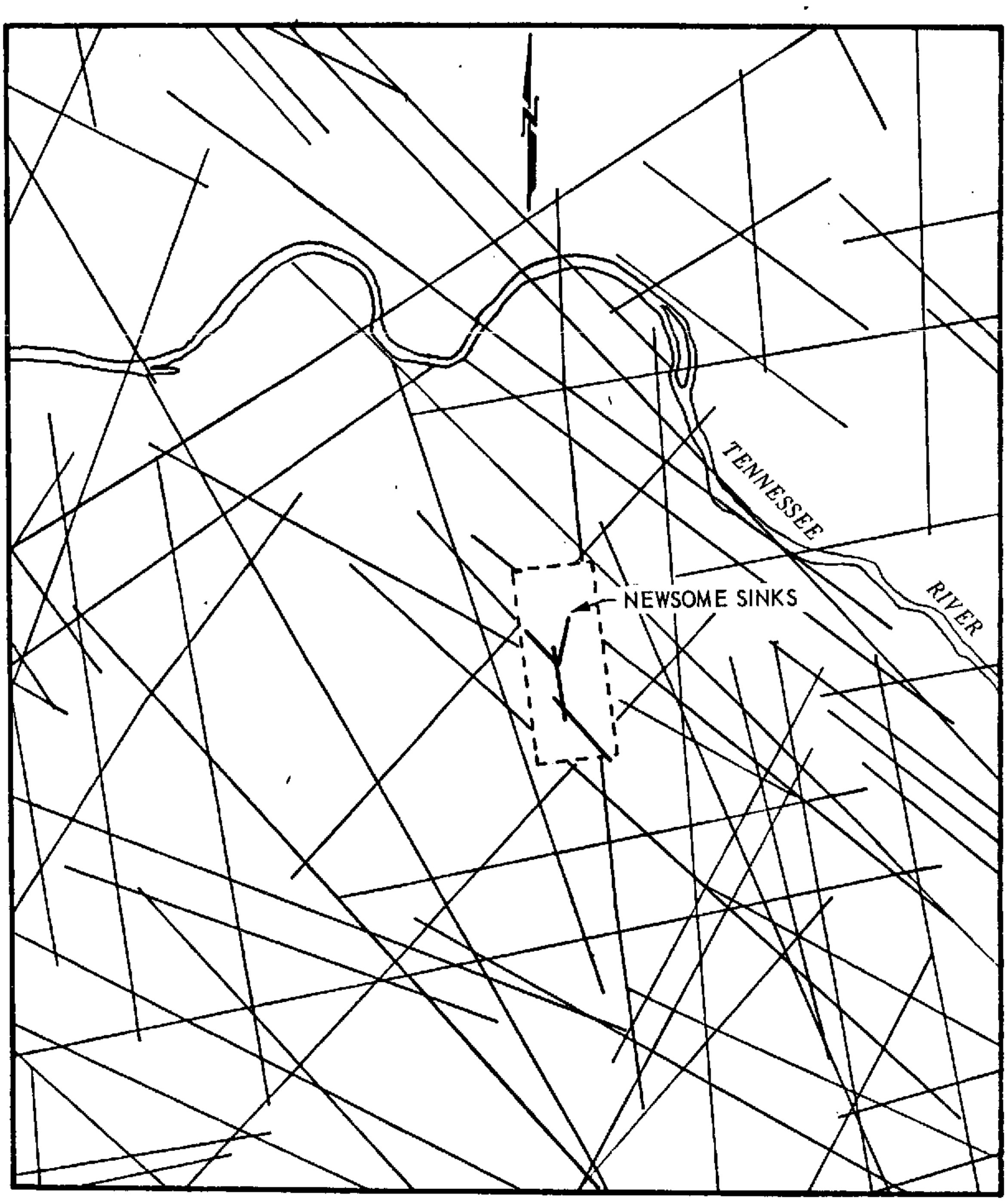

Figure 10.–Plate showing relationship of large scale ERTS lineaments and small scale lineaments in Newsome Sinks.

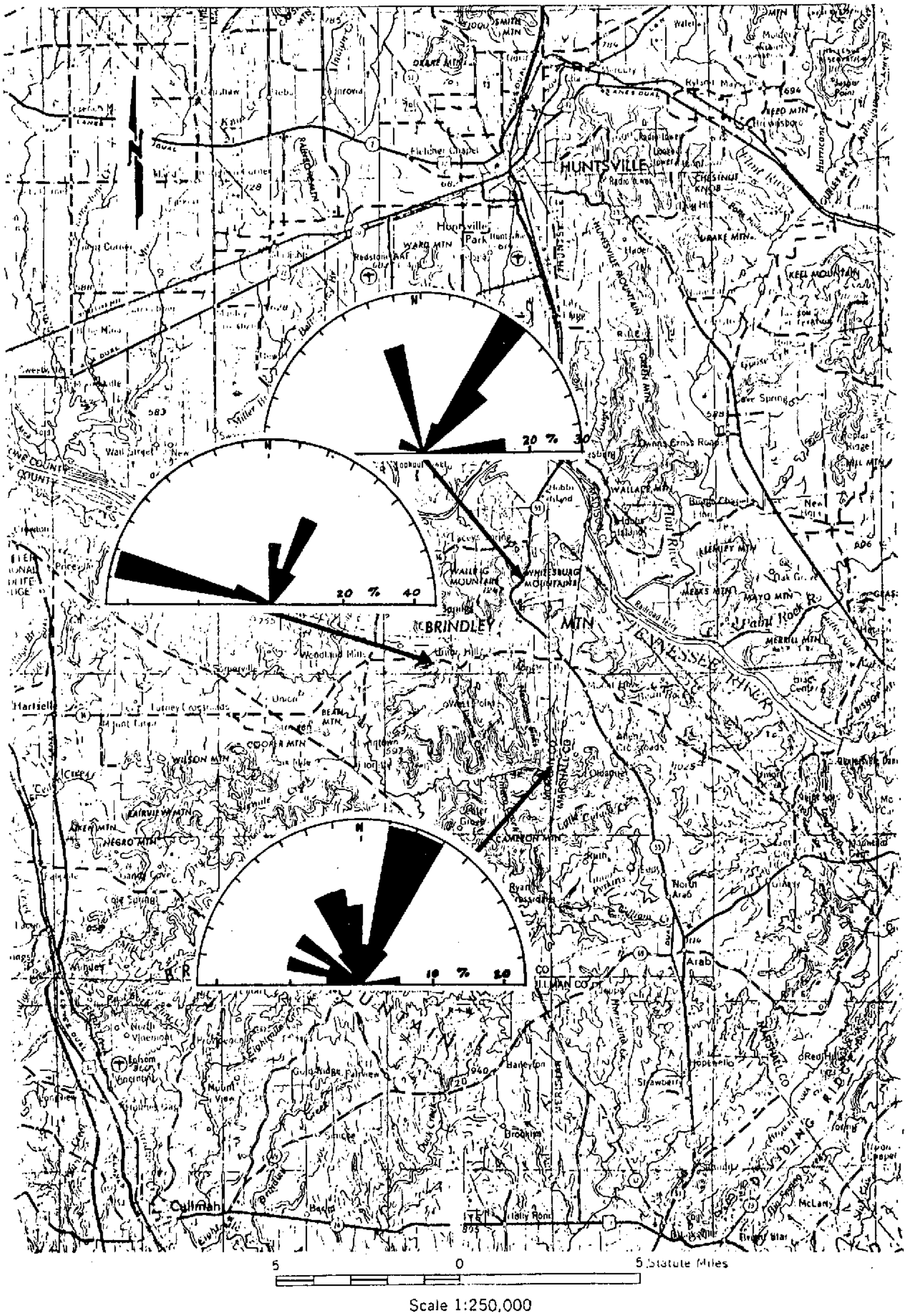

Figure 11.—Patterns of joint orientations in the vicinity of Newsome Sinks.

N. 10°-20° W. and eastwest. Varnedoe (1973) has plotted the relative abundance of cave passage directions in north Alabama cave passages (fig. 12). The dominant directions of cave passages are north-south and east-west, however, a significant number form a set N. 45° W. and N. 45° E. The cave passage directions in Newsome Sinks follow very closely to these trends but show a greater number of passages oriented N. 10°-20° W. The N. 10°-20° W. trend is significant in that it closely approximates the regional gradient direction and lineaments too (fig. 10).

CONCLUSION

The association of hydrologic anomalies and large-scale lineaments is apparent. Concentrations of high-yield water wells and springs occur on or in the immediate vicinity of lineaments. Caves in some areas particularly along the escarpment between the Highland Rims Physiographic section and the Cumberland Plateau Physiographic province show strong alignment or association with large-scale lineaments. However, in other areas, as in Madison County, little apparent relationship exists between cave orientation or occurrence and large-scale lineaments.

The association of hydrologic anomalies and large-scale lineaments has been demonstrated, but the relationship governing their association is very complex with many variables interacting. Much more quantitative work is needed before techniques for locating hydrologic anomalies and water supplies utilizing large-

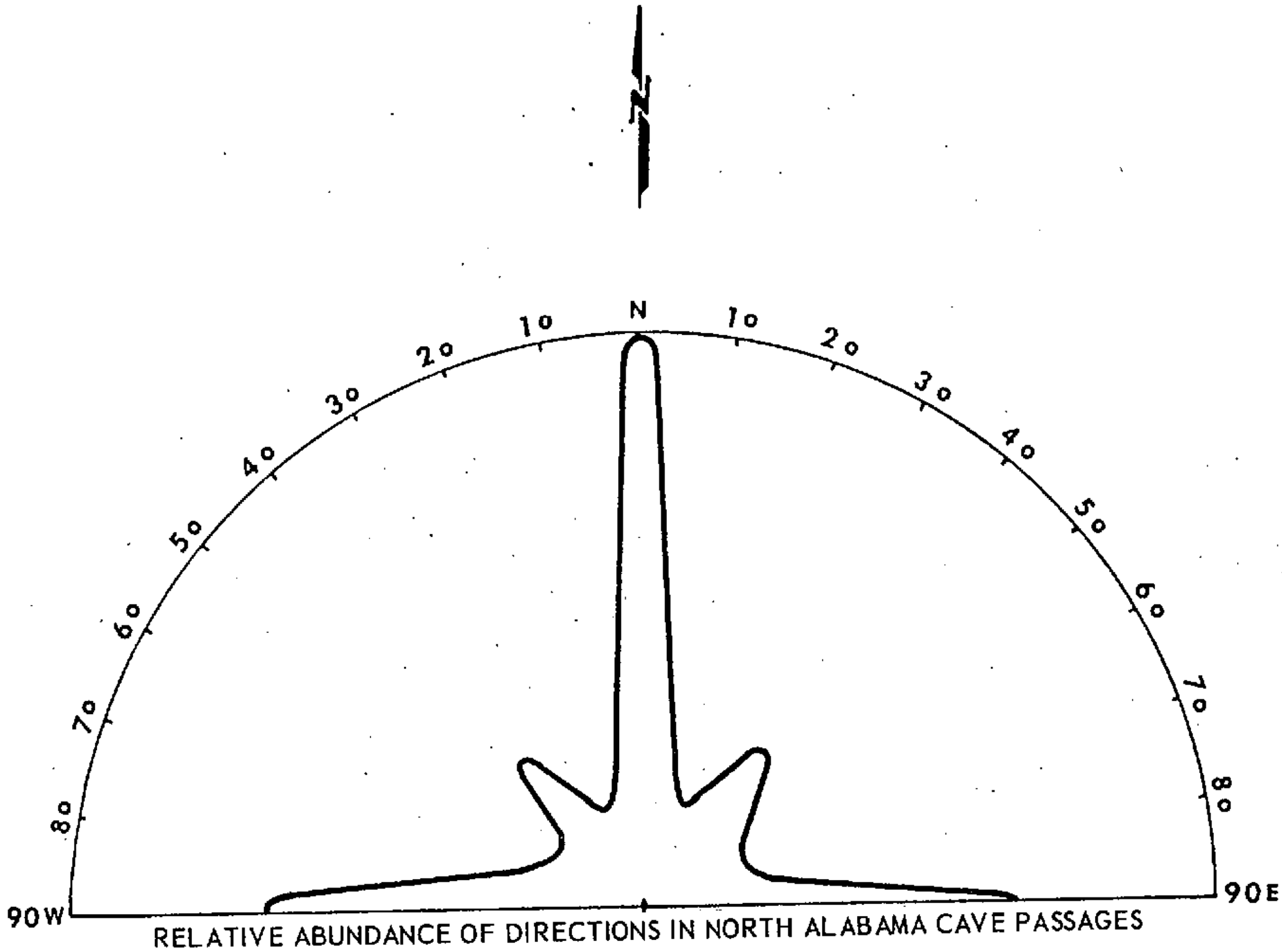

Figure 12.–Relative abundance of directions in north Alabama cave passages (from Varnedoe, 1973).

scale lineaments from ERTS images can be developed. The qualitative work of this study must be supported by a systematic detailed program of aquifer tests and well drilling. Lattman and Parizak, 1964, have completed such a program in Pennsylvania to develop quantitative relationships between ground water and small-scale lineaments with positive results. The same can also be done with large-scale lineaments. If successful, then a major tool for hydrologists and hydrogeologists can be developed for locating high-yield water supplies in limestone terranes, crystalline rock areas and areas with critical ground-water problems.

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A COMPARISON OF SINKHOLE, CAVE, JOINT AND LINEAMENT ORIENTATIONS

Paul H. Moser and David Ricci

Introduction

A preliminary study was made of the alignment of sinkholes, caves, joints and lineaments in an area of about 400 square miles in Lauderdale and Colbert Counties in northwest Alabama (fig. 1). This study was initiated because a cursory review of these features indicated that some correlation did exist.

Sinkholes

About 150 individual sinkholes were plotted on $7\frac{1}{2}$-minute topographic maps. Sources of data for the study of sinkhole alignment were the Florence, Killen, Leighton, Pride, Sinking Creek and Tuscumbia quadrangle maps in northwest Alabama. These quadrangles are to a scale of 1:24,000 and a 10-foot contour interval.

Three divisions of sinkhole alignments were used in determining degree of polarity, and therefore, the weight each sinkhole would have in the overall alignment evaluation. First degree alignments were those which exhibit only slight polarity; second degree alignments exhibited a moderate amount of polarity; and third degree alignments exhibited a high degree of polarity. Each sinkhole alignment was assigned a numerical value in accordance with this classification. Thus, the sinkholes with stronger polarity would have more influence on the overall evaluation of the alignment than those with no distinct orientation.

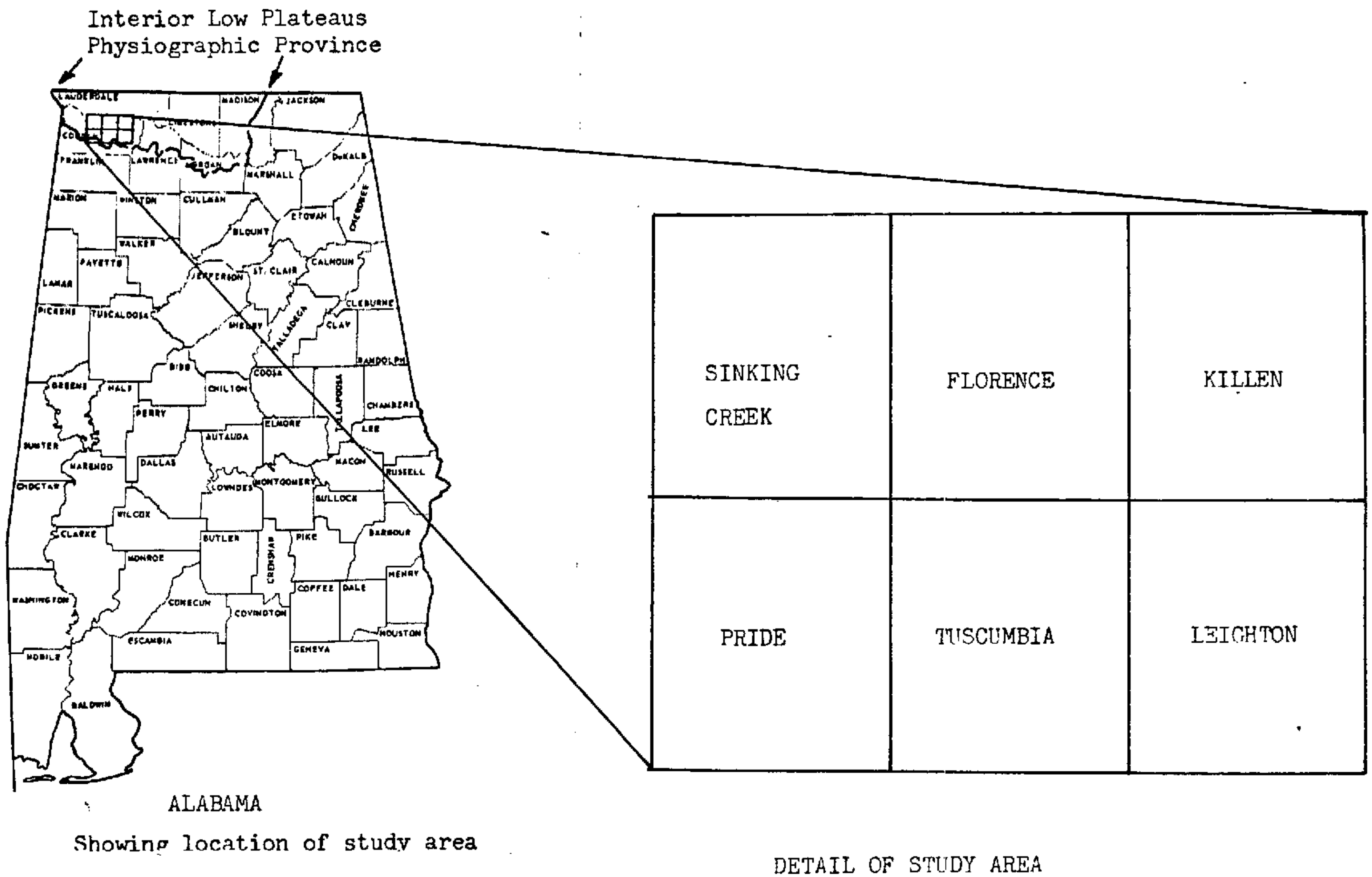

Figure 1.--Index map.

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Sinkholes that exhibited more than one definite orientation were assigned as many alignment values as required, and those with no orientation (basically round in outline) were not included in the study.

Each alignment was measured with a protractor and recorded under the proper categories of orientations and degree of polarity. The point values for each orientation were than totaled and plotted on a rose diagram (fig. 2), with the orientation plotted in 10 degree increments. No field measurements of the sinkholes were undertaken.

Caves

The alignment of caves and their chambers was determined from sketch maps obtained from the National Speleological Society.

The alignments of caves were accomplished by plotting their dominant elongate chambers. Therefore, a straight, long chamber would receive a value of three; whereas, relatively indistinctly oriented short chambers would receive a value of one. The results were, as was the case with sinkholes, measured with a protractor, tabulated and plotted on a rose diagram.

Two rose diagrams were plotted for cave chamber orientation. The first rose diagram (fig. 3) was for caves only in the area of heaviest sinkhole concentration.

It was felt the correlation of sinkholes and caves in the same quadrangle

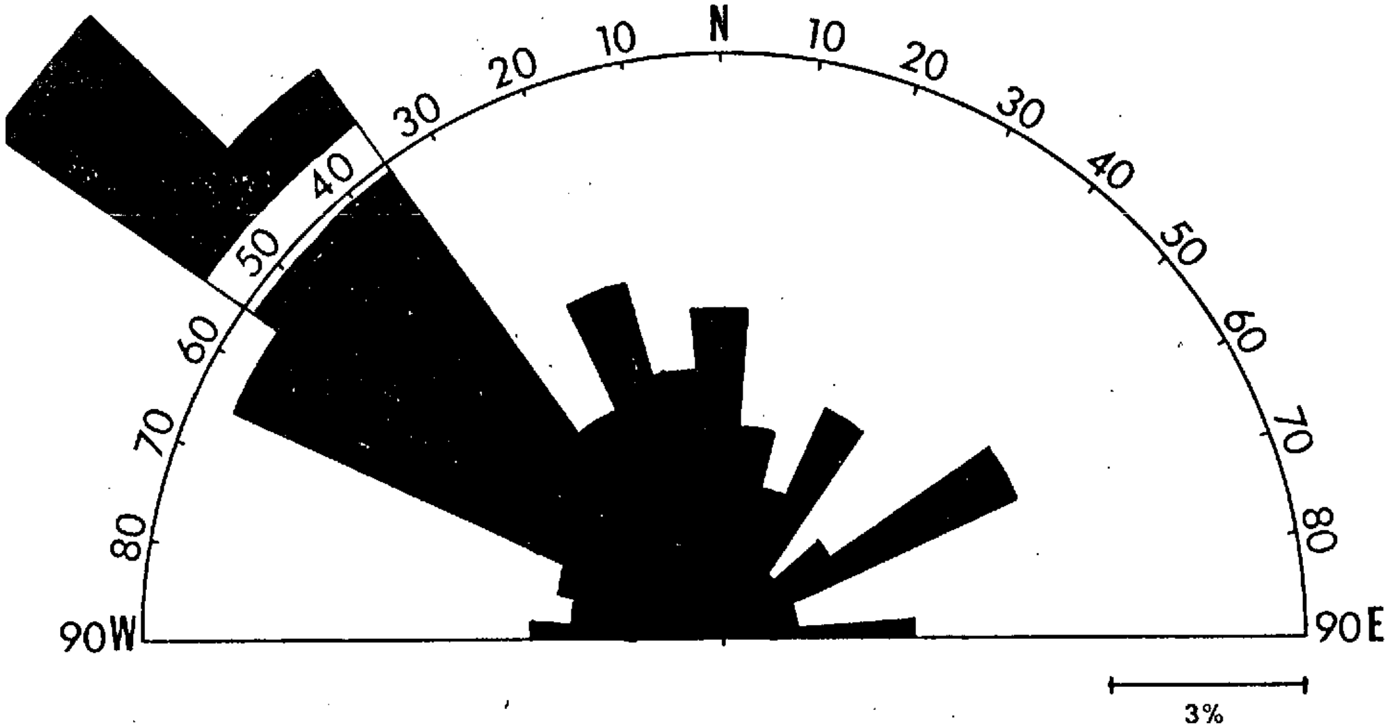

Figure 2.--Rose diagram of sinkhole alignments in parts of Lauderdale and Colbert Counties (Florence, Killen, Leighton, Pride, Sinking Creek and Tuscumbia $7\frac{1}{2}$-minute quadrangles).

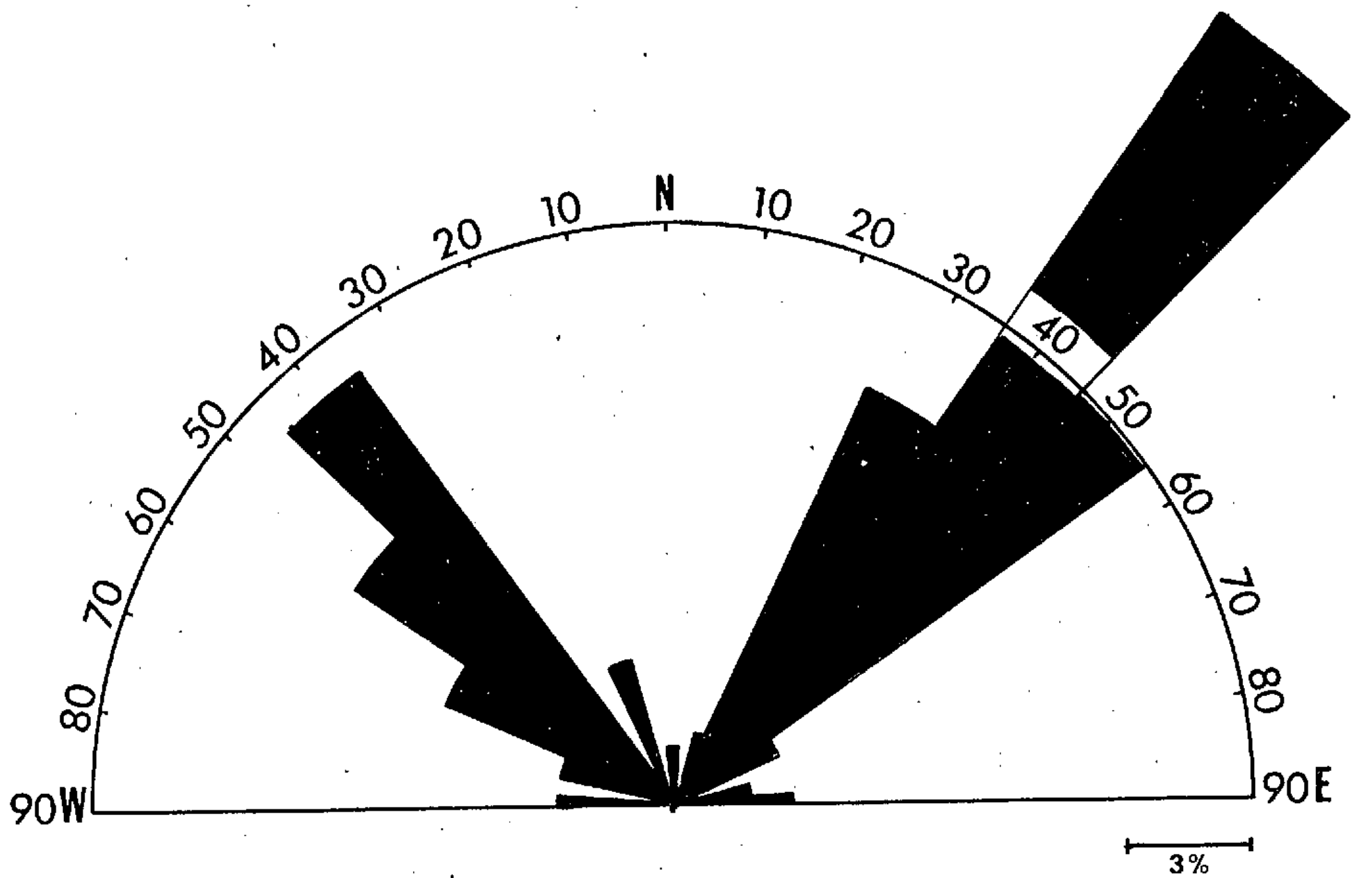

Figure 3.--Rose diagram of cave chamber orientations in parts of Lauderdale and Colbert Counties (Tuscumbia and Florence $7\frac{1}{2}$-minute quadrangles).

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would accentuate the possible correlation between the two features as they relate to solution activity in the underlying limestone. Eight caves with a total of 102 weighted orientations were used to analyze caves in the immediate area of heavy sinkhole orientation.

Twenty-five caves within a six-quadrangle area were studied. In these caves, a total of 484 weighted orientations were evaluated to determine trends. These were plotted on a rose diagram to evaluate the possible correlation of sinkhole concentration to cave chamber orientation over a wider area (fig. 4).

Joints

Joints are fractures or openings of no significant displacement in otherwise solid bedrock. They are usually representative of tension or compression and can be readily observed and measured.

A total of 158 joints were measured in the field on exposed limestone of the south side of the Tennessee River within an area of less than one square mile. No weighing or interpretation of data was necessary on the joint measurements, as they were direct measurements, and the tabulation is a simple addition of total joints measured. The results were plotted on a rose diagram (fig. 5).

Lineaments

Lineaments within the study area were plotted on ERTS imagery (pl. 1). The

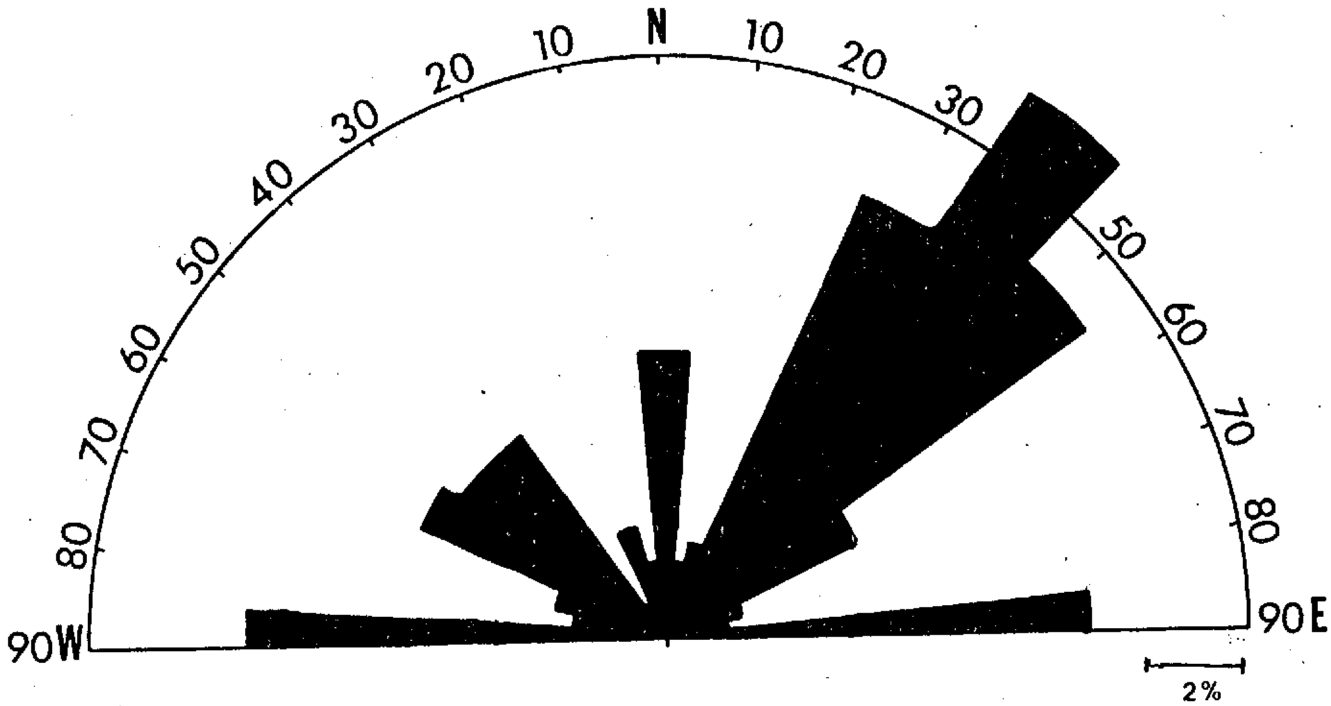

Figure 4.--Rose diagram of cave chamber orientations in parts of Lauderdale and Colbert Counties (Florence, Killen, Leighton, Pride, Sinking Creek and Tuscumbia $7\frac{1}{2}$-minute quadrangles).

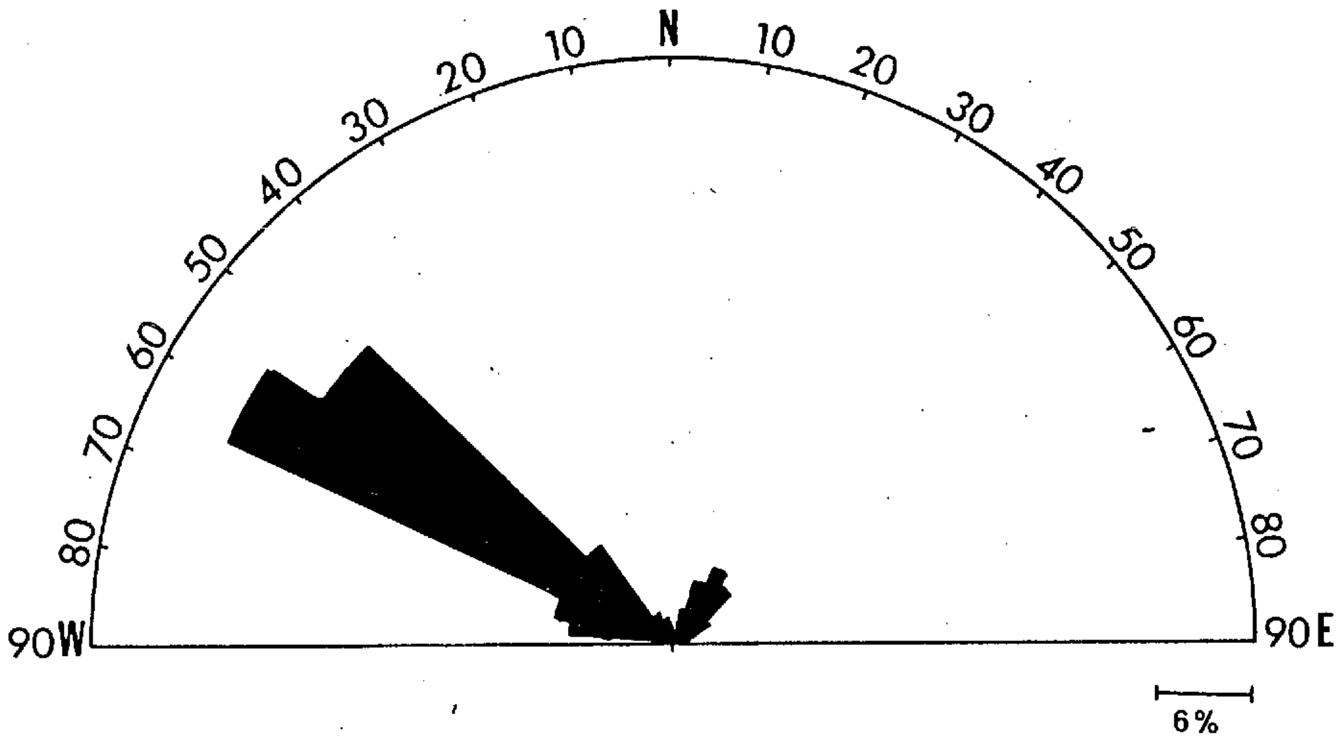

Figure 5.--Rose diagram of joint orientations in the Florence $7\frac{1}{2}$-minute quadrangle.

imagery reflects faint tonal variations on the earth's surface. These differentiations reflect possible structural features and may relate to fractures or faults in the bedrock.

Lineaments shown in plate 1 were plotted on a rose diagram for the six-quadrangle area depicted in figure 1 (fig. 6).

A second rose diagram was complied (fig. 7) to illustrate lineaments of the entire western part of the Interior Low Plateaus province in Alabama.

Conclusions

A preliminary analysis indicates a striking similarity between sinkhole alignment at the surface, cave chamber alignment underground, joint orientation on the surface of exposed rock, and lineaments plotted on ERTS imagery.

This preliminary evaluation of the three methods indicates that definite trends exist at approximately right angles (90°) to each other. This phenomenon is illustrated by the following table.

Method of of observation	Primary orientation	Secondary orientation	Other orientation
Sinkhole orientation	northwest	northeast	--
Cave chamber orientation	northeast	northwest	east
Joint orientation	northwest	northeast	--
ERTS imagery	northeast	northwest	north

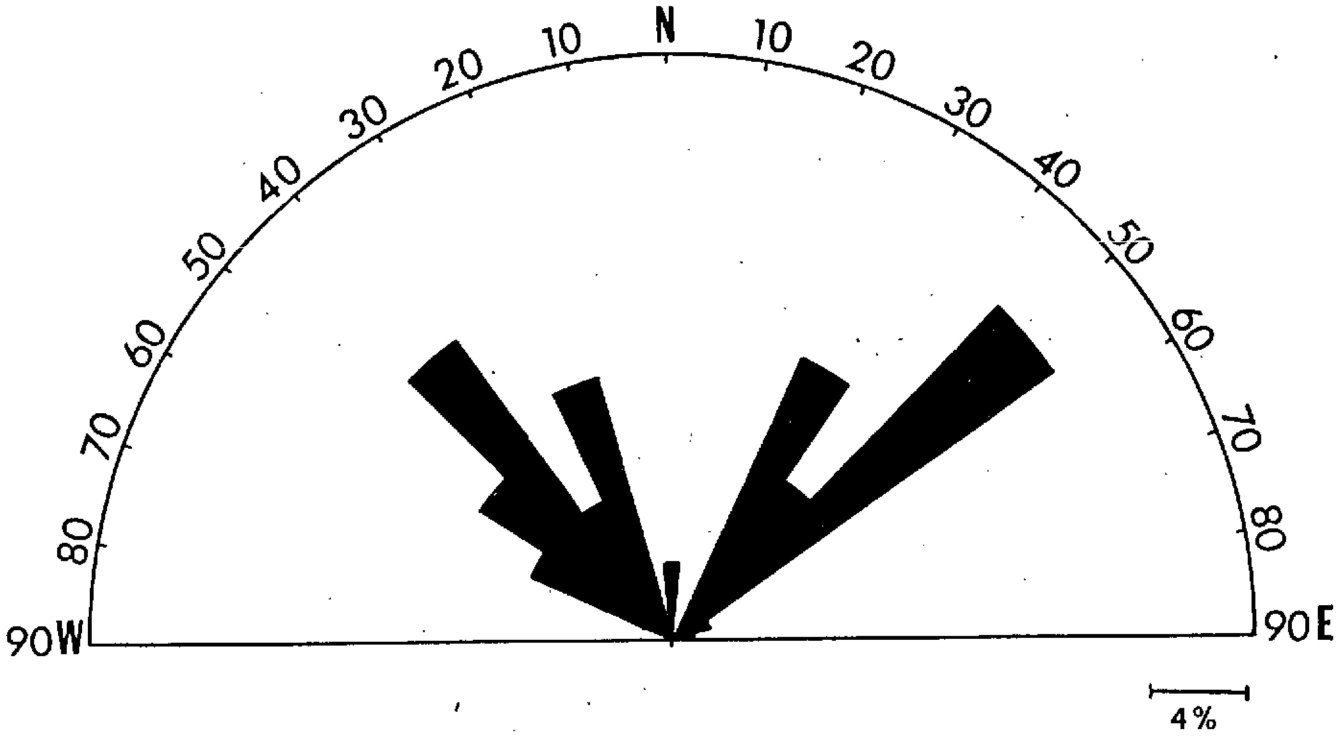

Figure 6.--Rose diagram of lineament orientations in parts of Lauderdale and Colbert Counties (Florence, Killen, Leighton, Pride, Sinking Creek, and Tuscumbia 7½-minute quadrangles). From plate 1.

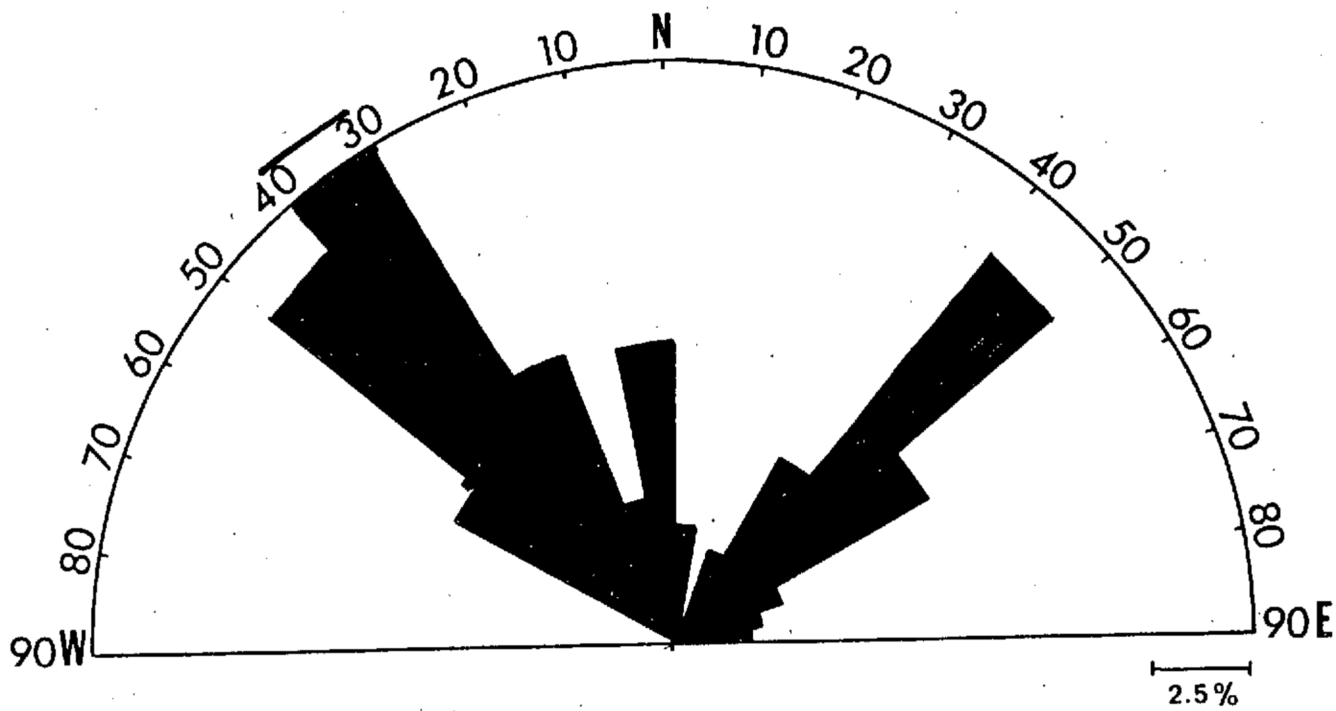

Figure 7.--Rose diagram of lineament orientations in the western part of the Interior Low Plateaus province. From plate 1.

These preliminary data indicate that additional research is needed to substantiate the correlation between the different methods of observation. This more detailed information should be supplemented with data concerning other features; for instance, river and stream alignment, escarpment face alignment and positive topographic feature alignment.

GRAVITY STUDIES ACROSS LINEAMENTS MAPPED FROM ERTS IMAGERY

By

Gary V. Wilson

INTRODUCTION

A total of 7 gravity traverses were made in north Alabama across lineaments mapped from ERTS imagery (pl. 1). The purpose of the study was to determine if any of these lineaments are surface expressions of major faults of enough magnitude to produce measurable gravity anomalies.

The gravity method of geophysical prospecting involves the measuring of minute changes in the gravitational field over the earth's surface. The interpretation of these small changes, although relatively simple in principle and theory, is generally quite complex due to the heterogeneous nature of the earth's crust.

Changes in the gravity field are caused by lateral variations in the distribution of rock masses in the subsurface. These changes can sometimes be measured by a delicate instrument known as a gravimeter, which is essentially a sensitive weighing device consisting of a small mass of only a few milligrams suspended from a delicate quartz spring in a vacuum tube (fig. 1). Changes in the force of gravity from one location to another will cause a minute movement of the mass, generally in the order of only a few thousandths of a millimeter. This movement is enlarged and magnified by mechanical and optical means. The gravimeter is not an absolute instrument and only measures changes or differences in gravity from one location to another. These changes are proportional to differences in the position of the reading dial when the system is balanced.

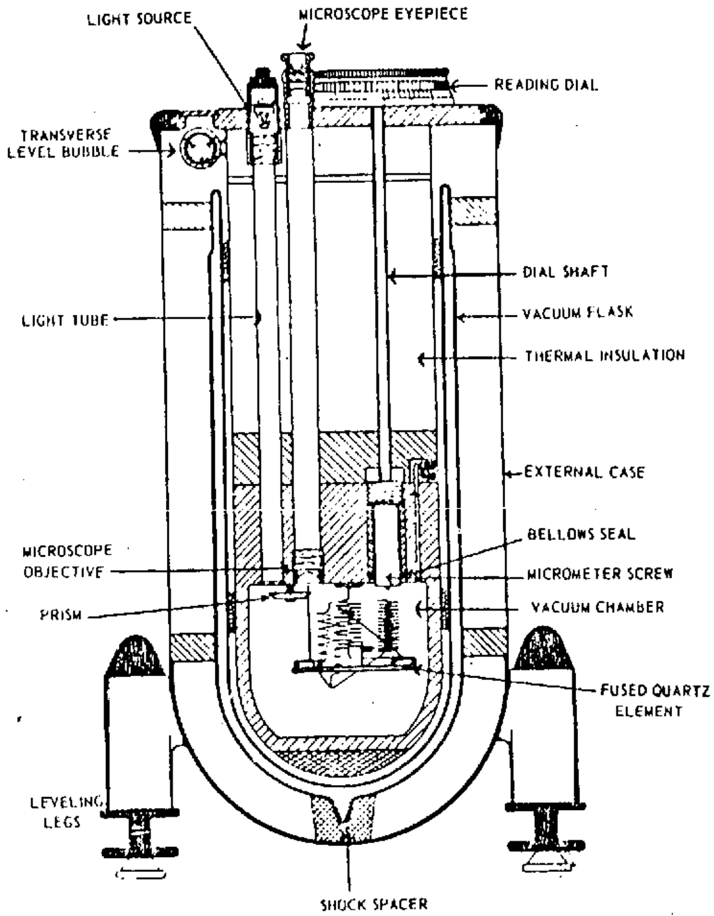

Figure 1.–Schematic diagram of a gravimeter.

Gravimetric Studies (General)

Geological structures such as faults and folds generally contribute very little to the total gravitational field. Structures will produce gravity anomalies only if they affect rocks of different densities, and importance is placed not on absolute rock densities but on density contrasts between rock bodies.

The magnitude of a gravity anomaly will depend upon the size of the structure, the density contrasts involved, and the depths to the density contrasts. The accuracy of defining a gravity anomaly is dependent upon: 1) the spacing of reference stations in relation to the horizontal extent of the anomaly; 2) the precision with which field data is obtained; and 3) the accuracy with which the gravity effects of extraneous sources are removed from the data. Station spacing is mainly determined by the depths to known density contrasts. If significant contrasts occur at relatively shallow depths, closely spaced stations will be required to define any local anomalies associated with geologic structures. Field data precision is dependent upon: 1) the precision of the gravimeter being used and the exactness with which instrument readings are made; 2) the accuracy of elevation control and horizontal control (especially in a north-south direction); and 3) the accurate determination of the effects of meter-drift and diurnal changes in the gravity field.

