N76-16558

CR-144109

NASA SKYLAB/EREP
FINAL REPORT
CONTRACT NAS 8-29617 EPN 507

Application of Multispectral
Photography to Mineral and Land
Resources of South Carolina

NASA SKYLAB/EREP

FINAL REPORT

CONTRACT NAS 8-29617 EPN 507

Application of Multispectral Photography to Mineral and Land Resources of South Carolina

Submitted by Norman K. Olson
Principal Investigator

South Carolina State Development Board
Division of Geology
Harbison Forest Road
Columbia, S. C. 29210

June 27, 1975

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

NASA Skylab/EREP photography was analyzed by a South Carolina team consisting of eight co-investigators, two advisors and the principal investigator (PI).

No data were collected from the SL-2 mission over the test site but some excellent features were revealed from SL-3 and SL-4 in the S190A and S190B transparencies. Analysis was entirely by visual interpretation plus field experience on the part of the various investigators.

Skylab photography gives a synoptic view in color, black-and-white, and combinations of these in infrared like no other sensors available to us. This ability to view stream patterns, structural lineaments and other surface geologic features is a most useful tool in the planning and beginning stages of mineral exploration. Ore-forming fluids (Piedmont and Blue Ridge) and many stratiform ore deposits (Coastal Plain) are localized by structural control such as joints, fractures and related features.

Our single most important use of Skylab photography was the detection on SL-4 transparencies (S190B) of fracture traces and related lineaments crossing Clark Hill Reservoir on the Savannah River north of Augusta. Epicenters of some earthquakes (maximum magnitude 4.5) occurring in 1974 are located in the same area. Although the field evidence is still being developed, Skylab photography has provided important new supportive data.

Skylab photography is useful for showing large areas of river floodplains, Carolina bays, karst terrain, beach ridges, marshlands, and hilly or mountainous topography--all natural land resources which must be considered in effective land-use planning and management.

INTRODUCTION

The topic of this proposal was selected in 1971 following some initial assistance from the EROS Program Office, U. S. Geological Survey. No funds were requested from NASA and no separate "ground truth" field sessions were conducted. The main objectives of the rather simple proposal were to try Skylab/EREP data products (S190A and S190B photography) as new tools for evaluation of geologic and soils data and changing land-use patterns.

On August 28-29, 1973 a two-day intensive short course in fundamentals of aerial remote sensing was conducted at the Department of Civil Engineering, Clemson University, by Prof. Donald B. Stafford. The South Carolina team of eight co-investigators, two advisors and the writer represented various disciplines from state and federal government agencies and academic institutions as follows:

<u>Co-investigators</u>

Dr. V. S. Griffin, Jr.	Geology, Clemson University
Dr. G. M. Haselton	Geology, Clemson University
Dr. R. D. Hatcher	Geology, Clemson University
Dr. Van Price	Geology, Furman University
Dr. W. E. Sharp	Geology, University of South Carolina
Mr. G. E. Siple	U. S. Geological Survey, Columbia
Dr. H. D. Wagener	Geological Consultant, Charleston
Mr. R. D. Wells	USDA-SCS, Columbia

<u>Advisors</u>

Dr. R. A. Holmes	College of Engineering, University of South Carolina
Dr. D. B. Stafford	Civil Engineering, Clemson University

Photography from both the S190A Multispectral Camera facility and the S190B Earth Terrain Camera were received as bulk transparencies from Skylab 2 (SL-2), SL-3, and SL-4 missions over South Carolina and adjoining states. A duplicate set of transparencies was provided from NASA-JSC for use by the Clemson area members of our team. In addition to the contact sizes from both cameras, NASA sent us enlarged bulk transparencies of 9x9-inch format from the S190A (4x) and S190B (2x) prints for the SL-3 and SL-4 missions. The enlarged S190B transparencies, at a scale of 1:500,000, were the most useful for details in photo interpretation. Our team also received a set of high-altitude color IR transparencies which at first glance appeared to be of excellent quality, but the enlarged prints were slightly fuzzy. Tables 1 and 2 give details on data products from all missions.

The writer is grateful to the co-investigators in general and especially to some of them for specific written contributions as follows:

Dr. V. S. Griffin, Jr.--SL-3, S190B frame 285
Dr. R. D. Hatcher, Jr.--SL-3, S190B frame 352;
.... --SL-4, S190B frame 044
Mr. G. E. Siple-- SL-4, S190B frame 049

Dr. Pradeep Talwani, geophysics professor, Dr. D. T. Secor geology professor, and their graduate students at the Department of Geology, University of South Carolina, assisted by D. E. Howell, Division of Geology, South Carolina State Development Board, provided most helpful comments in the interpretation of SL-4 S190B frame 046.

Special appreciation is extended to Dr. R. A. Holmes, Dean, College of Engineering, University of South Carolina, for his constructive review of the text, and to Mrs. Jacqueline W. Brown, Staff Assistant, Division of Geology, South Carolina State Development Board, for typing the manuscript.

STATEMENT OF WORK

SL-2: Photographs over Georgia

All data products received were supposed to have been from along ground track 19 (Savannah River Valley). An apparently slight westward drift of Skylab, however, caused all of the photographs to be over eastern Georgia. Furthermore, difficulties with the Skylab onboard power supply and our local and regional cloudy conditions over South Carolina seriously hampered the capability of NASA for delivering useful data products.

Our team of Co-I's, two advisors, and the writer took the opportunity of practicing our ability to interpret EREP photographs, even though the scenes did not come within our project area of South Carolina. The largest visible areas were on frames 09-165 (S-190A, color IR) and 81-216 (S-190B, color). Figure 1 is a map of Georgia (USGS, scale 1:250, 000) indicating the width of the ground track for each photograph. For positive geographic orientation and comparative annotation the Brunswick sheet (USGS, scale 1:250,000) was used. Frame 09-165 revealed Jekyll Island and the town of Brunswick at the extreme south edge and the southern tip of Ossabaw Island to the north. Frame 81-216 showed the village of Darien and the north half of Saint Simons Island on the extreme south south edge and the southern tip of Ossabaw Island to the north.

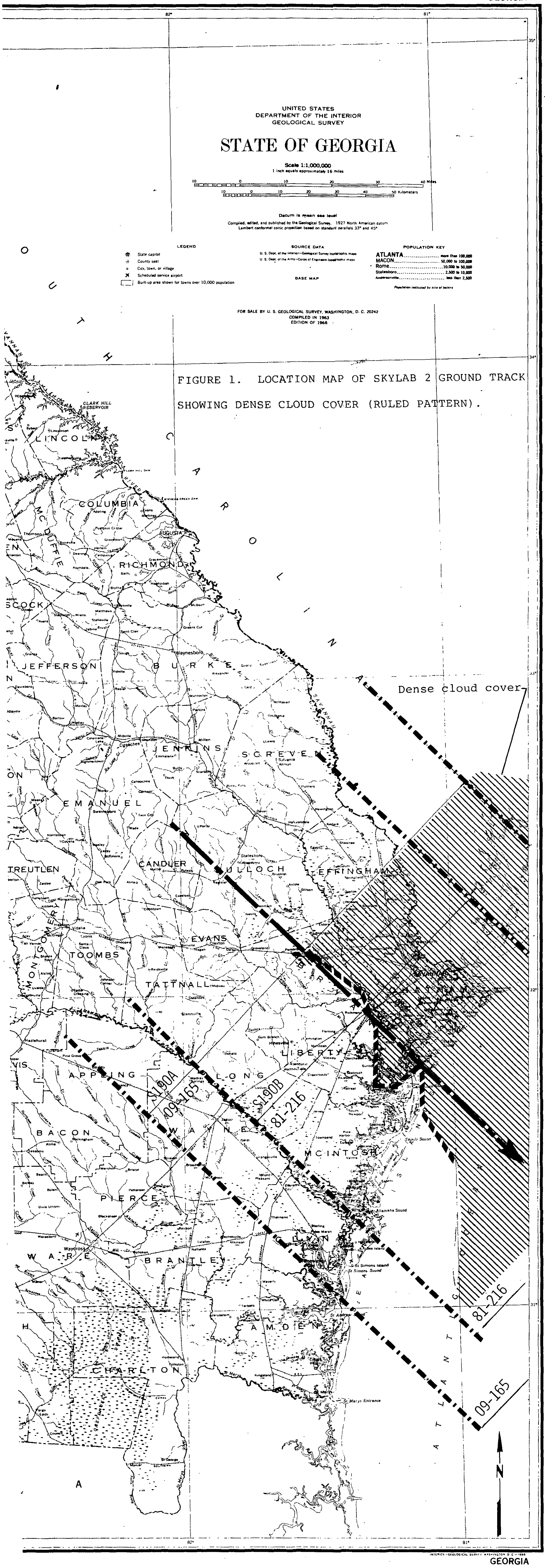


FIGURE 1. LOCATION MAP OF SKYLAB 2 GROUND TRACK SHOWING DENSE CLOUD COVER (RULED PATTERN).