After raw field data have been subjected to corrections for changes in elevation and latitude, diurnal changes and meter drift, and terrain effects, if needed, the resulting gravity values (Bouguer gravity) express the sum total of the effects of rock density contrasts and mass distributions from the surface down to great depths.

Regional Bouguer anomalies may be caused by variations in crustal thicknesses, intrabasement changes in lithology, isostatic variations from one area to another, and, in some instances, by the surface configuration of dense basement rocks. Because these regional anomalies are often unrelated to surface and near surface geologic features, their effects must be removed from the data in order to isolate and define the smaller and often hidden or obscured anomalies associated with significant geologic structures. The gravity anomalies remaining after the removal of regional effects are known as "residual" anomalies. Methods and problems of removing regional gravity effects are discussed by Nettleton (1954, 1971).

The interpretation of residual gravity anomalies can seldom give unique and unquestionable answers to geologic problems. Geologic interpretations as to the causes of gravity anomalies are limited by the fact that numerous mass arrangements and combinations of arrangements can produce the same anomaly. There is inherent ambiguity in the nature of the earth's gravity field, and, as pointed out by Skeels (1947) and Nettleton (1954), this ambiguity is independent of the precision of data and the spacing of observation points, and remains regardless of the amount of mathematical computations applied to the gravity data. Figure 2 gives an

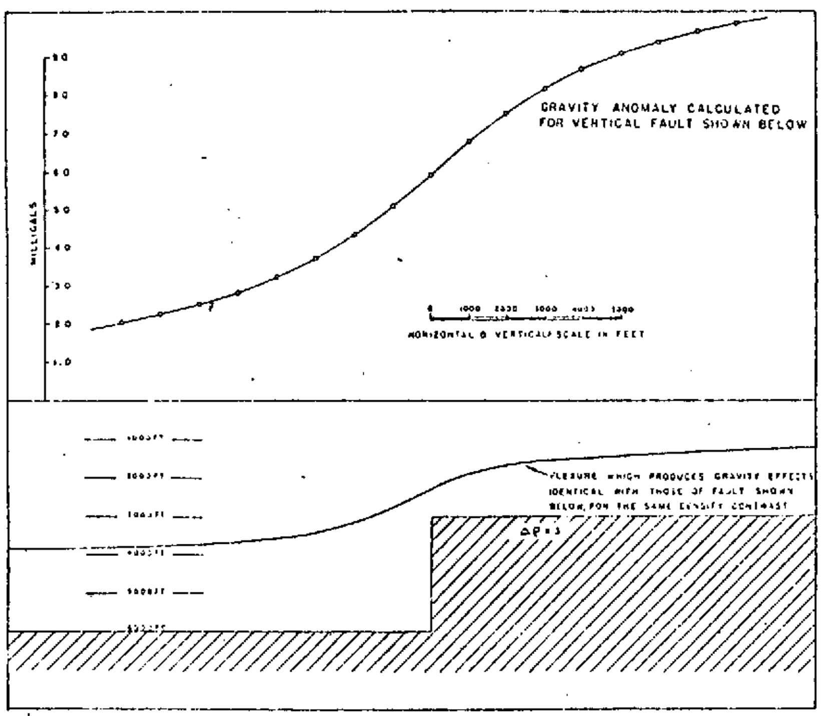

Figure 2.—Gravity profile for a vertical step fault, and, as an alternative solution, a flexure which would produce an identical gravity effect (after Skeels, 1947).

example of how the gravity effect of a fault can be duplicated by a flexure at a shallower depth.

The interpretation of gravity data is usually qualitative rather than quantitative. Without knowledge of the densities, depths, and thicknesses of subsurface rock masses in the area of study, it is difficult to translate gravity data into reliable subsurface information. Geologic interpretations of gravity data become less ambiguous as the amount of subsurface information increases.

Gravity Anomaly of a Known Fault Structure

The interpretation of gravity data may be aided by data over known structural features in or near the area of study. This type of knowledge, in conjunction with information on subsurface rock densities, is most useful to the interpreter. Unfortunately, gravity information is not available over known structures in the immediate vicinity of the areas included in this particular study.

An area in which gravity data is available over a known fault is located in the northwest corner of Lamar County, Alabama, which is approximately 90 miles southwest of gravity traverses 1, 2, and 3 of this study (Wilson, 1973). Although a close comparison of the gravity data in the two areas cannot be made since they are located in somewhat different geologic environments, a look at the gravity anomaly of this known fault is of interest in that it shows, in profile, a residual anomaly typical of a major fault (fig. 3). The profile illustrates the small magnitude of an anomaly that can be expected by displacement, along a moderately large fault, of sedimentary rocks containing relatively small density contrasts. The small aerial extent of the 0.5 milligal anomaly indicates that it originates from density contrasts within the sedimentary column.

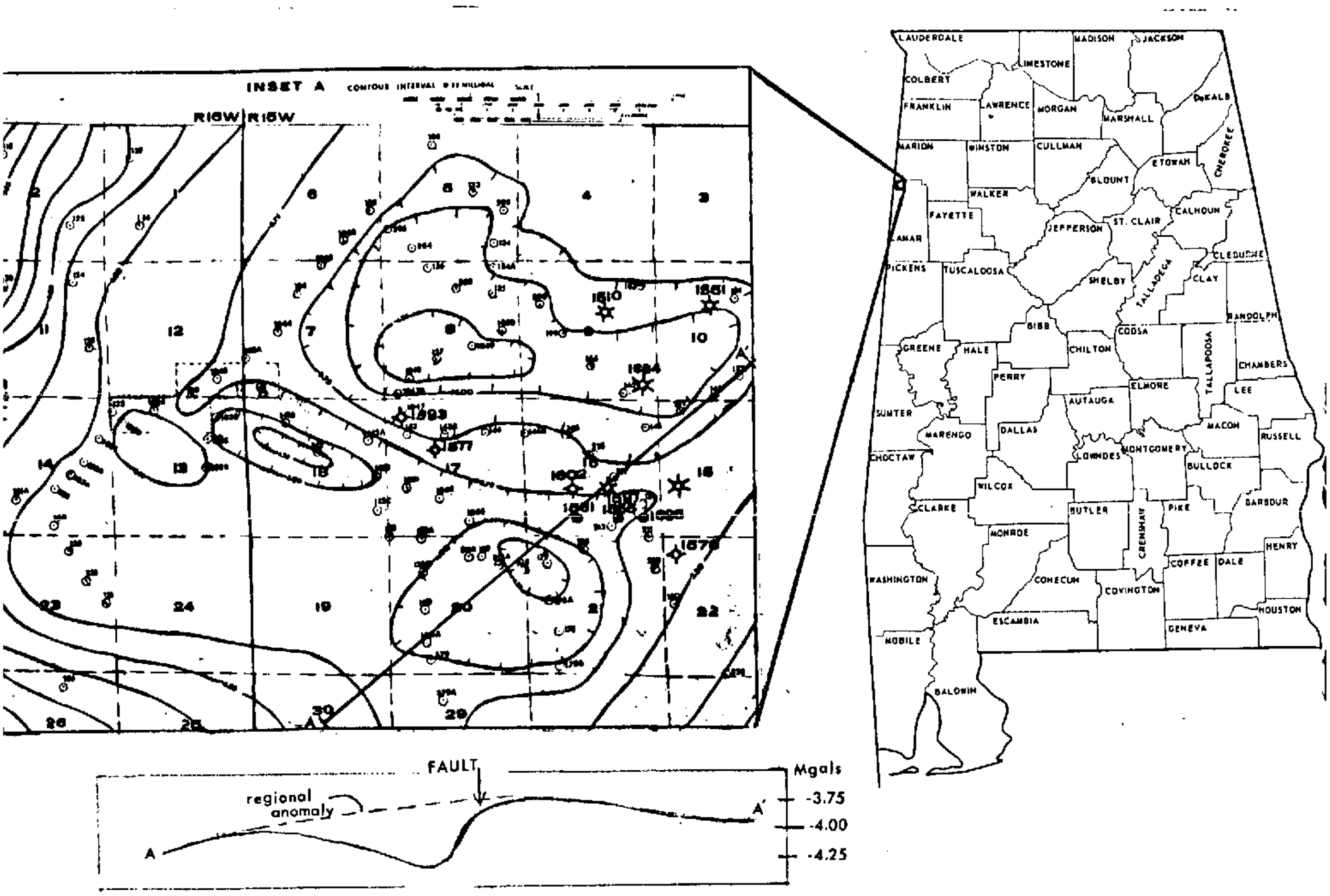

Figure 3.—Bouguer anomaly map of the northwest corner of Lamar County, Alabama and gravity profile across a major fault.

Figure 3 is a Bouguer anomaly map of the northwest corner of Lamar County. The area through which the fault extends has a relatively flat gravity field with three distinct depressions or minima. The northern boundaries of the minima centered in sections 18 and 21, T. 12 S., R. 15 W., are in alignment with a major fault which has been penetrated by oil and gas test wells in the area. These minima are obviously the gravity expression of down-faulted rocks. The profile (A-A') clearly shows the gravity effect of this fault, which has a vertical displacement (throw) of about 350 feet at a depth of about 1,600 feet.

A composite density profile made from formation density logs of wells in and near the area of the fault indicates those depths at which density contrasts may occur across a fault and shows that these contrasts can range from minute to 0.20 gram/cc (fig. 4). The largest density contrasts occur between rocks composed of clastic sediments (sandstone and shales) and nonclastic sediments (carbonates).

Correlation of a Lineament with a Gravity Anomaly

In late 1973 a gravity survey was completed for Fayette County, Alabama, which borders Lamar County on the east. A prominent gravity "nose" was discovered trending northwest-southeast through the southwestern part of the county (fig. 5). This feature is also in alignment with a gravity "nose" in Lamar County which was discovered by a survey completed in early 1972. These gravity anomalies were later found to be in alignment with a prominent lineament mapped from ERTS imagery (fig. 6). The correlation of these features indicates that this particular lineament may represent the surface expression of a major fault. This anomaly has about the same magnitude as the anomaly associated with the fault in northwestern Lamar County, however, the anomalies differ in appearance on their respective Bouguer anomaly maps since they are situated in dissimilar regional gravity fields.

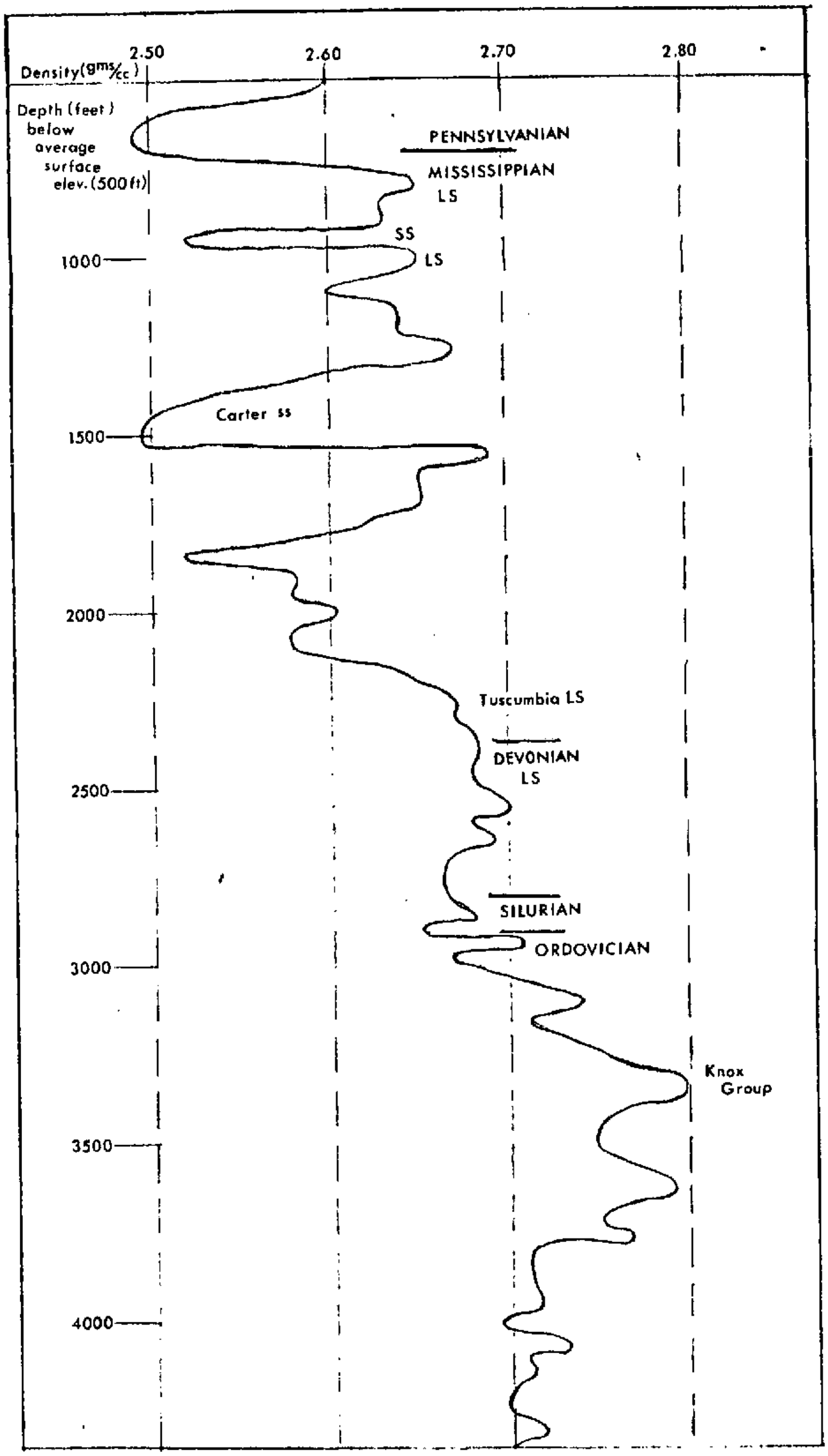

Figure 4.—Composite density log from oil and gas test wells in northern Lamar County, Alabama.

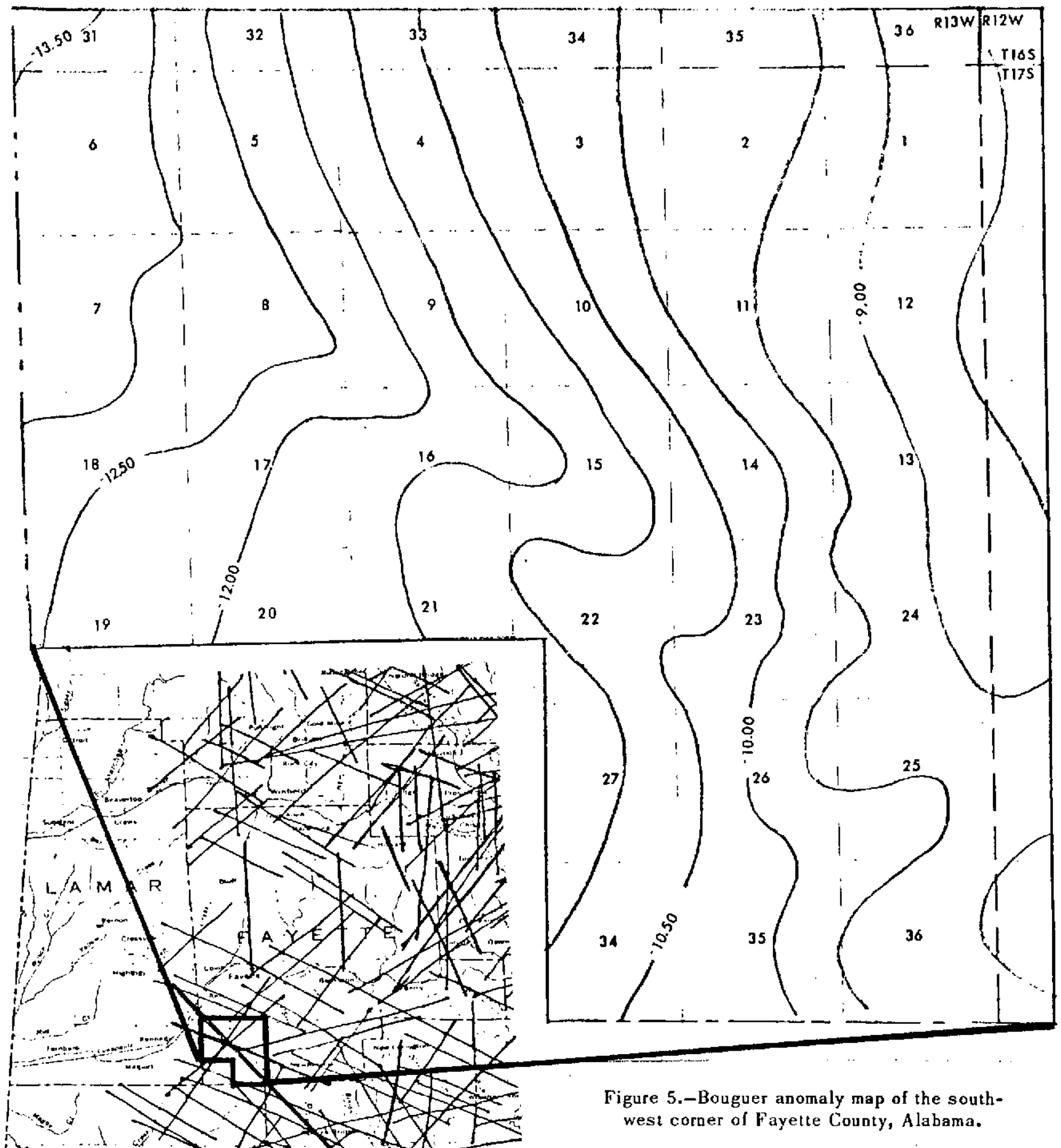

Figure 5.—Bouguer anomaly map of the southwest corner of Fayette County, Alabama.

Figure 6.—Surface lineaments mapped from ERTS imagery in Fayette and Lamar Counties, Alabama.

FIELD TECHNIQUES AND DATA ACQUISITION

Six gravity traverses were made along roads and one traverse along a railroad crossing prominent lineaments mapped from ERTS imagery (pl. 1). Five of the traverses were located across the Anniston lineament complex in Limestone, Madison, and Marshall Counties (Drahovzal, 1974). Two traverses were made across a prominent lineament extending northeastward from the Murphree Valley anticline (Wielchowsky, 1974). The traverses, which vary from 1½ to 8 miles in length, were located so that they would be relatively straight lines in order to make less difficult the task of determining regional gravity effects.

Gravity stations were spaced at intervals which averaged about 525 feet. This close spacing was required since significant density contrasts occur at relatively shallow depths in the area of study. Station elevations were surveyed with a telescopic level and surveying techniques were used to determine distances between stations. Station latitudes were determined from standard USGS 7½-minute quadrangle maps.

A base station location was arbitrarily chosen for each traverse. During the time in which gravity measurements were being made, base stations were reoccupied every 1½ hours in order to establish the rate of meter drift and diurnal changes in the gravity field.

DATA REDUCTION

Raw field data were subjected to standard corrections for latitude and elevation change. Meter drift corrections were applied to the data as determined from base station reoccupations.

Free-air and Bouguer corrections were combined into a single elevation correction. For gravity stations in traverses 1, 2, and 3, the elevation correction used was 0.060 milligal per foot (mgal/ft) change in elevation, assuming a density of 2.67 grams per cubic centimeter (gms/cc) for the limestone rock between the land surface and the datum plane (mean sea level). For stations in traverses 4, 5, 6, and 7, the elevation correction used was 0.062 mgal/ft, assuming an average density of 2.50 gms/cc for the sandstones, shales, and limestones between the land surface and the datum plane.

Since gravity traverses were made in generally straight lines and since stations were closely spaced, it was not imperative that latitude corrections be applied to the data. Interpretations of the gravity profiles can be made with the effects of latitude change incorporated in the curves. Latitude corrections were applied, however, to stations in traverses 2, 3, 5, and 7 for the purpose of comparing regional gravity gradients with a regional Bouguer gravity map of the area (fig. 7). The average effect of

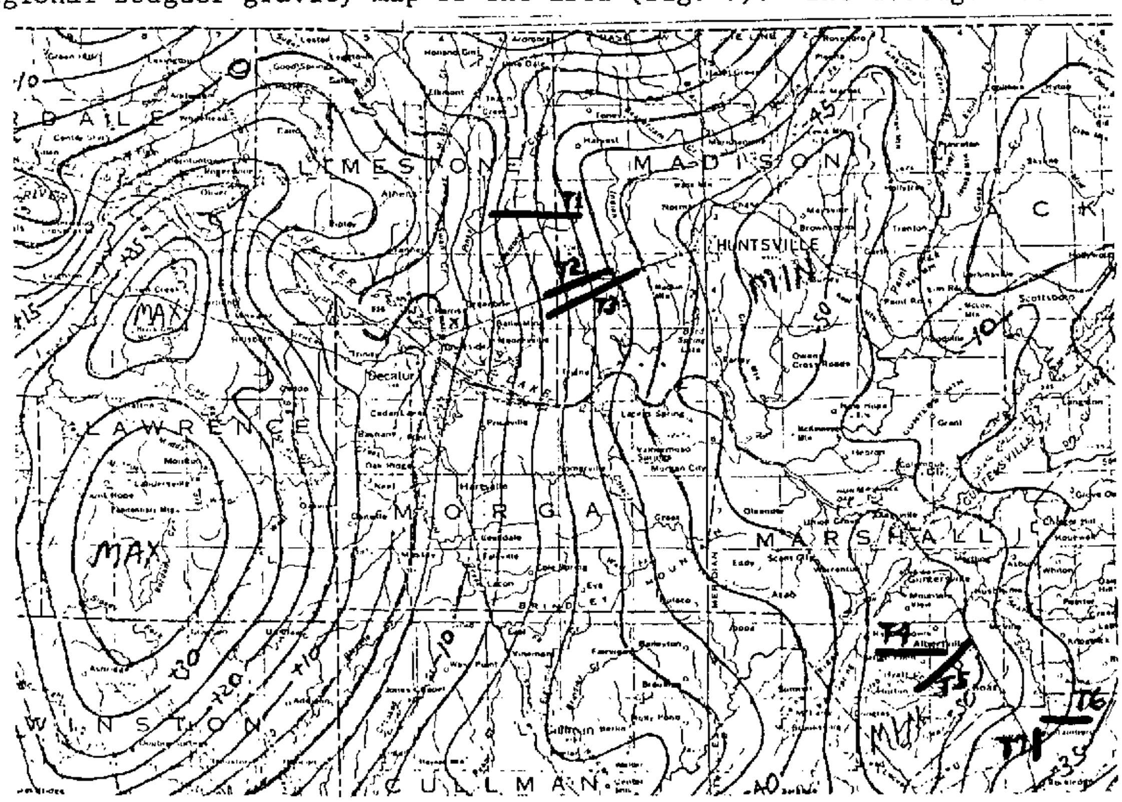

Figure 7.—Regional Bouguer anomaly map of north-central Alabama showing locations of gravity traverses (after Exploration Survey's Inc.).

latitude change from station to station (average distance, 525 feet) along each traverse was as follows: traverse 2, 0.04 mgal; traverse 3, 0.05 mgal; traverse 5, 0.08 mgal; and traverse 7, 0.13 mgal. Traverses 1, 4, and 6 are east-west lines and station latitude corrections were not needed.

PRECISION OF DATA

Because it was known prior to the survey that sedimentary rocks underlying the area of study contain zones capable of producing only very small density contrasts when structurally deformed, much care was taken to acquire accurate field data.

From previous field experience with the gravimeter used in this study, it is known that the instrument can be read to within an accuracy of $\pm$ 0.03 milligal, provided extreme care is used in its operation.

Station elevations are believed to be accurate within $\pm$ 0.3 foot. Such small elevation errors, coupled with the possible small discrepancy that may exist between the assumed and actual subsurface rock densities, are believed to produce errors in the data not exceeding $\pm$ 0.04 milligal. Relative station to station values probably do not exceed $\pm$ 0.02 milligal, since the surveyed areas are of low topographic relief.

As previously mentioned, base stations were reoccupied at about 1½-hour intervals in order to determine and make corrections for meter drift (spring fatigue and thermal effects) and diurnal changes in the gravity field. During the survey, these effects ranged from 0 to 0.4 milligal and averaged 0.2 milligal. Since these changes were small and since the elapsed time between station readings was only a few minutes, the effects on the relative accuracy of station to station gravity values are thought to be negligible.

The gravity profiles give evidence of very few "one station anomalies" or erratics and indicate a relative station to station accuracy well within $\pm$ 0.10 milligal and generally within about 0.05 milligal.

PRESENTATION OF DATA

The corrected gravity data for traverses 1 through 5 were plotted as profiles with horizontal scales of 1 inch = 1,000 feet and vertical scales of 1 inch = 1.0 milligal. Vertical scales of 1 inch = 0.5 milligal were used for profiles from traverses 6 and 7 (pl. 12 and fig. 11). Values were plotted on graph paper (10 x 10 to 1 inch), which facilitates interpretations of anomaly magnitudes and horizontal extent (pls. 7-12).

Regional anomaly effects were interpreted by visual inspection of each profile and drawn with a flexible engineers rule. Since geologic interpretations are based on the deviations from regional anomalies (residual anomalies), the accurate delineation of regional effects is most important. Although other techniques are available for determining regional effects, it is felt that the results of the "smoothing" method used here are satisfactory and that similar results would be obtained through the use of other techniques and by other interpreters.

(Note that the graph sheet for each traverse has been cut parallel to the slope of the regional anomaly and will, therefore, require orientation in order to utilize the background graph for the purpose of estimating residual anomaly magnitudes and horizontal extent. Orientation also assists in visualizing regional gravity anomaly gradients.)

Gravity traverses were not "tied" to pendulum stations and, therefore, absolute gravity values are not given in the appendix. Corrected values which are given for stations in each traverse are relative to the station in that traverse having the smallest Bouguer value which was considered to be zero. Latitude corrections given for stations in traverses 2, 3, 5, and 7 are relative to the southernmost station in each traverse, for which the latitude correction was considered to be zero.

GRAVITY INTERPRETATION

The degree with which gravity data can be used to make geologic interpretations depends to a large extent upon the amount of information available on the densities, depths, and thicknesses of subsurface rock masses down to at least the maximum depth to which it is believed that residual gravity anomalies originate. Unfortunately, in the immediate areas of study, subsurface density information is nonexistent.

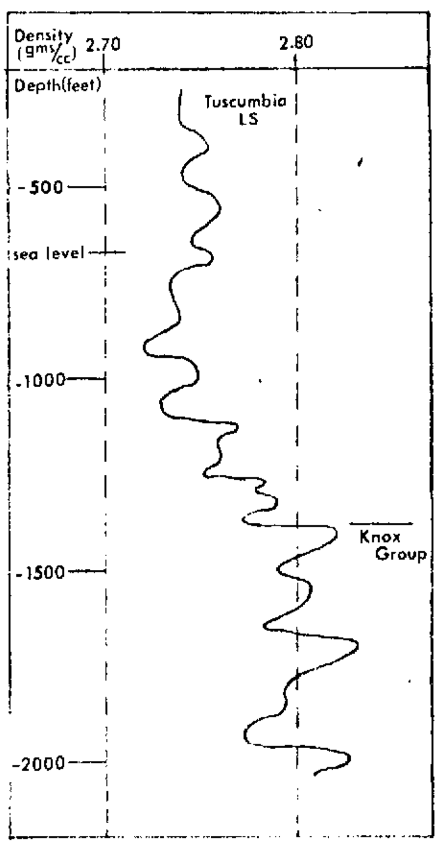

Figure 8.—Density log from oil and gas test well in east-central Madison County, Alabama.

Subsurface density information is available from an oil and gas test-well located some 20-25 miles east of the centers of traverses 1, 2, and 3. Figure 8 shows a density profile prepared from the formation density log of this well. (Note that the horizontal scale of 1 inch = 0.10 gms/cc shows even very small changes in density.) From this profile, it is apparent that, if structurally deformed, the zone at or near the top of the Knox Group would provide the largest density contrast (at least within 2,000 feet of the surface). The crystalline dolomites of the Knox Group show a density of from 0.02 to about 0.08 gram/cc greater than the overlying limestones and cherts. Although the entire Knox Group has not been drilled in this area of Alabama, it is thought to be about 4,000 feet thick. Small density contrasts may occur within the Knox Group (dolomite-limestone-shale) but these contrasts are not likely to be very large and are probably less than the density contrasts at and near the top of these massive dolomites. Rock densities below the Knox Group, including basement rocks, are not known.

Due to the distance between traverses 1, 2, and 3 and the test-well from which density information is available, gravity data from the traverses cannot be strictly interpreted by using this density information. However, although small changes in the rock densities may occur over this distance, it is believed that in the area of traverses 1, 2, and 3 the top of the Knox Group remains as an important density contrast zone. From structure maps made predominately from water-well data on a shallow mapping horizon (Chattanooga Shale of Devonian age), it is interpreted that the top of the Knox Group lies roughly 1,500 feet below these traverses (about 800 feet below sea level) (Jewell, 1969, and McMaster, 1963).

Traverses 4, 5, 6, and 7 are located in an area immediately underlain by sandstones of Pennsylvanian age (lower Pottsville Formation). Underlying these sandstones are Upper Mississippian limestones, shales, and sandstones, which are, in turn, underlain by the Lower Mississippian limestones that outcrop at traverses 1, 2, and 3 (Tuscumbia Limestone). The top of the Knox Group probably lies roughly 3,000 feet below the average surface elevation of traverses 4, 5, 6, and 7 (2,000 feet below sea level).

Oil and gas test-wells are very sparse in the area of traverses 4, 5, 6, and 7, and subsurface density information is nonexistent. Interpretations of the gravity data from these traverses are, therefore, quite limited, even more so than with data from traverses 1, 2, and 3.

LIMITATIONS

The lack of subsurface information on the densities, depths, and thicknesses of rock masses limits the geologic interpretations of gravity data in the surveyed areas. Theoretical methods of defining, with a high degree of accuracy, the geometry of fault structures by gravity data are, therefore, not applicable in this study.

As pointed out by previous authors (Geldart and others, 1966), the determination of density contrast values and the removal of regional gravity effects are not the only problems encountered in defining the geometry of faults from gravity data. Faults are seldom a single plane interface of constant dip. Also, calculations based on horizontal density interfaces may be erroneous when applied to areas underlain by dipping rock masses.

The accuracy with which regional gravity effects are removed is questionable with any gravity survey. Although residual anomalies often remain regardless of the methods used to separate regional effects, the magnitudes and aerial extent of these anomalies may change. Since these anomaly characteristics greatly effect calculations of the size and geometry of structures, such calculations may vary with each regional anomaly interpretation.

POSSIBLE FAULT RELATED GRAVITY ANOMALIES AND CORRELATION WITH LINEAMENTS

Interpretations in this report have been, for the most part, limited to locating those residual anomalies which may be associated with faults and relating these anomalies to locations of lineaments mapped from ERTS imagery.

Figure 9 shows the locations of gravity traverses 1, 2, and 3 and surface lineaments mapped from ERTS imagery. The member lineaments of the Anniston lineament complex that intersect gravity profiles 1, 2, and 3 are lettered A through L. Lineaments A, B, D, E, and G intersect traverse 1 only; C, F, and H intersect all three traverses; and I, J, K, and L intersect traverses 2 and 3 only.

The predominant regional gravity anomalies in the area of these traverses are the large maximum centered in Lawrence County, roughly 30 miles to the west, and the minimum centered in western Madison County about 15 miles east of the traverses (fig. 7). The gravity gradients which can be seen on the profiles from these traverses are governed by these large regional anomalies which are believed to be related to both intrabasement lithology changes and crustal thicknesses (pls. 7-12).

Traverse 1 is 7 miles long and extends east-west through the town of Capshaw in Limestone County. The gravity profile from this traverse is characterized by 5 small residual minima and 1 small maximum (pl. 7). Four of the minima have profiles similar to theoretical anomalies associated with normal faults of moderate dip. The eastern part of the anomaly situated between gravity stations 11 and 17 is correlated with the location at which lineament B intersects the traverse. This residual anomaly, which has a

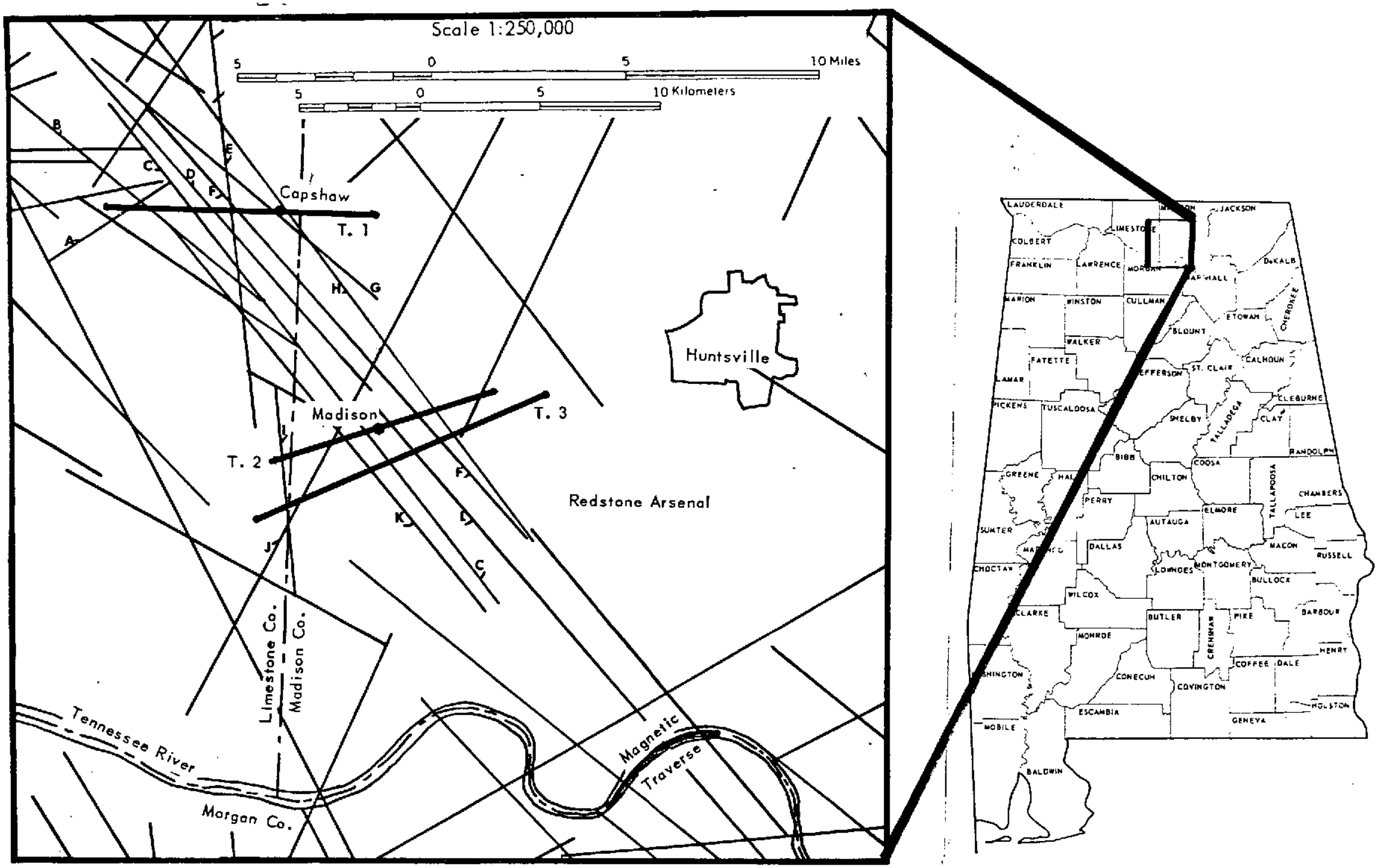

Figure 9.—Lineaments mapped from ERTS imagery in a part of north-central Alabama and locations of gravity traverses 1, 2, and 3 and magnetic traverse.

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maximum intensity of about 0.40 milligal and a horizontal extent of about 3,000 feet, possibly represents the gravity expression of a fault downthrown in a general westward direction. The eastern part of the residual anomaly located between stations 36 and 41 on traverse 1 is correlated with the location at which lineament F intersects the traverse (lineament E also intersects the traverse just west of this location). This anomaly has a maximum intensity of about 0.30 milligal and a horizontal extent of more than 2,500 feet. It too possibly represents the gravity expression of a fault downthrown in a general westward direction.

The traverse 1 residual minimum located between stations 29 and 34 may represent the gravity expression of a fault downthrown in a general eastward direction. The magnitude of this anomaly is about 0.30 milligal, and its horizontal extent is also slightly more than 2,500 feet. Lineament C, which is mapped as intersecting the traverse in the vicinity of station 28, may be the surface trace of a fault related to this anomaly.

The residual minimum located between stations 50 and 55 is possibly related to lineament H and may represent the gravity expression of a fault downthrown in a general eastward direction. This anomaly has a maximum intensity of slightly more than 0.30 milligal and a horizontal extent of about 2,500 feet.

Residual gravity anomalies are not interpreted to exist at the locations where lineaments A, C, and G intersect traverse 1.

Traverse 2 is 5½ miles long and extends northeast-southwest along the Southern Railroad line through the town of Madison, Madison County. The gravity profile from this traverse is characterized by 5 small residual minima, at least three of which may be related to fault structures (pl. 8). The minimum situated between stations 12 and 18 has an intensity of about 0.30 milligal and a horizontal extent of about 3,000 feet. The anomaly may represent a fault downthrown to the west, and lineament K, which is mapped as intersecting traverse 2 in the vicinity of station 20, may be the surface trace of this fault. Lineament J is mapped as intersecting the traverse a short distance west of lineament K.

A 0.20 milligal minimum located between stations 30 and 35 may be related to a fault downthrown in a general eastward direction. Lineament C, which is mapped as intersecting traverse 2 in the vicinity of station 28, may be the surface trace of this fault.

The residual minimum located between stations 35 and 40 on traverse 2 has an intensity of about 0.20 milligal and an apparent horizontal extent of about 2,500 feet. This anomaly may be due to a fault downthrown to the west. Lineament F is mapped as intersecting the traverse at about station 42 and is possibly the surface expression of such a fault. (Note: Lineament F also correlated with the location of a 0.30 milligal minimum occurring between stations 36 and 41 on traverse 1.)

The minimum located between stations 20 and 26 may be related to either lineaments K or C. The profile of this residual anomaly does not appear to be similar to a typical fault-related anomaly. This may be due, however, to the overlapping effect of anomalies or to the very small magnitude of the anomaly (0.15 milligal) and the difficulties related to defining such small gravity features. Lineament K is mapped as intersecting the traverse near the western end of the anomaly and lineament C near its eastern end.

Lineament H is mapped as intersecting traverse 2 in the vicinity of station 43. The station spacing in this area was, by necessity, greater than 2,000 feet, and therefore, anomalies of small horizontal extent may not be detected.

A residual minimum that has a horizontal extent of about 1,000 feet and an intensity of 0.25 milligal occurs near the western end of traverse 2 and at the approximate location of lineament I. The apparent small horizontal extent of this anomaly may indicate a much shallower origin than the other anomalies observed on traverses 1, 2, and 3. Cavernous limestone may underlie this area, or it is possible that overlapping anomalies exist, thus making interpretations more difficult, especially since the anomaly is located near the end of the traverse.

Traverse 3 is 8 miles long and extends northeast-southwest along highway 72A southwest of the city of Huntsville. The gravity profile from this traverse is characterized by a number of residual anomalies, most of which occur along the eastern-half of the profile (pl. 9). Perhaps the most significant anomaly occurs in the vicinity of station 46, where a 0.35 milligal minimum possibly represents the gravity expression of a fault downthrown in a general westward direction. Lineament L is mapped as intersecting the traverse in the vicinity of station 46 and may be the surface trace of such a fault. Faults and/or other structural features between stations 33 and 42 may be responsible for the apparent wide horizontal extent of this residual minimum (Note: Lineament C is mapped as crossing traverse 3 in the vicinity of station 38.).

Lineament K intersects traverse 3 in the vicinity of the small residual minimum (0.15 milligal) located between stations 28 and 32. The profile of this residual gravity feature does not appear to be that of a typical fault-related anomaly, but again this may be due to its very small magnitude.

Four other residual minima exist along traverse 3 between stations 51 and 69 and another between stations 73 and 76. For the most part, these anomalies do not have typical fault-related profiles and their origins and relationships, if any, to surface lineaments are highly uncertain. Lineament F is mapped as intersecting traverse 3 in the vicinity of station 53 and lineament H in the vicinity of station 58. The anomaly between stations 59 and 63 may be related to lineament H and represent the gravity expression of a normal fault downthrown in a general eastward direction. It is interesting to note that a similar anomaly on the profile from traverse 1 is possibly associated with lineament H. Surface lineaments are not mapped east of station 60.

A small anomaly of 0.15 milligal occurs between stations 5 and 9 and may be associated with lineament I. Just west of this anomaly, a small minimum between stations 1 and 4 is not associated with a lineament. Lineament J intersects traverse 3 in the vicinity of station 12 and is not associated with a gravity anomaly.

Traverses 4 and 5, located in Marshall County roughly 40 miles southeast of traverse 3, are crossed by a number of lineaments of the Anniston lineament complex (fig. 10). The profiles from these traverses and also traverses 6 and 7 contrast highly with the profiles of traverses 1, 2, and 3, both in the number and magnitudes of residual anomalies.

Traverse 4 is 5 miles long and located on an east-west road west of the city of Albertville. The residual minimum between stations 8 and 15 on this traverse may be related to lineament M which is mapped as intersecting the traverse in the vicinity of station 8 (pl. 10). The anomaly, which has an intensity of only about 0.15 milligal and a horizontal extent of approximately 3,500 feet, may represent the gravity expression of a normal fault downthrown in a general eastward direction. East of this feature is a 0.10 milligal residual minimum located between stations 18 and 23. Lineament N intersects the profile in the vicinity of station 17, and could be related to this anomaly. This particular anomaly, however, does not have the appearance of a typical fault-related gravity feature.

A small but distinct gravity minimum occurs between stations 39 and 44 on traverse 4. The anomaly, which has a magnitude of only 0.1 milligal and a horizontal extent of about 2,500 feet, may represent the gravity expression of a normal fault downthrown to the west. Lineament O intersects the traverse in the vicinity of station 44 and may be the surface expression of such a fault.

Traverse 5 extends northeast-southwest along highway 75 from the city limits of Albertville to 5½ miles southwest of the city. The gravity profile from this traverse contains two small, but possibly significant residual minima, both of which occur in the southwest part of the profile (pl. 11). Lineament N intersects traverse 5 in the vicinity of station 11 where a small 0.10 milligal minimum is located. The lineament also could be related to the 0.15 milligal minimum located between stations 13 and 17. This anomaly may be the gravity expression of a fault downthrown in a general eastward direction.

Excluding possibly lineament O, the lineaments crossing the eastern half of traverse 4 and the central part of traverse 5 are not associated with appreciable gravity anomalies. Lineament O is not associated with a distinct gravity anomaly on traverse 5 as it apparently is on traverse 4. The lineament intersects traverse 5 in the vicinity of station 32 where a very small minimum exists (0.07 mgal?). This anomaly is poorly defined and geologic interpretations cannot be made as to its origin or relationship, if any, to the lineament.

Traverses 6 and 7 are located in northern Etowah County which borders Marshall County on the southeast (fig. 10). The main purpose of these traverses was to determine if a gravity anomaly is associated with the ERTS lineament trending northeast from the Murphrees Valley anticline (lineament P) (Wielchowsky, 1974). This lineament may be the surface expression of a northeast extention of the "Straight Mountain fault", which a few miles southwest of the traverses, has brought rocks of Ordovician age into juxtaposition with rocks of Pennsylvanian age (high-angle reverse fault upthrown on northwest side). Although the lineament is prominent on ERTS imagery, a fault is not apparent on the surface at either traverse where weathered sandstones of Pennsylvanian age are exposed.