Cloud cover over all areas photographed was consistently about the same, averaging 80-90 percent, during June 1973 when all pictures were taken. The northern half of the coastal and inland areas, including the city of Savannah, was constantly beneath dense clouds. Figure 1 indicates an approximate boundary of the opaque cloud cover alone on frames 09-165 (S-190A) and 81-216 (S-190B). All inland areas were cloud-covered to a somewhat lesser degree.

Recognizable features on frame 81-216, in addition to those stated above, include the Altamaha River and Altamaha Sound, Sapelo Island, Saint Catherines Island, Interstate 95 (including interchanges), U. S. Highway 17, and the coastal wetlands. The latter, also called tidelands, marshlands, or coastal zone, are readily detected by EREP photography. The line of demarcation between the intertidal zone and the ground above mean high tide can be mapped easily, especially from the 4 1/2 x 4 1/2-in. transparencies. Widespread controversy still exists in South Carolina over boundaries, ownerships, and proper land use of her tidelands.

Recognizable features on frame 09-165, in addition to those previously mentioned, include the noticeably scoured channels (dark blue) of the Brunswick River and the Hampton River and the accompanying sediment plumes. Jekyll, Saint Simons, and Sea Island all are apparently receiving some natural beach nourishment. The sediment patterns north of Sea Island are obscured by clouds, but it is well known that beach erosion is prevalent in certain areas of the South Carolina coast (although comparable details for the Georgia coast are unknown to the writer).

Intensive Short Course

In accordance with the Milestone Plan, an intensive short course in aerial remote sensing was held at Clemson University during August 28-28, 1973. Professor Donald B. Stafford, Department of Civil Engineering, Clemson University (one of our two EREP advisors) conducted the course. Dr. Stafford prepared a rather extensive compilation of technical data which was bound into individual loose-leaf notebooks for each student.

The first day consisted entirely of lecture-discussion periods, beginning with the elementary physics of the electromagnetic spectrum and followed by the capabilities and applications of various sensors. Dr. Stafford included the international NASA-ERTS color slide set as part of his afternoon presentation. Dr. Roger A. Holmes, Dean, College of Engineering, University of South Carolina gave a morning lecture on the interaction of the different wavelengths as related to leaf structure and relative amounts of chlorophyll.

The second day was a combination of lecture-discussion which included other sensors, such as radar, and viewing of high-altitude color infrared bulk transparencies of the Atlantic Coastal Plain of South Carolina furnished by NASA at the request of the EROS Program Office of the U. S. Geological Survey. Finally, a workshop-display session--using the first package of NASA-selected SL-2 photographs (8 x 10 prints), ERTS-1 images of South Carolina, aerial remote sensing equipment brochures, and other items--concluded the two-day short course.

SL-3: Geologic Interpretation and Land-Use Patterns

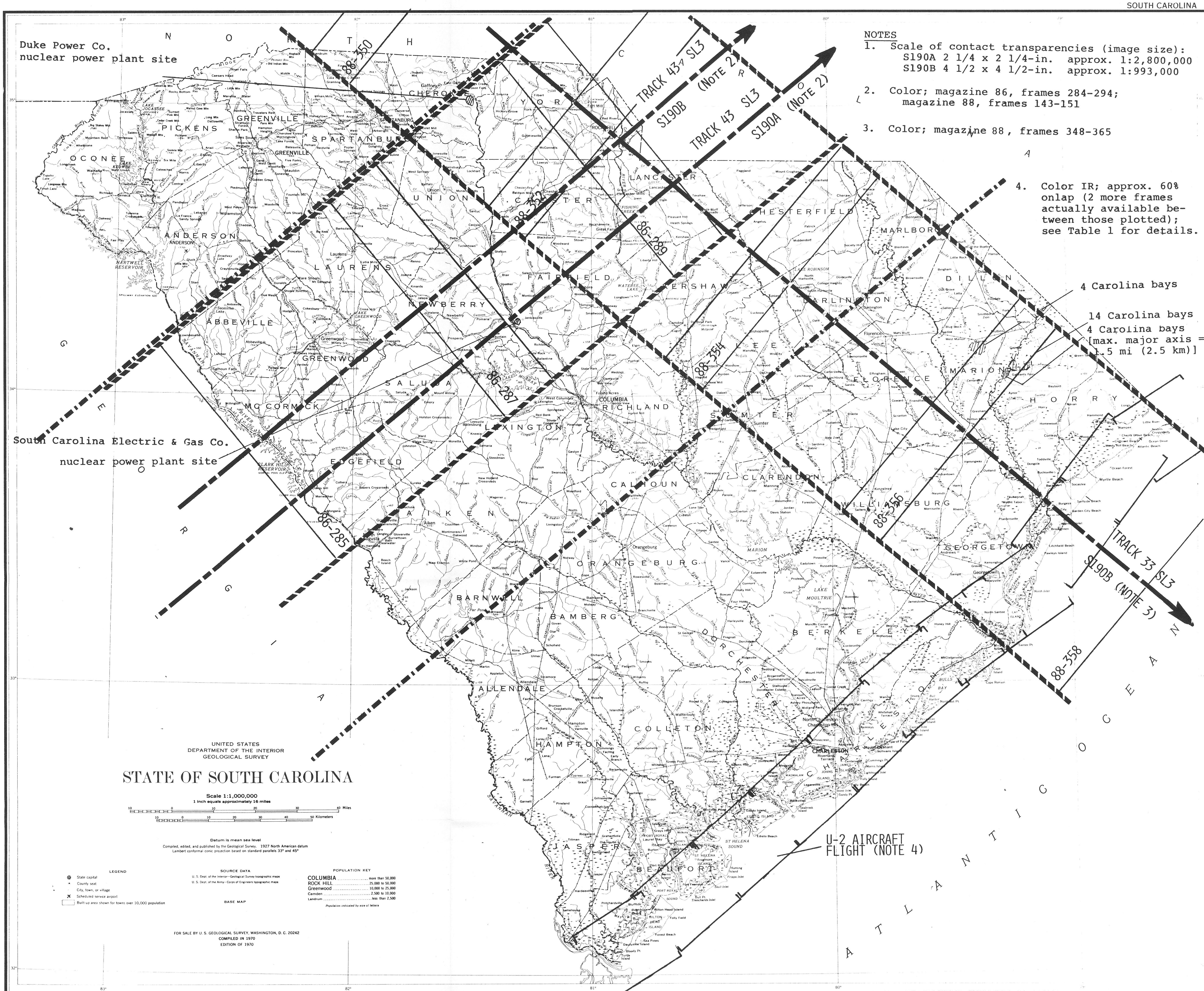
Introduction

Bulk transparencies of good to excellent photographic quality from both S190A and S190B were received from Skylab 3. Geologic interpretation, based upon past and present mapping of rock units in northwestern South Carolina was applied to these photographs, and a limited commentary on geologic features in eastern South Carolina, were made from the S190B photographs (fig. 2).

Color infrared bulk transparencies of very good quality, nearly cloud-free, were received from a NASA U-2 flight parallel to the entire South Carolina coastline. A summary of the data products received is presented in Table 1.

General Geologic Comments

There are significant differences in various types of features in the S190B color photographs. Structural features which are imprinted onto the topography may be readily seen. For example, the Brevard fault is faintly visible in photos 350 and 351 through the clouds. Valley and Ridge structures are visible in part of frame 348. Many lineaments, likely joint-controlled, are also visible, as in frames 286, 351 and 352.



SOUTH CAROLINA

Figure 2. Location map of Skylab 3 ground tracks over South Carolina and positions of selected S190B frames.

Table 1. Skylab/EREP (SL 3) and high altitude (U-2) aircraft photography over South Carolina and adjacent states received from NASA during fourth and fifth quarterly reporting periods, 1974.

Sensor	Image Size	Scale (approx.)	Conversion factor* 1:500,000 base map	EREP pass / ground track	Film magazines / frames	Remarks
S190A Multispectral Camera Facility	2 1/4 X 2 1/4 in. (contact)	1:2,800,000	5.6	36/43	37-42/ 109-118	All data products bulk transparencies, overall quality excellent, mostly less than 30 percent cloud cover, all over track 43 (Clark Hill Reservoir to Pee Dee River and beyond). Data products, in sequence, for magazines 37-42 as follows: b/w IR pos; b/w IR neg, color IR, color, b/w pos and b/w neg, and b/w pos. Identical kinds of photographs received from magazines 43-48. All photographs from EREP passes 36 and 46 received on both contacts and 4x enlargements.
				46/43	43-48/ 102-111	
	9 X 9 in.	1:700,000	1.4	(Same as contacts)	(Same as contacts)	
S190B Earth Terrain Camera	4 1/2 X 4 1/2 in.	1:1,000,000 (closer to 1:933,000)	2.0	7/33	88/348-365	Overall quality on Pass 7 fair, mostly greater than 30 percent cloud cover, colors somewhat overexposed (higher sun angle?). Frames 348-351 in Appalachians of North Carolina (greater than 75 percent cloud cover); frames 352-359 extend from Charlotte-Gaffney area to Myrtle Beach - Georgetown area; frames 360-365 all over Atlantic Ocean.
	9 X 9 in.	1:500,000	1.0	36/43 46/43	86/284-294 88/143-151	Overall quality on Pass 36 roll 86, good to excellent. Frames 284-288 extend from Savannah River (Clark Hill Reservoir) to Charlotte-Rock Hill area with excellent quality, less than 30 percent cloud cover; frames 289-294 extend from Charlotte area to North Carolina-Virginia line (Roanoke R.). Overall quality on Pass 46, roll 88, fair to good; some areas slightly overexposed; cloud cover approximately 20 to 25 percent over South Carolina (frames 146-148), greater over other areas. All photographs from EREP pass 7, 36 and 46 received on both contacts and 2x enlargements.
Conventional camera	2 1/4 X 2 1/4 in.	1:500,000	1.0	(Not applicable)	(Not applicable)	Total length of flight line extends from North Carolina line to Savannah Beach, Georgia; 29 frames of bulk color IR transparencies. Altitude of U-2 aircraft reported as 65,000 feet; area of ground coverage per frame = 16 X 16 miles (approximately). Flown in mid-September under nearly cloud-free conditions. Color IR quality good to excellent but all features appear to be slightly out of focus. See land resource applications in summary.

*Multiplication factor needed to plot ground tracks and frames from transparencies to South Carolina base map (USGS, scale 1:500,000).

Soils appear to be very excellent indicators of rock types in the Piedmont in these photographs, as they are on the ground. The deep red soils visible in the photographs are likely indicative of biotite-and/or amphibole-rich rocks (biotite schists and gneisses, amphibole gneisses). Soils can be seen in areas where vegetation has been removed by farming or urban development, and much of the Piedmont is suitable for this type of analysis. Lighter colored soils are indicative of granitic rocks and/or rocks low in total iron. Granitic gneisses and granitic plutons are recognizable on this basis (for example, frames 284, 285 and 286). Soils should be used with caution as bedrock indicators, for soil color could also be controlled by geomorphic factors, such as overall relief of the area and the depth of groundwater (see detailed discussion of frame 352).

Rock units in the southeastern region of the United States have a long geologic history of chemical weathering in which decomposition is prevalent, whereas the exposed formations of the western United States have recorded long periods of physical weathering characterized by rock disintegration. Rock formations in the Southeast occur in a low-contrast terrain, that is, features subdued by abundant vegetation.

<u>Specific geologic comments--S190B frame 352</u>

The area covered by frame 352 (fig. 3) includes Hickory, Charlotte and Shelby, North Carolina and Rock Hill and Gaffney, South Carolina. These frames cross parts or all of most of the major geologic provinces of the crystalline Southern Appalachians, including part of the Blue Ridge, the Brevard fault zone, Chauga belt, mobilized Inner Piedmont, Kings Mountain belt and most

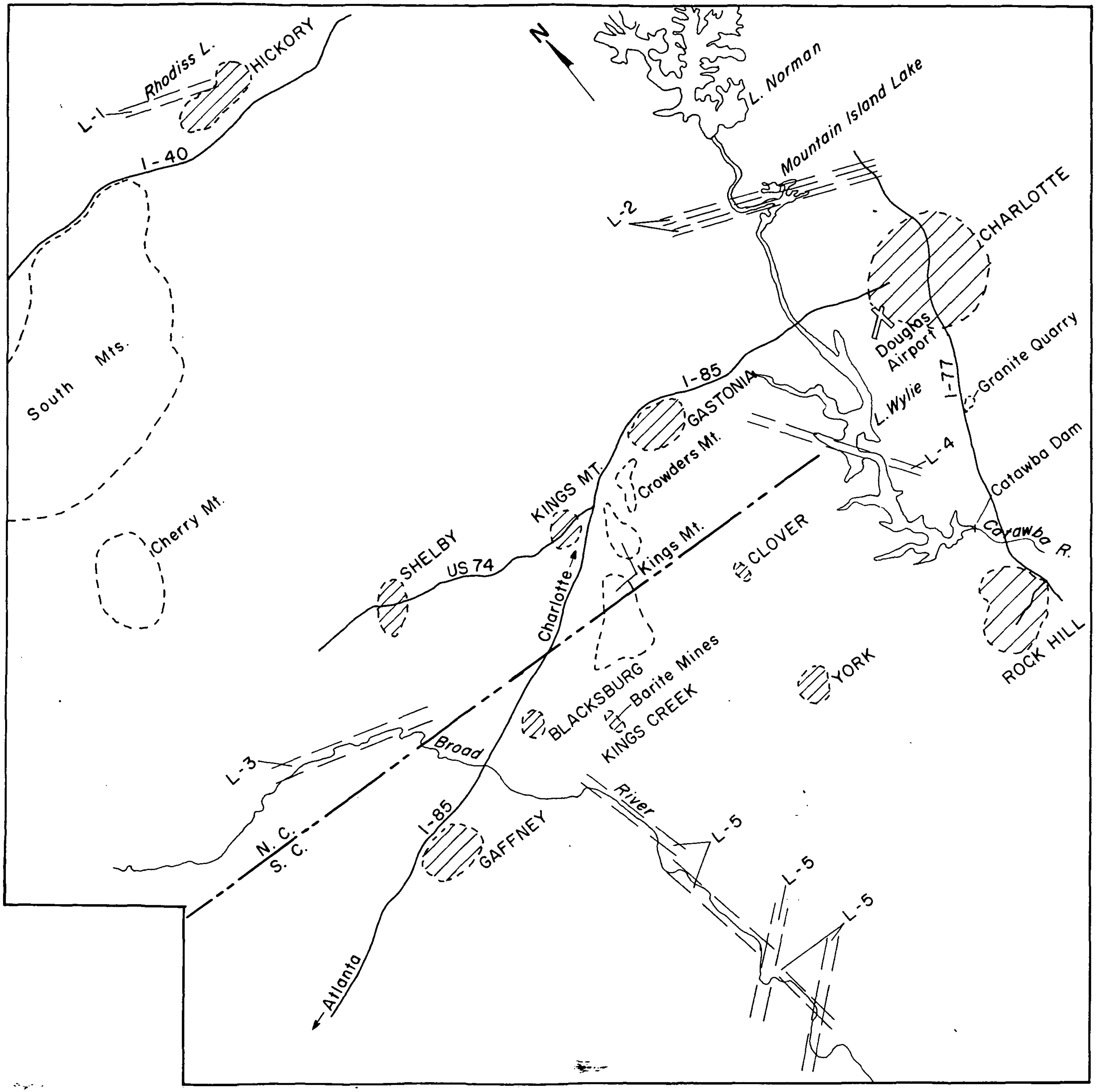


Figure 3. NASA Skylab 3 overlay to frame 352, magazine 88, ground track 33 EREP pass 7 (descending). Enlarge (2x) S190B color photograph; scale 1:500,000. L-1 through L-5 refer to lineaments described in text.

of the Charlotte belt (fig. 4). Physiographic provinces include part of the Blue Ridge and Piedmont which is divisible into an upper Piedmont and a more easterly lower Piedmont.

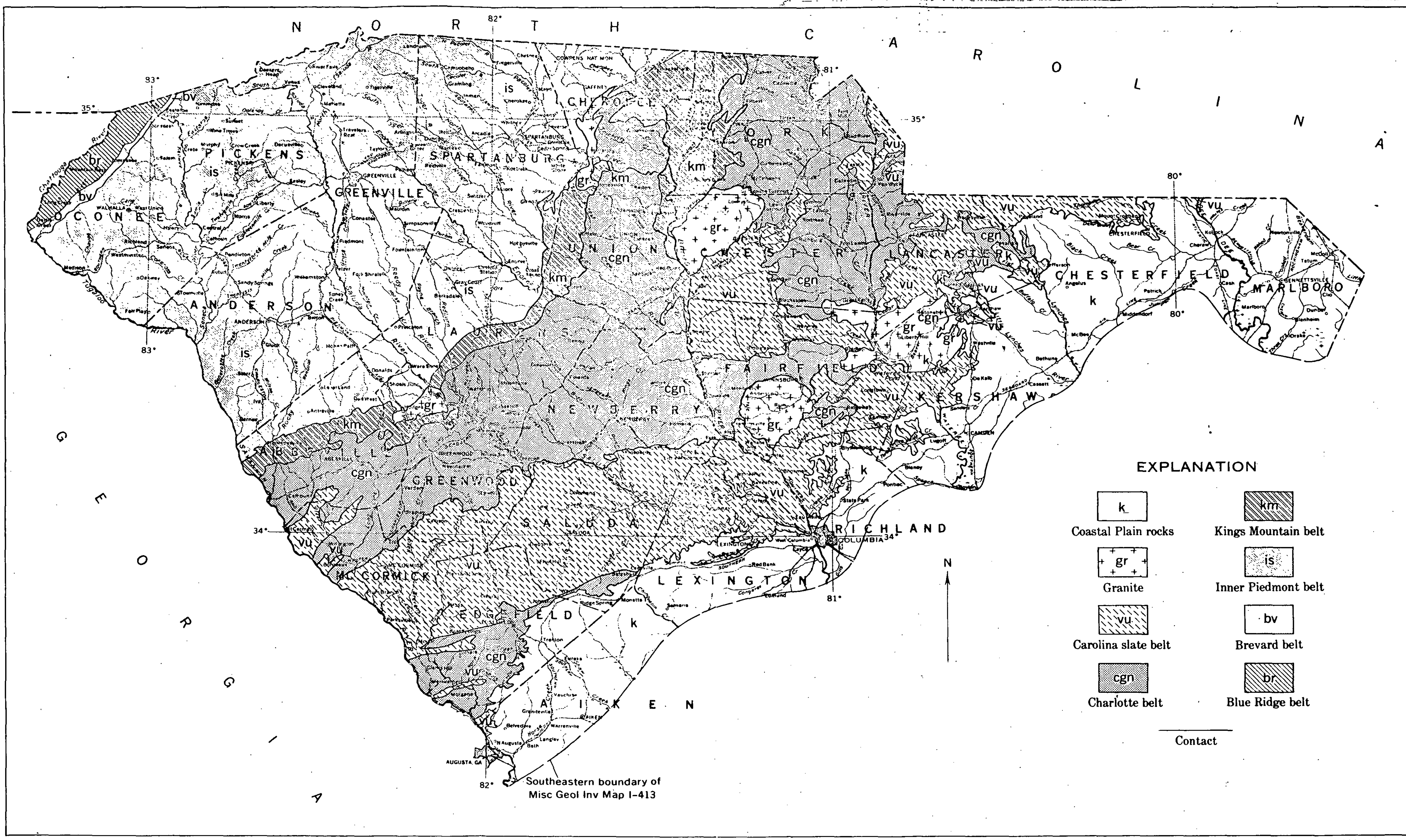
There are several strong lineaments present in this area (fig. 3, L-1). Rhodiss Lake and Lake Oxford, west and north of Hickory, lie on a strong nearly east-west lineament. One arm of Mountain Island Lake just west of Charlotte is on a N70°W lineament (fig. 3, L-2), as is the area of the Broad River north of Gaffney and southwest of Shelby (fig. 3, L-3). These are likely joint controlled but they are also parallel to zones of siliceous mylonite mapped and described by Conley and Drummond (1965) in this area. Similarly oriented zones of siliceous mylonite have also been described by Birkhead (1974) in Greenville County, South Carolina.