Traverse 6 is an east-west profile located about 10 miles southeast of traverse 5. The largest residual anomaly on the profile from traverse 6 is a small minimum located between stations 29 and 37 (pl. 12). This anomaly has a maximum intensity of only about 0.10 milligal in the vicinity of station 35 (Note: The vertical scale of this profile differs from previous profiles.). The apparent horizontal extent of the anomaly is about 4,000 feet which indicates that it originates at depths above the estimated top of

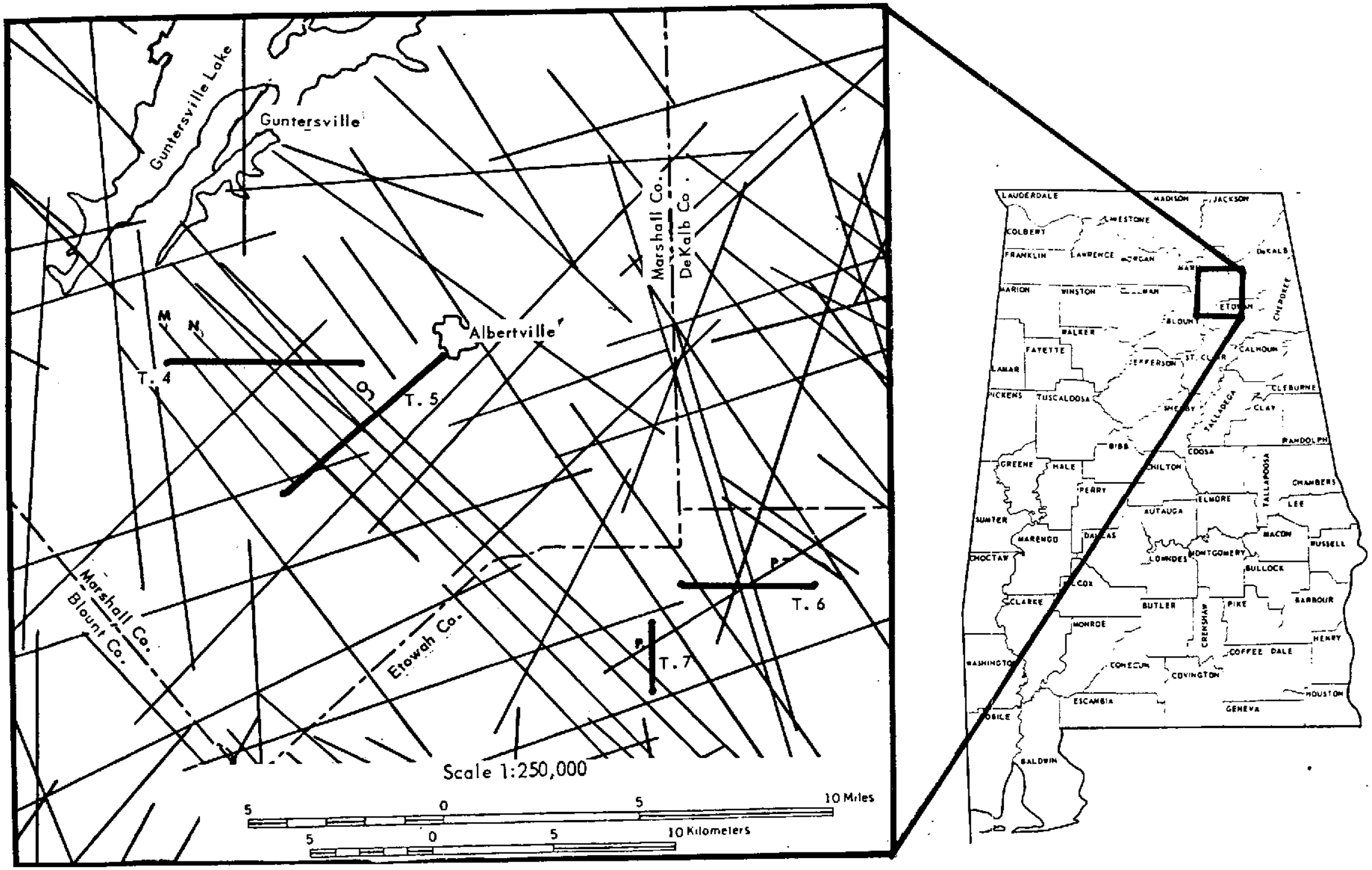


Figure 10.—Lineaments mapped from ERTS imagery in a part of northeast Alabama and locations of gravity traverses 4, 5, 6, and 7.

the Knox Group. This anomaly may represent the gravity expression of a fault downthrown in a general westward direction. A surface lineament is not mapped in the area of this anomaly.

The profile from traverse 6 does not indicate the presence of gravity anomalies in association with the group of surface lineaments extending through the central part of the traverse. This includes the lineament from the Murphrees Valley anticline (lineament P).

Traverse 7 is located just southwest of traverse 6. By necessity, the traverse was limited to a length of 1½ miles. This makes the task of interpretating regional effects more difficult than usual. Figure 11 shows the gravity profile from traverse 7 with two different regional anomaly interpretations (R1 and R2) and resulting residual anomalies. Lineament P is mapped as intersecting the profile in the vicinity of station 6. Regional interpretation number 1 indicates two residual minima, one between stations 2 and 7 and a larger one between stations 10 and 15. Regional interpretation 2 shows a residual maximum between stations 6 and 11 and a small minimum between stations 10 and 14. Neither of these interpretations agree with a theoretical gravity anomaly of a high-angle reverse fault in the area of station 6 (upthrown on northwest side). Theoretically, a positive residual anomaly would occur over the upthrown side of the fault, and a smaller negative anomaly over the downthrown side. (Note: This lineament is apparently not associated with a gravity anomaly at its intersection with traverse 6, however, this location is some 3 miles northeast along the lineament from its intersection with traverse 7. The lineament becomes less pronounced in a northeast direction and disappears a short distance northeast of traverse 6.) The anomalies of regional interpretation number 2 would correspond to a

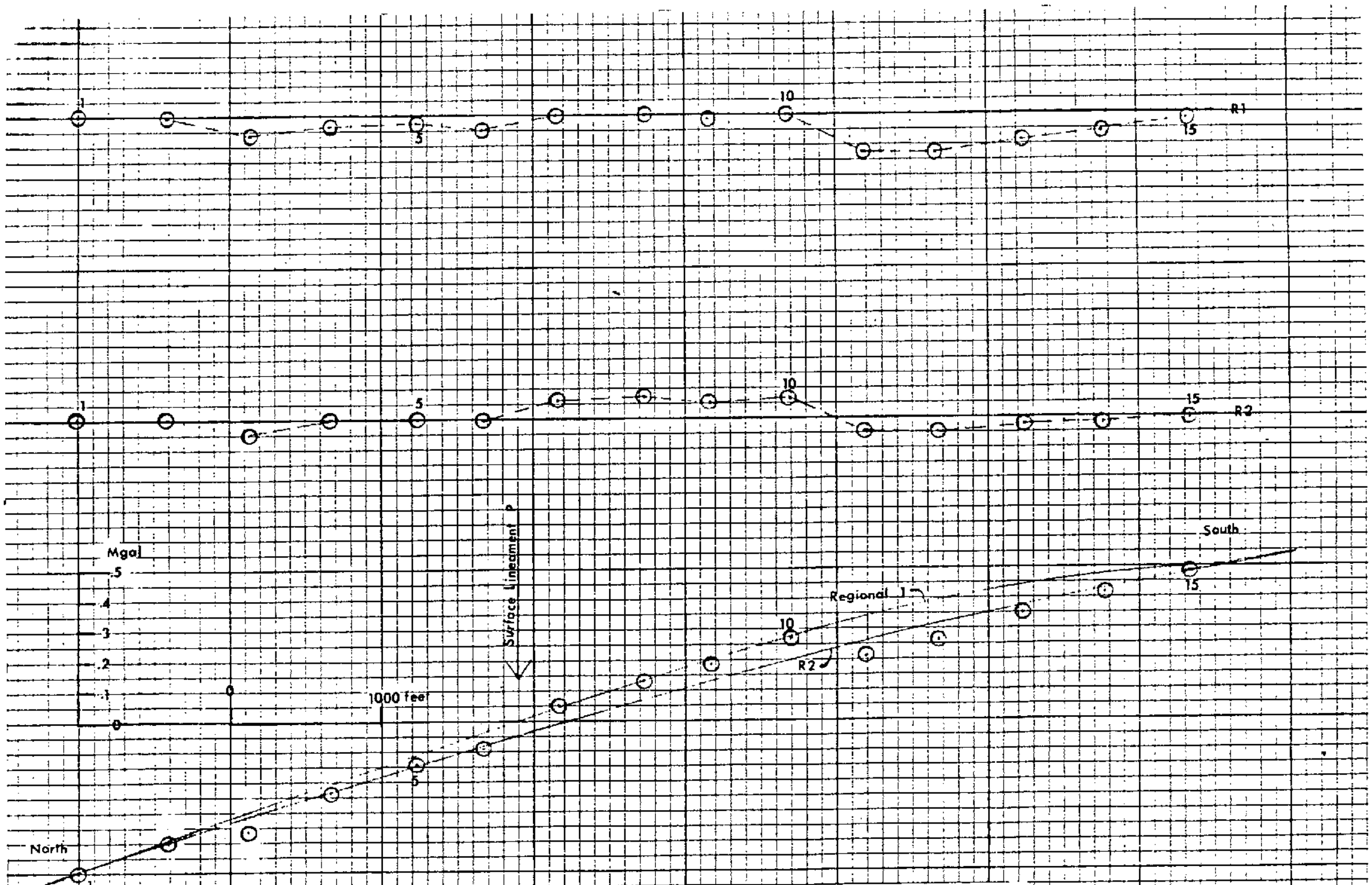


Figure 11.—Gravity profile from traverse 7 in northern Etowah County, Alabama and two possible regional anomaly interpretations and resulting residual anomalies.

high-angle reverse fault anomaly only if the fault plane were located south of station 10 or more than 2,000 feet south of its presently mapped location. However, lineament P is thought to be accurately mapped in the vicinity of stations 6 and 7 on traverse 7 where a private lake was visible on ERTS imagery and used in the horizontal control of the lineament.

On the basis of gravity data from traverses 6 and 7, geologic interpretations cannot be made as to the origin of lineament P. It is probable that the lineament represents a structure too small to be adequately defined by gravity methods.

SUMMARY AND CONCLUSIONS

The results of data from gravity traverses 1, 2, and 3 across the Anniston lineament complex indicate that several of the lineaments represent the surface expressions of major faults. Although the observed gravity anomalies can be theoretically duplicated by flexures at depths of less than 1,500 feet, the absence of large density contrasts at these shallow depths does not support such an interpretation. Given the small density contrasts from the surface to depths of 1,500 feet (less than 0.10 gms/cc), such flexures would have to be steep and of large magnitude in order to produce gravity anomalies resembling those observed in this study. The gravity data, therefore, supports a fault interpretation theory for several of the lineaments.

The Anniston lineament complex in the vicinity of traverses 1, 2, and 3 appears to be related to a fault block system (fig. 12). The locations

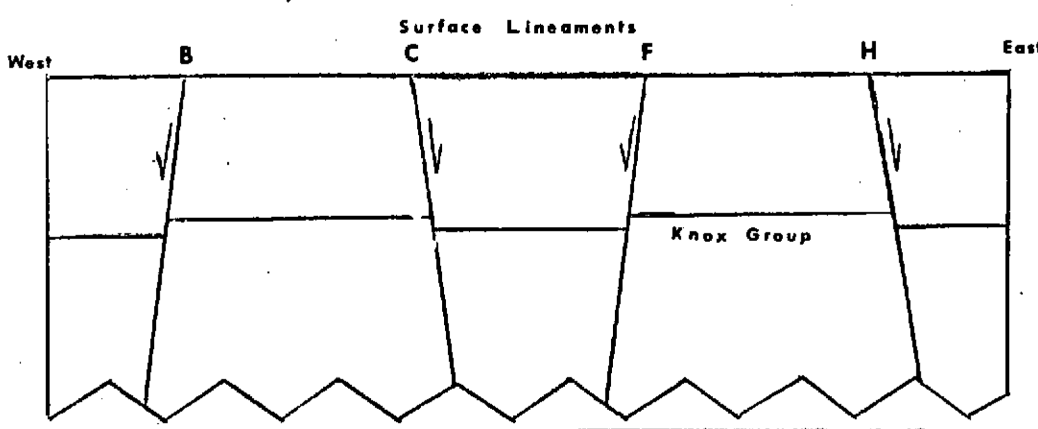


Figure 12.–Structural interpretation of the gravity data from traverse 1, Limestone and Madison Counties, Alabama (vertical exaggeration 2.5x).

of lineaments labeled B, F, L, and either J or K were correlated with the positions of gravity anomalies that indicate the presence of normal faults downthrown in a general westward direction. Lineaments labeled C and H appear to be associated with anomalies indicating normal faults downthrown in a general eastward direction.

Additional residual gravity minima were discovered, a few of which correlated with the locations of lineaments. These anomalies, however, do not have profiles distinctly similar to theoretical fault-related anomalies. This could possibly be due either to the very small magnitude of some of the anomalies and difficulties related to defining such small features in regional gravity fields, or to the effects of overlapping anomalies. Lineament N (fig. 10) appears to be associated with gravity anomalies of this type. Similar residual minima observed on profiles from traverses 4 and 5 were correlated with the location of this lineament. Both anomalies have an intensity of about 0.10 milligal and a horizontal extent of only about 1,500 to 2,000 feet. This lineament may very well represent the surface expression of a fault that has a displacement, or throw, too small to be adequately defined by gravity surveying but large enough to be considered a major fault (perhaps up to 150 feet or more in displacement).

The inexistence of gravity anomalies in association with surface lineaments in the area of study does not, by any means, signify the absence of faults. The small density contrasts present in the subsurface indicate that only faults having large vertical displacements will be detected by gravity surveying.

Due to the lack of precise subsurface density information in the immediate area of study, it is not possible to determine, with a high degree of accuracy, the geometries of the assumed faults. From the observed anomalies, however, it is possible to make certain generalized observations as to the nature of the faults.

The maximum depth to the origin of a fault-related gravity anomaly is approximately equal to the distance from the fault trace to the point at which the anomaly has decreased to one-half of the maximum intensity observed near the fault trace. From this general depth rule, it is apparent with most of the anomalies observed from traverses 1, 2, and 3 that the maximum depth of origin is about 1,500 feet or the approximate depth to the Knox Group in this area. It is therefore believed that the residual gravity anomalies observed in these areas originate at or very near the top of the dense dolomites of the Knox Group. In the area of traverses 4, 5, 6, and 7, the few residual anomalies observed appear to originate within about 2,500 feet of the surface.

Accurate determinations of fault displacements are not possible. However, the information on subsurface rock densities in nearby areas, in conjunction with the magnitudes of the probable fault-related anomalies observed in profiles from traverses 1, 2, and 3 (generally 0.20 to 0.40 milligal) indicate that fault displacements are probably in the range of 150 to 300 feet at the depth of the zone of major density contrast.

Gravity anomalies associated with faults always consist of troughs and peaks. The peaks or positive anomalies are often difficult to distinguish in regional gravity fields, especially if they are associated with faults of low or moderate dip. The relative amplitude of the positive and negative components of a fault-related anomaly is dependent upon the dip of the fault (fig. 13, after Geldart and others). With a high angle or nearly vertical fault, the amplitude of the positive component of the gravity anomaly approaches that of the negative. In the area of study, only two of the probable fault-related anomalies of traverses 1, 2, and 3 indicate the presence of a positive

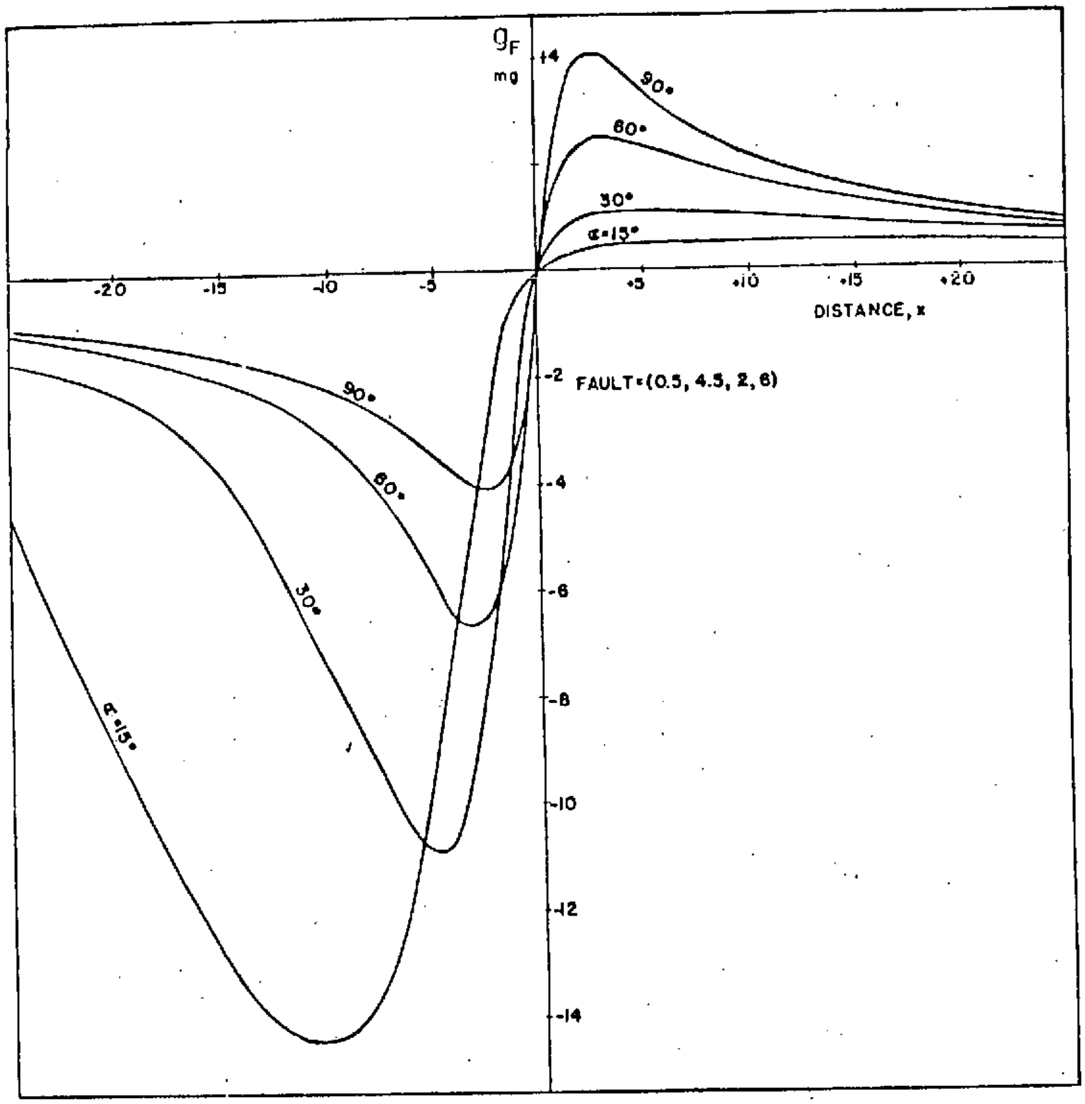


Figure 13.—Variation of the gravity effect of a fault with change in dip (for a thick bed) (after Geldart, Gill, and Sharma, 1966).

component, these being of very small magnitude (0.05 and 0.10 mgal). Other anomalies gave no indication of the existence of the positive components at the assumed fault traces. Also, most of the anomalies of traverses 1, 2, and 3 reach their maximum intensity within a one station interval of the inflection point (average distance of 525 feet). The interpreted faults in the area of these traverses are, therefore, believed to be of moderate dip, perhaps about 60 degrees from the horizontal. (Note: With dips of about 60° lineaments or surface traces of faults would occur roughly 1,000 feet from the inflection points of the gravity anomalies, assuming that the anomalies originate at or near the top of the Knox Group or at depths of about 1,500 feet.)

The degree of horizontal accuracy of lineament traces on base maps used in this report is unknown. Since lineaments were transferred from ERTS photographs to base maps, which were then used in attempts to correlate the locations of the lineaments with the positions of gravity anomalies, it is possible that small errors may exist in the horizontal positions of the lineaments in respect to the gravity profiles. This fact, coupled with the existence of a relatively large number of lineaments crossing traverses 1, 2, and 3, may cause some skepticism as to the validity of attempts to correlate lineament locations with gravity anomalies in this area. Some observers may feel that the large number of lineaments makes it probable that a lineament will be located in areas where gravity anomalies exist. Lineaments crossing traverses 1, 2, and 3 are believed, however, to be accurately mapped and correlations valid for several reasons.

In almost all cases, lineaments, or fracture traces, were mapped as being located very near the inflection points for the gravity anomalies of probable fault origin. Also, several lineaments, which crossed two or more traverses, were found to be closely associated with the locations of the inflection points of similar anomalies on the separate profiles. For example, the inflection points for similar gravity anomalies on traverses 1 and 3 were closely associated with the location (as mapped) of lineament H, which, from the nature of the anomaly, has been interpreted to be the surface expression of a normal fault downthrown in a general eastward direction. The inflection points for similar anomalies of traverses 1 and 2 were found to be closely associated with the location of lineament F, which, from the profiles, is interpreted to be the surface expression of a normal fault downthrown in a general westward direction. Also, similar anomalies on traverses 1 and 2 appear to be associated with lineament C and represent a fault downthrown in an eastward direction. Another interesting fact is the absence of residual gravity anomalies of probable fault origin in the southwestern part of traverse 3, an area mapped to be void of surface lineaments or fracture traces.

On the basis of the above mentioned observations, it is believed that lineaments crossing traverses 1, 2, and 3 are accurately located, perhaps within 1,500 feet. The horizontal accuracy of most of the lineaments mapped as crossing traverses 4, 5, 6, and 7 is somewhat uncertain since distinct anomalies of probable fault origin were not found to be associated with the majority of lineaments. Gravity minima are closely associated with the location of lineament N on traverses 4 and 5, and lineament O appears to be closely associated with an anomaly on traverse 4. These lineaments are therefore believed to be accurately mapped.

Residual anomalies interpreted for the profiles from traverses 4, 5, 6, and 7 are extremely small (0.15 milligal or less) and only a fraction of the magnitude of the anomalies observed in profiles from traverses 1, 2, and 3. Information is not available on the densities of subsurface rock formations in or near the area of traverses 4, 5, 6, and 7, and it is, therefore, not definitely known if the absence of prominent residual anomalies is due to the lack of significant density contrasts at depth. Gross density relationships of subsurface rock formations in this area, however, are thought to be somewhat similar to that of northern Lamar County, Alabama, where a fault with a displacement of about 350 feet (at a depth of 1,600 feet) produces a 0.50 milligal gravity anomaly. (Rocks which outcrop at the surface in the area of traverses 4, 5, 6, and 7 are stratigraphically equivalent to rocks approximately 600 feet below the average surface elevation in the area of the Lamar County fault.) In the area of these traverses, it is highly possible that the absence of prominent residual gravity anomalies is due to the inexistence of near surface geologic structures of large magnitude.

In the area of traverses 4 and 5 the absence of prominent residual anomalies in association with the Anniston lineament complex may indicate that the related faults decrease significantly in magnitude from the area of traverses 1, 2, and 3. It is also possible that fault magnitudes vary with depth and rock age. Fault displacements in rocks of Pennsylvanian and Mississippian age may be much smaller than displacements in rocks of Ordovician and Cambrian age (i.e. Knox Group). The absence of pronounced residual anomalies of probable fault origin at traverses 4 and 5 may be due in part to the fact that these older rocks, and therefore possibly the largest displacements along the faults, occur at more than twice the depth than at traverses 1, 2, and 3.

It is likely that many lineaments mapped from ERTS imagery are associated with faults that have displacements too small to be adequately defined by gravity surveying but large enough to be considered significant structures.

[Note: Attempts were made to obtain detail vertical magnetic data along gravity traverse lines. These efforts were unsuccessful, however, due to the magnetic interference from man-made sources. It was hoped that such information would be of value in determining whether or not surface lineaments are associated with magnetic anomalies indicating structural deformation in basement rocks.

One magnetic traverse was completed along the Tennessee River just south of the city of Huntsville (fig. 7). Three surface lineaments are mapped as crossing this vertical magnetic intensity profile, which has a station spacing of about 600 feet (fig. 14). As interpreted from gravity traverses 1 and 3, lineament H may represent the surface expression of a normal fault downthrown to the northeast. If this interpretation is correct and if the inferred fault is of moderate dip (approximately 60°), then at the estimated depth to basement rocks (7,000 feet), the fault plane would lie east of the east end of the profile.

Assuming that lineament L (at about station 14) represents the surface expression of a moderately dipping fault downthrown to the southwest (see gravity interpretation), then at the estimated depth to basement rocks, the fault would lie below the surface at about station 22 (dashed arrow) and at the eastern edge of the small magnetic trough which has an apparent intensity of about 20 gammas.

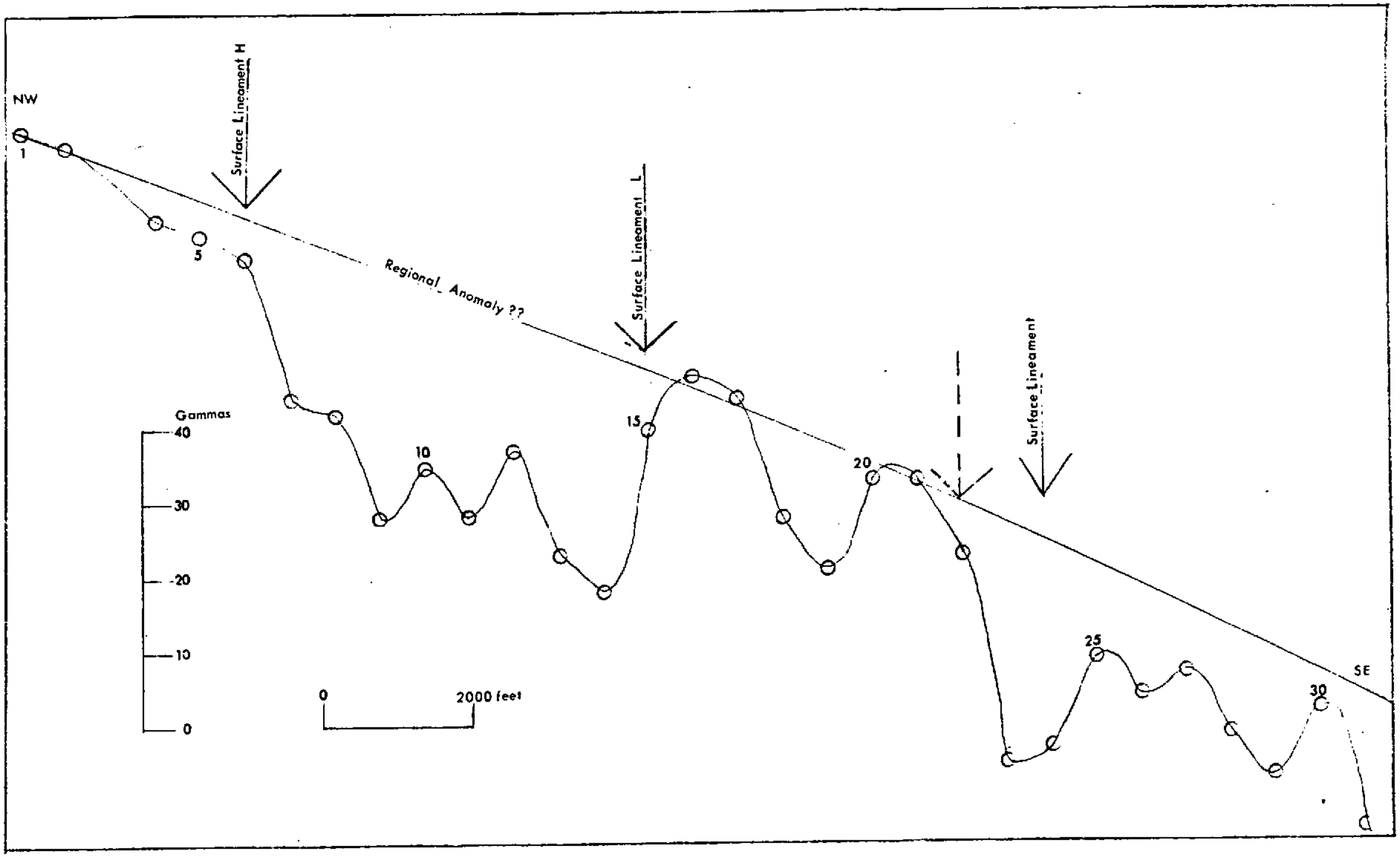


Figure 14.—Vertical magnetic intensity profile across lineaments mapped from ERTS imagery.

12-488

It was observed during field operations that small changes in magnetic intensities were due, in part, to variations in the concentration of heavy minerals in river sediments. This phenomenon was especially obvious in the immediate vicinity of station 23 where a small, isolated bedrock outcrop produced anomalously low magnetic readings. For this reason, it is not known if the magnetic trough southwest of station 20 is due to basement faulting or whether it is the result of a thinner veneer of river sediments in the vicinity of these stations. Without the support of data from additional magnetic traverses across these lineaments, interpretations of this one profile would be highly ambiguous.]

APPENDIX

BASIC GRAVITY DATA

TRAVERSE 1

STA. NO.	LATITUDE	LONGITUDE	ELEV. (ft.)	LAT. CORR.	STA. G*	CORR. G*	STA. NO.	LATITUDE	LONGITUDE	ELEV. (ft.)	LAT. CORR.	STA. G*	CORR. G*
1	34°46'25.0"	86°52'36.8"	701.5	0	33.34	30.77	37	34°46'24.4"	86°48'53.5"	719.5	0	14.24	12.76
2	46'25.0"	52'30.0"	690.7	0	33.27	30.06	38	46'24.3"	48'47.8"	716.8	0	13.91	12.27
3	46'25.0"	52'24.0"	683.8	0	33.20	29.57	39	46'24.2"	48'41.4"	715.9	0	13.47	11.78
4	46'25.0"	52'17.8"	686.4	0	32.40	28.93	40	46'24.2"	48'34.8"	713.2	0	13.19	11.34
5	46'25.0"	52'12.3"	686.3	0	31.91	28.43	41	46'24.0"	48'28.9"	701.3	0	13.78	11.23
6	46'25.0"	52'06.2"	690.3	0	31.18	27.93	42	46'23.3"	48'22.1"	681.8	0	14.65	10.94
7	46'25.0"	52'00.2"	692.7	0	30.63	27.54	43	46'23.2"	48'16.2"	668.1	0	15.19	10.65
8	46'25.0"	51'54.2"	688.1	0	30.54	27.17	44	46'23.1"	48'10.2"	661.7	0	15.20	10.28
9	46'25.0"	51'48.0"	694.6	0	29.74	26.76	45	46'23.1"	48'04.2"	662.3	0	14.75	9.87
10	46'25.0"	51'42.0"	708.7	0	28.43	26.29	46	46'22.9"	47'56.8"	663.5	0	14.04	9.25
11	46'25.0"	51'34.5"	707.8	0	28.01	25.82	47	46'22.8"	47'51.0"	659.9	0	13.84	8.82
12	46'25.0"	51'28.6"	715.6	0	27.11	25.39	48	46'22.6"	47'44.9"	661.5	0	13.24	8.32
13	46'25.0"	51'22.2"	719.3	0	26.42	24.92	49	46'22.4"	47'39.8"	667.2	0	12.64	8.08
14	46'25.0"	51'16.0"	712.5	0	26.32	24.41	50	46'22.1"	47'33.0"	675.3	0	11.71	7.63
15	46'24.8"	51'10.5"	712.4	0	25.76	23.85	51	46'22.1"	47'26.2"	707.5	0	9.02	6.88
16	46'24.8"	51'04.0"	722.2	0	24.84	23.51	52	46'22.0"	47'20.0"	703.5	0	8.97	6.59
17	46'24.8"	50'58.2"	715.8	0	25.10	23.39	53	46'22.0"	47'13.7"	710.0	0	8.35	6.36
18	46'24.8"	50'52.8"	716.4	0	24.69	23.01	54	46'21.8"	47'07.9"	727.5	0	6.90	5.96
19	46'24.7"	50'47.0"	720.0	0	23.98	22.50	55	46'21.8"	47'01.0"	732.4	0	6.32	5.67
20	46'24.7"	50'39.8"	725.2	0	23.03	21.89	56	46'21.8"	46'54.2"	738.3	0	5.47	5.18
21	46'24.7"	50'33.2"	726.0	0	22.35	21.25	57	46'21.8"	46'47.8"	731.8	0	5.48	4.80
22	46'24.6"	50'27.5"	729.5	0	21.40	20.51	58	46'21.8"	46'41.0"	732.9	0	4.92	4.31
23	46'24.6"	50'21.2"	725.7	0	20.95	19.83	59	46'21.8"	46'34.0"	742.4	0	4.14	4.10
24	46'24.6"	50'15.0"	728.9	0	20.16	19.24	60	46'21.7"	46'27.0"	760.8	0	2.55	3.61
25	46'24.5"	50'08.9"	728.2	0	19.70	18.74	61	46'21.7"	46'19.9"	775.3	0	1.17	3.10
26	46'24.5"	50'02.4"	727.4	0	19.12	18.12	62	46'21.7"	46'13.8"	770.0	0	1.15	2.77
27	46'24.5"	49'55.0"	724.8	0	18.75	17.59	63	46'21.7"	46'06.0"	780.6	0	-0.08	2.18
28	46'24.5"	49'49.8"	723.1	0	18.49	17.23	64	46'21.7"	45'59.8"	767.8	0	0.54	2.03
29	46'24.5"	49'43.9"	723.0	0	17.96	16.70	65	46'21.5"	45'53.1"	761.9	0	0.52	1.66
30	46'24.2"	49'37.5"	725.0	0	17.07	15.93	66	46'21.5"	45'46.9"	756.3	0	0.41	1.21
31	46'24.8"	49'30.8"	728.1	0	16.42	15.45	67	46'21.4"	45'40.8"	753.9	0	0.28	0.94
32	46'24.8"	49'24.9"	728.4	0	16.09	15.13	68	46'21.2"	45'33.2"	754.3	0	0.04	0.73
33	46'24.7"	49'19.0"	725.6	0	15.89	14.77	69	46'21.2"	45'27.5"	755.3	0	-0.20	0.55
34	46'24.6"	49'12.5"	722.9	0	15.65	14.38	70	46'21.2"	45'21.2"	746.0	0	0.33	0.52
35	46'24.5"	49'06.0"	720.6	0	15.33	13.91	71	46'21.2"	45'14.9"	744.7	0	0.15	0.27
36	46'24.5"	49'00.0"	723.8	0	14.55	13.33	72	46'21.2"	45'08.8"	742.8	0	0.00	0.00

* Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 72; an elevation correction of 0.060mgal/ft. was used for "CORR.G" —— Datum mean sea level

TRAVERSE 1

TRAVERSE 2

STA. NO.	LATITUDE	LONGITUDE	ELEV. (ft)	LAT. CORR.	STA. G*	CORR. G*
1	34°40'46.5"	86°47'44.8"	660.8	0.00	12.45	13.89
2	40'48.0"	47'39.5"	665.4	0.04	11.78	13.47
3	40'49.7"	47'33.8"	669.4	0.08	11.03	12.92
4	40'51.4"	47'28.3"	674.3	0.12	10.63	12.77
5	40'53.1"	47'22.8"	679.1	0.16	10.10	12.48
6	40'54.8"	47'16.8"	683.1	0.20	9.49	12.07
7	40'56.5"	47'11.2"	687.1	0.24	8.95	11.73
8	40'58.2"	47'05.8"	690.0	0.28	8.52	11.44
9	40'59.9"	47'00.0"	685.6	0.32	8.44	11.05
10	41'01.6"	46'54.2"	680.8	0.36	8.37	10.66
11	41'03.2"	46'48.3"	676.4	0.40	8.29	10.28
12	41'04.9"	46'42.4"	671.5	0.44	8.23	9.88
13	41'06.5"	46'36.6"	667.7	0.48	8.13	9.51
14	41'08.2"	46'30.8"	664.3	0.52	8.07	9.20
15	41'09.8"	46'24.9"	659.7	0.56	7.88	8.70
16	41'11.5"	46'19.1"	655.4	0.60	7.83	8.24
17	41'13.2"	46'13.3"	654.7	0.64	7.57	8.01
18	41'14.9"	46'07.6"	659.1	0.68	7.25	7.92
19	41'16.6"	46'01.9"	663.5	0.72	6.73	7.62
20	41'18.4"	45'56.2"	668.0	0.76	6.24	7.36
21	41'20.2"	45'50.6"	670.5	0.80	5.63	6.86
22	41'21.9"	45'44.9"	667.8	0.84	5.60	6.63
23	41'23.6"	45'39.3"	666.9	0.88	5.71	6.27
24	41'25.4"	45'33.6"	666.9	0.92	5.09	5.98
25	41'27.2"	45'27.9"	668.9	0.96	4.74	5.71
26	41'29.0"	45'21.9"	673.4	1.00	4.34	5.54
27	41'30.8"	45'16.0"	672.7	1.04	4.24	5.36
28	41'32.6"	45'10.1"	670.6	1.08	4.12	5.07
29	41'34.5"	45'04.2"	671.2	1.12	3.88	4.83
30	41'36.0"	44'58.2"	674.0	1.16	3.48	4.56
31	41'37.7"	44'52.6"	677.4	1.20	2.90	4.15
32	41'39.4"	44'47.0"	681.3	1.24	2.51	3.95
33	41'41.1"	44'41.3"	685.6	1.28	2.18	3.84
34	41'42.8"	44'35.7"	690.3	1.32	1.75	3.65
35	41'44.5"	44'30.0"	695.3	1.36	1.36	3.52
36	41'46.2"	44'24.3"	696.5	1.40	1.04	3.23
37	34°41'47.9"	86°44'18.5"	692.4	1.44	1.10	3.00
38	41'49.6"	44'12.8"	689.6	1.48	1.07	2.76
39	41'51.3"	44'07.1"	690.5	1.52	0.87	2.58
40	41'53.0"	44'01.5"	692.1	1.56	0.89	2.66
41	41'54.9"	43'56.0"	688.6	1.60	0.97	2.48
42	41'56.8"	43'49.8"	684.6	1.64	1.09	2.32
43	42'03.5"	43'28.0"	674.0	1.80	1.33	1.77
44	42'10.0"	43'07.0"	673.3	1.95	0.95	1.17
45	42'22.5"	42'25.0"	674.5	2.25	0.00	0.00

*Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 45; an elevation correction of 0.060 mgal/ft. was used for "CORR.G"__ datum mean sea level.

TRAVERSE 2

TRAVERSE 3

STA. NO.	LATITUDE	LONGITUDE	ELEV. (ft)	LAT. CORR.	STA. G*	CORR. G*	STA. NO.	LATITUDE	LONGITUDE	ELEV. (ft)	LAT. CORR.	STA. G*	CORR. G*
1	34°39'28.3"	86°47'57.0"	615.5	0.00	13.59	14.81	37	34°40'49.5"	86°44'34.5"	639.2	1.87	4.95	5.71
2	39'30.5"	47'51.2"	606.8	0.05	13.70	14.35	38	40'51.8"	44'28.7"	648.2	1.92	4.42	5.67
3	39'32.2"	47'47.0"	606.5	0.10	13.40	13.98	39	40'53.7"	44'23.9"	656.4	1.98	3.74	5.43
4	39'34.5"	47'41.2"	606.9	0.16	13.24	13.79	40	40'56.0"	44'17.9"	658.2	2.03	3.45	5.20
5	39'36.6"	47'35.0"	610.9	0.21	12.69	13.43	41	40'58.2"	44'12.5"	651.5	2.08	3.71	5.00
6	39'38.8"	47'29.8"	615.9	0.26	12.07	13.05	42	41'00.0"	44'07.8"	641.9	2.13	4.25	4.92
7	39'40.8"	47'24.3"	629.4	0.31	10.95	12.69	43	41'02.1"	44'02.2"	640.0	2.18	4.29	4.80
8	39'43.0"	47'18.0"	647.1	0.36	9.73	12.48	44	41'04.0"	43'56.2"	647.7	2.24	3.58	4.49
9	39'45.2"	47'12.5"	647.1	0.42	9.55	12.26	45	41'06.2"	43'51.0"	667.2	2.29	2.59	4.62
10	39'47.2"	47'07.8"	640.7	0.47	9.70	11.96	46	41'08.5"	43'46.1"	676.0	2.34	2.16	4.67
11	39'49.1"	47'01.8"	636.9	0.52	9.71	11.69	47	41'10.7"	43'40.2"	667.2	2.39	2.38	4.31
12	39'51.8"	46'55.9"	634.7	0.57	9.58	11.38	48	41'12.8"	43'34.5"	655.2	2.44	3.08	4.23
13	39'54.0"	46'50.0"	633.2	0.62	9.47	11.13	49	41'15.2"	43'28.8"	650.1	2.50	3.29	4.09
14	39'56.5"	46'44.9"	631.0	0.68	9.45	10.92	50	41'17.7"	43'23.0"	650.9	2.55	3.11	3.90
15	39'58.5"	46'39.0"	627.9	0.73	9.46	10.69	51	41'19.8"	43'17.2"	652.0	2.60	3.10	3.90
16	40'00.7"	46'33.2"	624.2	0.78	9.41	10.38	52	41'22.0"	43'11.5"	651.6	2.65	2.79	3.52
17	40'02.5"	46'29.0"	620.7	0.83	9.40	10.10	53	41'24.5"	43'05.5"	650.5	2.70	2.76	3.37
18	40'05.0"	46'23.5"	620.3	0.88	9.23	9.85	54	41'27.0"	42'59.8"	648.9	2.76	2.86	3.32
19	40'07.0"	46'18.5"	620.5	0.94	9.05	9.64	55	41'29.2"	42'53.6"	652.1	2.81	2.70	3.30
20	40'09.0"	46'13.5"	620.4	0.99	8.84	9.36	56	41'31.2"	42'48.8"	658.2	2.86	1.99	2.91
21	40'11.0"	46'08.2"	620.5	1.04	8.66	9.14	57	41'33.5"	42'43.2"	662.3	2.91	1.67	2.78
22	40'13.1"	46'02.7"	619.9	1.09	8.58	8.97	58	41'36.0"	42'37.5"	656.1	2.96	1.89	2.58
23	40'16.0"	45'56.8"	617.8	1.14	8.54	8.76	59	41'38.2"	42'31.5"	646.9	3.02	2.53	2.62
24	40'18.1"	45'51.1"	616.5	1.20	8.54	8.63	60	41'39.8"	42'25.8"	633.5	3.07	3.03	2.26
25	40'20.1"	45'46.0"	616.5	1.25	8.45	8.48	61	41'41.7"	42'20.0"	619.4	3.12	3.79	2.12
26	40'22.6"	45'40.2"	617.3	1.30	8.17	8.20	62	41'43.8"	42'14.3"	615.7	3.17	4.03	2.09
27	40'26.3"	45'30.3"	617.6	1.35	7.82	7.81	63	41'46.1"	42'09.0"	615.8	3.22	4.13	2.14
28	40'29.0"	45'24.2"	625.8	1.40	7.10	7.53	64	41'50.3"	41'58.0"	615.5	3.28	3.92	1.86
29	40'31.2"	45'18.6"	635.5	1.46	6.30	7.27	65	41'53.5	41'50.6"	621.5	3.33	3.42	1.67
30	40'33.7"	45'13.0"	638.3	1.51	5.91	6.99	66	41'56.0"	41'44.9"	635.0	3.38	2.48	1.48
31	40'36.0"	45'08.3"	639.4	1.56	5.73	6.82	67	41'58.0"	41'39.3"	647.9	3.43	1.74	1.47
32	40'38.5"	45'01.5"	635.9	1.61	5.90	6.73	68	42'00.0"	41'34.3"	661.5	3.48	0.89	1.38
33	40'41.0"	44'56.0"	631.9	1.66	6.10	6.64	69	42'02.1"	41'27.8"	671.1	3.54	0.23	1.24
34	40'42.9"	44'51.2"	629.5	1.72	6.02	6.36	70	42'04.9"	41'22.2"	674.4	3.59	0.36	1.52
35	40'45.0"	44'46.2"	631.6	1.77	5.74	6.16	71	42'07.1"	41'16.5"	676.2	3.64	0.02	1.24
36	40'47.0"	44'40.5"	635.1	1.82	5.32	5.89	72	42'09.7"	41'11.7"	677.8	3.69	-0.20	1.06

* Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 80; an elevation correction of 0.060 mgal/ft. was used for "CORR.G"______ datum mean sea level

TRAVERSE 3

TRAVERSE 3 continued

STA. NO.	LATITUDE	LONGITUDE	ELEV. ft.	LAT. CORR.	STA. G*	CORR. G*
73	34°42'11.8"	86°41'05.2"	675.6	3.74	-0.03	1.04
74	42'13.8"	41'00.0"	663.8	3.80	0.33	0.64
75	42'16.2"	40'54.2"	657.7	3.85	0.62	0.52
76	42'18.7"	40'48.8"	660.9	3.90	0.49	0.53
77	42'21.0"	40'42.9"	668.4	3.95	-0.03	0.40
78	42'22.2"	40'36.8"	671.8	4.00	-0.35	0.24
79	42'24.2"	40'30.2"	666.9	4.06	-0.08	0.17
80	42'26.1"	40'24.2"	663.7	4.11	0.00	0.00

TRAVERSE 4

STA. NO.	LATITUDE	LONGITUDE	ELEV. ft.	LAT. CORR.	STA. G*	CORR. G*
1	34°15'28.7"	86°20'21.0"	969.5	0	1.29	0.55
2	15'28.7"	20'14.1"	982.1	0	0.25	0.31
3	15'28.8"	20'07.8"	965.8	0	1.14	0.19
4	15'28.8"	20'01.5"	944.5	0	2.45	0.17
5	15'28.8"	19'55.7"	924.2	0	3.71	0.16
6	15'28.7"	19'49.2"	923.9	0	3.67	0.11
7	15'28 7"	19'44.2"	948.9	0	2.18	0.18
8	15'28.6"	19'38.0"	962.0	0	1.36	0 16
9	15'28.6"	19'32.0"	972.2	0	0.63	0.06
10	15'28.5"	19'25.1"	981.4	0	0.00	0.00
11	15'28.5"	19'19.0"	963.7	0	1.15	0.06
12	15'28.5"	19'12.9"	951.3	0	1.95	0.08
13	15'28.4"	19'06.8"	954.7	0	1.75	0.10
14	15'28.4"	19'00.3"	952.4	0	1.89	0.10
15	15'28.3"	18'54.5"	948.5	0	2.18	0.15
16	15'28.2"	18'48.8"	947.2	0	2.32	0.20
17	15'28.1"	18'43.0"	957.3	0	1.65	0.16
18	15'28.0"	18'36.0"	945.4	0	2.41	0.18
19	15'27.9"	18'29.8"	949.2	0	2.17	0.18
20	15'27.8"	18'24.7"	936.0	0	2.97	0.16
21	15'27.8"	18'18.0"	939.2	0	2.77	0.16
22	15'27.8"	18'12.1"	954.6	0	1.91	0.25
23	15'27.9"	18'06.2"	952.2	0	2.09	0.29
24	15'27.9"	18'00.0"	982.2	0	0.30	0.36
25	15'28.0"	17'53.8"	1009.8	0	-1.40	0.36
26	15'28.0"	17'48.0"	1005.7	0	-1.09	0.42
27	15'28.1"	17'41.2"	1006.4	0	-1.12	0.44
28	15'28.1"	17'34.8"	1007.7	0	-0.88	0.46
29	15'28.2"	17'28.8"	1003.5	0	-0.86	0.51
30	15'28.2"	17'22.9"	1004.9	0	-0.90	0.56
31	15'28.2"	17'16.3"	996.9	0	-0.40	0.56
32	15'28.3"	17'10.2"	1004.6	0	-0.91	0.53
33	15'28.4"	17'04.0"	1006.5	0	-0.98	0.58
34	15'28.4"	16'58.9"	1002.8	0	-0.78	0.55
35	15'28.5"	16'52.9"	994.5	0	-0.20	0.63
36	15'28.5"	16'47.1"	985.7	0	0.38	0.65
37	34°15'28.6"	86°16'41.0"	993.2	0	-0.05	0.68
38	15'28.6"	16'34.8"	1000.1	0	-0.47	0.70
39	15'28.7"	16'28.8"	1007.5	0	-0.89	0.73
40	15'28.7"	16'22.8"	1024.9	0	-2.03	0.67
41	15'28 7"	16'16.2"	1025.1	0	-1.98	0.73
42	15'28.7"	16'09.8"	1030.0	0	-2.32	0.70
43	15'28.7"	16'03.5"	1025.5	0	-2.00	0.74
44	15'28.7"	15'57.5"	1031.2	0	-2.22	0.88
45	15'28.7"	15'51.8"	1032.8	0	-2.34	0.85
46	15'28.7"	15'45.8"	1028.5	0	-2.04	0.88
47	15'28.7"	15'39.0"	1030.7	0	-2.16	0.90
48	15'28.7"	15'32.5"	1033.5	0	-2.26	0.97
49	15'28.7"	15'26.8"	1037.0	0	-2.49	0.96
50	15'28.7"	15'21.1"	1035.1	0	-2.27	1.06
51	15'28.7"	15'14.8"	1026.6	0	-1.65	1.16
52	15'28.7"	15'08.0"	1031.4	0	-2.01	1.10

* Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 10; an elevation correction of 0.062 mgal/ft. was used for "CORR.G"-- datum mean sea level.