Northwest-southeast and northeast-southwest lineaments also are discernible in these photographs. Lake Wylie, south of Charlotte, and meanders of the Catawba River, along with several smaller drainages contain both northwest and northeast lineaments (fig. 3, L-4) as are also observed along the Broad River south of Gaffney (fig. 3, L-5). These likely reflect the regional systematic transverse and longitudinal joint pattern recognized in northwestern South Carolina by Acker and Hatcher (1970). A N10°W lineament direction was also observed. This also likely represents another major joint direction recognized by Acker and Hatcher (1970).

The soils of the Piedmont when they are exposed probably allow for differentation of the various geologic provinces (fig. 4) represented in these photographs. The northeast-southwest trending belt of very red soils southeast of the Blue Ridge and northwest of the vegetated Kings Mountain belt are the iron-rich soils derived from weathering of the biotite and amphibole gneisses of the mobilized Inner Piedmont. The lighter soils southeast of Kings Mountain likely reflect the granitic plutons of the Charlotte belt. However, this may be a function of the change in relief, changes in drainage pattern and groundwater regime in the Charlotte belt. But, in general, this pattern is to some degree borne out by bedrock studies in this area by Keith and Sterrett (1931), Overstreet and others (1963a), Overstreet and others (1963b), Overstreet and Bell (1965), and Butler (1966). Likewise, the Charlotte belt in this area can be seen in the photograph (from Clover eastward) to have lower relief (swampy, otherwise poorly drained) and so some of these geomorphic factors may have a bearing upon the interpretation. Stream patterns and densities also change from a greater density of streams with well developed drainage basins in the mobilized Inner Piedmont to a lower stream density and streams which meander more in the Charlotte belt.

Specific geologic comments--S190B frame 285

The area covered by frame 285 (fig. 5) includes the towns of Greenwood, Newberry, Laurens, Clinton, Abbeville and other communities, all in South Carolina. Principal natural features are the Savannah and Saluda Rivers; Parsons Mountain, Boles Mountain and Mt. Carmel, all monadnocks (erosional remnants);



Base from U.S. Geological Survey State base map of South Carolina

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—G 64009

Geology modified from Overstreet and Bell, 1965

FIGURE 4 **MAP SHOWING GEOLOGIC BELTS IN SOUTH CAROLINA**

SCALE 1:1 000 000

25 0 25 50 75 MILES

25 0 25 50 75 KILOMETERS

Taken from Plate 2, Overstreet and Bell, 1965

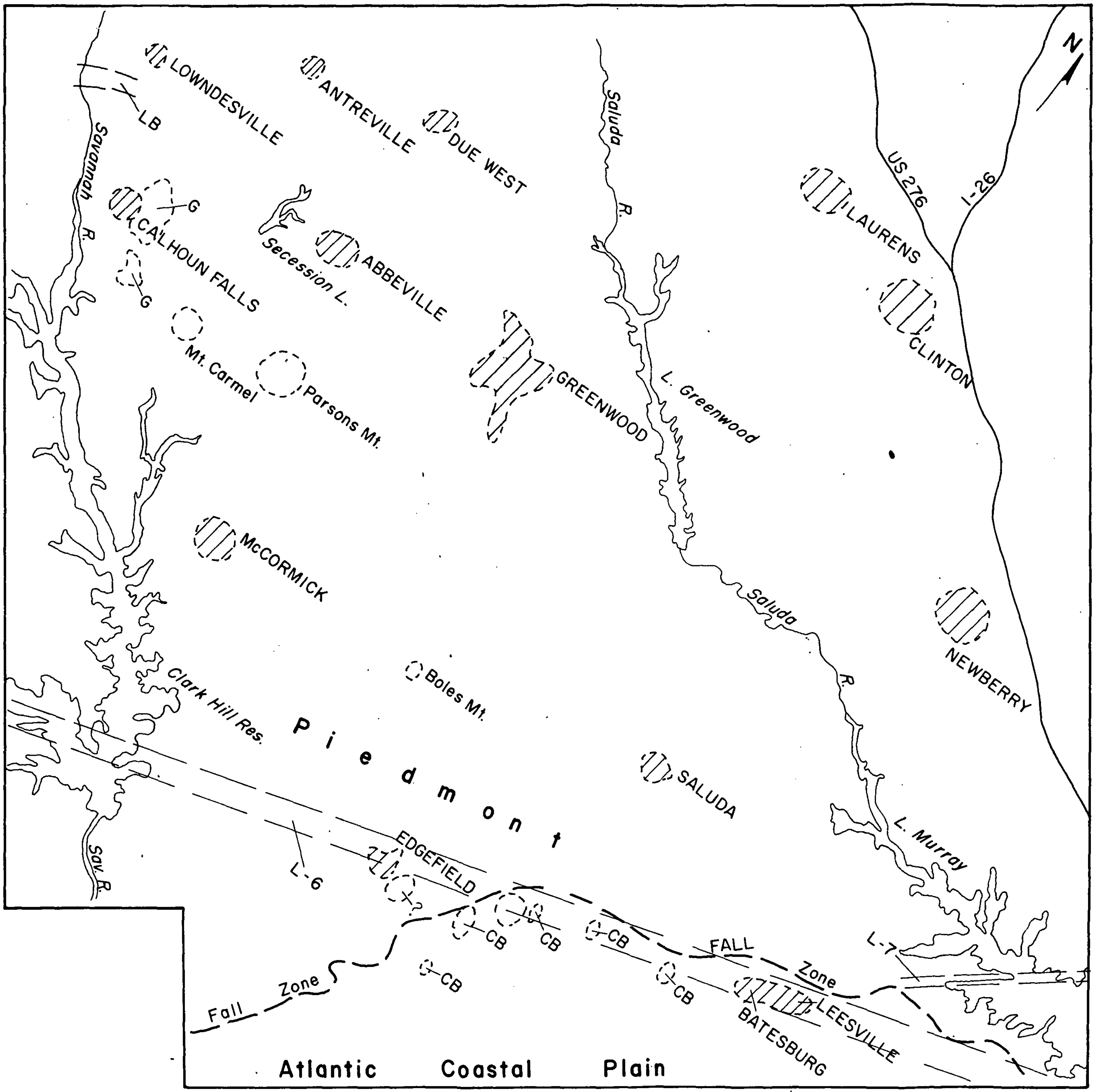


Figure 5. Overlay to NASA Skylab 3 frame 285, magazine 86, ground track 43, EREP pass 36 (ascending). Enlarged (2x) S190B color photograph; scale 1:500,000. L-B = Lowndesville Belt; CB = Carolina Bay; L-6 and L-7 = lineaments; G = gabbroid rock complex; ? = unknown feature.

and Carolina bays (CB), elliptical depressions confined to the Atlantic Coastal Plain province.