TRAVERSE 4

TRAVERSE 5

STA. NO.	LATITUDE	LONGITUDE	ELEV. ft.	LAT. CORR.	STA. G*	CORR. G*	STA. NO.	LATITUDE	LONGITUDE	ELEV. ft.	LAT. CORR.	STA. G*	CORR. G*
1	34°12'34.5"	86°17'10.9"	927.4	0.00	-0.25	0.02	37	34°14'41.2"	86°14'13.0"	1018.2	2.95	-1.27	1.70
2	12'37.8"	17'04.1"	924.4	0.07	0.00	0.00	38	14'44.0"	14'08.7"	1022.4	3.02	-1.45	1.72
3	12'40.5"	16'58.7"	914.8	0.14	0.65	0.01	39	14'48.0"	14'02.2"	1025.3	3.11	-1.48	1.79
4	12'43.8"	16'51.8"	886.2	0.21	2.51	0.02	40	14'51.2"	13'58.8"	1026.8	3.18	-1.41	1.87
5	12'46.8"	16'45.3"	878.3	0.28	3.11	0.08	41	14'54.8"	13'52.8"	1032.6	3.27	-1.65	1.91
6	12'49.3"	16'40.0"	911.2	0.34	1.25	0.18	42	14'57.9"	13'48.0"	1037.7	3.34	-1.86	1.94
7	12'52.8"	16'33.2"	947.9	0.42	-0.87	0.26	43	15'01.3"	13'43.0"	1040.4	3.43	-1.88	2.01
8	12'56.5"	16'28.3"	962.5	0.51	-1.59	0.35	44	15'04.3"	13'38.2"	1034.7	3.50	-1.37	2.10
9	13'01.2"	16'23.0"	972.8	0.62	-2.10	0.38	45	15'07.8"	13'32.9"	1039.7	3.58	-1.64	2.05
10	13'06.2"	16'17.5"	983.5	0.73	-2.62	0.43	46	15'11.0"	13'28.1"	1051.9	3.65	-2.27	2.11
11	13'09.7"	16'13.8"	989.0	0.82	-2.95	0.35	47	15'15.0"	13'22.1"	1049.9	3.74	-2.00	2.17
12	13'13.0"	16'09.0"	975.7	0.89	-1.99	0.40	48	15'18.2"	13'17.5"	1042.7	3.82	-1.39	2.25
13	13'17.7"	16'03.2"	975.6	1.00	-1.76	0.54	49	15'21.8"	13'12.7"	1032.0	3.89	-0.49	2.41
14	13'20.8"	15'59.5"	979.5	1.08	-1.98	0.46	50	15'24.9"	13'07.8"	1032.2	3.96	-0.40	2.42
15	13'24.2"	15'54.9"	983.6	1.15	-2.04	0.56	51	15'28.5"	13'02.3"	1032.8	4.04	-0.30	2.49
16	13'27.3"	15'50.8"	987.5	1.23	-2.17	0.60	52	15'31.9"	12'57.7"	1026.2	4.12	0.22	2.52
17	13'31.2"	15'45.9"	993.0	1.32	-2.29	0.74	53	15'35.0"	12'52.8"	1021.4	4.20	0.60	2.53
18	13'35.0"	15'41.1"	1001.7	1.41	-2.70	0.79	54	15'37.9"	12'48.8"	1030.5	4.27	0.22	2.64
19	13'38.6"	15'36.3"	1005.2	1.49	-2.80	0.81	55	15'41.5"	12'44.8"	1032.0	4.34	0.27	2.71
20	13'41.8"	15'31.8"	1006.9	1.57	-2.78	0.86							
21	13'45.5"	15'27.2"	1010.3	1.65	-2.88	0.89							
22	13'49.0"	15'22.0"	1015.7	1.73	-3.03	0.98							
23	13'52.2"	15'17.8"	1013.8	1.81	-2.85	0.98							
24	13'55.9"	15'13.2"	1018.2	1.84	-3.02	0.98							
25	14'00.0"	15'07.9"	1019.3	1.99	-2.84	1.14							
26	14'03.0"	15'03.0"	1016.4	2.06	-2.57	1.15							
27	14'07.0"	14'58.5"	1021.7	2.15	-2.79	1.15							
28	14'11.0"	14'53.2"	1018.0	2.25	-2.43	1.21							
29	14'14.5"	14'48.8"	1008.1	2.33	-1.67	1.28							
30	14'18.2"	14'44.0"	1003.7	2.41	-1.27	1.33							
31	14'21.7"	14'39.8"	1004.8	2.50	-1.25	1.36							
32	14'24.8"	14'35.2"	1007.4	2.57	-1.28	1.41							
33	14'28.2"	14'30.5"	1007.2	2.65	-1.08	1.53							
34	14'31.7"	14'26.2"	1001.4	2.73	-0.60	1.57							
35	14'34.8"	14'21.8"	1005.5	2.80	-0.73	1.61							
36	14'38.0"	14'17.0"	1012.6	2.88	-1.04	1.66							

*** Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 2; an elevation correction of 0.062 mgal/ft. was used for "CORR.G" --datum mean sea level.**

TRAVERSE 5

TRAVERSE 6

STA. NO.	LATITUDE	LONGITUDE	ELEV. ft.	LAT. CORR.	STA. G*	CORR. G*
1	34°10'17.8"	86°06'17.8"	1033.0	0	0.00	0.00
2	10'17.5"	06'13.0"	1024.4	0	0.61	0.07
3	10'17.4"	06'07.2"	1004.9"	0	1.95	0.20
4	10'17.2"	06'00.6"	1011.1	0	1.65	0.29
5	10'17.6"	05'54.8"	1007.7	0	1.92	0.35
6	10'17.0"	05'49.0"	1004.7	0	2.27	0.33
7	10'17.0"	05'43.3"	1033.8	0	0.55	0.60
8	10'17.0"	05'37.0"	1039.3	0	0.36	0.75
9	10'16.8"	05'30.5"	1037.6	0	0.51	0.79
10	10'16.7"	05'24.8"	1049.4	0	-0.10	0.92
11	10'16.5"	05'18.9"	1054.5	0	-0.33	1.00
12	10'16.3"	05'12.9"	1058.1	0	-0.36	1.19
13	10'16.1"	05'07.2"	1057.1	0	-0.26	1.23
14	10'16.0"	05'01.2"	1048.3	0	0.48	1.42
15	10'15.9"	04'55.2"	1049.1	0	0.54	1.54
16	10'15.8"	04'48.2"	1038.1	0	1.36	1.67
17	10'15.6"	04'41.5"	1044.5	0	1.03	1.68
18	10'15.6"	04'34.8"	1047.6	0	0.95	1.85
19	10'15.4"	04'27.7"	1041.6	0	1.46	1.99
20	10'15.0"	04'20.3"	1037.5	0	1.85	2.12
21	10'15.0"	04'14.0"	1036.7	0	1.97	2.19
22	10'15.0"	04'08.0"	1030.6	0	2.49	2.34
23	10'14.8"	04'01.0"	1016.1	0	3.48	2.43
24	10'14.5"	03'54.8"	1017.3	0	3.54	2.57
25	10'14.2"	03'48.8"	1028.9	0	2.95	2.69
26	10'14.0"	03'42.5"	1035.5	0	2.62	2.77
27	10'13.9"	03'36.3"	1036.6	0	2.68	2.90
28	10'13.8"	03'30.0"	1042.1	0	2.42	2.98
29	10'13.8"	03'24.0"	1040.4	0	2.64	3.10
30	10'13.8"	03'18.0"	1044.7	0	2.45	3.17
31	10'13.7"	03'12.5"	1051.6	0	2.08	3.23
32	10'13.6"	03'06.2"	1046.9	0	2.48	3.34
33	10'13.5"	03'00.5"	1056.3	0	1.95	3.40
34	10'13.5"	02'54.7"	1065.6	0	1.45	3.46
35	10'13.6"	02'48.8"	1073.6	0	1.03	3.55
36	10'13.7"	02'42.5"	1066.8	0	1.55	3.65
37	34°10'13.7"	86°02'37.2"	1060.1	0	2.14	3.81
38	10'13.7"	02.31.0"	1065.1	0	1.91	3.90

* Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 1; an elevation correction of 0.062 mgal/ft. was used for "CORR.G" --datum mean sea level.

TRAVERSE 6

TRAVERSE 7

STA. NO.	LATITUDE	LONGITUDE	ELEV. FT.	LAT. CORR.	STA. G*	CORR. G*
1	34°09'15.5"	86°07'03.2"	1038.9	1.67	0.00	0.00
2	09'09.1"	07'02.7"	1034.6	1.53	-0.23	0.10
3	09'04.1"	07'02.5"	1054.4	1.41	1.10	0.13
4	08'59.0"	07'02.3"	1046.5	1.28	0.60	0.27
5	08'53.9"	07'02.0"	1053.6	1.15	1.08	0.36
6	08'49.3"	07'01.7"	1050.7	1.04	0.95	0.42
7	08'44.2"	07'01.4"	1044.3	0.93	0.52	0.55
8	08'39.4"	07'01.2"	1037.9	0.80	0.18	0.63
9	08'34.5"	07'01.0"	1041.4	0.70	0.45	0.68
10	08'29.2"	07'00.8"	1061.7	0.58	1.74	0.77
11	08'24.3"	07'00.6"	1067.4	0.47	2.26	0.71
12	08'19.8"	07'00.4"	1047.7	0.36	1.10	0.76
13	08'14.3"	07'00.2	1027.9	0.24	-0.10	0.85
14	08'09.0"	07'00.0"	1041.1	0.12	0.77	0.92
15	08'03.4"	07'00.0"	1057.6	0.00	1.85	0.98

* Gravity values under "STA.G" and "CORR.G" are in milligals and relative to station 1; an elevation correction of 0.062 mgal./ft. was used for "CORR.G"----- datum mean sea level

TRAVERSE 7

MISCELLANEOUS ERTS-1 STUDIES

By Charles C. Wielchowsky

INTRODUCTION

Several ERTS-1 studies undertaken by various Geological Survey of Alabama (GSA) workers were either too brief to be included as separate sections of the entire report or were inconclusive in nature. These have been grouped into this section. They include the following: 1) Coastal Plain Studies; 2) Sedimentation and Erosion in Mobile Bay; 3) Flooded and Flood-Prone Area Mapping; and 4) Lawson Gap Lineament. Though each section of this report was written by Charles C. Wielchowsky, those workers responsible for the research are listed under each section title.

COASTAL PLAIN STUDIES

(Donald B. Moore, Charles W. Copeland, and Charles C. Wielchowsky)

General Geologic Mapping

Geologic mapping in the Alabama Coastal Plain has been completed on a regional basis for several decades (Monroe, 1941; MacNeil, 1946); however, mapping of detailed stratigraphic and structural relationships is presently being carried out by GSA personnel. ERTS data have been used to map lineaments that may be related to faulting (see section in this report by J.A. Drahovzal), annular features possibly related to subsurface structure, and several lithostratigraphic units that have distinctive signatures.

Band 5 imagery of west-central Alabama has been examined to check for possible extensions of the Livingston fault zone from Sumter County to the southeast. The fault zone can be observed on conventional air photo mosaics and on high-altitude air photo mosaics, but is not discernible on ERTS band 5 imagery.

Pleistocene marine terrace scarps and terrace deposits have been mapped in Mobile and Baldwin Counties. Efforts to trace these features using ERTS imagery have been mostly unsuccessful, but only February 1973 band 5 imagery has been examined. The terrace deposits are composed chiefly of sand and gravel, and the differences in soil moisture which possibly exist between the terrace deposits and the underlying more clayey deposits of the Citronelle Formation may be discernible on enlargements of ERTS imagery. This, however, cannot be demonstrated at this time.

A large lineament has been observed on ERTS band 5 imagery to extend in a nearly east to west direction for a distance of about 25 miles (40 km) from near Pickensville to the area northeast of Carrollton in Pickens County. The lineament is not discernible on air photo mosaics. To the north in Lamar and Marion Counties, faults have been mapped in the subsurface parallel to the trend of the Pickensville lineament.

A pronounced circular feature was noted on image 1050-15551-5 in the vicinity of the Alabama River in Lowndes County. The feature, situated in an ancient river meander or former oxbow lake, has been located on the Autaugaville topographic sheet with its center being located near the section corner common to secs. 32, 33, T. 16 N., and secs. 4 and 5, T. 15 N., R. 14 E. The area is underlain by Quaternary alluvial deposits and the Mooreville Chalk of Late Cretaceous age. The feature is probably not related to any subsurface structure.

An analysis was made of a 1:500,000 color composite of the Montgomery-Dothan-Brewton, Alabama, area scene (1067-15495) obtained from the EROS Data Center. Scale was actually 1:509,000 rather than the reported 1:500,000. Overlays were constructed which defined the important and readily visible cultural features and the salient geological features including lineaments and circular anomalies. The geology of the area was fitted to the frame using the geologic maps of Monroe (1941) for the Cretaceous rocks and MacNeil (1946) for the Tertiary rocks. It was noted that a great number of small lakes and ponds are present in the area of the Selma Group outcrop belt. To the east where the Selma Group becomes more silty and sandy, the belt exhibits fewer lakes and ponds and appears to be more forested. The less silty Selma Chalk is rather clearly defined on the photograph by the lack of forest cover. The drainage density in the Selma is more coarse than that of the rest of the scene. The eastern silty faces of the Selma, however, has a much finer texture.

Drainage density of the Tertiary is fine and most units are heavily forested. The Tuscahoma Sand can be mapped from the image because of the denser forest cover when compared to the overlying and underlying formations.

Lineaments and circular features were also mapped in the Tuscaloosa Group along the Sipsey River in northwest Tuscaloosa County. ERTS data provide an important tool in the mapping of structural features in unconsolidated sediments. Drennen (1953) has reported faulting in the Tuscaloosa Group that has yet to be mapped. ERTS data are presently being used to locate these faults.

Oil and Gas Exploration

Subsurface anomalies such as anticlines, domes, and faulting are numerous in Alabama and in general are the prime mechanism for the trapping of oil and gas. Some of these structural features have already given up large quantities of oil. For instance, the Citronelle oil field in northern Mobile County, a domal structure which has surface expressions, has produced over 100,000,000 barrels of oil. Many other subsurface structures have excellent potential for the production of hydrocarbons. The location and configuration of some are known, but undoubtedly, many others exist which have not yet been detected. Many of the subsurface anomalies, both known and unknown, have surface expression to varying degrees.

In an appraisal of the initial ERTS imagery, several surface anomalies were seen which are known to reflect subsurface geologic structure. In reviewing frame 1050-15560-5 (red band), radial anomalies can be pointed out in Mobile County which coincide with known subsurface structure; the most prominent is the apparent domal structure at Big Lake Creek.

Frame 1050-15553-6 (infrared) was of poor quality but a prominent lineament could be detected which extends from southern Monroe County across northern Baldwin County. This same lineament is even more pronounced on band 7 (imagery)

The ERTS imagery is an excellent tool in detecting surface anomalies which may reflect subsurface structure possessing excellent oil and gas producing potential. In some cases the location of these features were previously known, but in other instances geologic features were recognized which had not been heretofore recognized.

One of the most prominent structures is indicated by a radial drainage pattern approximately 10 miles west of Mobile in the area of Big Creek Reservoir. This feature indicated the possibility of a subsurface dome which might be favorable to the entrapment of hydrocarbons. Ironically, in the latter part of May, Forest Oil Company permitted an oil and gas test well over this surface anomaly. This proposed oil and gas test well will be drilled to a depth in excess of 19,000 feet. If this test proves successful there will be a very positive indication of how ERTS data might be applied in the search for crude oil and natural gas.

More detailed research activities were conducted by the Energy Resources Research Division using ERTS data on bands 5 and 7 of December 28, 1972. Surficial structural expressions revealed by the imagery were identified and correlated with known subsurface geologic features. This method of investigation proved to be quite satisfactory in that numerous correlations were possible. For example, in central Choctaw County, Alabama, where the Gilbertown Fault System extends east-west across the county, a definite distorted zone can be seen on band 7 of December 28, 1972. The Hatchetigbee anticline, a northwest-southeast trending anticline, lies just south of the distorted zone. The anticline is also very subtly expressed on band 7. There is also a fault system which bounds the south side of the Hatchetigbee anticline which can be identified very clearly on the ERTS imagery. This fault system is a northwest-southeast linear trend which is expressed as a disturbed belt. Also on band 7 a radial anomaly is identifiable in Clarke County. This radial anomaly coincides exactly with a subsurface high which was determined on the basis of well data.

The value of being able to detect surface expressions of subsurface structures on ERTS imagery becomes obvious when one considers that if it is possible to identify these features in areas of known subsurface structure, then it would also be possible to spot similar features in areas where the subsurface control is not yet available. For example, the Gilbertown fault system which was observed in central Choctaw County has been the site of the discovery of at least 10 oil fields; whereas, the unnamed fault system south of the Hatchetigbee anticline has been explored very little, and consequently, no oil fields have been found along this fault system.

On the band 5 image of the December 28, 1972, orbit, the actual well locations for the holes in the Jay-Little Escambia Creek fields can be detected. The Little Escambia Creek field is predominantly in a vegetated area of low relief, and 2 to 5 acres are usually taken up with a typical well location. In preparing a well location, the trees and other vegetation are removed, and consequently, these areas show up as small white dots on the imagery. Similar dots, which indicate well locations, can be observed in the area of the Citronelle field. However, since this field was discovered in 1955, these well locations are not nearly as distinct. Northwest and west-northwest of the Citronelle field, two distinct radial anomalies can be pointed out. These anomalies probably represent surface expression of a subsurface structural high and would be prime areas for oil and gas exploration.

The main advantage of the ERTS imagery in comparison to conventional low-altitude photographs is that it allows a broad perspective with no break in the continuity of the image. In summary, ERTS imagery can be employed as a valuable supplementary tool to understanding subsurface geology and thus aid in the exploration for oil and gas.

SEDIMENTATION AND EROSION IN MOBILE BAY

(Jacques L. G. Emplaincourt and
Charles C. Wielchowsky)

Introduction

The dynamic environment of Mobile Bay lends itself readily to study by means of earth-orbiting satellites. Such an undertaking is especially important since Mobile Bay will become the site of offshore drilling for oil and possibly for the location of a superport (Ameriport) in the near future. The bay and surrounding areas are presently the topics of extensive environmental geologic investigations by GSA. ERTS data allow an overall increase in mapping and inventorying efficiency of roughly 10 percent. These data have been used to detect shoreline changes caused by erosion and sedimentation and to map turbidity plumes in the Bay.

Detection of Shoreline Changes from ERTS-1 Data

As part of the geologic investigations of Mobile Bay at GSA, the Remote Sensing Section conducted a systematic study of shoreline configurational changes with several types of remotely sensed data. ERTS-1 imagery was found to be very valuable in these change detection investigations (see appendix 4).

Specifically, a series of band 7 images was compared to fairly recent (1953-1957) AMS maps at a scale of 1:250,000. The near infrared band was selected because it yields excellent land/water delineation. High-altitude color infrared photography acquired on two different dates, low-altitude USDA photo mosaics, and large scale topographic maps were employed to support the findings made from ERTS-1 data. Some rather drastic changes have been found with the imagery. Sand and Pelican Islands which were both located near the entrance of Mobile Bay have been modified into one narrow strip of land presently called Sand Island. Dauphin Island has prograded westward as much as 1 mile. A mapping error has been detected along the Fort Morgan-Mobile Pont Spit. A small island in Portersville Bay disappeared. Many man-made changes appear in the upper reaches of Mobile Bay.

The data utilized in the Mobile Bay study were collected between August 1972 and February 1973. October 1973 imagery now reveals that change has again occurred at Sand Island, which was originally made up of two islands (Pelican and Sand). The October data indicate that Sand Island has again been breached and now appears as two separate islands.

In order to better understand the geomorphic processes that shape the Alabama coastline, it was felt necessary to extend the area of study farther west along the Mississippi Sound. Indeed, changes similar to those found along the Alabama coast have occurred off the Mississippi coast. The westward-moving longshore current which modifies Dauphin Island also affects Petit Bois, Horn, Ship, and Cat Islands (fig. 1). Chandeleur Island has mainly been affected by direct wave action and subsidence (P. A. Boone, Personal Communication, 1974). Large additions of land appear at and near Spanish Point; several of the Grande Batture Islands have disappeared.

Even though it has been shown that ERTS-1 data cannot yet be used to prepare planimetric maps that meet U.S. National Map Accuracy Standards at scales larger than 1:500,000, the imagery can be an invaluable source of information in detecting shoreline configuration changes.

Sedimentation in Mobile Bay

Sequential bands 4 and 5 ERTS coverage of the Mobile Bay area was examined qualitatively by GSA personnel and select users to determine degree of turbidity plume development and circulation patterns. Band 5 imagery was found to be most suitable for this type of study. It appears that turbidity increases as winter and time of greatest discharge approaches, as was expected. A comparison of average suspended sediment load in the Tombigbee and Alabama River systems with ERTS imagery shows that the time of greatest plume development coincides with the months

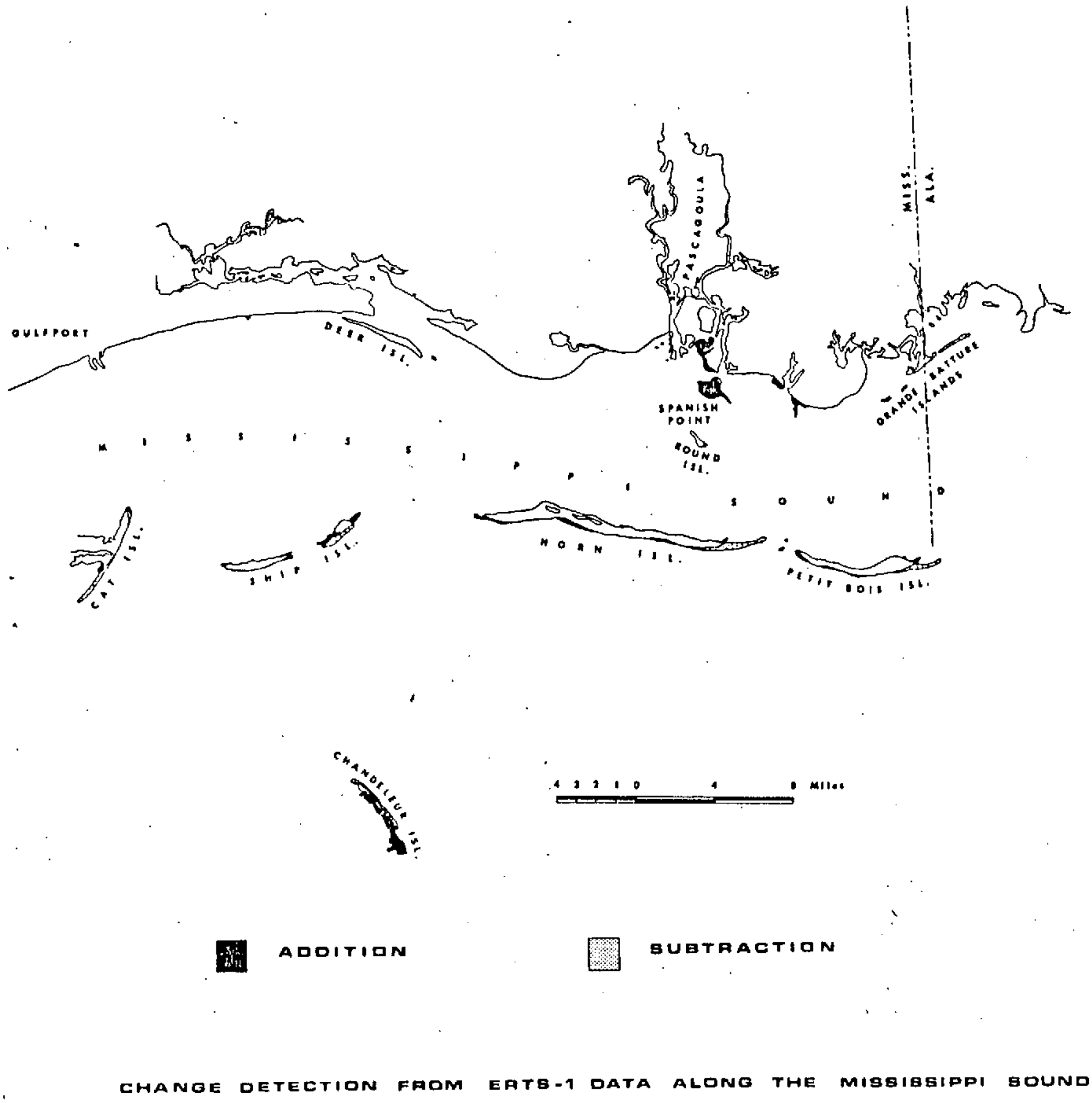


Figure 1.--Areas of land addition and subtraction since 1953.

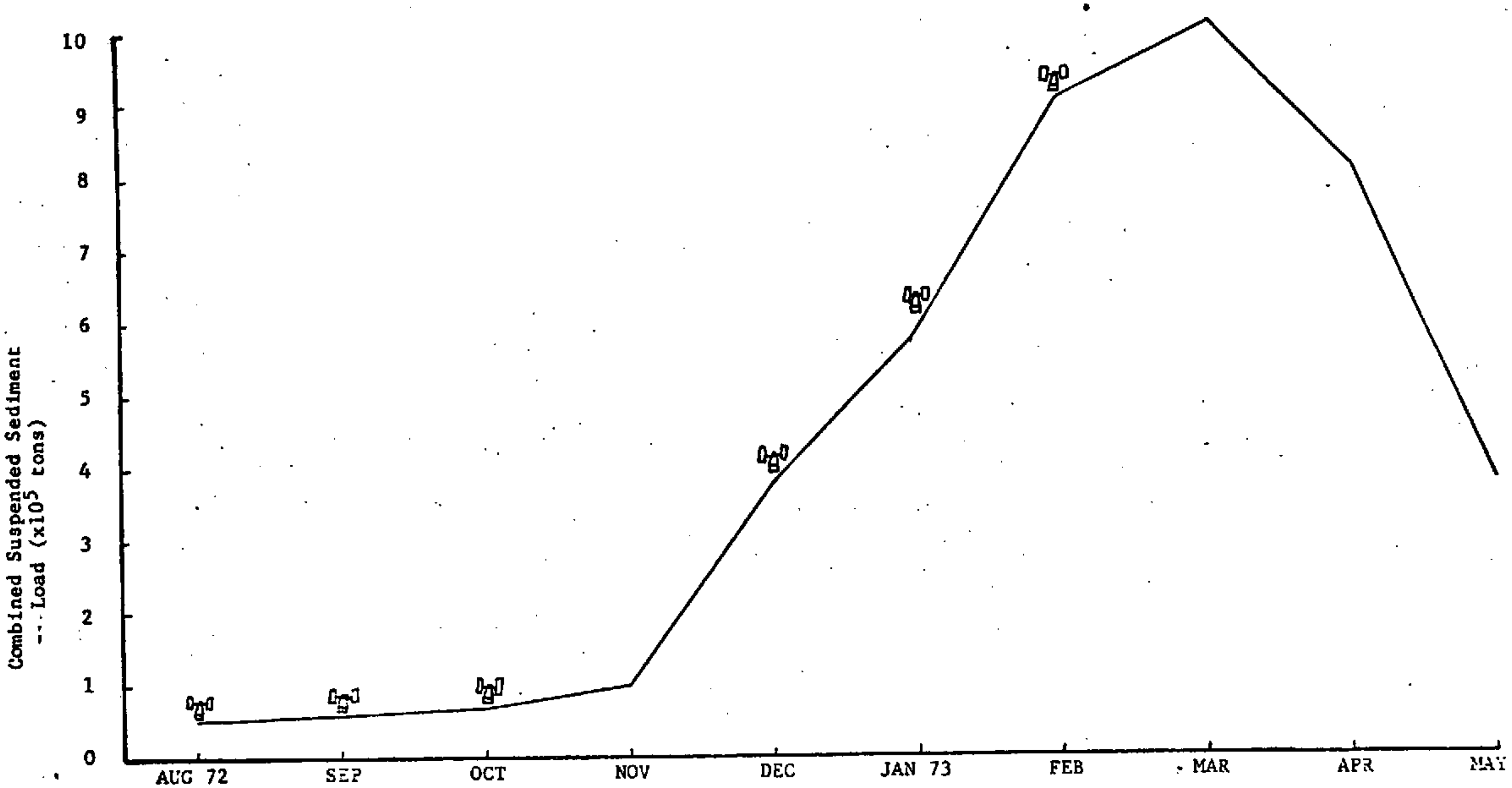
of greatest average suspended sediment load (fig. 2). Stow (1974) gives a more detailed description of the results and conclusions of this study.

FLOODED AND FLOOD-PRONE AREA MAPPING

(Stephen H. Stow and
Charles C. Wielchowsky)

The 1972-1973 floods of the Coastal Plain of southwest Alabama have been studied through the use of sequential ERTS-1 (band 7) and high-altitude (U-2) infrared imagery (see appendix 5). Similar studies were done by Hallberg et al (1973) and Rango and Anderson (1973). In comparing dark tonal anomalies that appear on ERTS imagery with USGS flood-prone area maps at scales of 1:250,000 and 1:100,000, a positive correspondence in area of over 90 percent was found (fig. 3). High altitude data were used to confirm the accuracy of ERTS imagery. Pre-flood high altitude and ERTS imagery indicate that flood-prone areas can be delineated prior to flooding, thus providing predictive capability. In areas where there are no existent flood-prone area maps, ERTS and high altitude imagery was used to map flood-prone areas.

Ground data were collected in April of 1973 in the upper Mobile River delta to support ERTS and U-2 data. Soil moisture samples were collected at selected points across a traverse of the flood plain. Flood conditions, vegetation, and evidence of standing water were noted. Results indicate that the very dark tonal



12-511

Figure 2.-- Suspended sediment load (12-year monthly average) for the Tombigbee and Alabama River systems, 1952-1963 (Ryan, 1969). Peak suspended sediment load for the Tombigbee and Alabama Rivers occurs in early spring. The small symbols over the months of August through October and December through February show that an ERTS-1 pass was available over the bay sometime during that month. Compare these data with the maps of sediment plume development in Stow's 1974 report.

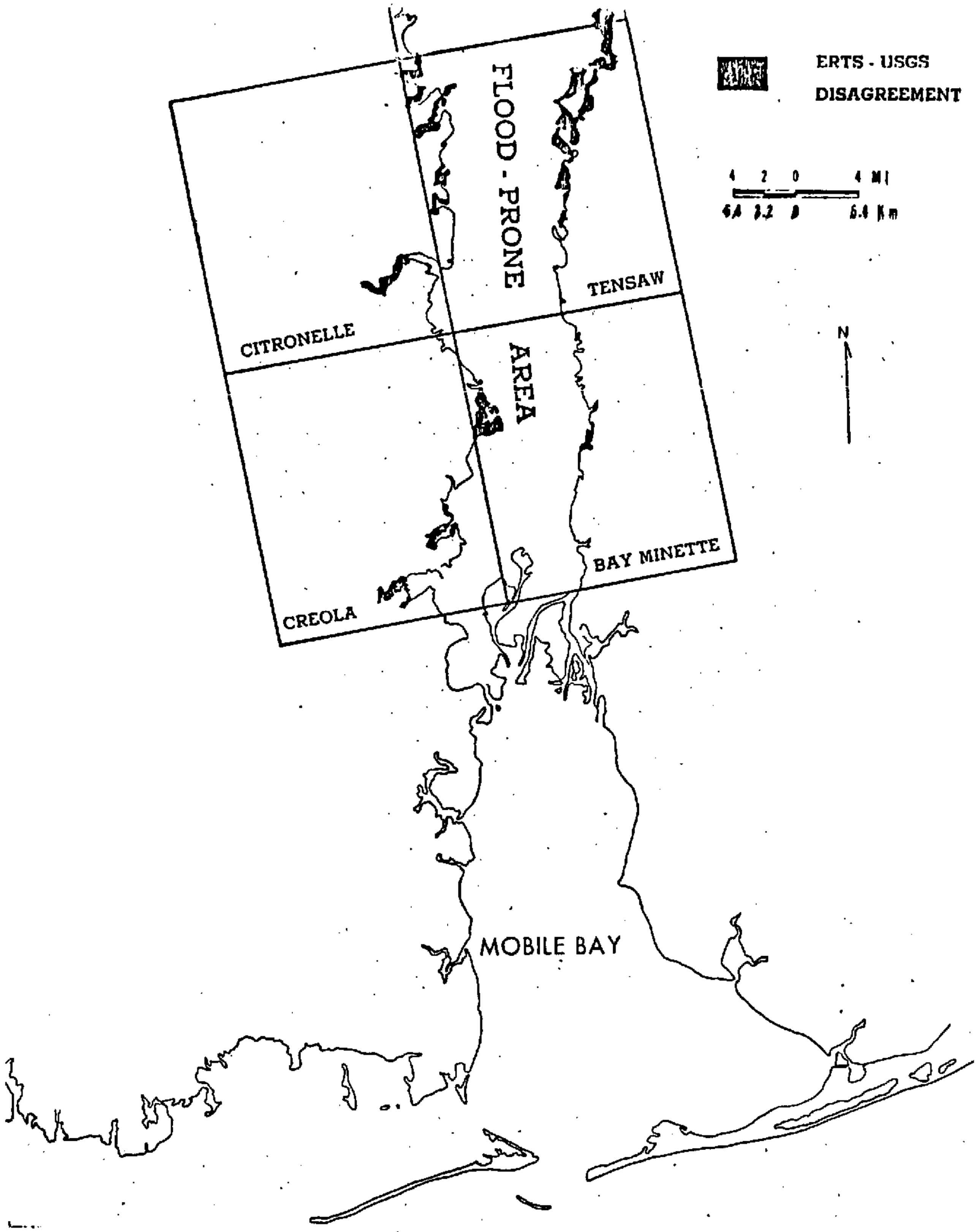


Figure 3.--Comparison between USGS flood-prone area maps and ERTS imagery no: of Mobile Bay, Alabama.

anomalies were due to standing water. Lighter shades of gray were due to vegetation rising above standing water and high soil moisture.

Benefits of using remotely sensed data for flood studies include: 1) low cost (less than $.05/mi at 1:250,000 scale); 2) verification of existent flood area maps; and 3) rapid mapping of unmapped areas. These studies indicate, however, that ERTS data should not be used for flood-area mapping at scales greater than 1:250,000.

LAWSON GAP LINEAMENT

(Charles C. Wielchowsky)

The Murphree Valley anticline is located in the Appalachian Plateaus Physiographic Province of Etowah, Blount, and Jefferson Counties, Alabama (fig. 4). The fold is overturned to the southeast and is bordered on its southeast side by the Straight Mountain Fault, which is a steep, northwesterly dipping reverse fault that brings Cambrian rocks into juxtaposition with Mississippian, Devonian, Silurian, and Ordovician rocks. The anticline is anomalous to the southern Appalachian in that it is faulted on, and overturned to the southeast rather than the northwest. The stratigraphy and structure of the fold have been treated by Gibson (1893), Hayes (1896), Adams et al (1926), Burchard and Andrews (1947), Rodgers (1950), Stose (1952), Causey (1961) and Neathery et al (in press). Figure 5 shows the general geology and structure in the region of the nose of the anticline. Pi diagram analysis yields a fold axis

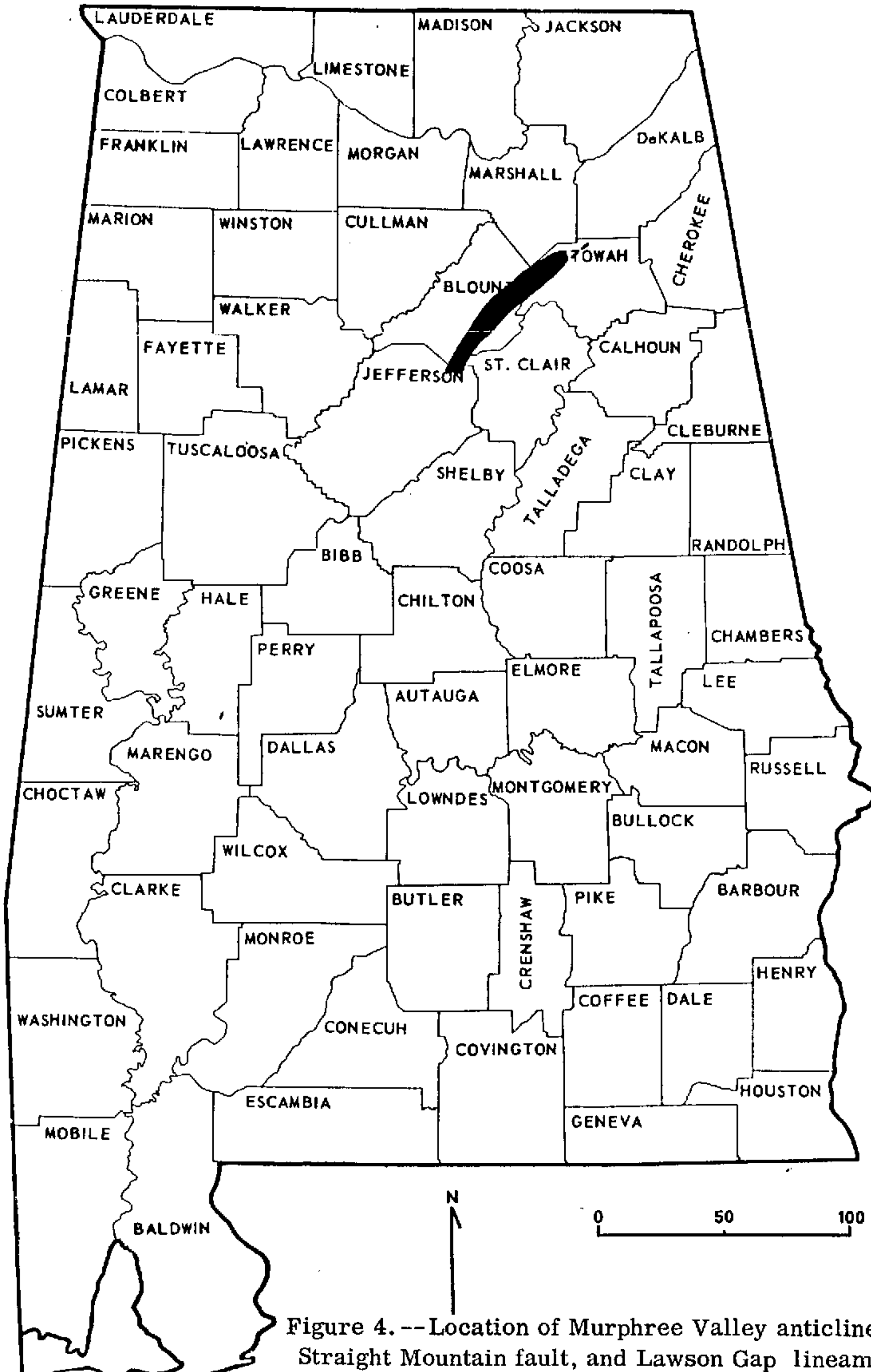


Figure 4.--Location of Murphree Valley anticline Straight Mountain fault, and Lawson Gap lineament.

GEOLOGIC UNITS

ℙ pv Pottsville Formation
Mℙ pp Parkwood and Pennington Formation
Mm Monteagle Limestone
Mtfm Tuscumbia Limestone, Fort Payne Chert, Maury Formation
Srm Red Mountain Formation
Os Sequatchie Formation
Oc Chickamauga Formation
€Ou Knox Group undifferentiated

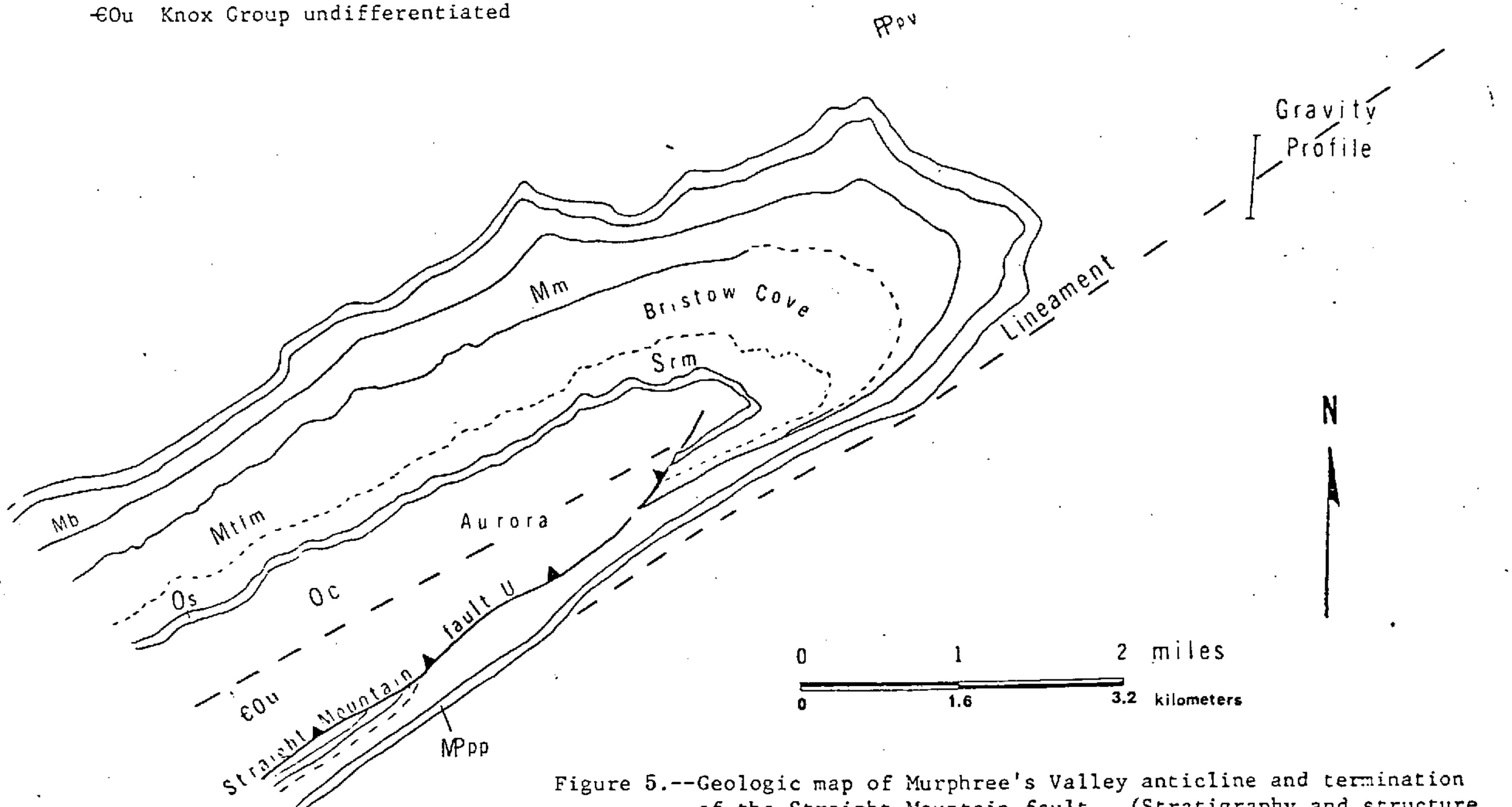


Figure 5.--Geologic map of Murphree's Valley anticline and termination of the Straight Mountain fault. (Stratigraphy and structure from unpublished field maps of T. L. Neathery.)

strike of N66E and plunge of 2°. On the southeastern limb of the fold, several zones of fracturing up to 4 feet (1.2m) thick were found parellel to bedding in the Pottsville Formation. These zones were exposed in the gap through Straight Mountain south of Aurora.

A prominent lineament was found (Lawson Gap lineament) which strikes N55E at the termination of the anticline and appeared to be an extension of the Straight Mountain fault (fig. 5). This lineament was visible on both ERTS and U-2 data. Gravity profiles run by Gary V. Wilson (see Wilson's section in this report) across the lineament were inconclusive. The feature may represent an extension or splay of the Straight Mountain fault into the Pottsville Formation north of the Murphree Valley anticline terminous, but no field evidence could be found to support this hypothesis.