The northwestern part of frame 285 covers an area discussed in a recent geologic report (Griffin, 1972). Main efforts in this analysis were directed toward determining if any geologic zones and structures discovered during the prior geologic mapping study were expressed in this Skylab photograph. Specifically, the preliminary geologic map of a major portion of Abbeville County and the northern McCormick County, South Carolina (Griffin, 1972), shown in fig. 6, was used as the geologic "ground truth" source, and a copy is included with this report for further reference.

Lineaments are very subtle in the photograph, and interpretations might differ significantly from one observer to another. However, major geologic features apparently have at least some photographic expression at high altitude. In the northwest the cataclastic Lowndesville (Kings Mountain) belt (fig. 4, LB) is recognizable on both sides of the Savannah River and probably continues northeastward across the photograph to the area south of Laurens (fig. 6).

Several other linear trends are associated with the Lowndesville belt, both on the northwest and southeast. On the southeast lineaments probably represent several northeast trending narrow cataclastic zones, apparently formed within the Charlotte belt in response to movements along the Lowndesville belt (fig. 6). Some trends in the eastern part of the photograph appear to splay eastward away from the main Lowndesville belt. Southeast of the Lowndesville belt easily defined lineaments become progressively sparser, and even speculative ones are not to be seen.

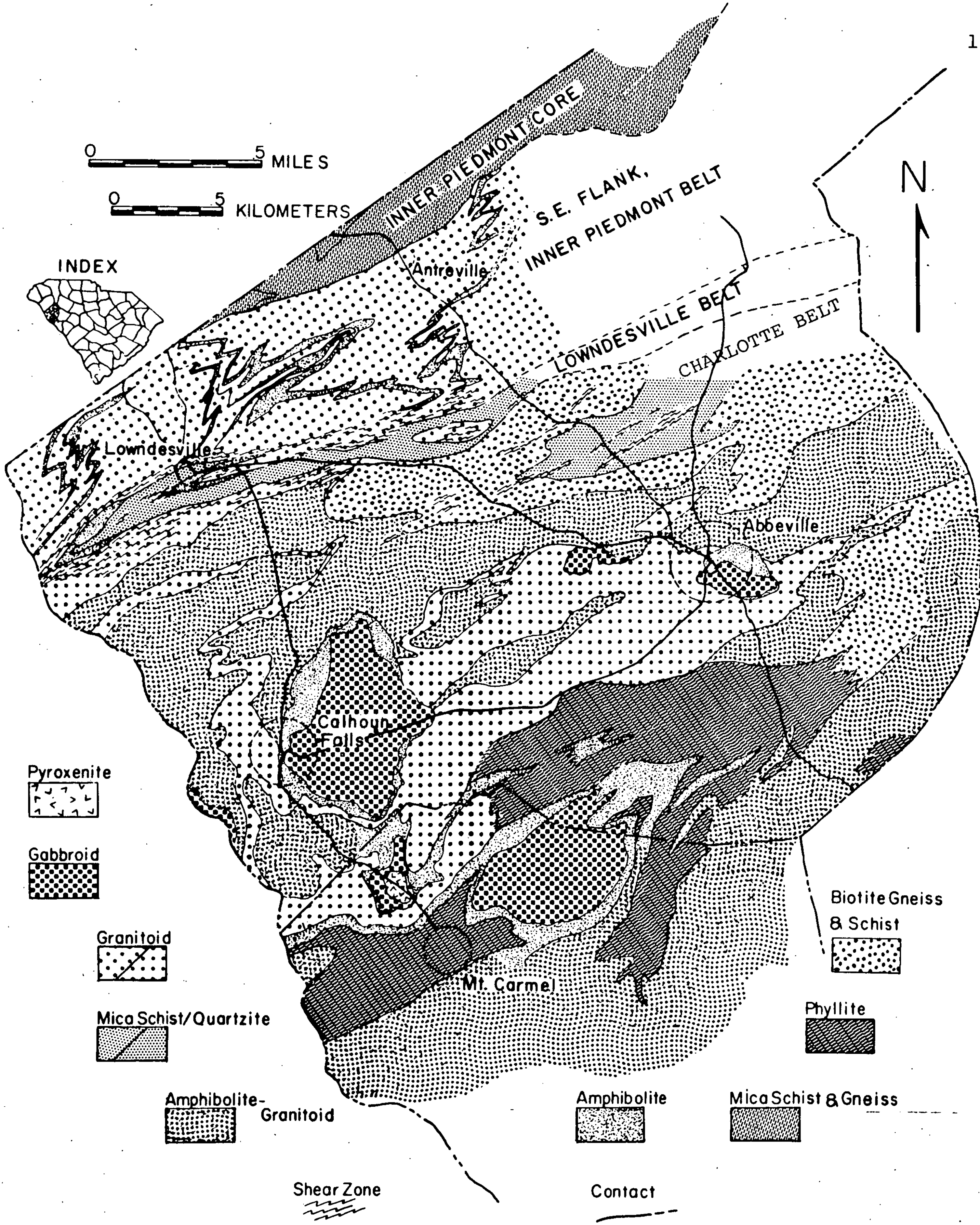


Figure 6. Preliminary geologic map of a major part of Abbeville County and northern McCormick County, South Carolina (from Griffin, 1972, p. 60).

This situation changes near the southern border of the photograph. Here a very strong lineament (L-6) trend runs across the Savannah River from Georgia and extends with clear photographic expression to Lake Murray. A cataclastic zone, similar in character to the Lowndesville belt, occupies this lineament and has been report by Tewhey (1963) in the Lake Murray area. Both W. A. Pirkle and V. S. Griffin, Jr. have observed it in Edgefield County. Linear trends northwest of the Lowndesville belt generally have a more northeasterly direction, although between Due West and Laurens more easterly trends occur adjacent to the Lowndesville belt. The trends of the southeast flank of the Inner Piedmont belt (Griffin, 1972, p. 63, fig. 1) have less continuity than comparable features farther southeast (fig. 6).

The Calhoun Falls and Mt. Carmel gabbroid complexes (Griffin, 1972, fig. 1) have expression in part within the photograph (fig. 4, G), as does the small satellite body immediately south of the Calhoun Falls complex. Gabbro is a dark rock composed mostly of aluminum silicates of calcium, magnesium and iron. The signature is no better than that seen on topographic maps with forest overlays, because extensive farming and pasturing are conducted in these fertile areas. The Abbeville gabbroid complex is not recognizable owing to its smaller area and partly because of relatively less cultivation in the urbanized Abbeville area.

Land-use patterns

Urban, forested, floodplain and water areas are obvious to the viewer of S190B transparencies, but all the foregoing areas are more sharply visible on S190A color IR transparencies although in less detail. Carolina bays and beach ridges are readily observed on EREP pass 51, ground track 19 in the Atlantic Coastal Plain (fig. 2).

Mining operations (fig. 3) can be located on S190B photography but the smaller mines and quarries were not observed partly because less bare soil is exposed and also dense vegetation can mask such smaller area activity. Cultivated lands and pasture could not be distinguished visually but regular agricultural patterns, for example, could be observed in the valley of the Wateree River (EREP pass 51 ground track 19).

The nuclear power plant site in South Carolina for South Carolina Electric and Gas Co. and for Duke Power Co. is each located on Frame 287 (EREP pass 36, ground track 43) on S190B. Preliminary engineering work has been done at the Duke site but SL3 photography clearly indicates the difference between little grading at the Duke site and the more advanced stage of construction at the SCE&G site (fig. 2).

Urban growth and economic development were compared for the Myrtle Beach area (fig. 7) by using special NASA U-2 color IR transparencies (Table 1). Enlarged prints (10x10 in) were obtained by our team and this increased the scale from 1:500,000 to 1:100, 000. Unfortunately, the contact photographs were slightly out of focus, thus preventing detection of the more detailed land use in the area. Both the size of the urbanized area and its intensity, according to U. S. Department of Agriculture aerial photographs (1968), have substantially increased since 1937, the edition of the USGS topographic base map (fig. 7). The U-2 color IR transparencies clearly show the present tidal marshlands and the swampy inland area, both of which affect the land-use patterns. Very