The Straight Mountain fault itself may represent a "chisel fault" (Jacobeen and Kanes, 1974) and it and the Murphree Valley anticline may have formed in response to decollement ramping caused by displacement in the basement. This, however, is extremely speculative. Nevertheless, the Lawson Gap lineament's proximity to the Anniston lineament (see James A. Drahovzal's section in this report), and association with an anticline that is faulted on, and overturned to the southeast rather than the northwest, suggests that this feature may be important to the understanding of such reversals of structure in the folded Appalachians.

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PHYSIOGRAPHIC REGIONS OF ALABAMA

by
C. Daniel Sapp and Jacques L. G. Emplaincourt

Introduction

This chapter discusses the compilation of a preliminary physiographic map of Alabama from traditional map and textual sources as revised with ERTS-1 imagery and field observation. The base for portrayal of the mapped physiographic units and features is the recently published ERTS Mosaic of Alabama (Svehlak and Wielchowsky, 1973).

Physiography is defined as the study of landforms. In the United States, the term is the approximate equivalent of geomorphology, which is the genetic study of landforms. Physiography is a branch of geology when it considers processes, principles, and laws. It is a branch of physical geography when it considers areal (spatial) distribution. Since these two aspects are inseparable in a practical sense, physiography is a transitional study, overlapping the disciplines of geology and geography. This conclusion is in line with the traditional views of noted physiographers including Fenneman, Atwood, and Thornbury.

The physiographic map shows physiographic regions, which are defined as "tracts in which the topographic expression is in the main uniform" (Bowman, 1911). A physiographic unit, a term used interchangeably with region, is defined by Malott (in Thornbury, 1964) as follows:

> A physiographic unit is an area or division of the land in which the topographic elements of altitude elevation , relief, and type of land forms are characteristic throughout and as such is set apart or contrasted with other areas or units with different sets of characteristic topographic elements.

The physiographic map shows physiographic regions, including 4 provinces, 5 sections, 28 districts, and 1 unclassified physiographic type defined as alluvial-deltaic plains. The hierarchy of classification units may appear rather complex to one who is unfamiliar with the scheme, but the progression is exactly that given above. Some confusion exists among those dealing with or describing physiographic regions apparently because many people use the term province for sections and districts. In this discussion the author will use these terms in their strictest sense, and the term physiographic region, which encompasses all the levels of the heirarchy, will be employed when reference to a particular level in the classification is not necessary.

Table 1 lists and describes the physiographic sections, districts, and alluvial plains portrayed on the preliminary map. Plate 13 shows the map itself, overprinted on the ERTS mosaic base. The procedure of compilation will be discussed below.

Methodology

The objective of this work was to produce an improved physiographic map of Alabama from the best available sources. It was not merely to determine what the researcher could do through interpretation of ERTS-1 imagery used in isolation without reference to other sources. The "best available" sources logically included: 1) published textual material; 2) topographic maps at 1:250,000 scale and larger; 3) geologic maps at many scales; and 4) small scale, generalized physiographic maps such as those found in older textbooks on regional physiography.

TABLE 1

PHYSIOGRAPHY OF ALABAMA

CLASSIFICATION[1]

Physiographic Section	District (and Map Symbol)	Characteristics
Highland Rim[a]	Tennessee Valley (TV*)	Plateau of moderate relief with elevations ranging from 600 to 800 feet. Chert belt in north, limestone plain along river.
	Little Mountain (LIM)	Submaturely dissected sandstone homoclinal ridge of moderate relief.
	Moulton Valley (MOV)	Homoclinal limestone valley of low relief.
Cumberland Plateau[b]	Warrior Basin (WB)	Synclinal submaturely to maturely dissected sandstone and shale plateau of moderate relief.
	Jackson County Mountains (JCM)	Submaturely dissected plateau of high relief (about 1,000 feet, total), characterized by mesa-like sandstone remnants above limestone lowland.
	Sand Mountain (SM)	Submaturely dissected sandstone and shale synclinal plateau of moderate relief.
	Sequatchie Valley (SQV)	Anticlinal tripartite valley of moderate relief. Elongate shape with approximate width of 5 miles.
	Blount Mountain (BM)	Submaturely dissected synclinal sandstone and shale plateau of moderate relief.
	Murphree Valley (MV)	Faulted anticlinal tripartite valley of moderate relief, with width of 2 to 3 miles.
	Wills Valley (WV)	Anticlinal tripartite valley; basically three limestone valleys separated by ridges of resistant sandstones.
	Lookout Mountain (LOM)	Narrow, synclinal, submaturely dissected, flat-topped remnant of Cumberland Plateau.
Alabama[c]	Coosa Valley (COV)	Plain with structural ridges of low relief. Some thrust faults. Variegated topography formed on limestones and shales.

*Map symbol in parentheses.

TABLE 1 - PHYSIOGRAPHY OF ALABAMA (Continued)

Physiographic Section	District (and Map Symbol)	Characteristics
Alabama[c] (continued)	Coosa Ridge (COR)	Series of parallel linear ridges formed by monoclinal resistant sandstones separated by carbonate and shale valleys.
	Weisner Ridges (WR)	Maturely dissected quartzite faulted and folded mountains of high relief with intervening narrow carbonate valleys.
	Cahaba Valley (CAV)	Narrow valley developed on faulted homocline. Valley widens at south.
	Cahaba Ridges (CAR)	Series of parallel northeast-striking ridges formed by gently folded sandstone and conglomerate beds with intervening shale valleys. Wide shale valley in south.
	Birmingham-Big Canoe Valley (BBC)	Narrow limestone valley 4 to 8 miles wide, developed on faulted anticlinorium. Shale, sandstones, and chert, also exposed. Birmingham Valley opens into the Big Canoe Valley in the north.
	Armuchee Ridges (AR)	Narrow northeast-trending chert and sandstone ridges and intervening lowlands. Simple thrust faulting present.
Piedmont Upland[d]	Northern Piedmont Upland (NP)	Well dissected upland developed on young metamorphosed sedimentary and igneous rocks. Elevations generally 1,000 to 1,100 feet in north and 500 to 600 feet in south. Rebecca and Talladega Mountains form a prominent northeast-trending ridge. Cheaha Mountain, whose elevation is 2,407 feet, is at northeastern part of this ridge and is the highest point in Alabama.
	Southern Piedmont Upland (SP)	Upland surface incised about 200 feet by tributaries of Chattahoochee and Tallapoosa Rivers. Developed on schist and gneiss. No prominent topographic features present.

TABLE 1 - PHYSIOGRAPHY OF ALABAMA (Continued)

Physiographic Section	District (and Map Symbol)	Characteristics
East Gulf Coastal Plain[a]	Fall Line Hills (FLH)	Dissected upland with a few broad, flat ridges. In this zone streams descend from resistant Paleozoic sedimentary and Piedmont crystalline rocks to the less resistant Cretaceous sands and clays of the Coastal Plain.
	Black Prairie (BP)	Undulating, deeply weathered plain developed mainly on chalk and marl.
	Chunnenuggee Hills (CH)	Pine-forested series of sand hills and cuestas developed on chalk in west Alabama and more resistant clays, siltstones, and sandstones in the east.
	Southern Red Hills (SRH)	Southward-sloping upland of moderate relief. Flatwoods (F) lowland along northern edge in west. Rugged Buhrstone Hills (BH) along southern edge of district is developed on indurated resistant siliceous claystone and sandstone.
	Lime Hills (LH)	Rugged topography developed on more resistant limestones. Hatchetigbee Dome (HD) or anticline is northwest-southeast-oriented flexure within this district.
	Dougherty Plain (DP)	Continuation of limestone upland westward from Georgia. Undifferentiated limestone residuum, greatly differentiated Miocene beds, and surficial terrace material. Active limestone solution has transferred most minor drainageways to subsurface, especially in extreme southeastern Alabama. Topography is that of low cuesta, more dissected in south-central Alabama than in southeast. Extensively cultivated.
	Southern Pine Hills (SPH)	Upland held up by Pliocene (?) Citronelle sands and gravels and younger fluvial and estuarine terrace deposits. Gradual slope southward from 400 to 500 feet elevation to 25 to 30 feet at southern limit of adjacent Pleistocene marine terraces. Relief up to 250 feet in north but slight in south.

TABLE 1 - PHYSIOGRAPHY OF ALABAMA (Continued)

Physiographic Section	District (and Map Symbol)	Characteristics
East Gulf Coastal Plain[e] (continued)	Coastal Lowlands (CL)	Flat to gently undulating coastal area fringed to seaward by salt marshes, estuarine swamps, and other wetlands. Deposits are of Holocene and late Pleistocene age. Landward edge of district is defined by base of Pamlico marine scarp at 25 to 30 feet elevation. Barrier islands offshore are undergoing continuing modification by erosion and deposition.
	Alluvial-deltaic Plain (A_s, A_d)	A_s - Alluvium and terrace deposits of larger river valleys. A_d - Alluvium of Mobile River delta.

[1]Classification system modified from N. M. Fenneman, 1938, Physiography of Eastern United States: New York and London, McGraw-Hill Book Company, 714 p. Division classification and characteristics of divisions modified from W. D. Johnson, Jr., 1930, Physical Divisions of Northern Alabama, Geological Survey of Alabama Bulletin 38. Coastal plain sources, W. H. Monroe, 1941, Notes on Deposits of Selma and Ripley Age in Alabama, Geological Survey of Alabama Bulletin 48, and F. S. MacNeil, 1946, Geologic Map of the Tertiary Formations of Alabama, Preliminary Oil and Gas Investigations Map 45: U. S. Geological Survey.

Section and Division boundaries were positioned through analysis of: 1) 1:250,000 scale USGS topographic maps of Alabama, and 2) ERTS-1 imagery of Alabama. This physiographic map is keyed to the ERTS-1 mosaic, 1:1,000,000 scale, of the state.

[a]Interior Plains physiographic division, Interior Low Plateaus province.

[b]Appalachian Highlands division, Appalachian Plateaus province.

[c]Appalachian Highlands division, Valley and Ridge province.

[d]Appalachian Highlands division, Piedmont province.

[e]Atlantic Plain division, Coastal Plain province.

Section boundary.

District boundary, approximate, lacking distinct topographic expression.

District boundary, firm.

Sub-district boundary.

Evaluation of Published Sources

The best textual descriptions of physiographic regions in general are those of Fenneman (1938) and Johnson (1930). Even these, however, are dated. Fenneman's work treats only briefly of Alabama, as it deals with the physiography of all of the eastern United States. Johnson classifies and describes the physiographic districts of northern Alabama, but the work suffers from uneven treatment and omissions of important detail. It is also out of date due to advancements in our knowledge of geology, particularly of the Piedmont Upland section, since 1930.

A good study of the physiography of a specific area is Monroe's (1941) publication covering the Cretaceous deposits of Alabama. Besides the text there is a 1:1,000,000 scale map of physiographic divisions, including cuestas and alluvial and terraced areas. Many of these features and boundaries were extracted directly from this map and included in either modified or unmodified form on the present physiographic map. Monroe's work is dated but is judged reasonably accurate.

Another outstanding publication is MacNeil's (1946) map of the Tertiary formations of Alabama. It aided in placing the boundaries of the Dougherty Plain and other districts of the East Gulf Coastal Plain of Alabama. The dearth of physiographic research in southeastern Alabama remains painfully obvious, however, in spite of MacNeil's contribution to geology.

Evaluation of ERTS-1 Imagery as a Source of Physiographic Data

The ERTS prints (1:1,000,000 scale) were interpreted in terms of their physiographic content in the following manner. The traditional boundaries gleaned from the literature (including texts and maps, as discussed above) were transferred to the ERTS mosaic base at the same scale. The scale variance of ERTS individual prints was found to be ±5 percent or better, so only minor cartographic adjustments were required to achieve a fit. Next, the latest topographic maps at 1:250,000 scale were studied and the boundaries and other detail were refined. These annotated maps were reduced photographically 4 times to 1:1,000,000 scale so they would fit the ERTS mosaic base, and then the revisions were transferred. Considerable improvement in detail was obtained, especially north of the Fall Line.

Following completion of the above revisions, the ERTS prints were studied in detail to further modify, confirm, or refine the physiographic map. ERTS was considered the primary source, for in every map compilation involving multiple sources of data one source must be designated primary, having priority over the others in cases of disagreement. ERTS imagery contains more bits of information than any map (for example, the imagery shows land-use patterns and variations within this category, whereas topographic maps do not) and is more up-to-date. Maps, being usually a derivative of aerial or space-acquired imagery*, are degraded but serve a useful function by simplifying complex, difficult-to-interpret images.

The ERTS images used were those of the Multispectral Scanner (MSS). The four wavelength bands (MSS-4, 5, 6, 7) were all studied and it was determined that MSS-5 and 6, which pass the red and red-near infrared parts of the spectrum, respectively, were judged superior for physiographic analysis. The overall value of ERTS imagery for physiography, however, was variable. The contribution will be described by considering each physiographic section separately.

* The term "imagery" as used in this report encompasses photography as well as line-scan images such as ERTS.

Highland Rim Section

ERTS imagery was used sucessfully to refine the boundaries of Little Mountain and Moulton Valley. The sandstone of Little Mountain contrasted strongly with the adjacent limestone, so this difference was used to advantage. Moulton Valley is sharply separated along its southern boundary by the Cumberland escarpment, which is sharply depicted on ERTS. The Tennessee Valley district outlines are obvious, but further differentiation beyond the district level to separate the chert belt from the limestone plain along the river could not be done. There is insufficient topographic expression, as the difference is mainly geologic. The section boundary along the east, where the Jackson County Mountains of the Cumberland Plateau section are encountered, is also clearly discernible due to differing lithologies.

Cumberland Plateau Section

The mesa-like uplands of the Jackson County Mountains contrast strongly with the intervening limestone lowlands. These escarpments are obvious on the ERTS imagery, and improvements over the topography shown on the 1:250,000-scale maps as well as the delineations of Hack (1966) were made. The rims of the Sequatchie, and Wills and Moulton Valleys are distinct as well. One problem area was not solved: The overlapping sediments of the coastal plain (Fall Line Hills district) along the western edge of the plateau present a ragged, transitional boundary which is indistinct on ERTS and is not detectable in detail on the topographic maps. The geologic boundaries of the Tuscaloosa Formation on the 1926 State geologic map could not be improved upon. This is one instance in which ERTS imagery was no help. There is no escarpment along the western boundary of the plateau, and no precise topographic difference of any kind was detected.

Alabama Section

This section has traditionally been called the Tennessee section of the Valley and Ridge province. This practice was begun apparently by physiographers who were interested in an overview of the United States physiography, as opposed to the more specific state level. They felt that this section had its best expression within Tennessee, hence its name. Our divergence from this nomenclature is justified on the basis that we are concerned with Alabama's physiography, not that of bordering states. Moreover, the Alabama section has a distinctive character within this state.

The Coosa Valley district created problems in classification because it has a heterogeneous physiographic character formed on limestone and shales. The boundary with the Cahaba Valley at the southwest has no definite topographic expression. The other districts within the Alabama Section were fairly well defined by Johnson (1930) and were retained without significant modification by topographic maps or ERTS imagery. The Armuchee Ridges have not been included on any previous physiographic map of Alabama, to the author's knowledge, but they have been included on physiographic maps of Georgia. These ridges straddle the Georgia-Alabama border.

Piedmont Upland Section

The Piedmont Upland in Alabama has been divided into two districts, one northern and one southern. The division is made along the Brevard fault, a prominent zone traversing the piedmont. The northern boundary of the Northern Piedmont Upland district is taken as the metamorphic front, a topographic boundary. The southern edge of the Southern Piedmont Upland is the fall line, where the coastal plain sediments overlap the crystalline rocks of the piedmont. The traditional terminology applied to the piedmont (i.e., the Ashland and Opelika plateaus) has been rejected as inappropriate.

The surfaces are more correctly termed uplands rather than plateaus, and the classical descriptions of the so-called plateaus have been found erroneous (personal communication, T. L. Neathery, March, 1974). Other terminology, referring to the northernmost division as "Inner Piedmont" and the southernmost as "Outer Piedmont," is equally unsatisfactory for physiographic purposes, although geologists may prefer these terms for geological nomenclature.

East Gulf Coastal Plain Section

A number of significant changes have been effected in the physiographic mapping of this section. First, the category of Alluvial-deltaic Plains and river terrace deposits has been included. These plains have been shown where they are reasonably extensive. Second, the Coastal Lowlands district (following Cooke's terminology) has been used in western Florida, was included to cover the terrain below the Pamlico scarp, to the present coastline. This includes deposits of late Pleistocene and Holocene age. The upland to landward is termed the Southern Pine Hills, in accordance with Fenneman's terminology. A third significant change is the inclusion of the Dougherty Plain, which is a continuation of a flattish limestone upland westward from southwest Georgia. The term Dougherty Plain has not been used generally in Alabama, presumably because the district does not retain the distinctive character (sinks, etc.) it exhibits in Georgia. Nevertheless, the Dougherty Plain exists as a separate physiographic unit, subtlely distinct from the bordering Southern Pine Hills, Southern Red Hills, and Lime Hills.

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TIDAL MARSH INVENTORY

Russell L. Lipp

A tidal marsh map of the north-central Gulf Coast from St. Joseph Bay, Florida, to the Mississippi-Louisiana state line has been completed (pl. 14). This project is a continuation of the Alabama marsh inventory described in the ERTS Eighth Bi-Monthly Report.

The Alabama marsh was delineated from ERTS MSS image 1158-15564-7 (28 Dec. 1972), the Mississippi marsh from image 1177-16020-7 (16 Jan. 1973), and the Florida marsh from images 1265-15512-7 (14 April 1973) and 1264-15454-7 (13 April 1973). Images taken in winter and early spring were employed because the moisture content of the tidal marsh areas is high at this time. Because of the high moisture content, the marshlands on the band 7 images have a dark-gray signature as opposed to the light-gray of the uplands and the black water bodies. Mapping was done at a scale of 1:250,000 with U-2 infrared photographs of the Mobile Bay area as support data.

The major problem encountered in compiling the map was the poor quality of the images both east and west of the initial study area. The marshlands were difficult to discern from the images and therefore no acreage estimates were attempted. However, the map does give a general picture of where major marshlands are located on the north-central Gulf Coast.

The Alabama tidal marshes, delineated from a good quality band 7 image, were measured with a planimeter to arrive at acreage estimates. A total of 30,200 acres of tidal marsh was measured. This compares with a published figure of 34,614 acres (Crance, 1971) that was derived from topographic maps (see table).

	ERTS	Published (Crance, 1971)
Mississippi Sound	11,366	11,762
Mobile Bay	2,867	6,224
Mobile Delta	15,155	15,257
Perdido Bay and Little Lagoon	819	1,371
Total	30,207	34,614

The figures derived from ERTS data are believed to be accurate within about 2 percent. This is based on measurement of known areas from ERTS data. The difference in areas between the published data and the ERTS data is thought to be a result of marshland draining especially along the eastern margin of Mobile Bay.

The major problem encountered in the Alabama inventory was the differentiation of marsh and upland vegetation in inherently wet areas such as the flood plain of the Mobile River. It was necessary to employ U-2 photography to map marshlands in these areas.

ERTS data has proven useful in rapidly mapping large areas of coastal marsh with a fair degree of accuracy when good images are used. However, a much more accurate map could be produced using U-2 photography.

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APPENDICES AND SPECIAL REPORTS

SECTION THIRTEEN

of

VOLUME THREE

INVESTIGATIONS USING DATA IN

ALABAMA FROM ERTS-A

APPENDIX I

SIGNIFICANCE OF SELECTED LINEAMENTS IN ALABAMA

James A. Drahovzal, T. L. Neathery and
C. C. Wielchowsky

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SIGNIFICANCE OF SELECTED LINEAMENTS IN ALABAMA*

James A. Drahovzal, Thornton L. Neathery,
Charles C. Wielchowsky, Geological Survey of Alabama,
P. O. Drawer O, University, Alabama 35486

ABSTRACT

Four lineaments in the Alabama Appalachians that appear on ERTS-1 imagery have been geologically analysed. Two of the lineaments appear to have regional geologic significance, showing relationships to structural and stratigraphic frameworks, water and mineral resources, geophysical anomalies, and seismicity. The other two lineaments are of local geologic significance, but, nevertheless, have important environmental implications.

INTRODUCTION

With the advent of orbital photography, a few geologists have reported hitherto unknown alignments, variously termed, "linears," "lineations," "lineaments," or "linear features" (e.g., Lowman, 1969; Powell and others, 1970; Lathram, 1972). Following the launch of ERTS-1 and with the subsequent acquisition of virtual world-wide coverage, a greatly increased number of workers have reported these features (e.g., Gold and others, 1973; Isachsen and others, 1973). In spite of the many reports, few lineaments have been carefully field checked, consequently their nature and genetic relationship remain largely unknown. In this paper, four selected lineaments in the Alabama Appalachians for which field data have been collected will be discussed. Two of the lineaments are relatively long, extending across the entire state and appear to have regional geologic significance; the other two are shorter and have only local geologic significance. Based on the field data collected in each case, speculations as to the nature of the lineament-causing features will be discussed and the importance of such information to the operations of the Geological Survey of Alabama will be pointed out.

MAJOR LINEAMENT COMPLEXES

The Geological Survey of Alabama first became aware of lineaments through an analysis of Apollo 9 multispectral photographs of east-central Alabama (Powell and others, 1970; Drahovzal and Copeland, 1970; Drahovzal and Neathery, 1972). Two lineaments were exceptionally well displayed on the areally limited Apollo photography. Recent ERTS data have permitted extension of these lineaments into areas of the state where satellite imagery was previously unavailable. Careful study of ERTS imagery at a scale of 1:250,000 has shown that the two lineaments are actually lineament complexes. The complexes are linear zones composed of a series of shorter discontinuous, en echelon lineaments, with an overall trend approximately at right angles to Appalachian structural strike. The individual

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segments occasionally cross one another or bifurcate, but generally are parallel to subparallel. Over the past several years, fairly extensive field data have been collected that show relationships and provide clues to the nature of the two lineaments.

Structural Relationship

Anniston Lineament

The northeastern lineament complex (A-A', fig. 1), herein designated the Anniston lineament (for the city of Anniston, Calhoun County, Alabama), is approximately 290 kilometers long in Alabama. The lineament extends from the vicinity of Riverview on the Chattahoochee River northwestward across the Piedmont province (not show in fig. 1). It crosses the Brevard fault zone (BF, fig. 1) with no apparent disruption and continues northwest to the Little Tallapoosa River where it parallels a short stream segment (not shown in fig. 1). Extensive field studies in this area, however, have not revealed the presence of any major structural features correlative with the Anniston lineament complex. The lineament complex northwest of this area parallels the Tallapoosa River for several kilometers before crossing it at a major gap through a series of moderately high ridges (not shown in fig. 1). Before transecting the metamorphic front (MF), the lineament trace passes along the northeast limit of Talladega Mountain (TM) whose topographic expression is controlled by the underlying quartzites. North of the lineament, the quartzites change to fine-grained meta-arkose with interbedded slate. The lineament crosses the metamorphic front near the northeast side of a left-lateral 10-11 kilometer recess. Just beyond the metamorphic front, the lineament trace transects a prominent quartzite ridge at the point where the ridge abruptly changes strike from north-south to nearly east-west (not shown in fig. 1). The northwest flank of the ridge is bounded by the Jacksonville thrust fault (JF) where the main lineament and a short branch pass along either side of a narrow 5-6 kilometer southeasterly recess on the fault trace (fig. 2). The overridden block contains a small northwesterly elongate fenster (A, fig. 2) and several abruptly terminated, faulted synclines (B, fig. 2) near where the lineament complex passes. To the northwest, the lineament complex crosses just northeast of a 7-kilometer right-lateral displacement in the Pell City thrust fault (PCF, fig. 1) and crosses a narrow zone characterized by block klippen and thin imbricate thrust sheets on the lower plate (C, fig. 2). Much of the complexity of this zone appears to result from the abrupt change in strike near where the lineament complex crosses it. Southeast of the Lookout Mountain syncline (LMS, fig. 1), the main lineament trace is intersected by other traces having slightly different orientations. Near the intersection points, the lineament complex crosses an east-dipping homocline at a point where it is right-laterally offset 5-6 kilometers (D, fig. 2). Farther to the northwest, the Gadsden-Rome fault (GRF, fig. 1) abruptly cuts obliquely to regional structure for 10-11 kilometers, terminating the Lookout Mountain syncline. Just southwest of the lineament trace, the Helena thrust fault (HF) terminates. Northwestward, the lineament crosses Wills Valley anticline (WVA) near a point where its structural style changes from an asymmetrical thrust-faulted fold to the northeast to a more nearly symmetrical anticline to the southwest. The lineament continues northwestward crossing the end of the Murphrees Valley anticline (MVA) and the terminus of the Straight Mountain fault (SMF). The lineament crosses the Sequatchie anticline (SA) with little apparent effect and bisects the sharp bend in the trace of the Cumberland escarpment (CE). The southwest-flowing Tennessee River abruptly veers out of the Sequatchie anticlinal structure and flows northwest paralleling the lineament for about 40 kilometers. The lineament extends beyond the state line into Giles County, Tennessee, where its trace coincides with the northwest-southeast structural grain on the southwest flank of the Nashville dome (Wilson, 1949, pl. 1). Charles Wilson (1949, p. 333) has speculated that the grain, expressed by closely spaced sharply asymmetrical minor parallel folds, was the result of vertical movement along a set of northwest-southeast fractures in the basement complex. More recent mapping in Tennessee has revealed low-magnitude normal faulting in the vicinity of and on trend with the lineament (Miller and others, 1966).

Harpersville Lineament

The Harpersville lineament complex (named for the town of Harpersville, Shelby County, Alabama; B-B', fig. 1) crosses the low-rank metamorphic rocks of the Piedmont, and passes near the point where the Brevard fault becomes covered by the Coastal Plain onlap (not shown in fig. 1). If the Towaliga fault to the southeast is part of the Brevard zone and they together make up an Inner Piedmont mega-nappe as suggested by some (e.g., Bentley and Neathery, 1970), then the lineament passes very near to the southern termination of this feature. The lineament crosses within approximately 6 kilometers of the southern terminus of Talladega Mountain (fig. 1). The lineament trace transects the metamorphic front along the southwestern edge of the major recess in the front. Northwestward along the lineament, the Pell City fault block is folded into a series of overturned structures that include rocks younger than those composing the block to the immediate northeast and southwest. These younger rocks suggest downwarping where the lineament crosses the block. The Pell City fault itself splays and becomes less distinct in the vicinity of the Harpersville lineament. The rocks within and just northwest of the Pell City block along the lineament complex exhibit a north-northwest strike orientation rather than the typical northeast strike. In addition, overturned thrust slices occur in this block in contrast with the right-side-up thrust slices to the immediate northeast. Northwestward, the lineament trace crosses the Coosa thrust fault at a point where it is left-laterally offset 3-4 kilometers. On the downthrown side of the Coosa fault in the Coosa synclinorium (COS), the lineament passes through a narrow structural high separating two oppositely plunging synclines (not shown in fig. 1). Farther northwestward, in the Coosa and Cahaba (CAS) synclinoria, the lineament transects several major ridges at points of saddle development. The northeast prong of the complex crosses a synclinal feature on the southeast flank of the Birmingham anticlinorium (BA) at a point of major gap development in the ridge and structural change. At this locality, the Middle Ordovician Chickamauga Limestone has been interpreted as being absent across a narrow zone, although 140-180 meters of the unit are present in the immediate vicinity (Butts, 1910). Detailed field studies have not located the limestone in the narrow zone, but have shown that the dip of overlying and underlying beds is markedly steeper where the lineament crosses the syncline. These dips are more than 80°SE as opposed to 10-15°SE on either side of the zone along strike. It is quite probable that the limestone is completely masked in the area of steep dip by the thick mantle of colluvium. Both prongs of the lineament complex cross the southern terminus of the Blount Mountain syncline (BMS) and the Straight Mountain fault. The lineament cuts across the Birmingham-Murphrees Valley anticlinal complex where a change in structural style occurs. Southwest of the lineament, the Birmingham anticlinorium has a steep to overturned northwest limb that is cut by steep southeast-dipping faults including the Opossum Valley fault (OVF). Northeast of the lineament, however, the Murphrees Valley anticline exhibits a vertical to steeply overturned southeast limb cut by the nearly vertical northwest-dipping Straight Mountain fault. The northeast prong of the complex continues to the northwest where it intersects the Sequatchie anticline, the Warrior Basin (WB), and the Cumberland escarpment. At the present time, no known structural changes are apparent along its trace northwest of the Murphrees Valley anticline, but some gap development appears to correlate. The southwest prong crosses the Sequatchie anticline at the point where local upwarp along the anticlinal axis brings to the surface beds as old as Silurian. The prong crosses the eastern part of the Warrior Basin and becomes indistinct.

The offsets, terminations, and changes in structural style apparent along the two major lineaments may reflect the influence of geofractures that bound basement blocks. Because offsets along individual lineaments are not in the same direction, and because faults and folds terminate rather abruptly or change in style near the lineaments, vertical, rather than horizontal movement of the basement blocks may be the dominant form of displacement. Offsets in opposite directions along the same lineament may be explained by block rotation in the vertical plane. Similar situations have been described by Gwinn (1964, p. 891) in the Central Appalachians but have been attributed to upward shearing, inclined or vertical nonoutcropping faults that connect two glide levels along strike. The changes in the decollement-glide levels of local sole thrusts or higher branching stepped thrusts both across and along strike, may be the result of vertical movement in basement blocks. The foregoing structural studies have had an influence on the Geological Survey's concept of the tectonic framework of the southern Appalachians and are currently influencing geologic mapping programs in the province.

Stratigraphic Relationships

In addition to structural relationships, the two major lineaments appear to coincide with variations in Paleozoic stratigraphy in the southern Appalachians.

A succession that appears to show a strong relationship to the major lineaments is the Middle Ordovician. Over much of the southeastern United States, the Lower Ordovician is separated from the Middle Ordovician by a paleokarst unconformity, and the basal Middle Ordovician locally consists of conglomeratic beds having clasts that range from sand to boulder sizes. In Alabama, this unit is called the Attalla Chert Conglomerate Member of the Chickamauga Limestone. In general, the coarsest and thickest development of the Attalla in Alabama lies adjacent to the two major lineaments (fig. 3). The conglomerate is unknown northeast of the Anniston lineament complex. Immediately southeast of the Anniston lineament complex on Wills Valley anticline and near the termination of the Helena thrust fault, clasts, ranging from 15 to 92 cm in diameter occur in pockets as much as 21 m thick (Drahovzal and Neathery, 1971, p. 11, 185). The conglomerate becomes finer and thinner southwestward ranging in thickness from 1-6 m. Immediately southwest of the Harpersville lineament, at the up-plunge end of Blount Mountain syncline, another locally coarse deposit approximately 13 m thick occurs with chert clasts ranging up to 50 cm (Thomas and Joiner, 1965, p. 13). The thickest and coarsest development of the Attalla immediately adjacent to the major lineaments suggests that the lineament-causing structures are in part responsible for the anomalous occurrences. Differential vertical movement of the individual basement blocks contemporaneous with or prior to deposition may have formed the restrictive pockets, or selective karst development along lineament-related fractures during the Early Ordovician may be responsible for the anomalous distribution.

Similar lineament-related changes in lithologies and thicknesses for Cambrian, upper Middle Ordovician and Mississippian rocks of the Alabama Appalachians are known. The apparent relationships between the two lineaments and Paleozoic depositional cycles suggest that differential movement prior to or contemporaneous with these cycles occurred along lineament-related crustal block boundaries.

Relationship to Water Resources

Results of Apollo 9 studies in Alabama have shown relationships between the occurrence of water resources and lineaments in the Valley and Ridge and Piedmont provinces. High-yield springs and wells show a number of excellent lineament correlations (Powell and others, 1970). In addition, it has been demonstrated that certain surface flow anomalies in eastern Alabama are directly related to the occurrence of lineaments. Detailed low-flow studies made in adjacent subdrainage areas along Talladega Creek in Talladega County, Alabama have shown that there is an abrupt pickup in flow at a point where two lineaments intersect the stream. Pickup at the intersection point increases more than 70 times from a flow of 6.6×10^{-4} $m^3/sec/km^2$ to 4.7×10^{-2} $m^3/sec/km^2$ (Powell and LaMoreaux, 1971; U. S. Geological Survey, 1972, p. 190-191).

The recent extension of the Anniston lineament into Madison County, Alabama through the use of ERTS-1 data has been significant to the intensive study of the hydrology of limestone terranes presently being carried out by the Geological Survey of Alabama. The region, therefore, provides an excellent test area for determining the nature of relationships between lineaments and the occurrence of ground-water resources in limestone terranes. Preliminary results indicate a striking correlation between high-yield springs and wells and areas of lineament concentration. In the southwestern part of Madison County, where the Anniston lineament complex crosses, data for nearly 80 wells and springs are available (fig. 4). The 4-kilometer-wide zone associated with the Anniston complex encompasses wells whose yields range as high as 0.318 m^3/sec and average nearly 0.032 m^3/sec.

Wells located on either side of the zone exhibit markedly lower yields, averaging only about 0.010 m^3/sec. For the area, yields greater than 0.016 m^3/sec are considered to be anomalously high (George Moravec, oral communication, 1973). Structural data for the area indicate a series of low, undulating folds that trend generally northwest-southeast, subparalleling the lineaments (fig. 5). High well yields only generally correspond to structural lows and are probably influenced more by fracturing in the underlying limestone. Correlation of high-yield wells and springs to the lineaments suggests that the lineaments represent fractures and possibly low-magnitude faults that influence the movement and distribution of ground-water resources. Low variabilities in water-level fluctuation amplitudes for some of the lineament-related wells in Madison County appear to parallel the low-discharge variability noted by Powell and others (1970) for lineament-related limestone springs in the Valley and Ridge province. Low variabilities, uncommon for wells and springs in limestone terranes, suggest special recharge conditions. The plotting of lineaments derived from ERTS-1 and other available imagery is becoming an important part of exploration procedures for ground-water resources at the Geological Survey of Alabama.

Relationship to Mineral Resources

The lineaments show remarkable correlation with many of the hydrothermal mineral deposits of Alabama. The occurrence of barite and lead and zinc sulfides in the Valley and Ridge and barite, gold, manganese, tin, and copper, lead, zinc, arsenic, and iron sulfides in the Piedmont has been related to lineaments drived from Apollo 9 photography (Smith and Drahovzal, 1972). Barite appears to show the closest correlation with about 40 percent of the known prospects coinciding with the two major lineament complexes (fig. 1). The richest barite deposits known in Alabama occur along the Anniston lineament where the main branch changes trend slightly and is intersected by a number of shorter segments. Many of the other barite prospects correlate with shorter, less prominant lineaments.

To further evaluate the apparent mineral-lineament relationship, "B" horizon soil samples were collected at about 300-meter intervals along traverses crossing selected lineaments and analysed for eight metals. Preliminary results have been mixed, however, a number of traverses show anomalously high metal concentrations at the points of intersection with the lineaments. Two geochemical profiles across the Anniston lineament complex show excellent correlation (figs. 6 and 7). One traverse (A, fig. 6) crosses an area in the Piedmont province underlain by garnet schist. Dispite a consistent lithology along the traverse, three metals - lead, zinc, and chromium - show anomalously high concentrations where the traverse intersects the Anniston lineament (A, fig. 7). Chromium concentration reaches 179 ppm, more than 4 times the estimated background of 40 ppm; whereas lead and zinc anomalies are about twice their estimated backgrounds. The other traverse (B, fig. 6), also in the Piedmont, crosses a variety of metamorphic lithologies and exhibits two anomalously high chromium concentrations (B, fig. 7). The higher chromium peak reaches a concentration of

374 ppm, more than 5 times the estimated background for the area, and is related to a branch off of the main trace of the Anniston lineament. The second peak is lower, being only about twice the estimated background, but is, nevertheless, sharp and distinct. It correlates extremely well with the main segment of the Anniston lineament.

On the basis of this work, it appears that the distribution of some potentially important mineral resources is related to the lineament-causing structures. The relationship suggests that these structures may be crustal penetrating fractures that serve as migration channels for mineralized fluids and sites of deposition for certain hydrothermal minerals. Additional studies are currently underway in other parts of the state and especially near lineament intersections where samples will be collected on a grid pattern rather than along single line traverses. The lineament-geochemical sampling approach to exploring for potential mineral resources is becoming an important procedure for the Mineral Resources Division of the Geological Survey of Alabama.

Geophysical Evidence

In addition to the geochemical surveys, several gravity surveys have been conducted in the vicinity of the Anniston lineament complex of northern Alabama. Although regional gravity shows no particular relationship to the lineaments, detailed surveys utilizing approximately 160-meter station spacing exhibit anomalies that are correlative with the linear features. A gravity survey conducted in a Mississippian limestone terrane just southwest of Huntsville in Madison County, Alabama (A, fig. 6) shows a sharp 0.4 milligal negative anomaly at the point where ERTS imagery indicates the presence of the main branch of the Anniston lineament complex (A, fig. 8). Figure 8 shows only a small part of the 13-kilometer profile, but to the southwest the anomaly slowly decreases in intensity for a distance of about 2 kilometers. Beyond that point, gravity readings vary only slightly from the regional gradient. To the northeast, several other smaller, but nevertheless sharp, anomalies are present. These appear to relate very closely to northeastern segments of the Anniston lineament complex. The sharpness of the 0.4 milligal anomaly suggests that it represents either a sharp flexure or a fault downthrown to the southwest. Applying the "half-maximum" rule, the anomaly could originate as much as 1,500 meters below the surface. Depth to basement in the area is unknown, but is estimated to be between 1,500 and 1,900 meters below the surface based on scattered well information. The anomaly, therefore, could reflect offset in the basement complex or possibly in the Cambrian Copper Ridge Dolomite. A structure map contoured on the top of the Devonian Chattanooga Shale in the vicinity of the profile and lineament shows a structural low trending in a subparallel fashion to the lineament trace (fig. 5). Some workers have preferred to interpret the data of figure 5 with a fault that parallels the lineament (Geological Survey of Alabama, open file maps). This flexure or fault may also be responsible for the gravity anomaly. A second gravity survey was run across the Anniston lineament complex in the Cumberland Plateau province (B, fig. 6). A negative anomaly of about 0.17 milligal correlates with the lineament complex (B, fig. 8). If the anomaly represents a fault, it is downthrown to the northeast rather than to the southwest as in previous case. It is possible that the thick Pennsylvanian succession has the effect of masking and thereby reducing the magnitude of the anomaly, but final interpretation awaits detailed analysis and correlation with other recently conducted surveys in the area.

Gravity results to date look most encouraging and suggest that, at least in part, the Anniston lineament is the surface expression of a sharp flexure or fault in the subsurface. Future gravity surveys are being planned along both complexes and magnetic surveys will be conducted in association where possible. Some preliminary ground magnetic surveys seem most encouraging but await confirmation before being reported in detail. Detailed ground geophysical surveys appear to be extremely important in evaluating the nature of the lineament-causing structures.

Relationship to Seismicity

Between 1886 and 1971, 14 earthquake epicenters have been reported in Alabama (Eppley, 1965; Woollard, 1968; U. S. Department of Commerce, 1971; C. A. Bollinger, written communications, 1971-1973). Although the earthquakes are rather infrequent and of relatively low intensities (between I and VIII on the Modified Mercalli Intensity Scale of 1931), they may be highly significant to the understanding of the nature of the two major lineament complexes. Those epicenters occurring in the northeastern quarter of the state are shown in figure 1. Four of the epicenters lie directly on the main branches of the Anniston lineament complex and two on the main segment of the Harpersville lineament complex. Coincidence of epicenters with the major lineament traces not only implies that the lineaments are related to basement structures, but also indicates that they may represent structures that are currently active. Microseismic studies are planned as part of proposed ERTS-B research.

TWO MINOR LINEAMENTS

In addition to the two major lineaments, there are a myriad of other lineaments for which very little or no field information is available. The latter are presently considered to be of lesser geologic significance and are classified herein as minor lineaments. There are, however, two minor lineaments for which fairly extensive field data are available.

Wesobulga Creek Lineament

As part of routine geologic investigations and ERTS-1 research, lineament analyses and a ground investigation were conducted in a 420 km^2 area of the northern Alabama Piedmont. Lineament locations and orientations were derived from ERTS-1 and side-looking airborne radar (SLAR) imagery supplemented with low-altitude conventional photographs. Two hundred-forty-two tonal and topographic lineaments were transferred from the various images and plotted on 7½-minute topographic maps for field checking. In the course of the field investigation, more than 2,500 stations were established for which structural data including the orientation of cleavages, foliations, joints, faults, and folds were recorded. The relationships of most of the structural data to lineament traces is inconclusive, although a rough correlation appears to exist between joint orientations (273 stations) and the lineament orientations (fig. 9). Correlation is somewhat better than one might at first believe because compilation of the lineament data on a SLAR base has imparted as much as a 10-degree north-bias due to variable distortion of the SLAR imagery.

A detailed search was made over approximately 195 km^2 of the study area for surface manifestations of any of the image-derived lineaments. A small normal fault that is exposed in a road cut (fig. 10) was discovered and found to coincide with the trace of a lineament expressed both on ERTS-1 and SLAR imagery. The lineament, herein referred to as the Wesobulga Creek lineament, is approximately 4 kilometers in length on SLAR imagery and corresponds with an ERTS lineament about 15 kilometers in length. On both SLAR and ERTS data, orientation of the lineament averages N45°W. The Wesobulga lineament is no more prominant than many other such features for which no structural evidence exists.

The corresponding Wesobulga Creek fault zone is approximately 3 meters wide and has an approximate strike of N40-45°W with displacement of 3-15 meters in the roadcut. The principal zone of movement occurs on the east end of the fault zone where a mylonite-phyllonite zone 10 cm wide marks the fault. The remaining 2.9 meters of the zone is composed of a series of closely spaced vertical shear joints that decrease in number to the west end. To fully investigate the orientation and extent of the fault, eight trenches were dug across its projected trace (fig. 11). Six of the eight trenches nearest to the road exposure cut the fault. One trench located approximately 700 meters north of the road failed to intersect the fault trace (not shown in fig. 11). The trenches show that the fault zone narrows in both directions from the 3-meter-wide zone at the road cut to a half-meter-wide kink band in trench TN-4 and to a disturbed zone less than 2 meters wide in trench TS-3. The trend of the fault, as exposed, coincides with the orientation of the lineament derived from both SLAR and ERTS data. The general shape of the fault zone and its topographic position along the flank of a steep-sided valley suggest that the feature may not be tectonic, but may represent a recent rotational shear related to slumping. Radiogenic age dates (K/Ar) are currently being determined on the mylonitic rock of the principal fault zone. Approximately 500 meters east of the fault, on the adjacent valley wall, another small fault and drag fold are exposed in a road cut, but the relationship of this feature to the Wesobulga Creek fault is unknown at this time.

This example of a positive relationship of one of the ERTS-derived lineaments to a small fault is noteworthy, but certainly not statistically significant. It is not to be regarded as indicating that all or even most lineaments are related to faulting. On the contrary, evidence based on this test area suggests that most of the minor lineaments are not related to obvious structural features. More detailed work is required to determine the significance, if any, of the many other lineaments to the structure of the area.

Kelly Creek Lineament

The other minor lineament for which considerable field data exists was originally discovered on Apollo 9 photography (Powell and others, 1970). Follow-up studies utilizing SLAR and ERTS-1 data have added to our understanding of the feature. The lineament also appears on U-2 photography and conventional panchromatic photo mosaics. Low-level aerial reconnaissance has revealed erosion-deepened hollows and gaps along the lineament, as well as linear regions characterized by trees whose foliage appeared to be slightly darker green than those of the surrounding area (Bailey, 1970). The lineament strikes about N49°W and has been traced for 8 kilometers on SLAR imagery, but appears on ERTS-1 imagery to be part of a somewhat longer linear feature.

The lineament has been the subject of extensive study because it strikes along the axis of Logan Martin dam on the Coosa River (fig. 12). Since impoundment in 1964, leakage from the reservoir has occurred beneath and to the sides of the dam through the highly weathered and fractured limestones and dolostones that underlie the area. Flows of up to 20 m^3/sec have been measured below the dam and during one 2-year period total leakage increased, though it has now stablized (Alverson, 1969). Structural, hydrologic, subsurface, and seismic data show that the lineament represents a deeply weathered fracture zone. Vertical joints coincident and parallel with the lineament were measured at several locations northeast of the dam (Spigner, 1969). The existence of hydraulic connection through solution-widened fractures developed along the lineament has been demonstrated by the following: 1) dye injected into well 262 was detected in well 222 within 24 hours (fig. 12); 2) well 238 has an anomalously high specific capacity of such a magnitude that it must be connected to the reservoir; 3) the lowering of water in a cofferdam on the west side of the river resulted in the lowering of water levels in two wells along the lineament on the east bank (not shown in fig. 12); and 4) sizable increases in surface flow have been noted during low-flow periods where the lineament crosses Kelly Creek just northwest of the dam (Alverson, 1970; Powell and LaMoreaux, 1971). Test drilling west of the dam on the lineament trace encountered nearly 200 meters of highly fractured rock before solid bedrock was encountered. Holes not on the lineament penetrated solid rock at much shallower depths. Several seismic and resistivity profiles confirm the presence of the fracture zone in the areas that correspond to the trace of the lineament (W. L. Scarbrough, oral communication, 1973).

The Kelly Creek lineament, in part at least, most certainly represents a fracture zone. At the present time, it is not known whether this fracture is a fault, but it is contributing to reservoir leakage.

CONCLUSIONS

The major lineaments such as the Anniston and Harpersville lineament complexes are probably related to basement structures. Because the structural offsets and changes do not necessarily parallel the lineament traces and because the lineaments may affect all parts of the Paleozoic succession, the lineaments appear to represent basement geofractures, which have been vertically active throughout much of geologic time. The geofractures may be partly responsible for the present geologic configurations of the Appalachians because of their direct tectonic effect at the time of deformation and their earlier tectonic control of sedimentation. Coincidence of high-yield wells and springs, hydrothermal mineral deposits, geochemical highs and geophysical anomalies with the major lineaments suggests that fracturing of the basement is also expressed in the Paleozoic cover. Seismic activity along the same lineaments indicates that they are related to basement geofractures that are still active.

The evidence relating to these lineaments leads us to speculate about their significance to the tectonic framework of the Appalachians. It is possible that much of the driving force for the thin-skinned tectonics of the Appalachians was derived from primary vertical movement in the basement. The vertical uplift and the attendant development of tectonically unstable conditions in the overlying Paleozoic cover may have resulted in horizontal forces that expressed themselves in the formation of decollement-glide planes in the incompetent units of the Valley and Ridge synclinorium. Such a concept combines parts of both "thin-skinned" and "thick-skinned" ideas which have been expressed before (e.g., Cloos, 1948; Boos and Boos, 1957; and Eardley, 1963), but generally not for the Appalachians.

The northwest orientation of the major lineaments in Alabama is closely similar to the trend of the postulated Bahama fracture zone off the southeast coast of North America (LePichon and Fox, 1971). This and other fracture zones along and seaward of the present coast of North America are thought to be genetically related to the open ocean fractures lying perpendicular to the Mid-Atlantic ridge and to complimentary marginal fracture zones along the African coast. Some of the marginal fracture zones are known to be related to basement ridges farther onto the continent, such as the Cape Fear fracture zone that is aligned with the axis of the Cape Fear arch. The similarity in orientation between the major lineaments in Alabama and the Bahama fracture zone may represent an analogous relationship. This concept is consistent with J. T. Wilson's (1965) suggestion that the pre-rift continental mass was broken by faults or ancient lines of weakness that after rifting and rotation, represent less tectonically active continental equivalents of active Mid-Atlantic transform faults.

The minor lineaments are believed at the present time to have limited geologic significance. The two discussed--the Wesobulga Creek and Kelly Creek lineaments--have demonstrated local geologic and environmental importance. Most of the minor lineaments, however, seem to have little or no obvious relationship to the local geology, but detailed information is lacking in most areas.

A great deal of field data and analysis will be required to determine the genetic nature and significance of the lineaments. It is hoped that this paper has presented a beginning in that direction. The ERTS-1 program in some respects has not saved the geologist field time and expense, as may be validly claimed for some problems, but it has sharpened his sensitivity to certain aspects of regional geology that may be highly significant to a fuller understanding of geologic relationships and environmental perspectives.

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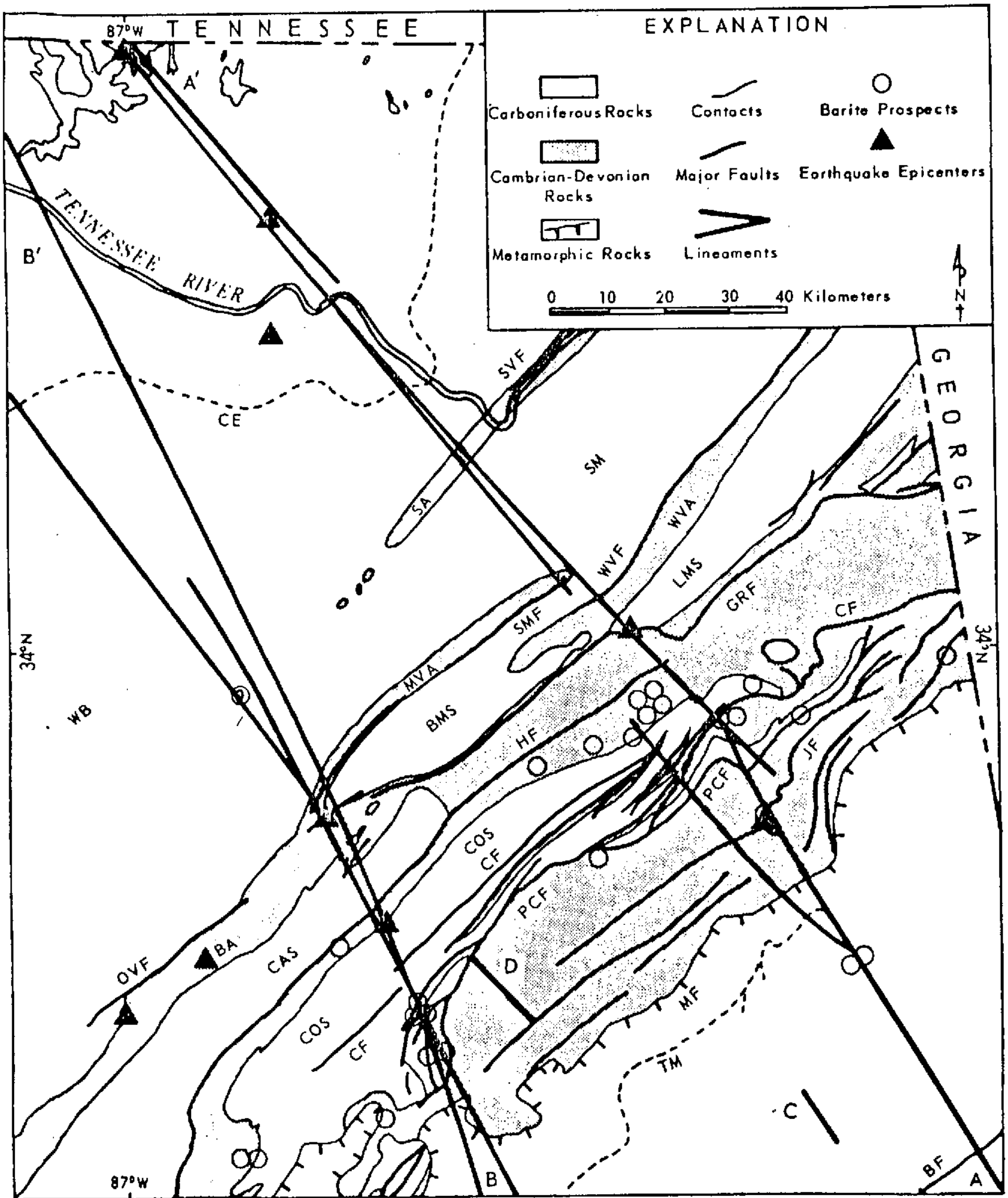

Figure 1.—Generalized geology of northeast Alabama, showing structural and physiographic features, barite prospects, earthquake epicenters and lineaments (A-A'—Anniston, B-B'—Harpersville, C—Wesobulga Creek and D—Kelly Creek). BA—Birmingham anticlinorium, BMS—Blount Mountain syncline, BF—Brevard fault, CAS—Cahaba syncline, CE—Cumberland escarpment, CF—Coosa fault, COS—Coosa synclinorium, GRF—Gadsden-Rome fault, HF—Helena fault, JF—Jacksonville fault, LMS—Lookout Mountain syncline, MF—metamorphic front, MVA—Murphrees Valley anticline, OVF—Opossum Valley fault, PCF—Pell City fault, SA—Sequatchie anticline, SM—Sand Mountain, SMF—Straight Mountain fault, SVF—Sequatchie Valley fault, TM—Talladega Mountain, WB—Warrior basin, WVA—Wills Valley anticline, WVF—Wills Valley fault. Geology modified from Adams and others, 1926.

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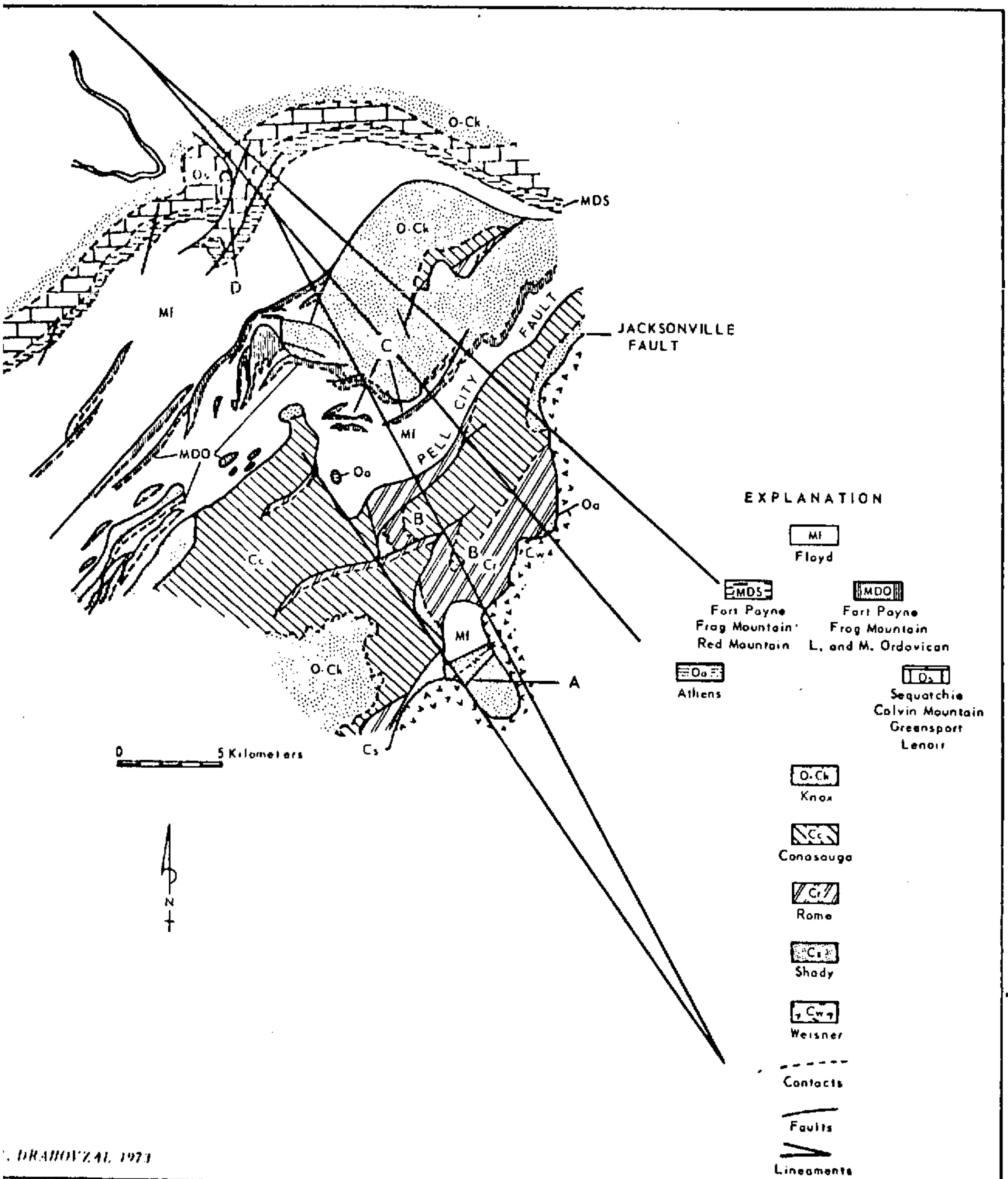

ure 2.--Generalized geology of the Anniston - Gadsden area, Alabama showing its relationship to the Anniston lineament complex. Geology modified from unpublished field maps of T. L. Neathery (1968) W.A. Thomas and J.A. Drahovzal (1969-1970) and J.A. Drahovzal (1971-1973).

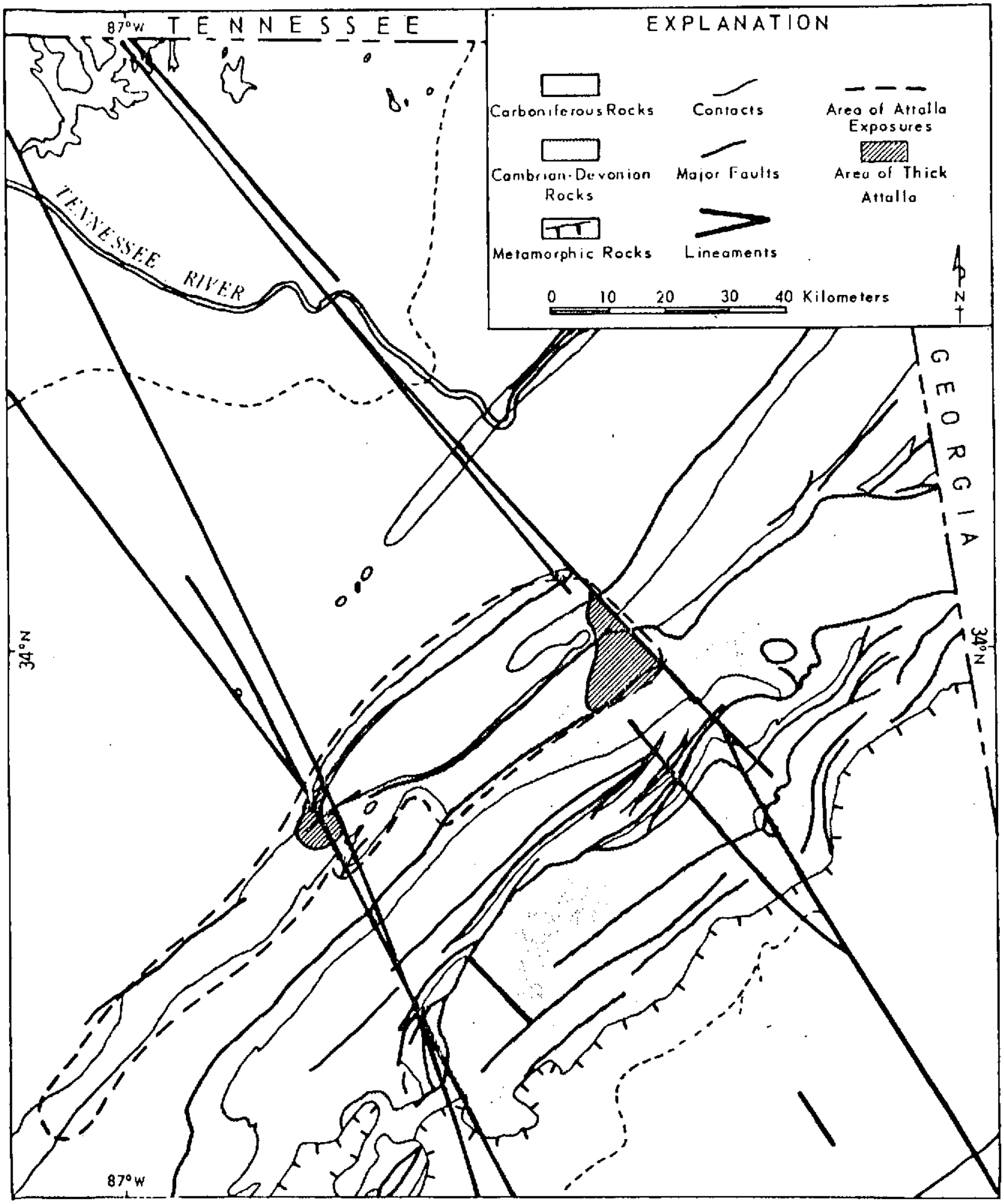

Figure 3.–Generalized geology of northeastern Alabama showing the approximate limits of the Attalla Chert Conglomerate Member of the Chickamauga Limestone and the areas of thick and coarse development. Data modified from Butts (1910), Thomas and Joiner (1965), and Drahovzal and Neathery, (1971).

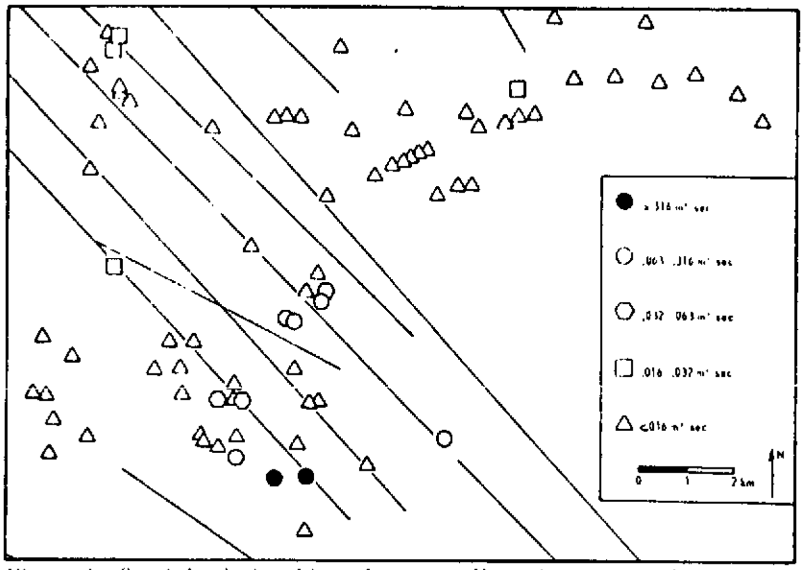

Figure 4.—Spatial relationships of water wells and springs to lineaments associated with the Anniston lineament complex in southwestern Madison County, Alabama. See figure 6 for location.

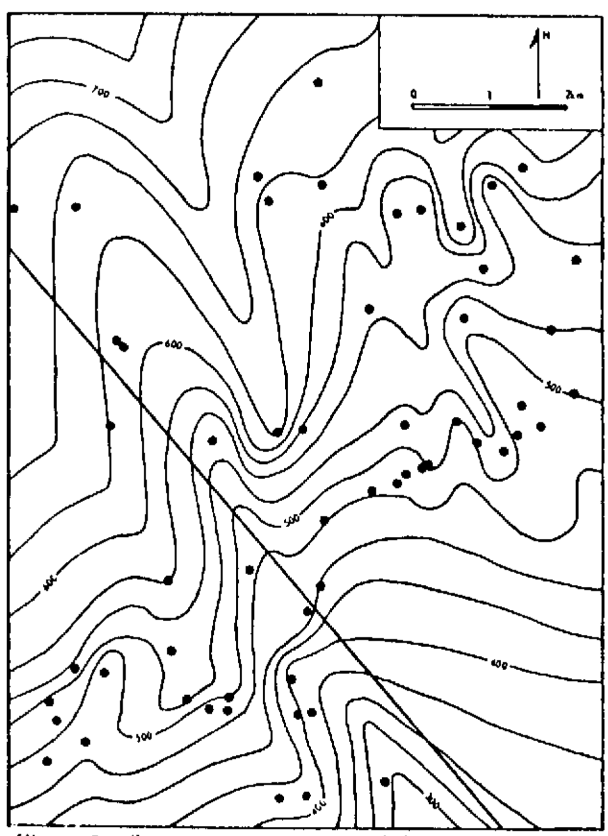

Figure 5.—Structure contour map of the southwestern part of Madison County, Alabama, showing the trace of the Anniston lineament. Contour interval is 25 feet and is drawn on the top of the Chattanooga Shale. Dots represent well locations.

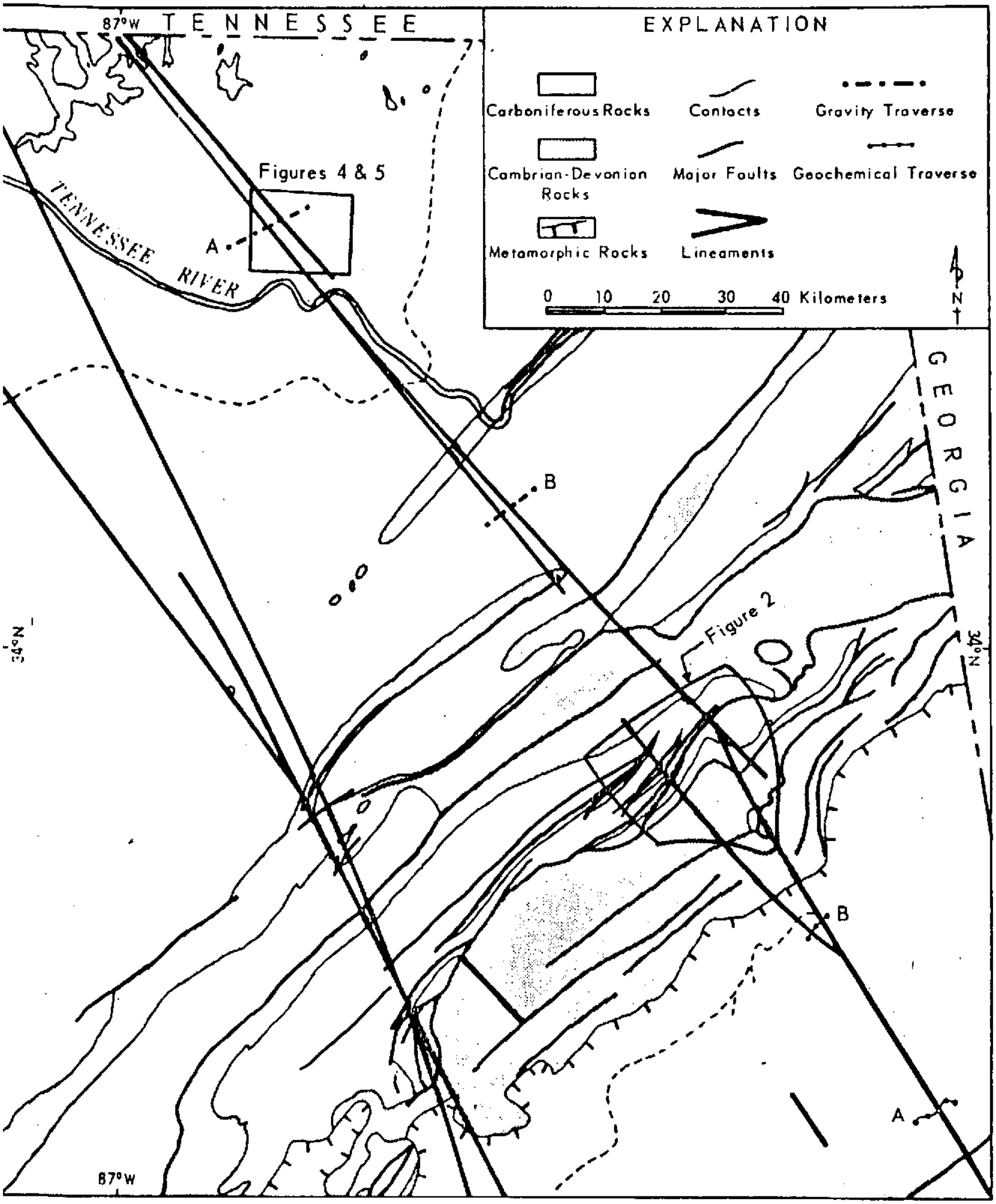

Figure 6.—Locations of geochemical and gravity profiles across the Anniston lineament complex and locations of figures 2, 4, and 5.

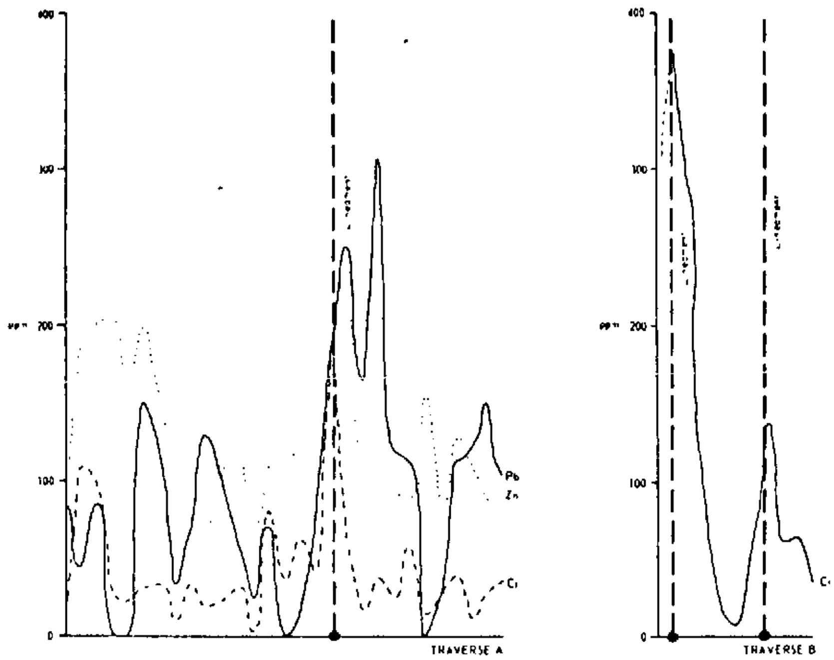

Figure 7.—Geochemical profiles across the Anniston lineament complex. See figure 6 for locations. From unpublished field and laboratory data (W. E. Smith, J. A. Drahovzal, and N. A. Lloyd, 1972).

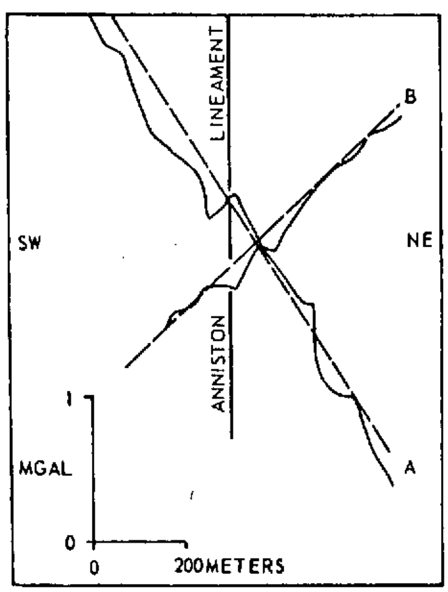

Figure 8.—Gravity profiles across the Anniston lineament complex. See figure 6 for locations. Dashed lines represent interpreted regional gravity; solid lines gravity anomalies. From unpublished field data collected by G. V. Wilson (1973).

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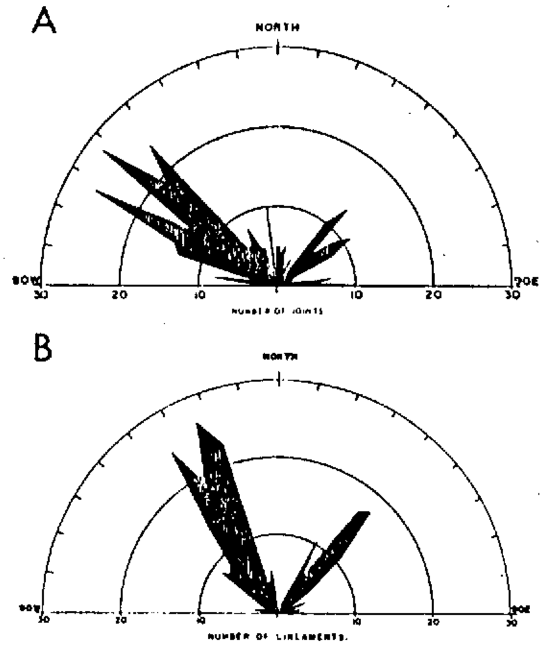

Figure 9.—Rose diagrams comparing the orientations of lineaments to joints in the vicinity of the Wesobulga Creek lineament.

Figure 10.—Road cut exposing a normal fault that coincides with Wesobulga Creek lineament. Fault is 3 meters in width and downthrown to the right.

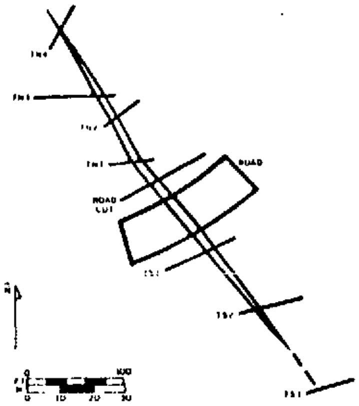

Figure 11.—Map showing the fault trace, road cut and trenches associated with the Wesobulga Creek lineament.

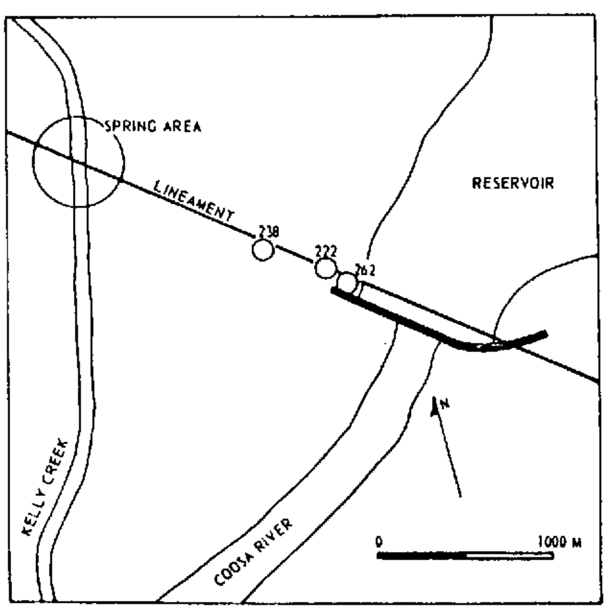

Figure 12.—Kelly Creek lineament in the vicinity of Logan-Martin Dam (modified from Alverson, 1970).

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APPENDIX II

A SMALL-SCALE INFORMATION SYSTEM FOR REMOTELY SENSED DATA

C. C. Wielchowsky

Abstract and text of paper presented
at the 22nd Ann. Mtg., Southeastern
Sec., Geol. Soc. America, Knoxville, 1974.

A SMALL-SCALE INFORMATION SYSTEM FOR REMOTELY SENSED DATA[1/]

Wielchowsky, Charles C., Geological Survey of Alabama, University, Alabama 35486

Many state geological surveys and university geology departments are acquiring large volumes of remotely sensed data for analysis. The utility of these data in solving geological problems is well documented; however, due to the great amount of variance in output format, sensing systems, and areal coverage, large volumes of data are difficult to access. This difficulty can be alleviated by the creation and utilization of an efficient data-management system.

The Geological Survey of Alabama, which has acquired much diverse, remotely sensed imagery, employs a computer-based data-management system that can be used for the retrieval of remotely sensed imagery or imagery information. IRIS (Imagery Retrieval and Information System) is a practical system designed only for in-house use. It consists of a cross-indexing subsystem that contains, for example, such information as UTM coordinates of coverage, sensor type, imagery format and scale, and a geographic locator subsystem that contains information on various man-made and natural features covered by the imagery. IRIS has the capability of retrieving any image file number or information based on any single criterion or group of criteria. With a few modifications the system can be effectively used without a computer.

[1/] Approved for publication by the State Geologist.

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A SMALL-SCALE INFORMATION SYSTEM FOR REMOTELY SENSED DATA

By Charles C. Wielchowsky

INTRODUCTION

The Geological Survey of Alabama has been actively involved in the application of remotely sensed data to the solution of geologic and hydrologic problems since the 1950's. Renewed impetus was given to the remote sensing program of the Survey with the acquisition of the first Apollo 9 photographs of east Alabama and the subsequent discovery of large scale lineaments that cut across Appalachian structural grain and apparently influence the geology and hydrology of the Alabama Appalachians. From 1969 to the present the Survey has acquired over 5,000 individual data products (i.e., images and photographs) in support of various studies related to these lineaments as well as to problems of subsidence in limestone terranes, power plant site selection, stream flow analysis, and others.

With the funding of two ERTS-1 projects in 1972, the proposed launch of Skylab in 1973, and the prospect of obtaining a large volume of remotely sensed data from the USGA's Prescott Research Group, it was realized that some type of data-management system would have to be designed so that these diverse data products could be easily catalogued, stored, and retrieved. Other state surveys and university geology departments have acquired or will acquire similar volumes of remotely sensed data and will therefore be faced with a similar problem - the creation of an efficient data-management system.

Creation of such a system involves three phases: 1) design, 2) implementation, and 3) operation. Due to possible hardware changes at the computer center of the University of Alabama, we are still in the latter design and early implementation phase of this project; therefore, this paper is a progress report on the creation of a system for the cataloguing, storage, and retrieval of remotely sensed data, and information about those data.

In essence, a system for the management of great volumes of imagery and photography may be defined as a formal, organized approach to facilitate the handling, coordination, interpretation and general use of remotely sensed data and information pertaining to those data within one or more organizations, or, in other words, a glorified filing system. There are many problems associated with the use of great volumes of remotely sensed data and information about those data. These include: 1) collection of the data, 2) cataloguing of the data, 3) data storage, and 4) data accession. Assuming that data collection is no great problem (i.e., one is already inundated with various images, photographs, and computer tapes of different areal coverage, sensing systems, ad infinitum) let us address ourself to the sources of cataloguing, storage, and accession problems. These are caused by shear data volume and variance in sensing systems, output format, and areal coverage.

For example, as previously stated, the Survey now has over 5,000 individual data products. Now let us consider the fact that ERTS-1 passes over Alabama every 18 days and let us assume that both the RBV (which is at present turned off) and the MSS subsystems are operating. Twelve scenes will cover Alabama, but both sensors yield a total of 7 data products in different bands. Therefore, 84 different products became immediately available for Alabama after every 18-day cycle. This comes to a total of 1,705 individual data products per year which could be multiplied by a factor of two if one requested products in addition to the 70 mm negatives (e.g., 70 mm positive transparencies, 9 x 9 prints, 9 x 9 positive transparencies, etc.). In the mean time let's say that a U-2 underflight is made of a portion of the state in support of an ERTS-1 project. If 100 frames are taken by two filtered RC-8 cameras and a bank of 6 Hassolblads, the data volume of Alabama coverage would increase by 800 individual products. Add to this any other missions flown in the atmosphere and the problem of data volume becomes acutely evident.

Sensing systems and platforms are greatly varied. For example, aircraft may carry scanners, SLAR, photographic sensors of every description, radiometers, or other sensor types. Output format is primarily a function of sensing system and planned use of the data. If the product is a single photograph it may be a positive or negative transparency or print that is either in black and white or color. Size can vary from 40 x 40 to 35mm. Products may also include flightline stripes, mosaics, or digital tapes.

Areal coverage and scale is generally a function of platform height and sensing system. For example, ERTS-1 9 x 9 frames at a scale of 1:1,000,000 cover an area of 115 x 115 miles whereas USDA black and white low altitude photographs cover an area of 2.5 x 2.5 miles at a scale of 1:20,000. This slide compares areal coverages of several sensor platforms.

Now that the problems that are associated with a management system for remotely sensed data have been identified, the next step in design is to define what information should be included in this system. Obvious sources for this information are the individuals who wish to use remotely sensed data (i.e., the user). We have found that most often the user of remotely sensed data wants to know: 1) where coverage is available, 2) the system that collected the data, 3) the altitude of the platform or scale of the data, 4) data format, 5) time and date of acquisition, and 6) image quality and cloud cover.

With the problems and information content now defined, system concepts can be evolved. These three concepts are that the system should: 1) be able to rapidly retrieve any image or photograph file number or information subject to any single criterion or group of criteria, 2) allow rapid location of actual photographs or images, and 3) be able to record who has checked out images or photographs and the dates involved. As a corollary to the first concept, we hope to let the user directly interface with the system (i.e., he may modify his request as he interacts with the computer). We also feel that the system should be evolutionary in nature and capable of interfacing with present systems such as the EROS Data Center's MAP program. Two solutions to the data-management problem will be discussed, neither of which is presently fully operational at the Survey. The first solution, or data-management system is a computer based filing and retrieval system called IRIS (Imagery Retrieval and Information System), and the second solution for less ambitious remote sensing programs is called "Little"IRIS. This system utilizes keysort cards and a knitting needle.

IRIS

IRIS (Imagery Retrieval and Information System) is a computer based filing and retrieval system designed for the cataloguing, storage, and retrieval of remotely sensed data and information about those data. As presently conceived, it will utilize IBM's Generalized Information System (GIS) which is a user oriented information handling system that enables a computer facility to perform spontaneous creation and maintenance of, and retrieval from, formatted data files.

IRIS can be divided into two subsystems, a Cross-Indexing Subsystem (CIS) and a Geographic Locator Subsystem (GLS). The CIS consists of three groups of elements while the GLS consists of 6 groups of elements and is capable of retrieving data file numbers based on geographic location as well as information on the areas covered. The Ground Data Group of the CIS relates the image to the ground by UTM coordinates of coverage and by scale. The Image Data Group is simply an image descriptor that includes information on operational category of sensor, positive-negative nature, physical appearance, format/size, time and date of coverage, whether the data is bulk or precision, cloud cover, platform altitude and attitude, and product generation. The Mission and Accession Group (MAG) number contains information on collection agency and the mission or platform that collected the data. The imagery or photography is filed by a 10 digit MAG number.

This NASA Apollo 9 frame, AS9-26-3790A, would have the CIS number that you see in this slide.

The catalogue/file operations involved are shown on this slide. When a photograph or image is received in the remote sensing laboratory an Image Data Card (IDC) is generated. This card contains both CIS and GLS numbers as well as explanatory text. The MAG number is then written on the image or photograph and the data is filed. Since the information on the IDC is in the same sequence as the keypunch operator will use, he may then take the imagery or photography information directly from the IDC and add it to the IRIS data base. The IDC is then filed in the remote sensing laboratory for future reference and data checkout purposes. Space is provided on the back of each IDC for additional image data not stored in the computer and for user category/ID number.

For the six types of previously mentioned desired information, IRIS probably "fills the bill"; however, we would like to eventually incorporate within the system a latitude-longitude converter, an estimate of image quality, the availability of stero coverage, the film and filter type used, and perhaps eventually information on imagery or photography not available at the Survey and the location of a supplier and sufficient information to obtain copies of such data. Initially though, IRIS will only handle data that is available in-house.

"LITTLE" IRIS

"Little" IRIS is also a filing and retrieval system designed for the cataloguing, storage, and retrieval of remotely sensed data and information about those data. It utilizes 10½ x 8 inch keysort or punch cards that contain 40 four hole fields and two three hole fields. Utilizing the direct and numerical coding methods of Breger (1958) a seven digit file number (MAG number), sensor category, positive or negative nature, format, size, scale, date and time of coverage, cloud cover, and counties covered can be indexed. The cards are punched with this instrument and sorted with this fancy knitting needle. Catalogue/file operations for "Little" IRIS are similar to those of IRIS. When the imagery is received a 4 x 6 Data Card (4 x 6 DC) is generated on a normal 4 x 6 index card. This card contains numerical punch codes with explanatory text. The photograph or image is labeled and filed and the 4 x 6 DC is sent to the typist. Imagery information is typed directly on the keysort card and then the keysort and 4 x 6 Data Cards are sent back to the remote sensing laboratory. The 4 x 6 DC is filed, and the keysort card is punched and added to the data base. Advantages of "Little" IRIS over IRIS are cost and response time.

Disadvantages include smaller information content, non-evolutionary nature, and lack of a precise geographic locator system.

DISCUSSION

IRIS offers no miracle solution to the handling problems associated with the great volumes of remotely sensed data that are now being acquired by various institutions. We feel, however, that it can solve many of our in-house and eventually intrastate data handling problems so that the tool of remote sensing can be more readily applied to the various scientific disciplines in general, and to our own discipline in particular, geology. Thus, we feel that if this system allows the field geologist to easily obtain data that will aid him in his studies, then we will have been successful in our efforts.

APPENDIX III

REMOTE SENSING OF EARTH RESOURCES IN ALABAMA: A NEW ENVIRONMENTAL PERSPECTIVE

J. A. Drahovzal, C. C. Wielchowsky
and
J. L. G. Emplaincourt

Abstract of paper currently in editing,

Alabama Geological Survey, 1973

REMOTE SENSING OF EARTH RESOURCES IN ALABAMA:
A NEW ENVIRONMENTAL PERSPECTIVE

In the past 10 to 15 years earth scientists have been able to study the earth through new perspectives provided by remote sensing technology. Platforms placed at various altitudes offer a number of principal applications. Such platforms capabilities can vary from: 1. low altitude aircraft for large scale topographic and urban land use mapping; 2. medium altitude aircraft for large scale mapping, structural analysis; 3. high altitude aircraft for large perspective providing detail mapping; 4. Gemini, Apollo, and Skylab for small scale synoptic mapping of gross geology, land use, vegetation, and floods; and 5. Earth Resources Technology Satellites such as ERTS-1 which offers the same application capabilities as Gemini, Apollo, and Skylab, but with the addition of marine and fresh water turbidity plume delineation. ERTS, moreover, provides repetitive coverage on a regular basis. Depending upon the specific applications, sensors placed on those platforms can range from cameras, radiometers, scanners, and radars.

In Alabama, the results obtained in the geologic studies from Apollo 9 photographs have helped in bringing attention to the importance of remote sensing in the state. Major lineaments discovered on Apollo 9 have led to major geologic investigations with the use of ERTS data. Side looking airborne radar, thermal infrared, black and white infrared, color infrared, and other types of imagery have been found invaluable in geologic and hydrologic research such as sinkhole development and dam leakage problems.

Geographic applications in remote sensing have been brought to the forefront in the last 8 years. Cartographic experiments are underway to determine the feasibility of deriving maps from space acquired data. Radar has already been proven to be the only technique to map heavily clouded tropical regions. Automated land use mapping from multispectral photography has been successfully accomplished in northern Alabama. In the Coastal region of the state, oceanographic studies from ERTS data are in progress to detect turbidity plumes in and around Mobile Bay; moreover, changes in the configuration of the shoreline has also been detected within the bay and along the Mississippi Sound.

Remote sensing techniques have helped in solving environmental problems in the state of Alabama and will continue to play an important role in the future.

The information in APPENDIX III is an abstract of information found in "Remote Sensing of Earth Resources in Alabama: A New Environmental Perspective" by James A. Drahovzal, et al., Geological Survey of Alabama, 1974, Unpublished.

APPENDIX IV

DETECTION OF SHORELINE CHANGES FROM ERTS-1 DATA

Jacques L. G. Emplaincourt
and
Charles C. Wielchowsky

Manuscript copy of a paper currently in press,

Assoc. Am. Geographers Bull.

DETECTION OF SHORELINE CHANGES FROM ERTS-1 DATA*

Jacques L. G. Emplaincourt
Charles C. Wielchowsky

Geological Survey of Alabama
University, Alabama

Four ERTS-1 band 7 (near-infrared) images collected over Mobile Bay, Alabama, during a period of six months (August 1972 to February 1973) were compared to 1953 and 1957 AMS maps at a scale of 1:250,000. ERTS-1 data indicate that significant changes have taken place in the configuration of the shoreline in the past 15 to 20 years, and that cartographic errors were made during the preparation of the 1:250,000 maps. Sand Island and Pelican Island have been reduced to one narrow strip of land; Dauphin Island has prograded westward as much as 1.6 km (1 mi). The Fort Morgan-Mobile Point spit was originally mapped wider than it actually appears at present. In Portersville Bay, Isle aux Dames and another small island have completely disappeared. Some rather drastic changes have occurred in the upper reaches of the bay. For example, islands are now joined to the mainland, passes and bays have been filled, and promontories have been added.

The changes that did not result from cartographic error can be attributed to: 1) man's activities, and 2) physical processes such as wind, waves, tides, and associated currents. Changes detected on ERTS-1 data were supported by high-altitude color infrared photographs, low-altitude black and white photo mosaics, and large-scale topographic maps. ERTS-1 data cannot yet be used to prepare planimetric maps that meet U. S. National Map Accuracy Standards; however, such data can be extremely valuable in detecting shoreline configuration changes in a dynamic estuarine environment.

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*Approved for publication by the State Geologist.

DETECTION OF SHORELINE CHANGES FROM ERTS-1 DATA

Geographers have always had a desire to reach high observation points in order to obtain a synoptic view of the earth's surface; however, their efforts have, until now, been frustrated by the limitations of available tools. Areal coverage under uniform lighting conditions, for example, has always been restricted because observations have been confined to suborbital views of a few tens of square miles. Furthermore, there have been limitations in the timing of observations. A world-wide view of any geographic phenomena formerly had to be obtained by piecing together a great number of observations made at different times. In many cases the phenomena of interest are changing at such a rate that the big picture is obsolete before it is put together (1). Another restriction has been that heretofore the earth could be seen only through the sensing of visible light with the naked eye or camera. Today, however, with new sensors capable of gathering environmental information in a much wider band of the electromagnetic spectrum, earth scientists are able to observe phenomena in totally different "lights."

With the launching of ERTS-1, NASA's first Earth Resources Technology Satellite and the first satellite dedicated entirely to the study of the earth, geographers have an excellent opportunity to apply their expertise in making and updating maps and in analyzing the physical and cultural dynamics of the environment. To date, however, ERTS data have been regarded by some as "the universal geographic tool" and by others as nothing more than an interesting experiment with little practical geographic value. The authors feel, however, that the true geographic value of ERTS data lies somewhere between these two extremes. Therefore, the purpose of this paper is to demonstrate how ERTS-1 imagery can be used in a limited study of a relatively small but dynamic area. Specifically, ERTS-1 data were used to detect changes in the configuration of the land/water interface (shoreline) that have taken place in the last 15 to 20 years in the Alabama coastal zone (fig. 1). This was done by comparing ERTS-1 images (see fig. 2) to fairly recent (1953 and 1957) AMS 1:250,000 scale maps. Further investigation revealed that the configurational changes noted on the maps resulted from either cartographic error or the addition or subtraction of land area by the continuation of the physical processes that shaped the shoreline, or by an interruption of the dynamic equilibrium that was present. The physical and cultural agents responsible for addition or subtraction of land area over the last 15 to 20 years were also identified on a preliminary basis.