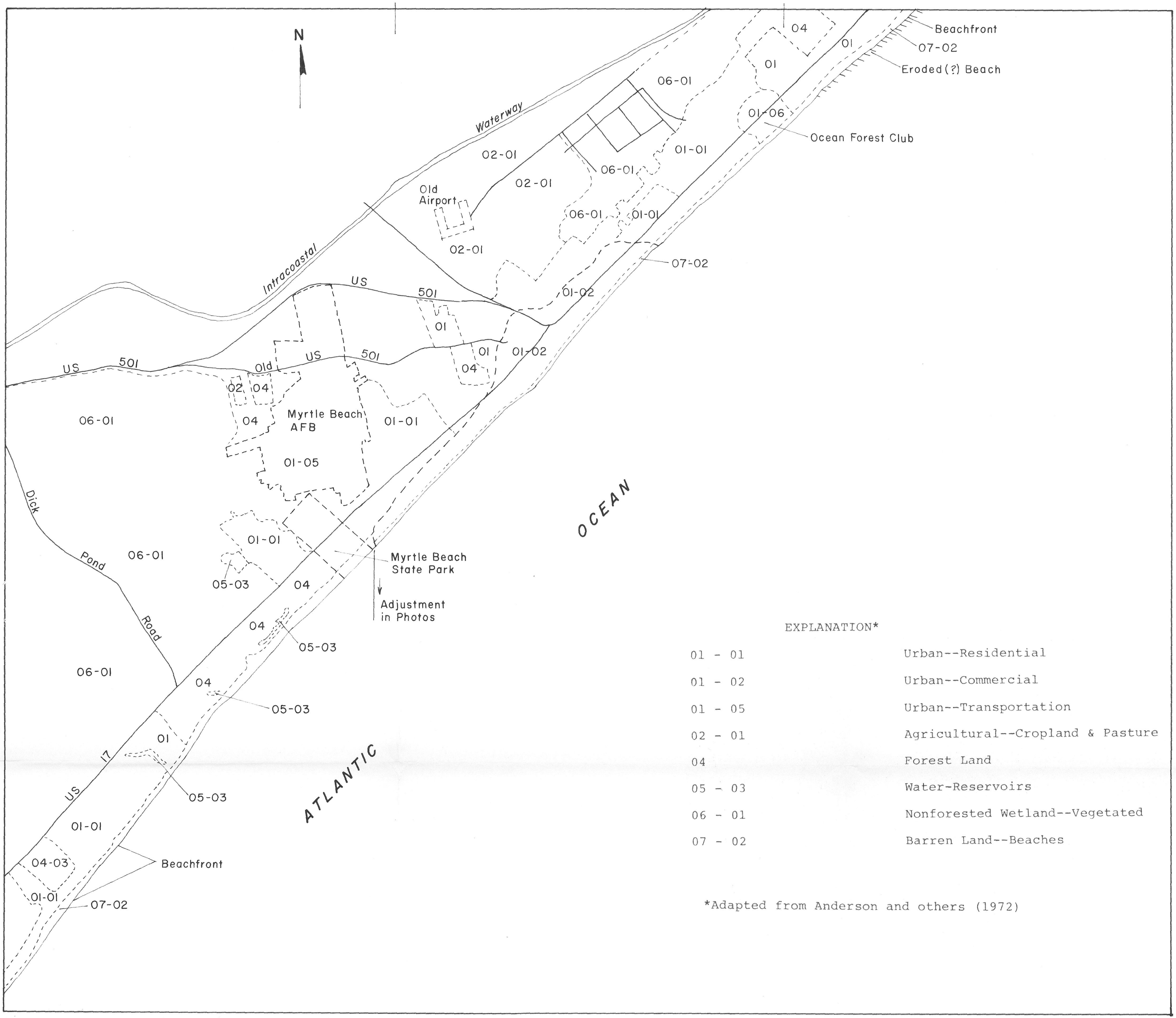
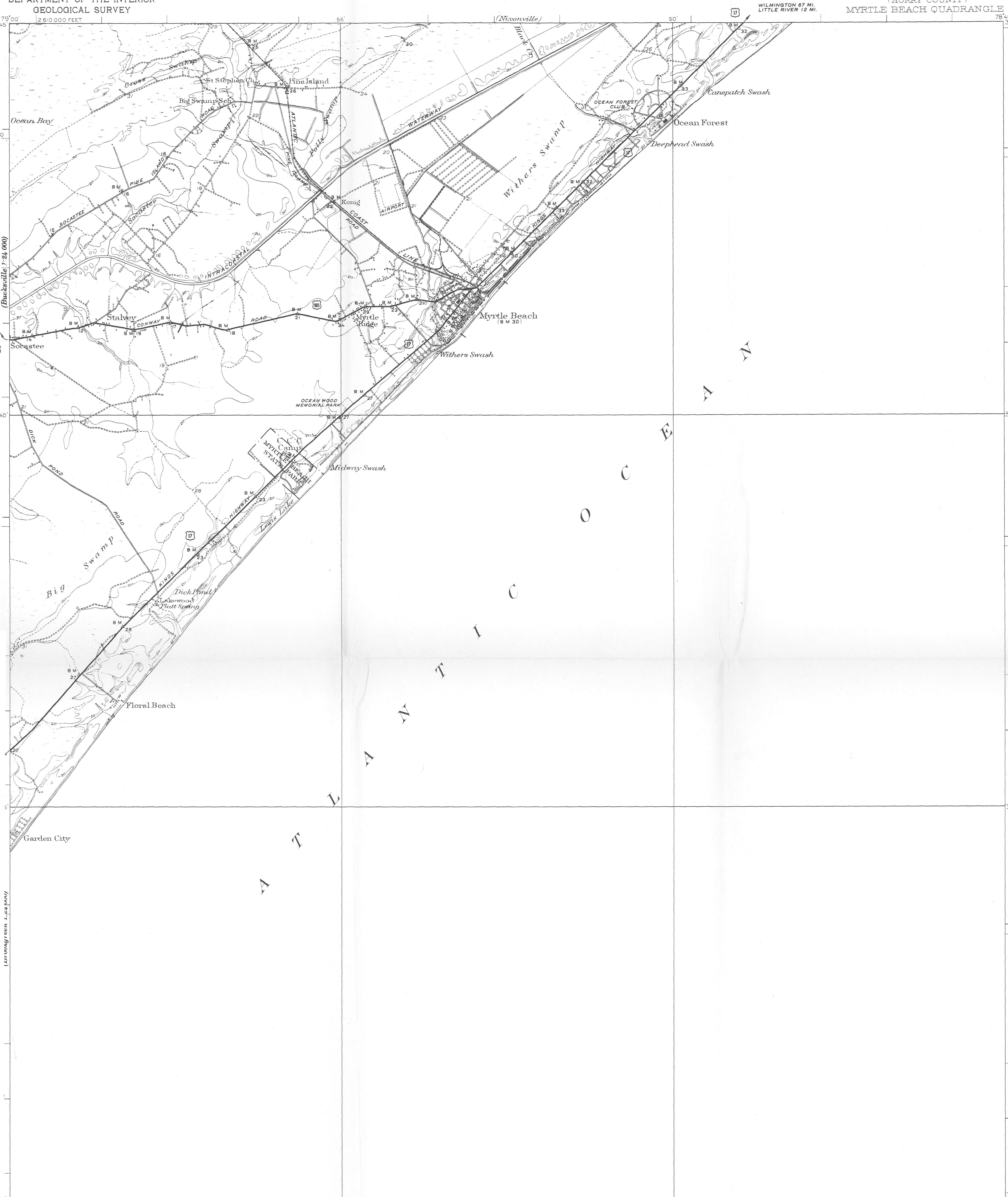


Figure 7. Changes in land-use patterns from 1937 to 1968. Map overlay was traced from 1968 U. S. Department of Agriculture photo index #7 of Horry County, South Carolina. Base (topographic) map from 1937 Myrtle Beach quadrangle (USGS, 1:62,500).

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOUTH CAROLINA
(HORRY COUNTY)
MYRTLE BEACH QUADRANGLE



Topography by R.J.Belton
Culture and drainage in part compiled from aerial photographs
Surveyed in 1936-1937

1 205 000 YARDS

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965

2 680 000 FEET

190 000 FEET

TRUE NORTH
MAGNETIC NORTH
2°
APPROXIMATE MEAN DECLINATION, 1937

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles
5000 0 5000 10000 15000 20000 Feet
1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 10 feet
Datum is mean sea level

Polyconic projection. 1927 North American datum
5000 yard grid based on U.S. zone system, B
10000 foot grid based on South Carolina (North) rectangular coordinate system

ROUTES USUALLY TRAVELED
HARD IMPERVIOUS SURFACES
OTHER SURFACE IMPROVEMENTS
1940
U. S. ROUTE
STATE ROUTE

MYRTLE BEACH, S. C.
N3330—W7845/15
1937

little intense urban development has yet occurred inland from U. S. Highway 17 in the Myrtle Beach area.

Development of roads and housing in rural areas is taking place along ridges and higher areas in the Piedmont, while development in more urban areas occurs more randomly (for example, frames 351 and 352). In many places in the more urbanized areas it appears that construction of housing or other structures has taken place in flood-prone areas. Large (50 - or 100 -) year) floods would result in heavy property damage.

The overall drainage pattern developed in the Piedmont is random (in frames 351 and 352); yet, closer examination of meandering reaches of major and minor streams exhibits control by the joint-directed lineaments mentioned above.

SL-4: Geologic Interpretation and Land-Use Patterns

Introduction

Bulk color transparencies from both S190A and S190B cameras, in contacts and enlargements were received from the SL-4 mission. All photographs were from EREP pass 54 (descending), ground track 19 (fig. 8). A summary of the data products received, and brief remarks, are presented in Table 2.

General Geologic Comments

Three frames were selected from the S190B enlargements (2x). Frames 044, 046, and 049 are representative of the Blue Ridge, Piedmont and Atlantic Coastal Plain provinces, respectively, in South Carolina and adjoining areas. Frame 044 contains the prominent Blue Ridge escarpment, Hartwell Reservoir and Tallulah gorge on the Savannah River, and the site of a major U. S. nuclear fuel reprocessing plant. Frame 046 contains two small, active earthquake zones, Clark Hill Reservoir, and the Fall Line area

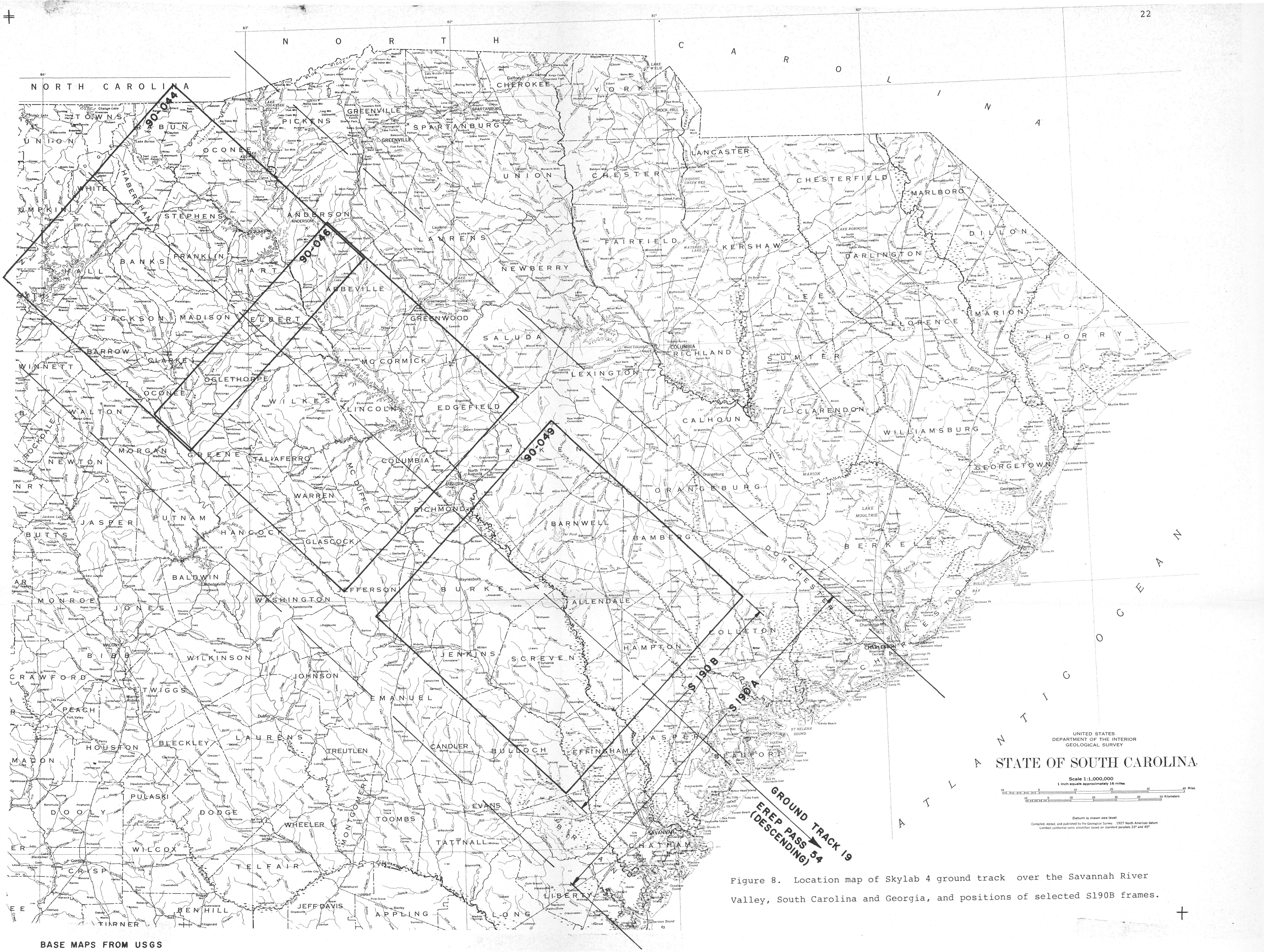


Figure 8. Location map of Skylab 4 ground track over the Savannah River Valley, South Carolina and Georgia, and positions of selected S190B frames.

Table 2. Skylab/EREP (SL-4) photography over South Carolina and adjacent states received from NASA during 1974 and early 1975.

Sensor	Image Size	Scale (approx).	Conversion factor* 1:1,000,000 base map	EREP pass/ ground track	Film magazine/ frames	Remarks
S190A Multispectral Camera Facility	2-1/4"x2-1/4" (contact)	1:2,800,000	2.8	54/19	52/66-79	Overall quality on pass 54 (descending pass), magazine (roll) 52 good; all in color, no color IR. Nearly all photographs along track 19 are along Savannah River Valley. From northwest to southeast general geographic limits are the Chattanooga and Copperhill areas in Tennessee to several miles seaward of Savannah, Georgia.
	9 x 9 in.	1:700,000	0.7	54/19	52/66-79	
S190B Earth Terrain Camera	4-1/2x4-1/2 in.	1:1,000,000 (closer to 1:933,000)	1.0	54/19	90/39-55	Overall quality on pass 54, magazine 90, good to excellent. Three S190B frames were selected from the 9 x 9 in. enlarged transparencies (S190A corresponding frames in parentheses) as follows: 044 (069) - Hartwell Dam, Lakes Hartwell and Lanier (Ga.); Brevard zone; Savannah, Tugaloo and Chattooga Rivers; Talullah gorge; Gainesville, Athens, and Elberton, Ga.; Edgefield, Anderson (part), and Seneca (part), S. C.; I-85. 046 (070) - Clark Hill Dam and Reservoir; Savannah, Ogeechee, Salkehatchie and Coosawhatchie Rivers; Augusta (part), Athens, Thomson, Sylvania, and Elberton, Ga.; Allendale, Barnwell, Williston, and New Ellenton, S.C. 049 (072) - Savannah River Plant; Savannah, Ogeechee and South Fork Edisto Rivers; Augusta, Ga.; Aiken, and Langley, S.C.; I-20.
	9 x 9 in.	1:500,000	0.5	54/19	90/39-55	

* Multiplication factor needed to plot and transfer ground tracks and frames from transparencies to South Carolina base map (USGS, scale 1:1,000,000).

(Piedmont-Atlantic Coastal Plain boundary). Frame 049 contains the Savannah River Plant (ERDA), karst topography (sinkholes), numerous Carolina bays (elliptical depressions of uncertain origin), and undeveloped sandstone outcrops.

Specific geologic comments--S190B frame 044

The area covered by this frame extends from the Anderson-Clemson, South Carolina area to the Gainesville-Athens, Georgia area (fig. 9). It spans the central and westerns portions of the Mobilized Inner Piedmont, the Chauga belt, the Alto allochthon resting upon Chauga belt rocks from near the Georgia-South Carolina border to near Gainesville, the Brevard Zone and the eastern edge of the Blue Ridge.

Red soils dominate the Piedmont in the south and southeast sides of the photograph, as well as in the northwest portion. These red soils probably were derived from amphibolites. Lighter tan soils derived from granitic gneisses dominate the central part of the Piedmont portion of the photograph.

Many lineaments, likely fracture controlled, are visible in the Blue Ridge as northwest and northeast sets. A strong nearly east-west fracture set is present in the Blue Ridge of northeast Georgia along the crest and north flank of the Tallulah Falls dome. Several of these lineaments have siliceous mylonite along them but geologic contacts can be traced across them with no offset (Hatcher, 1974). A similar nearly east-west set of siliceous mylonite bearing fractures has been recognized in the Mobilized Inner Piedmont by R. D. Hatcher (1975, written commun). These also have the property of not offsetting contacts. The east-west set in the Piedmont is accompanied by a north-north-

Figure 9. Overlay to NASA SL-4 frame 044, magazine 90, ground track 19, EREP pass 54 (descending). S. 190B enlarged (2x) color transparency, scale 1:500,000. L_1 through L_3 belong to same lineament group as many more indicated in Figure 10. L_4 - L_7 are Brevard zone lineaments, locally parallel to the Blue Ridge escarpment. L_8 - L_{13} are Blue Ridge lineaments. NFR = nuclear fuel reprocessing plant site.

west set.

Lineaments in the Blue Ridge are so numerous that only several prominent ones were labeled. The Chattahoochee River, structurally controlled here near its headwaters, flows more or less parallel to many fracture or joint traces which are roughly aligned with the Blue Ridge escarpment in a general northeasterly direction. L_1 through L_3 are generally east-northeast; L_1 is the same lineament as L_1 of frame 046 (fig. 10). L_4 through L_{13} include only the more prominent lineaments locally within the Blue Ridge and these range in their general directional trend from northeast to east-northeast.

Low mountains in the northwest part of this frame express several things: (1) The northeast-southwest fracture pattern in the Chauga belt rocks along the Georgia-South Carolina border. (2) Dip-slope-scarp-slope relations in the mountains northeast of Gainesville, Georgia, indicate the rocks dip northwestward here. Investigations on the ground verify this and show that this is the southeast edge of the Alto allochthon which rests atop the Chauga belt rocks in this area. (3) The strong northeast Brevard Zone lineament (L_6) may be seen crossing the state line at Yonah Dam. (4) The contrast in lineament pattern (L_8-L_{13}) in the area near Clayton, Georgia, to the Brevard lineament. Structural features, in addition to fracture patterns, may be delineated by the shapes, linearity and spacing of ridges and valleys and by the distribution of vegetation patterns in areas where there is some farming.