METHODS. The ERTS-1 Multispectral Scanner Subsystem (MSS) images the earth's surface in four different bands of the electromagnetic spectrum (2). These bands are:

Band 4 (0.5μ - 0.6μ) - Green

Band 5 (0.6μ - 0.7μ) - Red

Band 6 (0.6μ - 0.8μ) - Near Infrared

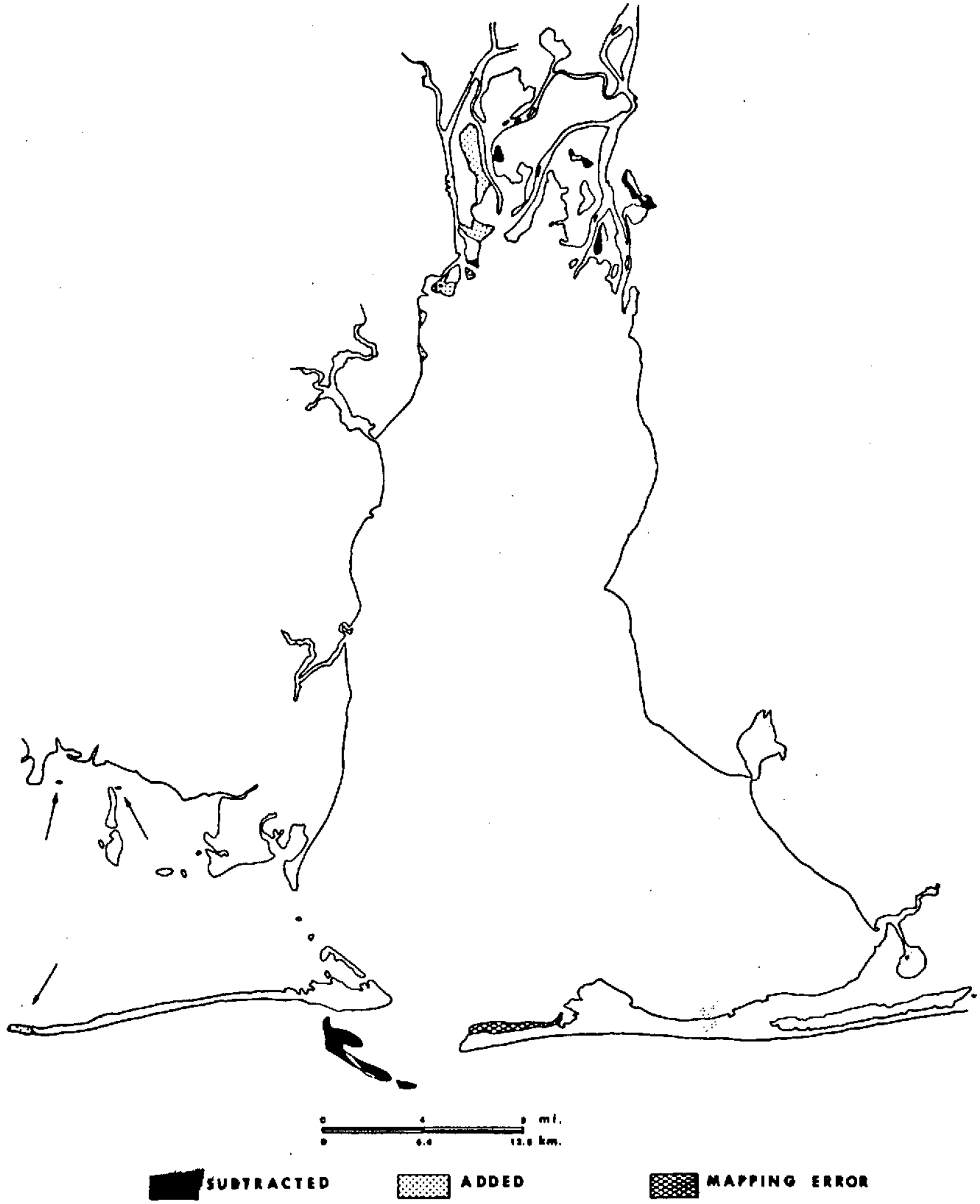
Band 7 (0.8μ - 1.1μ) - Near Infrared

The Return Beam Vidicon (RBV) subsystem, which was turned off early in the mission because of technical problems, images the earth's surface in three separate bands (3). These are:

Band 1 ($.475\mu$ - $.575\mu$) - Blue-Green

Band 2 ($.58\mu$ - $.68\mu$) - Green-Yellow

Band 3 ($.698\mu$ - $.83\mu$) - Red-Near Infrared



CHANGES IN MOBILE BAY

Figure 1

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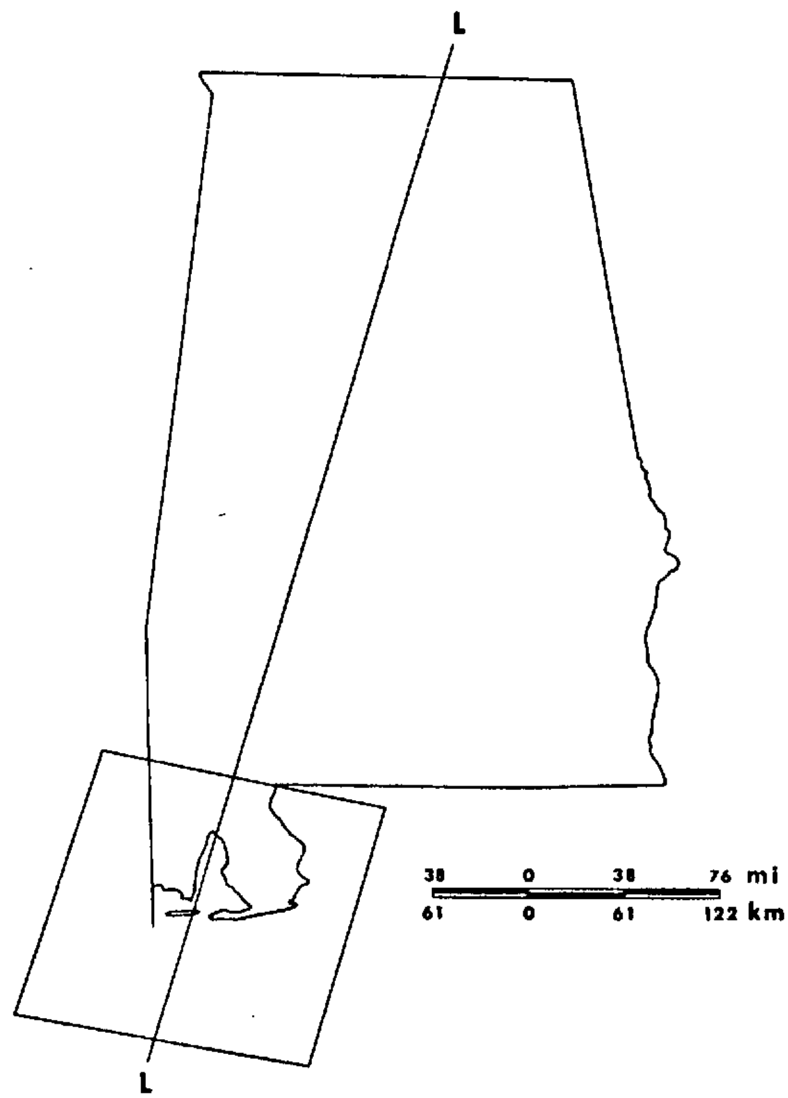
OF POOR QUALITY



ERTS-1 COVERAGE OF MOBILE BAY

Figure 2

Band 7, the farther of the two near-infrared bands of the MSS, is perhaps the most useful for cartographic applications. It allows penetration of thin clouds, yields excellent land/water delineation, and gives superior natural-feature definition (4). Therefore, transparencies of band 7 MSS images acquired on four different dates over Mobile Bay, Alabama, were enlarged to a scale of 1:250,000 so that they could be compared with AMS maps of the same scale. This scale was selected because: 1) only two AMS 1:250,000 maps are required to cover the entire study area; 2) perceptional image quality is good on MSS bulk data to scales of 1:250,000 (5); 3) 1:250,000 is a scale that is compatible with the magnitude of the major detected changes. In addition, one band 3 RBV image was used to support the findings on the MSS data. Tidal fluctuations were ignored in this study due to the fact that mean tidal range is only about 1 foot (30 cm) at the lower end of the bay and 1.5 feet (45 cm) at the upper end (6). Also, no significant differences were noted in the shoreline configuration when comparing ERTS and U-2 data from the various passes (TABLE 1) though tidal stages were significantly different.

It has been shown that bulk MSS data cannot yet meet U. S. National Map Accuracy Standards, because root mean square (rms) error in position should be less than 75 meters at a scale of 1:250,000, but rms error can be as great as 450 meters for both MSS and RBV data (7). This error is distributed randomly over the image and is due to both internal and external distortions. Also, ground resolution for these data is 250 meters (8), which is greater than the allowable rms location error. Due to these handicaps, it was decided that a totally empirical approach should be taken in locating changes in the Mobile Bay area.

TABLE 1

TIDE CHART FOR SELECTED ERTS-1 FRAMES
AND U-2 FLIGHTS

Date	Tide	Time	ERTS-1 Time	ERTS Frame ID#/ U-2 Flight #	U-2 Time
6 AUG 72	H	9:42 a.m.	10:00 a.m.	1014-15555-3	---
	L	9:32 p.m.		(RBV)	
24 AUG 72	H	1:04 p.m.	10:00 a.m.	1032-15555-7	---
	L	10:12 p.m.		(MSS)	
24 SEP 72	H	12:09 a.m.	---	72-170	9:30 a.m.
	L	9:23 p.m.			
28 DEC 72	H	7:15 p.m.	10:00 a.m.	1158-15564-7	---
	L	7:29 a.m.		(MSS)	
15 JAN 73	H	8:51 p.m.	10:00 a.m.	1176-15562-7	---
	L	8:12 a.m.		(MSS)	
2 FEB 73	H	No high occurred	10:00 a.m.	1194-15564-7	---
	L	10:20 a.m.		(MSS)	
22 FEB 73	H	3:45 p.m.	---	73-023	12:30 p.m.
	L	1:32 a.m.			

NOTE: These data were compiled at the northern end of Mobile Bay. To obtain times for high and low tides at the southern end of the bay at Fort Morgan, 1 hour 40 minutes should be subtracted from the above figures.

The ERTS-1 images were overlain on AMS 1:250,000 scale maps NH 16-5, Pensacola, Florida; Alabama (published 1957, limited revision, 1966), and NH 16-4, Mobile, Alabama; Mississippi; Louisiana (published 1953, limited revision, 1962). Four separate sheets of each map were used to minimize any distortion that might be present due to changes in the dimensions of the paper. It was found that there were no significant differences from one map sheet to another.

Once the areas of change were delineated, a polar planimeter was used to calculate the approximate loss and gain of land area. No volumetric calculations were attempted.

Sources of data used to support the finding made on the ERTS-1 images included: 1) high-altitude color infrared photography taken at a scale of 1:130,000 during two NASA/Ames U-2 flights made on September 24, 1972, and February 22, 1973; 2) low-altitude 1:62,500 USDA photo mosaics collected on December 2, 1970; and, 3) 1:62,500 topographic maps published in 1941 and 1958 and 1:24,000 topographic maps published in 1953 and 1958, some of which were photorevised in 1967.

CHANGES. Some of the offshore islands have undergone major configurational changes (fig. 3). Sand Island and Pelican Island, which were both located near the entrance of Mobile Bay, have been modified into one narrow strip of land that is now called Sand Island (9). In addition, Dauphin Island has prograded westward as much as 1 mile (1.6 km).

When the 1:250,000 AMS maps were compiled, the Fort Morgan-Mobile Point spit (fig. 4) was depicted as being about 1 mile (1.6 km) wide from north to south. ERTS-1 imagery indicates that the spit is only about 0.6 mile wide. This is confirmed by U-2 photography and detailed 1:24,000 maps.

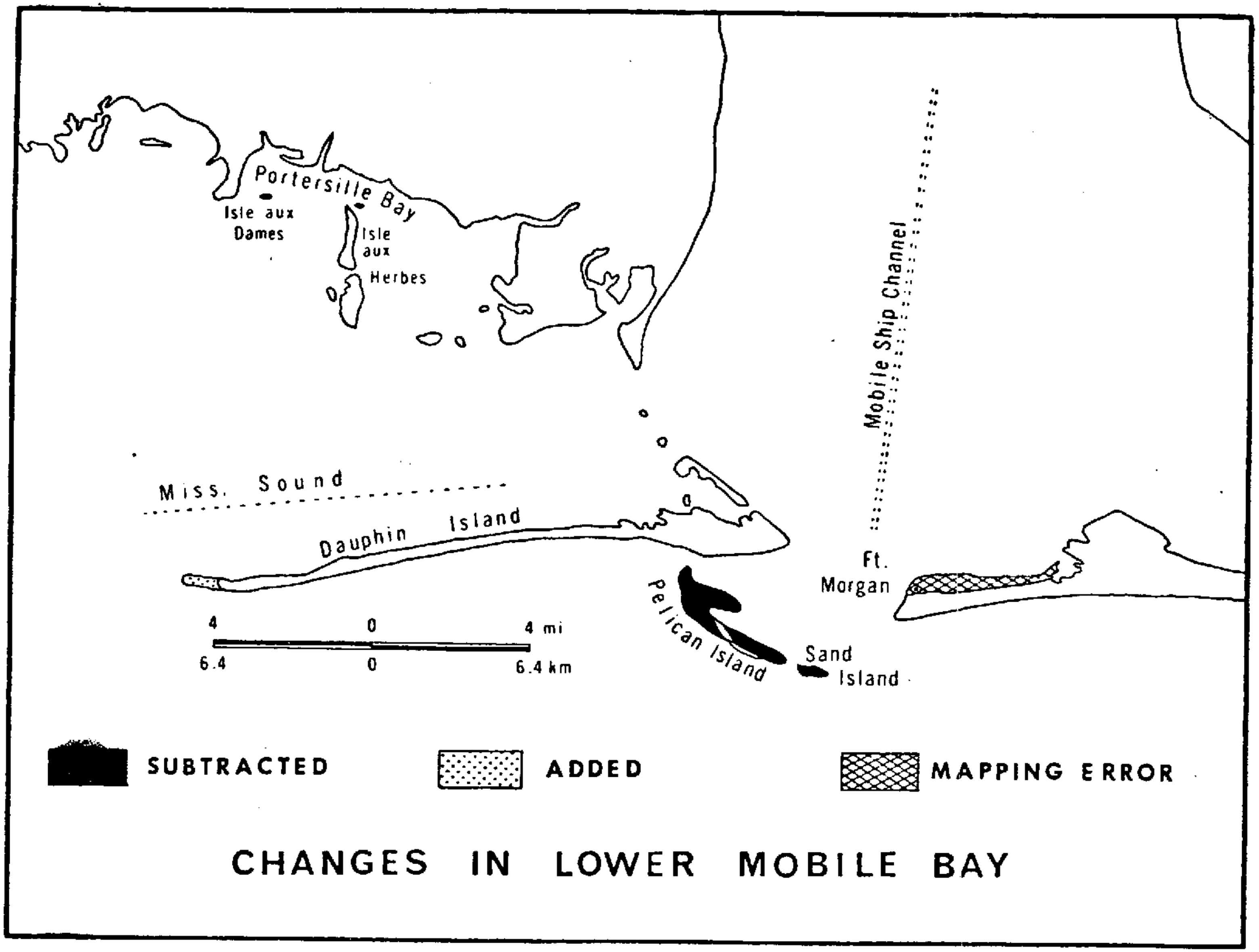
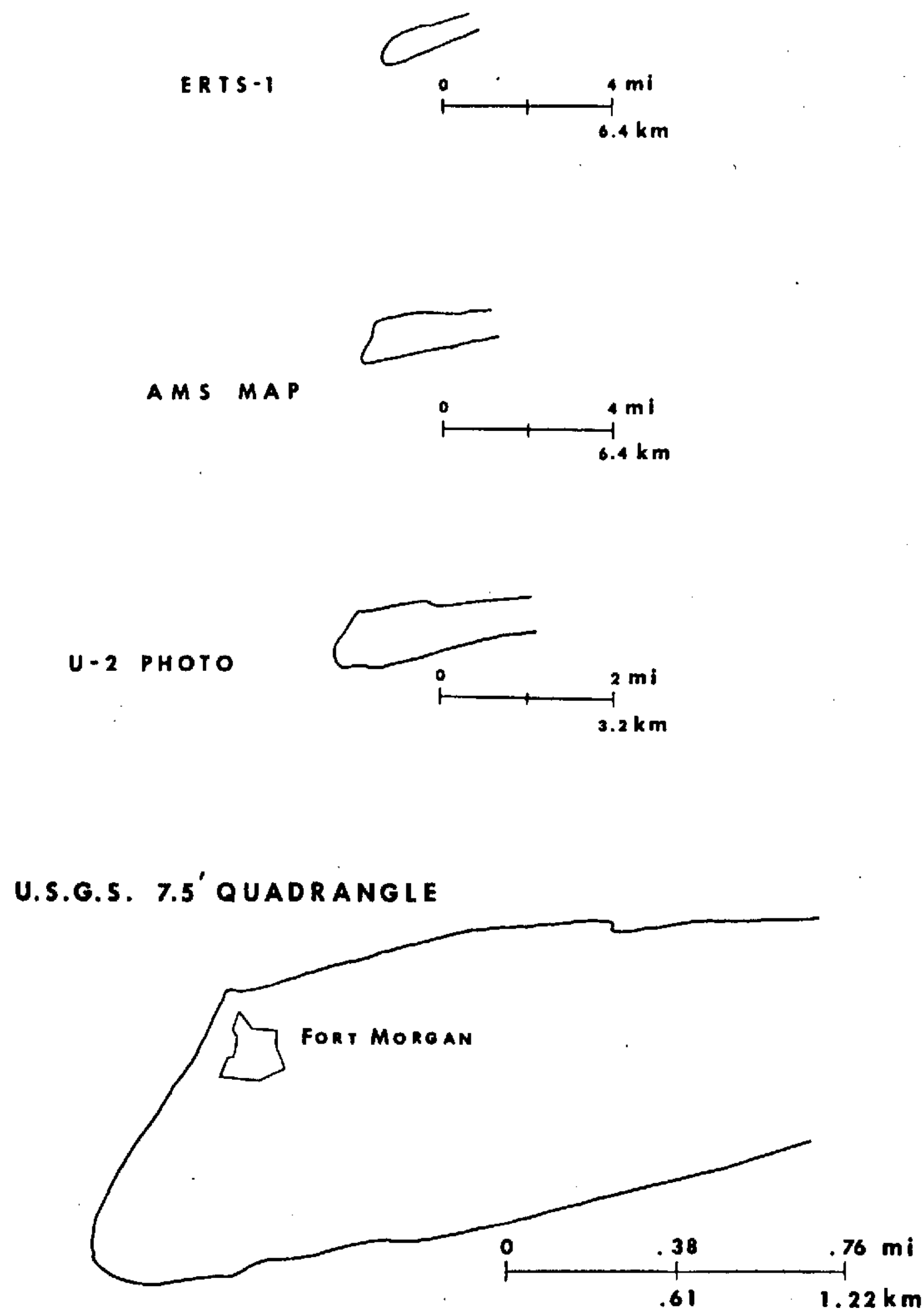

Portersille Bay
Isle aux Dames
Isle aux Herbes
Mobile Ship Channel
Miss. Sound
Dauphin Island
Ft. Morgan
Pelican Island
Sand Island
4 0 4 mi
6.4 0 6.4 km
SUBTRACTED
ADDED
MAPPING ERROR
CHANGES IN LOWER MOBILE BAY

Figure 3



COMPARISON OF DATA FOR FORT MORGAN

Figure 4

Since shorelines are mapped at mean high water, it appears that a cartographic error was made.

In Portersville Bay, west of Mobile Bay (fig. 3), two islands depicted on the AMS maps, Isle aux Dames and a small island located off the northeast coast of Isle aux Herbes, do not appear either on the ERTS imagery or on the recent U-2 photographs.

According to ERTS data, some rather drastic changes have occurred in the upper reaches of Mobile Bay where the Mobile, Tensaw, Appalachee, Spanish, and Blakeley Rivers empty into the bay (fig. 5). McDuffie Island appears to have linked up with the mainland and has been enlarged so that now it extends some distance into the bay. The link with the mainland may represent a cartographic error, because the 1953 1:24,000 quadrangle shows this connection, whereas the 1953 1:250,000 does not. Little Sand Island has also been enlarged. Pinto Pass, located between Blakeley Island and Pinto Island, has been filled as has most of Polecat Bay. Directly south of the City of Mobile, two coastal points have been added. In addition, several areas in the delta have been inundated.

CAUSES OF CHANGES. The configurational changes noted in the shoreline of the Mobile Bay area resulted from both cartographic error and subtraction and addition of land area (TABLE 2). These subtractions and additions were caused by the processes of erosion, sedimentation, and compaction, along with subsequent subsidence in the delta region (10). The following agents were identified as the probable causes of erosion and sedimentation: 1) waves; 2) tides; 3) wind; 4) currents associated with the previous agents; 5) streams; and 6) man. These agents were all instrumental in shaping the shoreline in the Mobile Bay area.

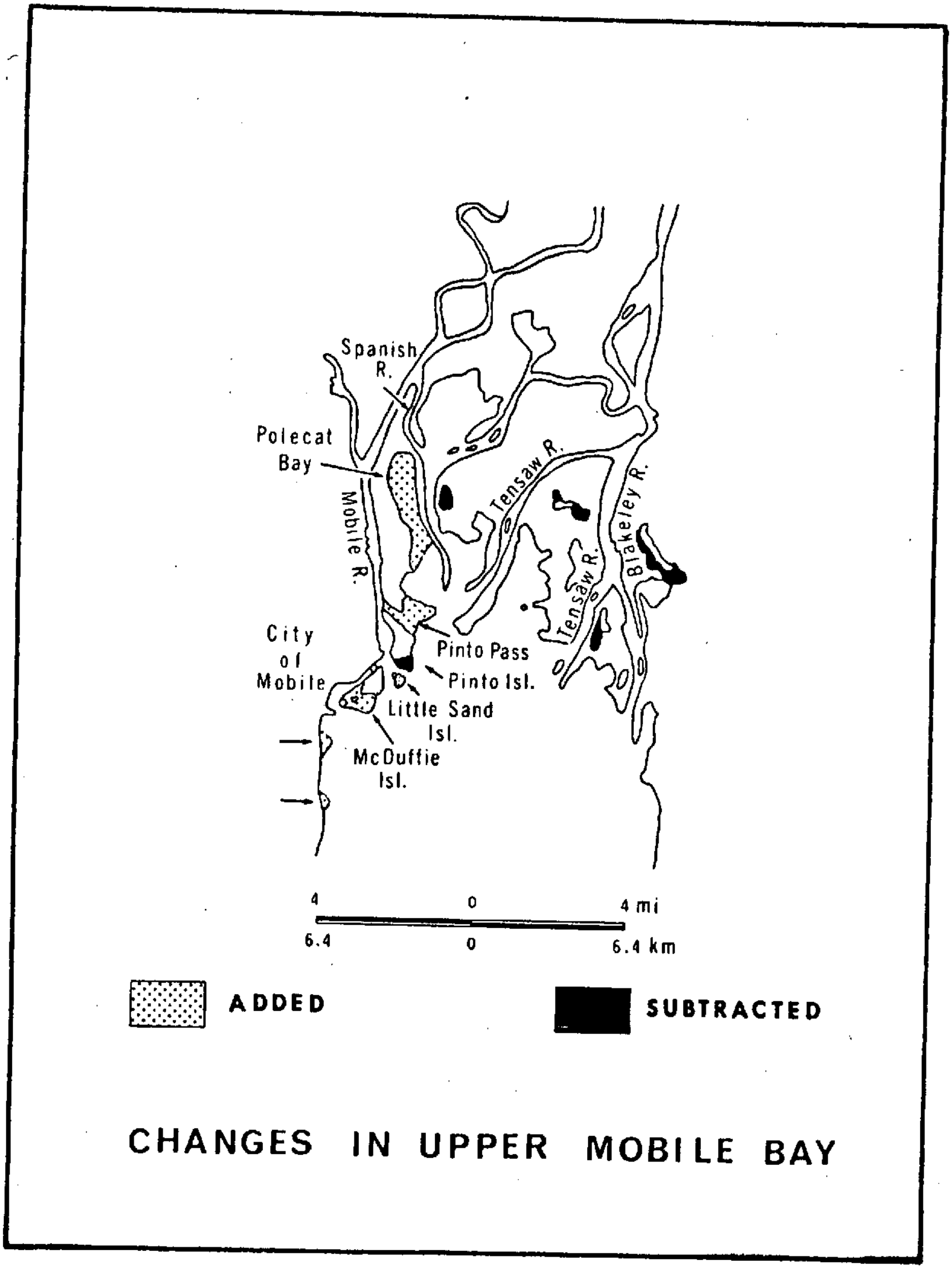

Spanish R.
Polecat Bay
Mobile R.
Tensaw R.
Tensaw R.
Blakeley R.
City of Mobile
Pinto Pass
Pinto Isl.
Little Sand Isl.
McDuffie Isl.
4 0 4 mi
6.4 0 6.4 km
ADDED
SUBTRACTED
CHANGES IN UPPER MOBILE BAY

Figure 5

TABLE 2

APPROXIMATE AREAL CHANGES

Location	Change (sq mi)	(sq km)
Pelican/Sand Island	-1.87	-4.84
Dauphin Island	+ .31	+ .80
Portersville Bay Area	- .05	- .13
Delta Area	+2.65	+6.86
	- .93	-2.41
	+1.72	+4.45

Pelican and Sand Islands were actually emergent parts of a tidal delta that extends some 5 miles (8 km) seaward from the pass between Dauphin Island and Mobile Point (11). The prevailing southeasterly winds generate waves that in turn produce a westward-flowing longshore current of 1 to 2.5 knots, which increases to 2.5 to 5 knots with the incoming tide. Also, tidal current velocities of as much as 7 knots have been measured in the various passes (12). These currents, along with the direct action of storm waves, probably caused the changes in the configuration of Pelican and Sand Islands.

Dauphin Island is part of a chain of barrier islands that extends about 150 miles along the coast of Florida, Alabama, and Mississippi. It is being extended to the west by accretion of sediment transported by the westward-moving longshore current. May (13) reports that the western end has been extended 4 miles (6.4 km) in the last 100 years. In addition ERTS data appear to indicate a loss of land area on the Gulf side of the island; however, due to the very narrow strip of land involved (probably less than 200 meters in width), this change cannot be supported at this time. Boone (14) points out that significant erosion has taken place on the Gulf side since marsh deposits and tree stumps are exposed in the surf zone. This possible change warrants further investigation.

The two small islands that have disappeared in Portersville Bay were probably removed by the direct action of storm waves and by the slow (.8 knots) westward longshore drift in the Mississippi Sound area. Foxworth and others (15) have reported that this current is strong enough to move sand-size sediment. Tidal currents and stream discharge also affect circulation patterns in the bay area and thus influence sites of erosion and deposition.

The most striking changes noted were in north Mobile Bay and in the delta region. Here man has played a major role in causing the configurational changes detected on ERTS data. The two promontories immediately to the south of the City of Mobile and the southern extension of McDuffie Island are areas that have been filled by man. The southernmost of the two promontories was made so that Brookley Field (presently a commercial airfield) could be extended; the land added to McDuffie Island was placed there for a bulk processing plant (16). Polecat Bay was filled as a result of the dredging of the Mobile River (17). Other filled areas that are probably related to either dredging activity or natural deltaic sedimentation are located at Little Sand Island, Pinto Island, and Pinto Pass. The areas of land subtraction in the delta are probably related to natural sediment compaction with subsequent subsidence (18). It is known that the Mobile River delta is prograding and that the entire bay is being filled at a rate of about 1.7 feet (0.5 m) per century (19); however, no distinctive progradation above water was noted in this study.

<u>CONCLUSIONS</u>. Though ERTS-1 data cannot yet be used to prepare planimetric maps that meet U. S. National Map Accuracy Standards, ERTS-1 imagery can be used for the following:

1. to detect cartographic errors on maps of 1:250,000 or smaller scale;
2. when compared to maps of the same scale, to delineate changes in the configuration of the land/water interface.

ACKNOWLEDGMENTS. This paper is an outgrowth of ERTS-1 research supported by the National Aeronautics and Space Administration and the Department of Interior's Earth Resources Observation Systems (EROS) program.

FOOTNOTES

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APPENDIX V

ERTS IMAGERY FOR FLOODED AND FLOOD-PRONE AREA MAPPING: SOUTHWEST ALABAMA

S. H. Stow and C. C. Wielchowsky

Abstract and text of a paper presented
at the 23 Ann. Mtg., Southeastern Sec.,
Geol. Soc. America, Atlanta, 1974

ERTS IMAGERY FOR FLOODED AND FLOOD-PRONE AREA MAPPING: SOUTHWEST ALABAMA[1]

Stow, Stephen H., Department of Geology and Geography, University, Alabama 35486; and Wielchowsky, Charles C., Geological Survey of Alabama, University, Alabama 35486

Sequential satellite coverage of late 1972-early 1973 flooding in southwest Alabama was examined in order to determine the feasibility of the use of ERTS (Band 7) imagery for the mapping of flooded and flood-prone areas.[2] Flooding appeared on ERTS imagery as dark tonal anomalies. ERTS data, enlarged to a scale of 1:250,000, were statistically compared to published USGS flood-prone area maps. High correlation between flooded areas as depicted on the ERTS imagery and flood-prone areas was noted in most places; discrepancies are explained. In certain regions of southwest Alabama where no flood-prone maps exist, ERTS data were used as an initial mapping tool for the delineation of future flood-prone areas. ERTS images of southwest Alabama collected prior to and after flooding were also examined to delineate signatures and map flood-prone areas at times of nonflooding, thus providing predictive capacity. Such mapped areas were also compared with USGS maps and with actual flooded areas.

The benefits and capabilities of ERTS data for flood studies are that: 1) cost of mapping is at least four orders of magnitude less expensive than standard mapping methods for a similar scale, 2) data can be used for verification of published flood-prone area maps, 3) data can be used for flood-prone mapping of unmapped regions, and 4) data provide repetitive coverage of flooded areas. The major disadvantage is that the ERTS data cannot meet National Map Accuracy Standards at scales greater than 1:250,000.

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[1] Approved for publication by the State Geologist.

[2] Research supported by USGS EROS Program (EROS 14-08-001-13377).

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ERTS IMAGERY FOR FLOODED AND FLOOD-PRONE AREA MAPPING: SOUTHWEST ALABAMA

By S. H. Stow and C. C. Wielchowsky

A paper presented at the 23rd Annual Meeting of the Southeastern Section, Geological Society of America

We are all quite familiar with the potential dangers and costs of the development of flood-prone areas. Annual loss to flooding in this country often exceeds $1.5 billion; moreover, it has been estimated that over 12 percent of our populace lives in flood-prone areas and that this figure is growing at a rate greater than population increase.

With these figures in mind, it becomes immediately obvious that the demand for flood-prone area mapping is great and will continue to increase as population and urbanization increase, for flood plains represent extremely attractive land for development. A variety of techniques have historically been used for flood plain mapping. These include the use of physiography, soils, vegetation, the occasional flood, the regional flood of selected frequency, and, the most accurate method--flood profiling and determination of back-water curves. The cost of flood area mapping is variable, but generally expensive, and has been estimated by Wolman (1971) to be as great as $6,000 per mile of river. The use of satellite imagery offers potential for large-scale flood area mapping and checking of existing flood-prone area maps at relatively low cost. Today we would like to discuss the feasibility of the use of ERTS imagery for such mapping.

During the fall and winter of 1972 and 1973 heavy rains, which caused flooding in the lower Mississippi Valley, also caused extensive flooding in some of the river systems of Alabama, especially on the Tombigbee and Mobile Rivers of western and southwestern Alabama. Significant inundation of the land began on or about December 20th at Mt. Vernon, north of Mobile Bay and persisted in the southern area throughout the spring months. ERTS imagery of the area, pictured on two successive frames and obtained on an 18-day sequential basis from October 15, 1972, to April 15, 1973, reveals very interesting and potentially economically useful dark tonal anomalies which aid in flood-prone area mapping and serve as a means for the verification of existing flood-hazard maps.

The objectives of this study are therefore:

1. To determine if ERTS imagery can be useful for mapping of flooded and flood-prone areas,
2. To determine if ERTS imagery can be used for verification of existing flood-prone maps,
3. To determine the greatest scale at which ERTS data can be used, and
4. To examine the costs of ERTS mapping versus standard methods for flood-prone studies.

Two January 15 images for the southwest Alabama area were used. This slide shows the four multispectral bands obtained from each ERTS scene. The scene is the southern most of the two examined and shows the river systems north of Mobile Bay. The inundated flood-prone land is best seen on band 7 which records the near infrared wave lengths, and our work has involved use of only the band 7 imagery which is seen enlarged in this slide. The northern portion of the study area is seen in the next slide. Flood plains are not as dark to the north and are somewhat less easy to distinguish although certain features such as natural levees, land use patterns, and abandoned stream channels help in the delineation of the flood plains. Let us look first at the correlations of these dark low reflectance areas with known flood-prone areas during flooding, prior to flood, and after flooding. Then we will look at the causes for the low infrared reflectance and the economic considerations involved.

The next slide shows an overlay depicting the extent of the dark low reflectance areas and the correlation with standard USGS flood-prone areas at a scale of 1:250,000 for the area just north of Mobile Bay. Flood data exist for only these five quadrangles; therefore, correlations can be drawn in only these areas. Notice the extremely close correlation between ERTS data and USGS data. The flood-prone areas are estimated to correspond 90 percent of the time. Areas where the correlation is poor, marked in white, can generally be explained. The greatest discrepancies occur for small local flood-prone creeks which do not appear dark on the ERTS imagery. Flood waters were derived from the drainage basins far to the north, not locally, and therefore, the local creeks which rise quite steeply to their heads, were not flooded.

The recurrence interval of this flood in this area was about 30 years; however, the USGS maps are drawn on the basis of a 100 year recurrence interval. Therefore, it appears that in this area ERTS data can be used to at least verify existing flood hazard maps and, even more importantly, to map areas where no flood hazard data are presently available.

Now let's look at the scene to the north. The dark tonal anomalies are quite distinct over much of this area and are easily delineated, but near the junction of the Black Warrior and Tombigbee Rivers, the dark areas are less prominent; therefore, we attempted to use such features as abandoned river channels, swamps, and land-use patterns to help map the flood plains.

The next slide is the overlay at a scale of 1:250,000 made from the ERTS image. The limits of the flood-prone areas, as mapped from the ERTS data, are depicted and their correlation with the USGS data is shown for the areas where flood hazard mapping has been done. In the southern portion of this scene on the next slide where the dark anomalies are well-defined, the correlations are quite good. Again the white areas represent the discrepancies between USGS and ERTS data and correspond generally to non-flooded creeks.

To the north, however, at the junction of the Black Warrior and Tombigbee Rivers the correlations, although in broad agreement, are poorer. The flood crest here occurred prior to January 15th when the ERTS image was taken and the recurrence interval for the flood was also 30 years. Again the USGS maps are drawn on the basis of 100-year recurrence floods. Thus, it's not surprising that there are discrepancies in this area. It appears, however, that the ERTS data might be used here to map the extent of flooded areas and, of course, furnish information on the hazard area for a specific flood, even though they don't correlate extremely well with the 100-year recurrence interval flood limits.

South of the river junction no flood-hazard maps exist and the tonal anomalies are quite distinct, so we feel that the ERTS imagery provides reliable flood-prone information and we have mapped the flood-prone areas for this region. Their extent is depicted on the slide.

We have also examined the use of the ERTS imagery for flood mapping at a scale of 1:100,000 for the first scene, the area north of Mobile Bay. Generally, the correlations at this scale appear to be good. Disagreements between USGS and ERTS data along the edges of the flood-plains represent distances of about 450-600 meters, while the flood plain in the Tensaw quadrangle, for instance, is about 12.8 kilometers wide. A few large areas of disagreement exist which we feel are due to the fact that this was a 30-year flood.

In general, however, we feel that 1:250,000 is the maximum scale at which ERTS data should be used for flood-plain mapping. There are three reasons for this assertion:

1) Perceptional image quality is good only to scales of about 1:250,000;

2) To meet U. S. National Map Accuracy Standards at scales of 1:250,000, root mean square (rms) error in the location of well defined objects should be less than 75 meters. Ground resolution of ERTS data has been reported to approach this 75-meter figure;

3) A third consideration is the internal and external distortions that cause locational error. Unfortunately, rms error in position for the first ERTS multispectral scanner data was as great as 450 meters, however, it is reported that this has now been reduced to roughly 150 meters. This 150-meter figure is even less for high contrast linear objects such as the dark flood-plains versus the lighter uplands.

It is interesting to note that the dark low reflectance areas which correlate with flood-prone areas are visible in the southern scene as early as October 17th, over three months prior to inundation of the land. The correlation between the October and January imagery is quite obvious as seen in this slide. We have not yet quantitatiously compared these images but it appears that some predictive capabilities can be obtained from the use of ERTS data prior to flooding, and that pre-flood imagery might be used for flood hazard mapping.

Also the dark anomalies indicative of flood-prone areas can be observed as late as May 21st, two months after inundation of the land. Although this image is partially cloud covered, it shows that imagery taken 2 months after inundation might be used for the delineation of the extent of flooding in this area.

Up to this point we have correlated the dark, low reflectance areas in the river valleys with the flood prone regions but have not discussed the causes for the low reflectance. The low reflectance is noted most predominantly on bands 6 and 7 which are in the infrared region of the spectrum and can be contributed to three possible causes:

1) The presence of standing or flowing water;

2) High soil moisture;

3) Vegetation which is stressed due to extreme hydrologic conditions, thus reflecting less infrared energy than unaffected plants.

Any one or combination of these factors may result in the low infrared reflectance observed for the flood plains. The reflectance anomalies were noted as early as October 17 prior to flooding and at that time were probably the result of soil moisture and/or stressed vegetation. The cause of the low reflectance at later times during inundation appears to be, of course, principally due to the high water table. After inundation the cause is probably high soil moisture and possibly vegetation which was stressed by flooding.

The economic considerations of the use of ERTS imagery for flood hazard mapping are attractive. Costs for traditional mapping methods are highly variable and can be as extreme as $6,000/mile when ground surveys and hydrologic data must be generated. Costs for physiographic and pedologic mapping techniques are low, $1 to $4/mile, but assume the existence of topographic and soils maps.

Our costs for mapping over 250 miles of the river systems seen in the two ERTS images was about $9.50 including the price of the ERTS photograph and man hours, or about 3.8¢ per mile for mapping at a scale of 1:250,000. Notice also that no prior existence of topographic or soils maps is required. Therefore, the costs of ERTS flood area mapping appear to be extremely attractive and the method could be readily and inexpensively used for large scale land-use planning in rural or underdeveloped areas.

In conclusion, looking back at our initial objectives, we find that ERTS imagery can be used for mapping of flooded and flood-prone areas, can be used to verify existing flood prone maps, can be used at a scale of up to 1:250,000, and appear to be of economic benefit when compared to traditional approaches to flood hazard mapping.

APPENDIX VI

STATE OF ALABAMA

UNCONTROLLED ERTS-1 MOSAIC

H. T. Svehlak and C. C. Wielchowsky

Image 1, Geological Survey of Alabama

(in pocket)

APPENDIX VII

THE REMOTE-SENSING PROGRAM OF THE GEOLOGICAL SURVEY OF ALABAMA

James A. Drahovzal, Jacques L. G. Emplaincourt,
and Charles C. Wielchowsky

Abstract and manuscript copy of a paper currently in press, Ninth Internat. Symposium on Remote Sensing of the Environment; Michigan University.

THE REMOTE-SENSING PROGRAM OF THE GEOLOGICAL SURVEY OF ALABAMA*

James A. Drahovzal, Jacques L. G. Emplaincourt,
and Charles C. Wielchowsky

Geological Survey of Alabama
University, Alabama

ABSTRACT

During the past four years, the Geological Survey of Alabama has been involved in the application of remote-sensing techniques to exploring and inventorying the State's mineral, water, and energy resources. Demonstrations of the usefulness of these techniques and data led to the establishment of the Remote-Sensing Section that 1) administers the remote-sensing program of the Survey; 2) conducts and stimulates research in remote-sensing applications; 3) assists Alabama users in the acquisition and use of remotely sensed data. The Survey's remote-sensing program currently includes two ERTS investigations, a Skylab experiment, and cooperative research with the U. S. Geological Survey.

The Survey first became aware of the great potential of orbital remote-sensing to geologic research in 1969 when it acquired Apollo 9 photographs of the Alabama Appalachians. Long, relatively straight lineaments appearing on the Apollo data stimulated investigations into the nature and origin of these previously unknown features. Significant relationships have been established between these lineaments and mineral deposits, water resources, earthquake activity, geologic hazards, structural style, and tectonic and sedimentologic models.

At present, ERTS-1 data are adding significantly to the lineament studies in all parts of the state. Both annular features and apparent fault zones discovered on ERTS data have been correlated with subsurface domes and normal faults in the Alabama Gulf Coastal Plain. Flooding along the Mobile River and shoreline-configuration changes along the Gulf Coast have been delineated using ERTS-1 data. As part of a user-application study, ERTS imagery has been used to produce rapidly and inexpensively a map of the entire state showing forested versus nonforested areas. In all the above cases, ERTS data are proving to be valuable in updating existing maps.

The Survey has also been involved in utilizing data provided by suborbital platforms. Emphasis has been placed on defining geologic hazards critical to land-use planning. Research in the Tennessee Valley of Alabama has demonstrated the utility of low-altitude panchromatic, color, and color-infrared photography in the locating of fracture traces, which are in turn related to the occurrence of ground water. Remote-sensing research at Roberts Industrial Park and Greenwood, both in the Birmingham area, has resulted in the development of methods of locating, predicting, and monitoring collapse features in carbonate terranes. Similar methods have also been used in Shelby County, where in December of 1972 an extremely large sinkhole suddenly appeared. Examination of low- and high-altitude infrared photography has revealed the presence of hundreds of collapses and related features in the immediate area. These data have served as a substantial aid not only in locating and mapping collapse features in a heavily forested area, but also in monitoring the further development of a karstic region. Remote-sensing studies of carbonate terranes have employed black and white, color, black and white infrared, and color-infrared photography, as well as thermography and side-looking airborne radar (SLAR). SLAR imagery has also been used to study more closely a lineament that Apollo 9 photography and ERTS imagery reveal in the vicinity of a dam in east-central Alabama. Follow-up geological, geophysical, and

*Approved for publication by the State Geologist.

hydrological studies indicate that the lineament represents a solution-widened fracture zone in Cambrian and Ordovician dolomites that is contributing to reservoir leakage in the vicinity of the dam.

The Geological Survey of Alabama is finding the perspective provided by aerial and space imagery to be extremely important to operational procedures. The survey plans to continue remote-sensing research related to the nature and origin of lineaments and to the monitoring of active carbonate terranes.

THE REMOTE-SENSING PROGRAM OF THE GEOLOGICAL SURVEY OF ALABAMA*

James A. Drahovzal, Jacques L. G. Emplaincourt, and Charles C. Wielchowsky

Geological Survey of Alabama
University, Alabama

1. INTRODUCTION

Successful results obtained from applications of remote-sensing technology at the Geological Survey of Alabama, and the acquisition of large amounts of remotely sensed data from several sources, led to the establishment of the Remote-Sensing Section and Laboratory in October 1972. The Geological Survey of Alabama has used conventional panchromatic aerial photography since the mid-1950's for geological studies. An early study used black and white aerial photographs to directly map the Livingston fault zone by virtue of the fact that horsts of barren, highly reflective Demopolis Chalk could be easily distinguished from surrounding forest-covered sands of the Ripley Formation in Marengo County, Alabama (Newton and others, 1961). In spite of the utility and success of these methods, the concentrated effort to apply remotely sensed data to geologic problems did not begin until late 1969, when the Geological Survey first acquired Apollo photography of east-central Alabama. The discovery on these photographs of previously unknown lineaments transecting the Appalachian structural axis and the apparent geologic and hydrologic significance of these features stimulated Survey research and development in the methods and techniques of applying all types of remotely

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sensed data to geologic studies. The high interest in the applicatic of remote-sensing technology led to the acquisition of large amounts of data available for the state, including side-looking airborne radar (SLAR), thermography, and multispectral photography. Acquisition and analysis of these data together with the Survey's involvement in two pre-ERTS experiments (Identification of User Categories and Users of EROS Acquired Data in Alabama--EROS-supported; and Mineral Exploration Based on Space-Acquired Data--EROS-supported), two ERTS-1 projects (User Acceptance and Implementation of ERTS-A Data in Alabama--EROS-supported; and Investigation Using Data in Alabama from ERTS-A--NASA-supported), a Skylab Earth Resources Experimental Package (EREP) experiment (Irreversible Compression of EREP Data Flow--NASA-supported) and cooperative research with the Prescott Research Group of the U. S. Geological Survey, made the formation of the Remote-Sensing Section and Laboratory essential to efficient operations. In addition to managing the Survey's remote-sensing programs and projects, the section continually acquires, catalogues, stores, and manages remotely sensed data. Section personnel, in addition to carrying out remote-sensing research, also assist the Survey staff and other Alabama users in the acquisition and interpretation of remotely sensed data.

The Survey has been able to apply remote sensing successfully to a variety of problems in the earth sciences. This paper reviews some of these results and comments on their significance.

2. LINEAMENTS

Workers at the Geological Survey of Alabama first became aware of a series of alignments variously termed "linears," "lineations," "lineaments," or "linear features" through analysis of Apollo 9 multispectral photographs of east-central Alabama (Powell and others, 1970; Drahovzal and Copeland, 1970; Drahovzal and Neathery, 1972). Two major lineaments were exceptionally well-displayed on the areally limited Apollo 9 photography and through the use of ERTS data have been recently extended into areas of the state where satellite imagery was previously unavailable (fig. 1). Both of the lineaments, termed the "Anniston (A-A', fig. 2) and Harpersville (B-B', fig. 2) lineament complexes" are oriented at approximately right angles to Appalachian strike, continue for at least several hundred kilometers, and appear to have regional geologic significance. In addition to the two major lineaments, many shorter, less prominent lineaments have also been mapped.

The two major lineaments have been shown to correlate with major structural offsets and terminations as well as with changes in structural style. The lineaments intersect the metamorphic front (MF, fig. 2) near points of offset, forming between them a shallow recess in the front. The Pell City fault (PCF, fig. 2) also shows offsets in the vicinity of the two lineaments. The Helena fault (HF, fig. 2) and the Murphrees Valley anticline (MVA, fig. 2) terminate along the Anniston lineament, and the Blount Mountain syncline (BMS, fig. 2) terminates at the Harpersville lineament. A marked change in structural style occurs along the Murphrees Valley-Birmingham anticlinorium (BA, fig. 2) where the Harpersville lineament transects the fold complex. The Murphrees Valley anticline is asymmetric to the southeast with a steeply dipping bounding fault on the southeast flank; the Birmingham anticlinorium is asymmetric to the northwest with a northwest-bounding thrust fault. Other examples of offsets, terminations, and changes in structural style are shown on the map in figure 2 and have been discussed previously (Powell and others, 1970; Drahovzal and others, 1974).

In addition to structural changes, the major lineaments have been shown to correlate with changes in thicknesses, lithologies, and distribution patterns of several Paleozoic units, as well as with gravity and magnetic anomalies (Drahovzal and others, 1974).

The occurrence of high-yield springs and wells appears to show a direct relationship to lineament density in southwest Madison County, Alabama, where the Anniston lineament complex crosses the area (fig. 3; Drahovzal and others, 1974). Other similar studies have also indicated a relationship between water yields and the occurrence of lineaments (Powell and others, 1970; Powell and LaMoreaux, 1971; U. S. Geological Survey, 1972).

The occurrence of barite, gold, manganese, tin, and copper; and lead, zinc, arsenic, and iron sulfides has been related to lineaments in Alabama (Smith and Drahovzal, 1972). Barite prospects, in particular, show the best correlation and appear to be significantly related to the two major lineaments (fig. 2). Geochemical sampling across the lineaments has revealed anomalously high concentrations of lead, chromium, and zinc in the vicinity of some lineament traces (Drahovzal and others, 1974).

Seismicity also seems to be related to the lineaments. Approximately 43 percent (6 out of 14) of the earthquake epicenters reported for Alabama coincide with the two major lineaments (fig. 2; Drahovzal and others, 1974).

The relationships of the major lineaments to the various aspects of the geology of the southern Appalachians suggest that the lineaments represent basement geofractures that bound basement blocks and along which vertical movement has taken place throughout much of geologic time. Coincidence of high-yield wells and springs, hydrothermal mineral deposits, geochemical highs and geophysical anomalies with the major lineaments suggests that fracturing of the basement is also expressed in the Paleozoic cover. Differential vertical uplift along block boundaries may have controlled deposition of the Paleozoic sediments and also may have had a later tectonic effect during deformation. Seismic activity along the same lineaments indicates that they are related to geofractures that are still slightly active. This seismic activity may be related to the current crustal uplift in the Atlanta area (Meade, 1971, fig. 9). This activity, during the past century, may result from flexure and slip along the preexisting lines of weakness that cross the southwest flank of the uplift in northeastern Alabama. Bollinger (1973) has proposed a similar mechanism for the transverse South Carolina-Georgia seismic zone along the northeast flank of the Atlanta uplift. The major lineaments may also represent the continental ancient lines of weakness described by Wilson (1965) and therefore may be genetically related to the open-ocean fractures perpendicular to the mid-Atlantic ridge and the marginal fracture zones off the continental margins (LePichon and Fox, 1971).

Shorter and less prominent lineaments appear to have only limited geologic importance but may be of considerable environmental significance. Studies now in progress have revealed a large number of these features and their full significance awaits further field and laboratory analysis. Field studies and laboratory optical diffraction studies of ERTS images that are currently underway should reveal more information about the Alabama lineaments. Certain of the minor lineaments, however, have been studied in some detail through field investigations. For example, it has been demonstrated that certain surface stream flow anomalies in eastern Alabama may be directly related to the influence of lineaments. Detailed low-flow studies made in adjacent subdrainage areas along Talladega Creek in Talladega County, Alabama, have shown an abrupt pickup in flow along a segment where two lineaments intersect the stream. Pickup in the intersectior area increases more than 70 times from a flow of 6.6 x 10^{-4} $m^3/sec/km^2$ to 4.7 x 10^{-2} $m^3/sec/km^2$ (Powell and LaMoreaux, 1971; U. S. Geological Survey, 1972).

Another minor lineament for which considerable field evidence exists was originally discovered on Apollo 9 photography (Powell and others, 1970). Follow-up studies using SLAR, ERTS-1, and high-altitude multispectral data have added to the understanding of the feature. The lineament, called the "Kelly Creek lineament," passes along the axis of Logan Martin Dam on the Coosa River in eastern Alabama (C, fig. 2). Since impoundment in 1964, leakage from the reservoir has occurred beneath and to the sides of the dam through highly weathered and fractured limestones and dolostones that underlie the area. Structural, hydrologic, drilling, and seismic data show that the lineament represents a deeply weathered fracture zone (Spigner, 1969; Alverson, 1969, 1970; Powell and LaMoreaux, 1971). Although the lineament represents a fracture zone, it is not known whether the fracture is a fault or simply an open joint. In either case, it is significantly contributing to reservoir leakage.

The nature of lineaments is still very much open to question, and it is most likely that they are polygenetic in origin. An increasing number of workers are reporting these features and many of them believe that most or all of the lineaments represent faults. Although evidence does exist that some lineaments are faults, it has been our experience from field studies to date that most of the minor lineaments are not related to obvious structural features of any type. It is urged that utmost caution be exercised in interpreting lineaments until adequate field investigations can be undertaken. The discovery and analysis of lineaments may be one of the most significant results derived from orbital imagery, but a great deal of detailed field work will be required to determine the genetic implications and full significance of these features.

3. OTHER APPLICATIONS FROM ORBITAL DATA

The dynamic environment of Mobile Bay lends itself readily to study by means of earth-orbiting satellites. Such an undertaking is especially important, because the Mobile Bay region will become the site of offshore oil drilling and possibly for the location of a superport (Ameraport) in the near future. The bay and surrounding areas are presently the topics of extensive environmental geologic investigations by the Survey.

As part of the geologic investigation of Mobile Bay, the Remote-Sensing Section has conducted a systematic study of shoreline configurational changes, as shown by several types of remotely sensed data. Specifically, a series of band 7 ERTS images were compared to fairly recent (1953-1957) AMS maps at a scale of 1:250,000. The near-infrared band was selected because it yields excellent land/water delineation. High-altitude color infrared photography acquired on two different dates, low-altitude USDA photo mosaics, and large scale topographic maps were employed to support the findings made from ERTS-1 data. Some rather drastic changes have been found using the imagery. For example, in upper Mobile Bay former islands are now joined to the mainland, former passes and bays have been filled, and promontories have been added (fig. 4). Many of these changes have been the result of man's activity in the Mobile area. In lower Mobile Bay, islands have been reduced in size, some have disappeared, while another prograded in a westward direction (fig. 5; Emplaincourt and Wielchowsky, 1974). For example, the Pelican-Sand Island complex showed a reduction in size during the past 20 years; moreover, changes that have occurred during the past year have also been detected through the use of ERTS data. Many of these changes have been caused by natural processes.

In order to better understand the geomorphic processes that shape the Alabama coastline, change detection investigations using ERTS data were extended farther west along Mississippi Sound. Changes similar to those along the Alabama coast have occurred off the Mississippi coast, especially with respect to the westward progradation of the offshore islands.

Although it has been shown that ERTS1 data cannot yet be used to prepare planimetric maps that meet U. S. National Map Accuracy Standards at scales larger than 1:500,000, the imagery can be an invaluable source of information in detecting shoreline configurational changes (Emplaincourt and Wielchowsky, 1974).

Another study has been conducted utilizing sequential satellite coverage showing late 1972-early 1973 flooding in southwest Alabama. The data were examined to determine the feasibility of using ERTS (band 7) imagery for the mapping of flooded and flood-prone areas. These data, enlarged to a scale of 1:250,000, were quantitatively compared to published USGS flood-prone area maps (fig. 6). High correlation between flooded areas as depicted on the ERTS imagery and flood-prone areas was noted in most places. In certain regions of southwest Alabama where no flood-prone area maps exist, ERTS data were used as an initial mapping tool for the delineation of flood-prone areas. ERTS images of southwest Alabama collected prior to and after flooding were also examined to delineate signatures and map flood-prone areas at times of nonflooding, thus providing predictive capability (Stow and Wielchowsky, 1974).

The benefits and capabilities of ERTS data for flood studies are: 1) cost of mapping can be as great as four orders of magnitude less expensive than standard mapping methods for similar scales; 2) data can be used for verification of published flood-prone area maps; 3) data can be used for flood-prone mapping of unmapped regions; and 4) data provide repetitive coverage of flooded areas (Stow and Wielchowsky, 1974).

Alabama contains numerous physiographic provinces and sub-provinces. Some of these regions can be easily delineated from ERTS imagery, while others are not discernible. However, members of the Remote-Sensing Section were able to draw a detailed physiographic map of the state at a scale of 1:1,000,000. The map is derived from both existing geologic and topographic maps and ERTS-1 data. In some instances ERTS data were very valuable in delineating boundaries between physiographic regions, and the ERTS base for the map resulted in a much more useful and graphic product than conventional physiographic maps.

Further geographic investigations using ERTS data have been carried out on a statewide basis under the EROS project. One investigator derived a map from ERTS data showing cleared versus forested land in Alabama, at a scale of 1:500,000 (fig. 7). The results of this investigation showed that at the present time, about 57 percent of the state is forest covered. This map is an example of a simple and rapid method of deriving first-order land-use information.

4. APPLICATIONS OF SUB-ORBITAL DATA

Although great emphasis has been placed on satellite-acquired data in the past two years, the Geological Survey of Alabama has also gained useful results from sub-orbital data analyses.

In 1972, the Survey was engaged by the State Highway Department to investigate potential sinkhole problems in a section of a proposed interstate highway underlain by carbonate rocks and located in an area of active sinkhole development near Greenwood, Alabama. The objectives of the study were: 1) to define the area where sinkholes have occurred and where future collapses may occur; 2) to determine how the formation of sinkholes relates to the geology and hydrology of the area; and 3) to define the history and status of sinkhole development (Newton and others, 1973).

Multispectral photography, including conventional color, and color and black and white infrared, was obtained from an altitude of about 480 meters above mean terrain to provide sufficient resolution for the recognition of objects as small as 0.5 square meter in area. The photography was used primarily in locating sinkholes and incipient collapse features in the unconsolidated deposits overlying the carbonate bedrock and also in providing information on soil moisture, fractures, and areas of water loss. Incipient collapse features are best defined on the color and black and white infrared photographs because vegetative stress is recorded by these films (fig. 8). The stressed conditions in the vegetation result from subsidence and interior drainage associated with cavity development in the residual and alluvial materials, thereby providing an excellent tool for the location of incipient collapse. Daytime thermal infrared imagery was found to be useful in locating areas where surface waters discharge into streambeds and sinkholes. An enhanced thermal infrared product was found to be helpful in confirming traces of faults mapped by conventional methods and in showing the location of a previously unmapped normal fault.

Many geologic and hydrologic features in the area were located prior to the acquisition of photography and thermal mapping. The availability of these tools during the early stages of the project would have resulted in less test drilling and field work. This, in turn, would have resulted in an earlier completion date and monetary savings. The locating of geologic and hydrologic features that cause or are related to the development of sinkholes indicates the potential value of applying multispectral photography and thermal imagery in the evaluation of proposed highway corridors (Newton and others, 1973).

Recent subsidence and collapse of the land surface in carbonate terranes has created a great demand for developing predictive capabilities and for monitoring sinkhole activity. In December 1972, a sinkhole 98 meters long, 90 meters wide, and 36 meters deep suddenly developed in Shelby County, Alabama (fig. 9). On the basis of ground reconnaissance and aerial photographs, it is estimated that about 1,000 collapses or related features have formed in the surrounding 40-square-kilometer area. Information derived from repetitive high- and low-altitude photography and SLAR imagery has proven valuable in the study of carbonate terranes and the problems associated with subsidence and collapse. Not only can large areas be examined in a short period of time, but in this application, remote-sensing technology can also be useful for: 1) inventorying sinkholes; 2) monitoring sinkhole development; 3) mapping sinkhole alignments; 4) investigating the relationships of sinkhole development to ground-water movement, fracture traces, and lineaments; and 5) detecting areas of abnormal surface drainage (Warren and Wielchowsky, 1973).

5. CONCLUSIONS

A few of the areas of remote-sensing research at the Geological Survey of Alabama have been briefly reviewed. Remote-sensing technology has been and continues to be of practical use to members of the Survey staff involved in structural and stratigraphic research as well as to those seeking new ways of searching for water, mineral, and energy resources. Other uses involve the inventorying and monitoring of geologic processes critical to responsible land-use planning and geologic hazard evaluations. Remote-sensing technology not only allows the Geological Survey of Alabama to carry out its duties more efficiently, but also, in some instances, is indispensible in providing data that cannot be obtained by other methods.

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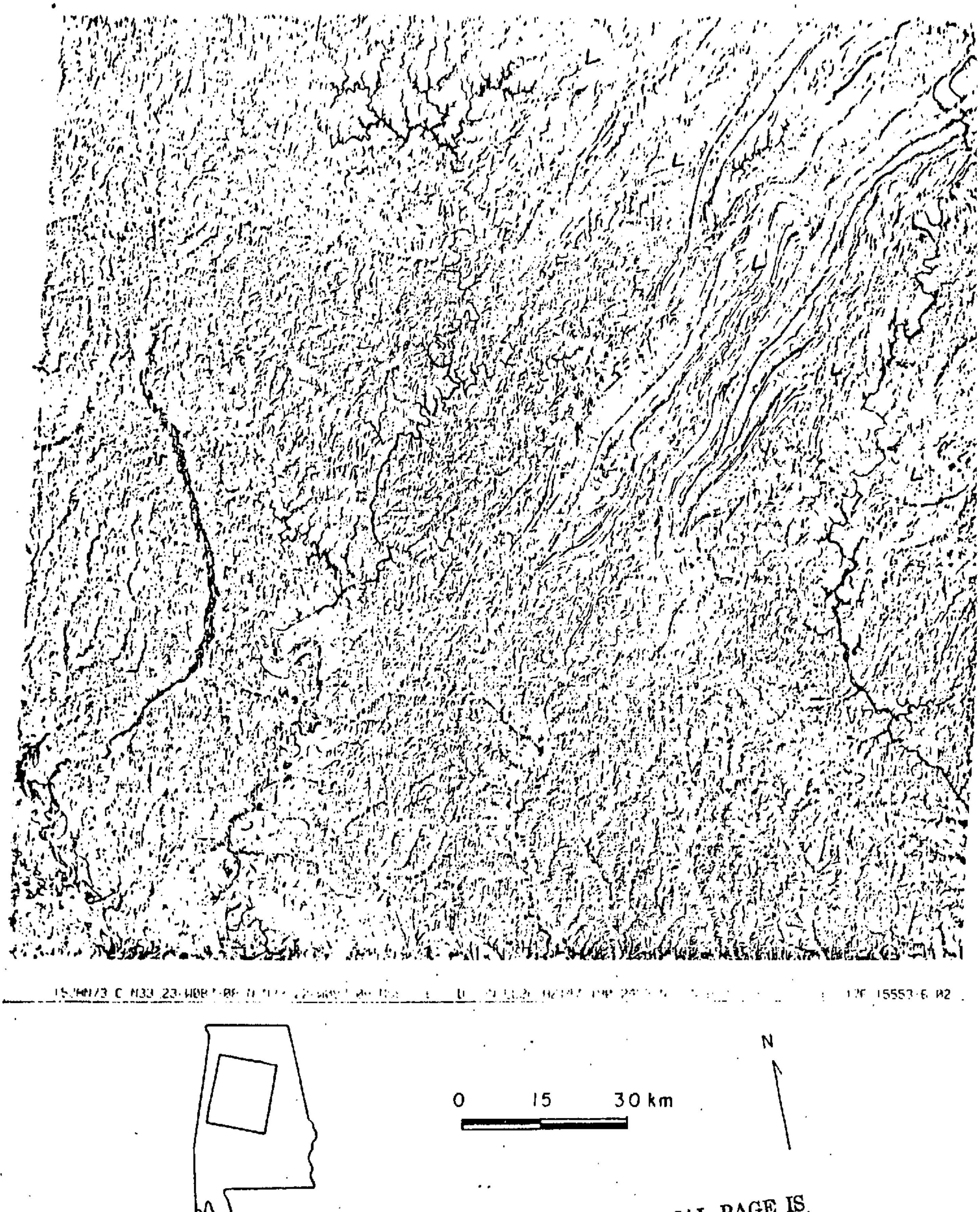
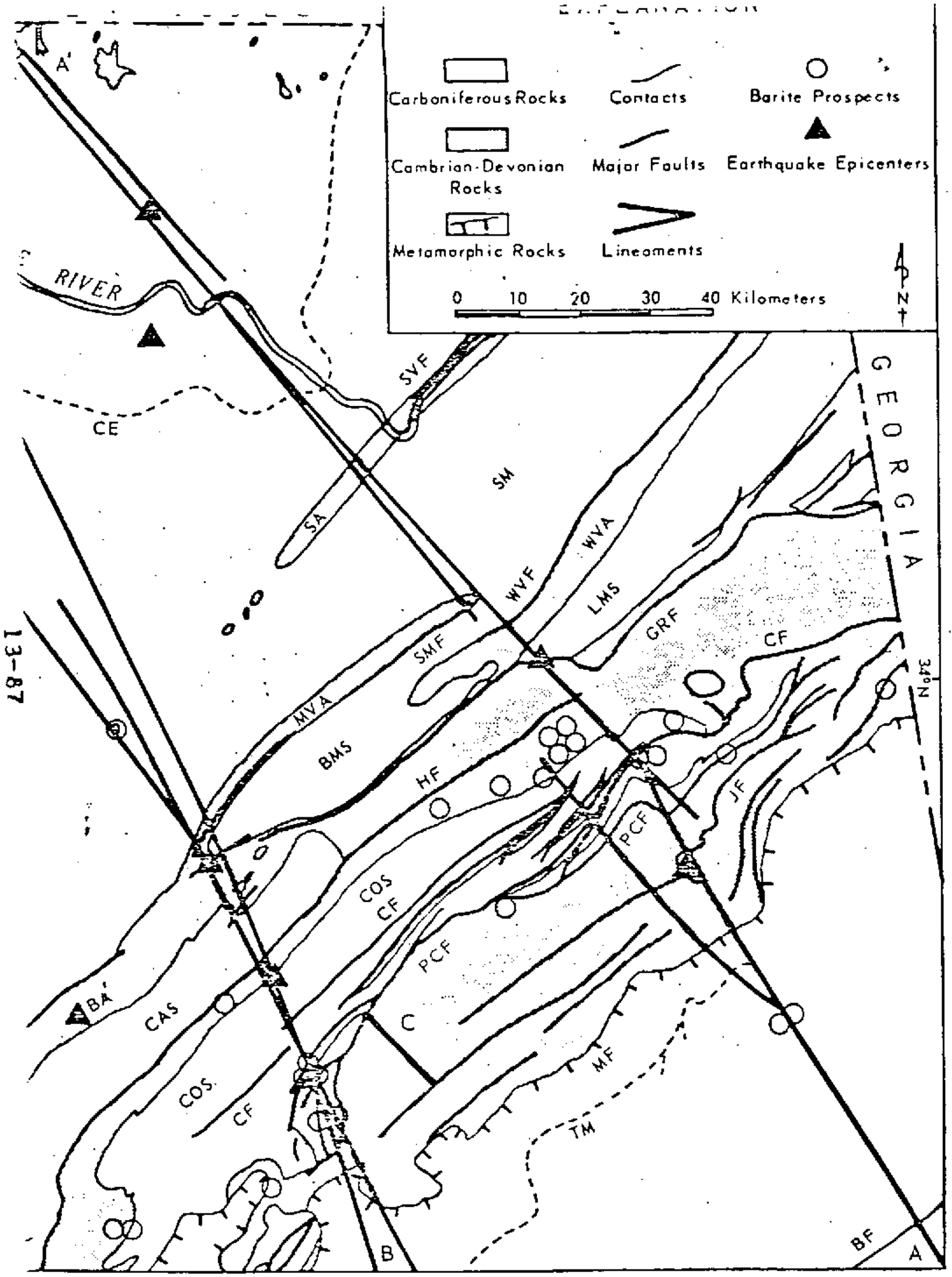


Figure 1.--ERTS-1 image of central Alabama, showing the trace of a part of th Harpersville lineament complex. The "V's" point toward the lineament (image courtesy of EROS Program).



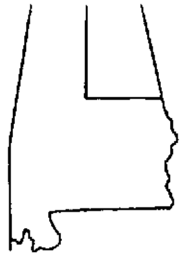
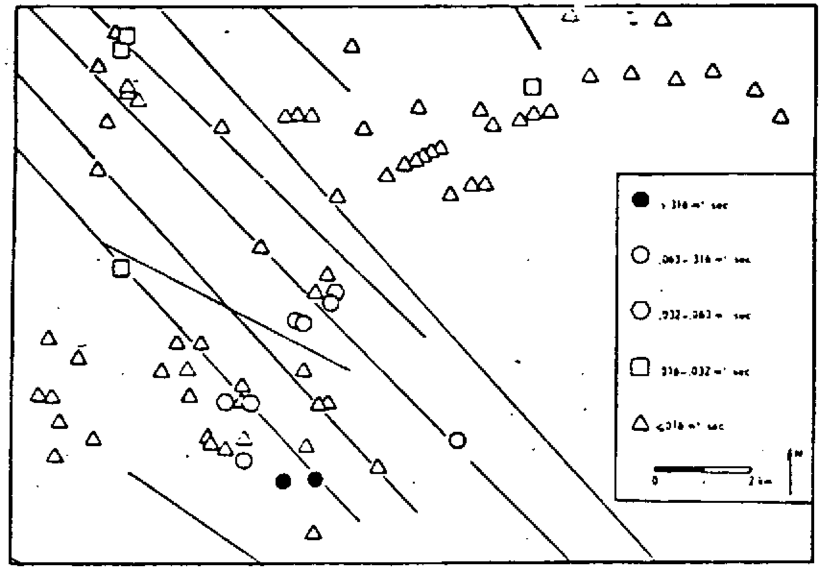


Figure 2.--Generalized geology of northeast Alabama, showing structural and physiographic features, barite prospects, earthquake epicenters and lineaments (A-A'-Anniston, B-B'-Harpersville, and C-Kelly Creek). BA-Birmingham anticlinorium, BMS-Blount Mountain syncline, BF-Brevard fault, CAS-Cahaba syncline, CE-Cumberland escarpment, CF-Coosa fault, COS-Coosa synclinorium, GRF-Gadsden-Rome fault, HF-Helena fault, JF-Jacksonville fault, LMS-Lookout Mountain syncline, MF-metamorphic front, MVA-Murphrees Valley anticline, OVF-Opossum Valley fault, PCF-Pell City fault, SA-Sequatchie anticline, SM-Sand Mountain, SMF-Straight Mountain fault, SVF-Sequatchie Valley fault, TM-Talladega Mountain, WB-Warrior basin, WVA-Wills Valley anticline, WVF-Wills Valley fault (modified from Drahovzal and others, 1974).



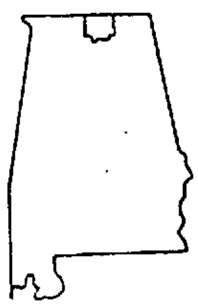


Figure 3.--Spatial relationships of water wells and springs to lineaments associated with the Anniston lineament complex in southwestern Madison County, Alabama (from Drahovzal and others, 1974).

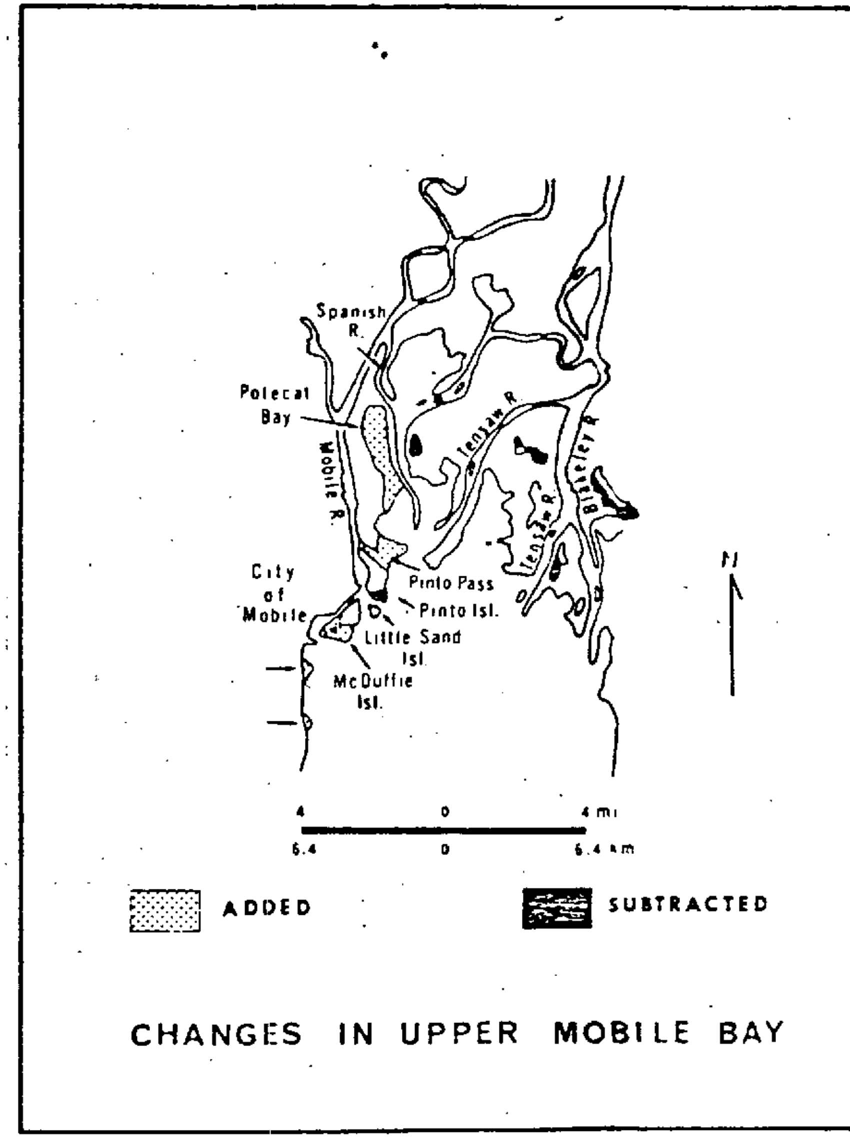
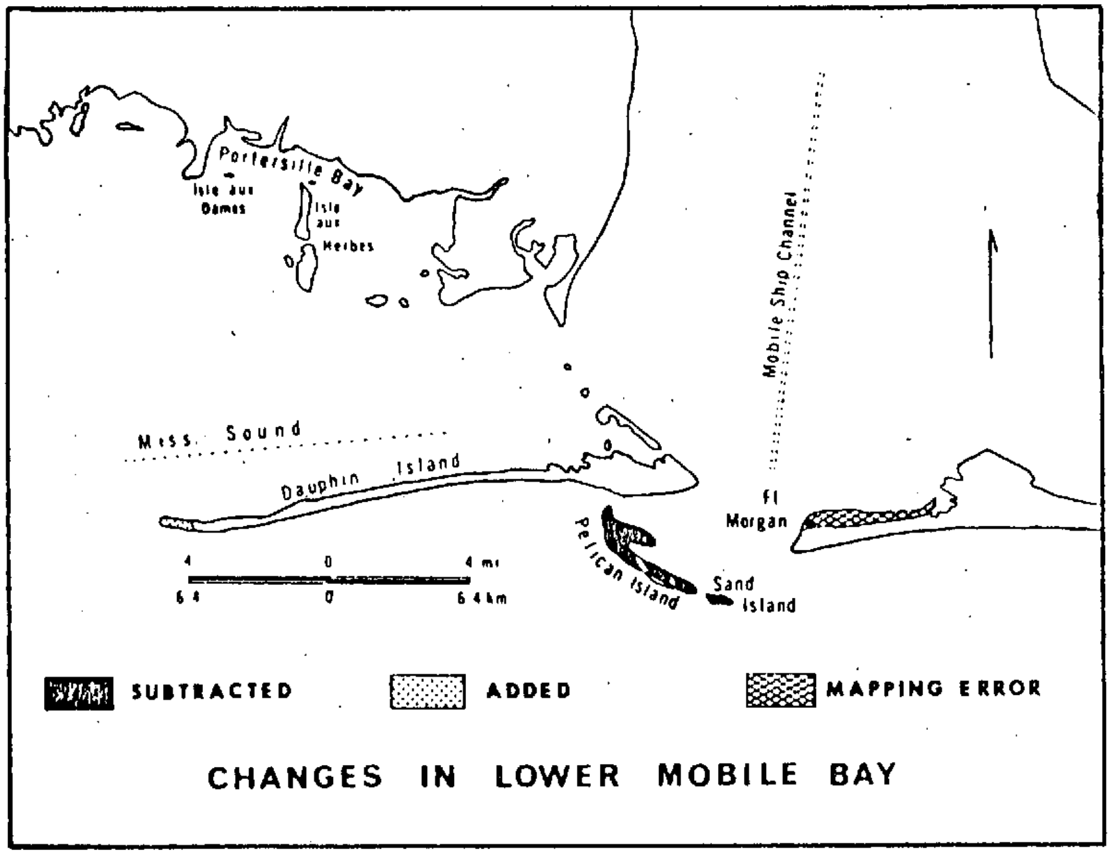


Figure 4.--ERTS-derived changes in upper Mobile Bay, Alabama (from Emplaincourt and Wielchowsky, 1974).



e 5.--ERTS-derived changes in lower Mobile Bay, Alabama (from Emplaincourt and Wielchowsky, 1974).

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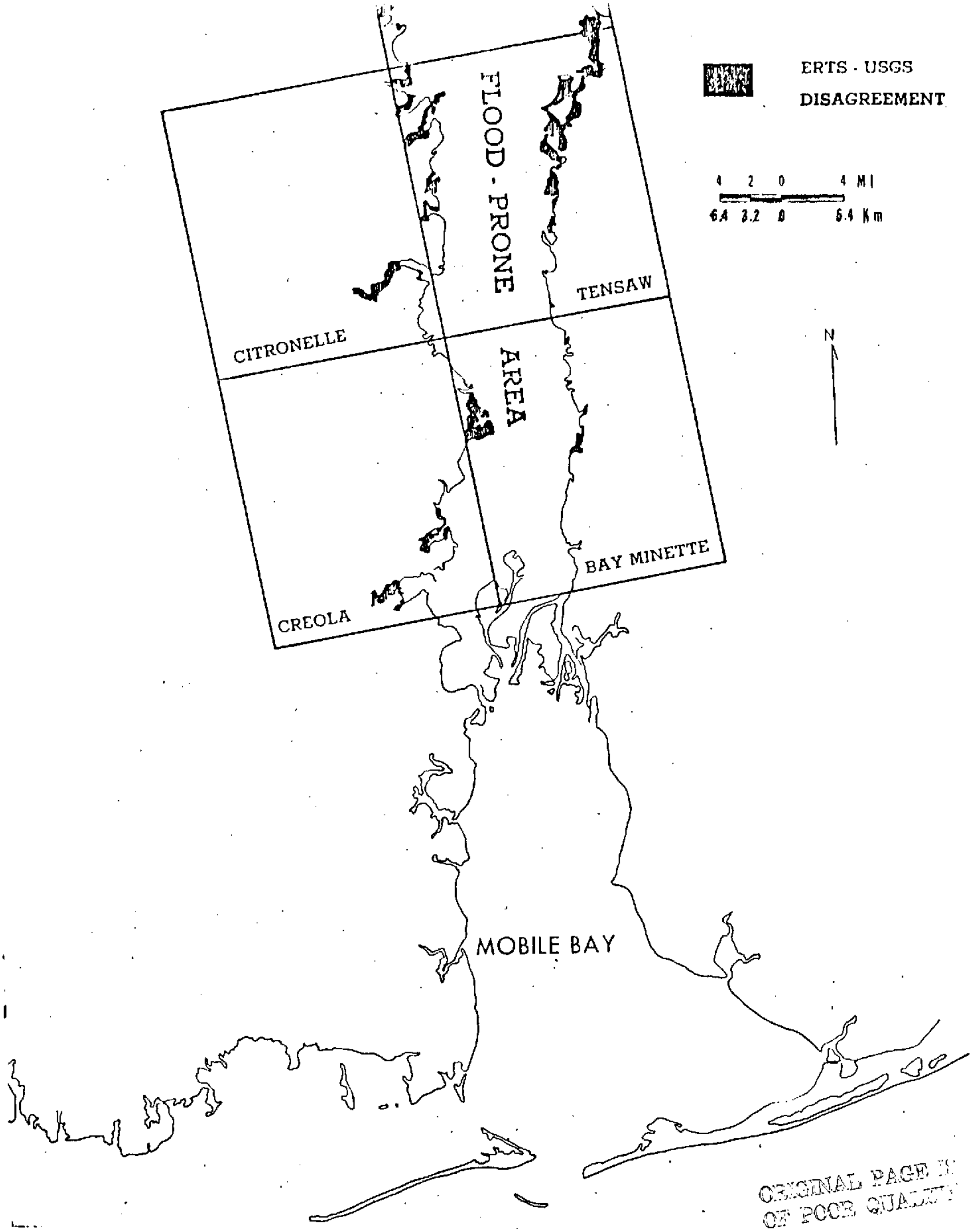

Figure 6.--Comparison between USGS flood-prone area maps and ERTS imagery north of Mobile Bay, Alabama.

Figure 7.--Alabama state map showing cleared land (black) vs forested land (white) obtained from ERTS-1 imagery (map courtesy of Neal G. Lineback, Department of Geology and Geography, University of Alabama).

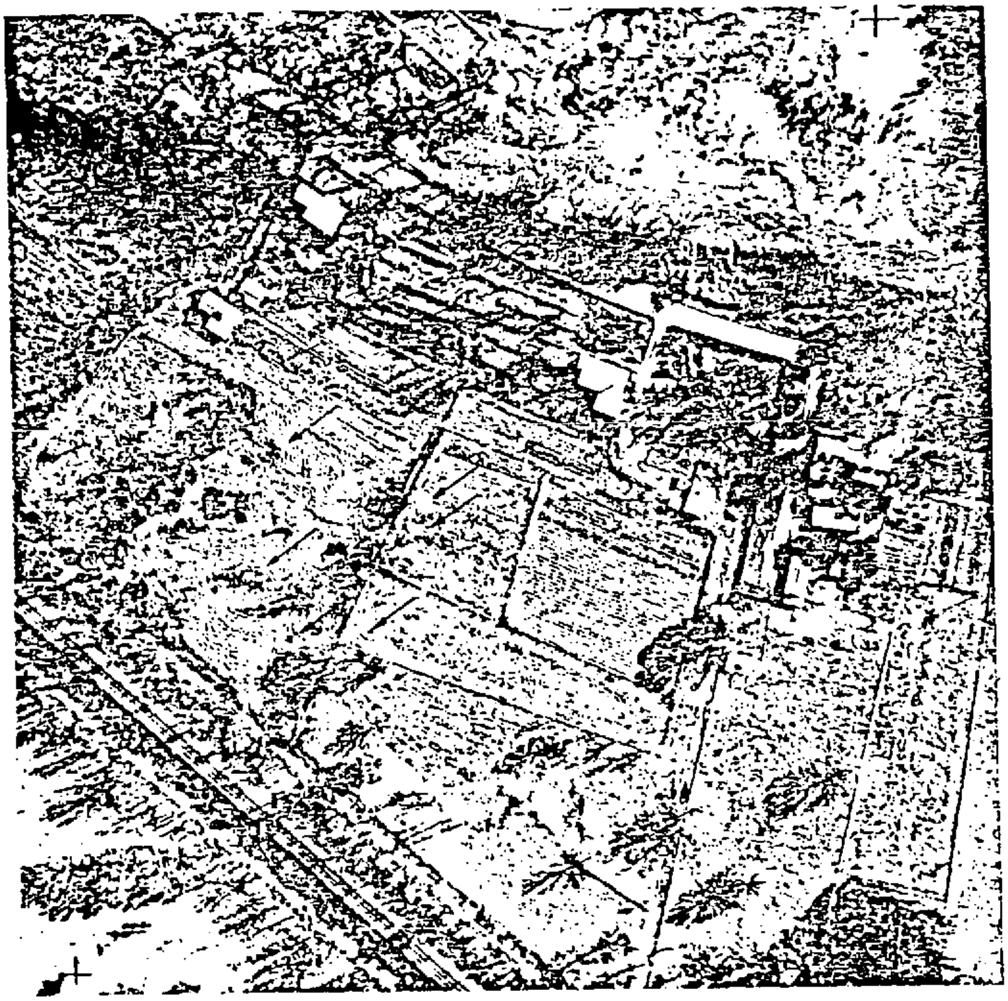

Figure 8.--Black and white infrared photograph showing vegetative stress (arrows) above subsurface cavities near Greenwood, Alabama (photograph courtesy of Environmental Systems Corporation).

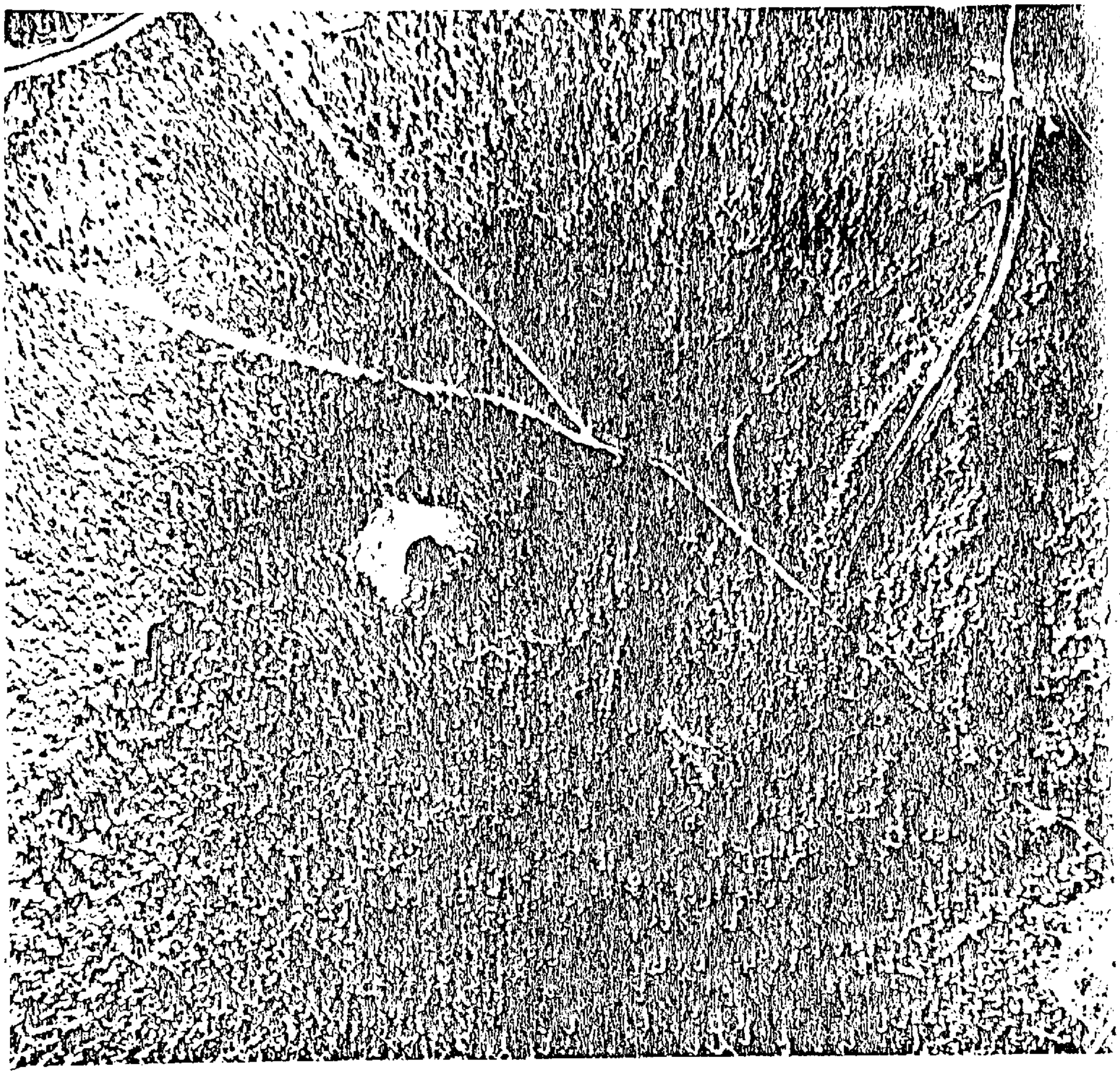

Figure 9.--Black and white infrared photograph of a large sinkhole near Calera, Alabama (photograph courtesy of U. S. Geological Survey, Prescott Remote-Sensing Research Group).

APPENDIX VIII

THE SIGNIFICANCE OF LINEAMENTS IN THE ALABAMA APPALACHIANS

James A. Drahovzal

Abstract of a paper published in the First Intern. Conf. on the New Basement Tectonics, Utah Geological Association, Salt Lake City, 1974, p. 11-12.

THE SIGNIFICANCE OF LINEAMENTS IN THE ALABAMA APPALACHIANS

Drahovzal, James A., Geological Survey of Alabama, University, Alabama

Lineaments consisting of relatively long, generally continuous tonal alignments on Apollo 9 multispectral photographs of the Alabama Appalachians were first noted in 1969. Since that time, the lineaments have been confirmed, and many extended, using ERTS-1 imagery and Skylab photography. In addition to the analysis of orbital data, side-looking airborne radar (SLAR) imagery and high-altitude aircraft photography have also been used in lineament studies.

Several long, continuous complexes of lineaments that cross the Alabama Appalachian axis at nearly right angles appear to have marked geologic and hydrologic significance. The apparent relationships of the lineament complexes to regional structural geology, stratigraphy, mineralization, and seismicity suggest that they may reflect geofractures that bound major basement blocks. Differential vertical movements of the blocks may have occurred since at least the Early Paleozoic and may be responsible for the present-day seismicity and crustal uplift. The thin-skinned structures of the Appalachians may also be intimately related to the vertical motion of the basement. In addition, the basement geofractures may be genetically related to the marginal fracture ridge zones lying off the North American continent and the transform faults of the Mid-Atlantic Ridge.

The numerous shorter lineaments in the Alabama Appalachians are not well known, but the majority appear to have little regional significance. In several cases, however, these lineaments have local geologic and environmental importance.

The lineament of the Alabama Appalachians are probably polygenetic in origin. Much more field study will be required to determine their nature and origin and to fully assess their significance.

APPENDIX IX

REMOTE SENSING OF GEOLOGIC HAZARDS IN ALABAMA

J. A. Drahovzal, C. C. Wielchowsky,
J. L. G. Emplaincourt, W. M. Warren, and C. W. Copeland

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and Resources Conf., Philadelphia, 1974

ABSTRACT

REMOTE SENSING OF GEOLOGIC HAZARDS IN ALABAMA*

by

J. A. Drahovzal, C. C. Wielchowsky, J. L. G. Emplaincourt,
W. M. Warren, and C. W. Copeland

Geological Survey of Alabama
P. O. Drawer O
University, Alabama 35486
205/759-5721

The Geological Survey of Alabama has used remotely sensed data in: 1) mapping lineaments; 2) delineating flood-prone areas; 3) predicting and monitoring subsidence in carbonate terranes; and 4) studying erosion and sedimentation problems.

*Approved for publication by the State Geologist.

SUMMARY

Remote Sensing of Geologic Hazards in Alabama*

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Geological Survey of Alabama
P. O. Drawer O
University, Alabama 35486
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During the past 4 years the Geological Survey of Alabama has applied remote-sensing technology to a wide variety of earth science problems. Interpretation of remotely sensed data has aided in the delineation of geologic hazards including: 1) lineaments related to fractures; 2) flood-prone areas; 3) subsidence in carbonate terranes; and 4) sedimentation and erosion in coastal areas.

Orbital imagery from some of the early space photography experiments, ERTS-1, and Skylab has been used to map previously unknown, long, linear surface features (lineaments) in Alabama. Although the nature and origin of the lineaments are not yet completely known, some of them appear to be related to regional structure, seismicity, fracture zones, and zones of mineralization suggesting a relationship to zones of fundamental crustal weakness. Such information is critical to any evaluation of regional stability and seismic risk.

Sequential ERTS-1 coverage of flooding in southwest Alabama has been used to map flooded and flood-prone areas. A high degree of correlation exists between flooded areas as depicted on the ERTS-1 imagery and published

* Approved for publication by the State Geologist.

U. S. Geological Survey flood-prone area maps. In areas where flood-prone area maps have not yet been compiled, ERTS-1 data were used as an initial mapping tool. In addition, ERTS-1 images obtained prior and subsequent to flooding can be used to develop predictive methods.

Studies in several carbonate terranes in Alabama have indicated that aerial infrared photography, thermography, and side-looking airborne radar (SLAR) imagery can be used in: 1) locating, inventory, and monitoring sinkholes; 2) predicting potential collapses; 3) mapping fracture traces, lineaments, regional geologic structure and alignment of sinkholes; and 4) assisting general project planning. Already, several highway collapses have been successfully predicted, and in another area, potential subsidence problems along a proposed interstate route have been averted through detailed studies involving remotely sensed data.

ERTS-1 imagery has proven useful in delineating and monitoring shoreline configuration changes in the vicinity of Mobile Bay. Direct comparisons between existing 1:250,000 scale maps and ERTS-1 imagery show marked differences that are due to man's activities, natural processes, and mapping errors. Minor configuration changes over a single year's period can be detected through the use of ERTS-1 data.