Specific geologic comments--S190 frame 046

The outstanding features in this color transparency of the

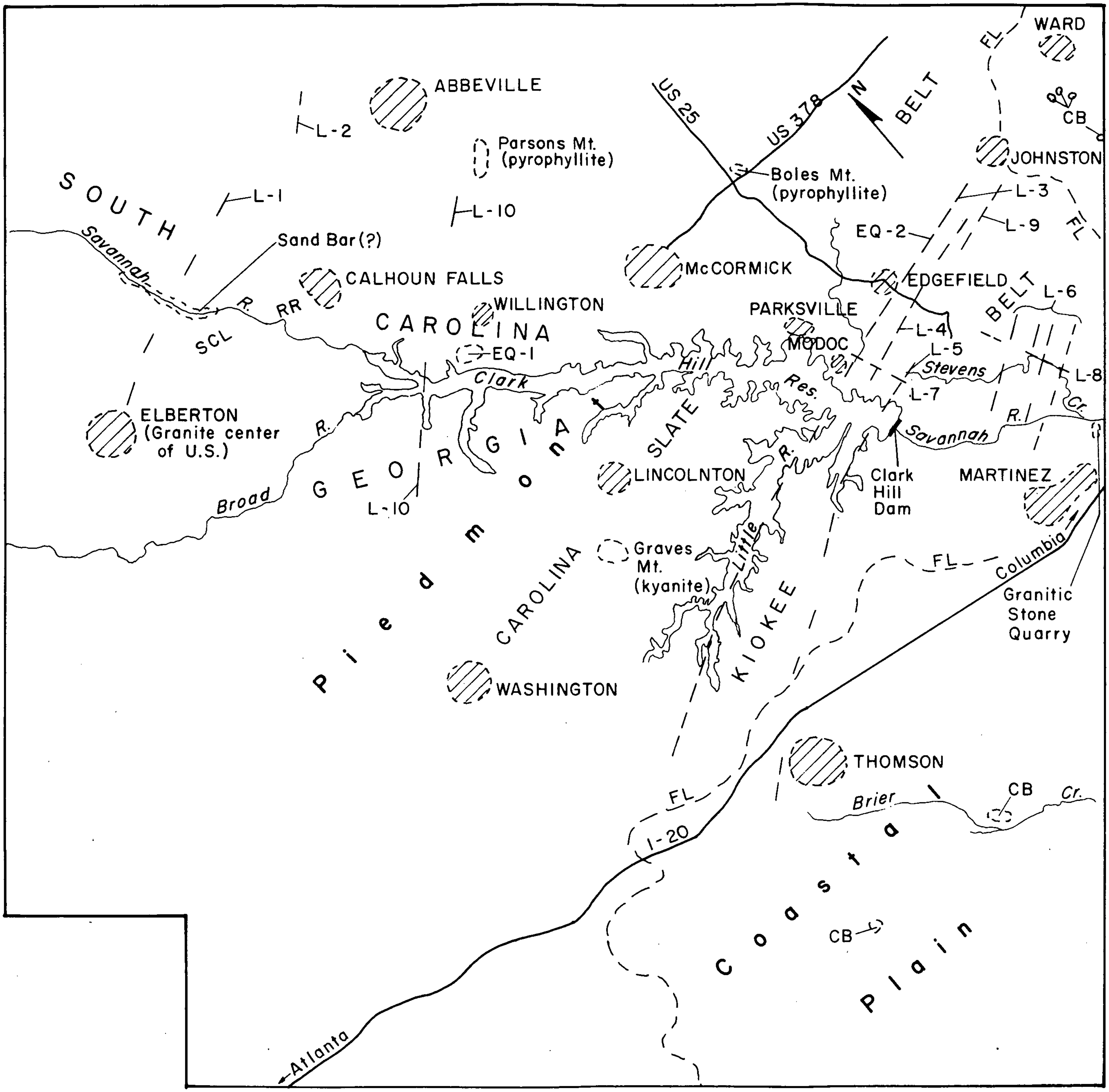


Figure 10. Overlay to NASA SL-4, frame 046, magazine 90, ground track 19 (Savannah River Valley), EREP pass 54 (descending). S190B enlarged (2x) color transparency, scale 1:500,000. L_1 through L_{10}: fracture or joint lineaments (L_1 same as L_1 of Figure 9). FL: Fall Line area which separates crystalline rock units of the Piedmont from sedimentary rock formations of the Atlantic Coastal Plain. CB: Carolina bays, elliptical depressions of uncertain origin. EQ-1, -2: earthquake areas of activity since 1974.

area surrounding Clark Hill Reservoir are the fracture trace lineaments. More field and instrument verification is needed to support any definite statements about geologic structure of the area, but there is a strong suggestion of modern instability along a general NE-SW trend in the area. The lineaments marked L_1-L_{10} (fig. 10) are but a representation of perhaps two or three times the number of observable fracture traces. Skylab photography reveals this area--particularly within the Piedmont near the Savannah River and along its tributary, Stevens Creek--as if a giant blade had come down and sliced the terrain into a multitude of parallel segments. The area has been studied by faculty members and graduate students of the Department of Geology, University of South Carolina, Columbia, and assisted by Division of Geology, S. C. State Development Board.

Earthquake epicenters lie in two general areas (fig. 10). An earthquake of magnitude 4.5 (Richter scale) occurred near Willington on August 2, 1974. This was followed by several hundred aftershocks, the largest of which was of magnitude 3.0 on December 3, 1974, concentrated in the area EQ-1 near L_{10} (Pradeep Talwani, 1975, oral commun). The second earthquake zone, designated EQ-2 (fig. 10), is believed to be an extension of the Goat Rock fault in Georgia and Alabama and lies along lineament L_3. The epicenters of felt earthquakes lie along the "Modoc trend" (town of Modoc, fig. 10). This trend identifies the fault boundary between two major crystalline rock suites, the Charlotte belt (generally granitoid rocks) and the Carolina slate belt (generally mudstone and slaty, schistose rocks) of Overstreet and Bell (1965). Geologic interpretation of aeromagnetic and aeroradioactivity mapping over the Savannah River Plant and vicinity (Daniels, 1974) indicated a fault contact between the Carolina slate belt to the north and the Kiokee belt (Crickmay, 1952; Charlotte belt of Overstreet and Bell, 1965) to the south. The same fault was indicated earlier on a geologic map of metamorphic rocks of the Appalachian Mountains (Morgan, 1972). Area EQ-2 of Dr. Talwani and his associates (fig. 10) lies within the Kiokee belt. A third monadnock is Graves Mountain near Lincolnton, Georgia. Graves, the only one of the three in which commercial mining is being conducted also contains pyrophyllite but kyanite is the mineral which is extracted and sold for refractory use.

The Fall Line area (FL in fig. 10) separates the Atlantic Coastal Plain sandy deposits of high photographic reflectance from the weathered clay-rich crystalline rock units of the Piedmont.

Other geologic features are Parsons Mountain and Boles Mountain, both monadnocks (erosional remnants) containing pyrophyllite, an uncommon aluminum silicate mineral used in refractories.

The granitic stone quarry northeast of Martinez is operated by a major crushed stone producer. Much of the stone produced there is sold for railroad ballast (roadbed material) because of its superior hardness. The quarry also offers the best exposures in the area for Kiokee belt rock units. Within the Elberton, Georgia area more granite (dimension and crushed) is produced than anywhere else in the nation; however, the quarries were not plotted on the overlay (fig. 10) because no ground verification was conducted.

A few miles southwest of the town of Ward, and also south of Thomson, Georgia, Carolina bays, geologic features observable only in the Coastal Plain, are present as well as segments of terrain suggesting former solution features like sinkholes even though no limestone is known to occur in the area today. Limestone and other sedimentary rock units approximately 30 miles to the southeast thicken toward the Atlantic Ocean.

Specific geologic comments--S190B frame 049

Some geologic and geomorphic, and hydrologic features are visible with good resolution, considering the altitude of Skylab 4 (fig. 11). The boundaries of the Savannah River Plant (SRP) under the Energy Research and Development Administration, and its internal highways and principal installations have good resolution, largely due to the fact that most of the area has been reforested. Parr Pond, used to cool process water, is the most striking water feature which can be seen within the SRP boundary. Upper Three Runs Creek and other subsequent tributaries are not easily traceable on the film and do not show their asymmetrical form.

The major consequent streams are most prominent in this frame owing largely to the presence of wide flood plains. The major extended consequent stream, the Savannah River, is the most prominent, and its junction with the Fall Line is readily apparent in the sharply reduced width of its flood plain at that point (left edge of fig. 11).

The Citronelle scarp is not easily traceable on the film although its location could roughly be indicated from the concentration and distribution of definitive Carolina bays. Solution depressions are also indicated in this area, but not as readily discernible as in aerial photography.

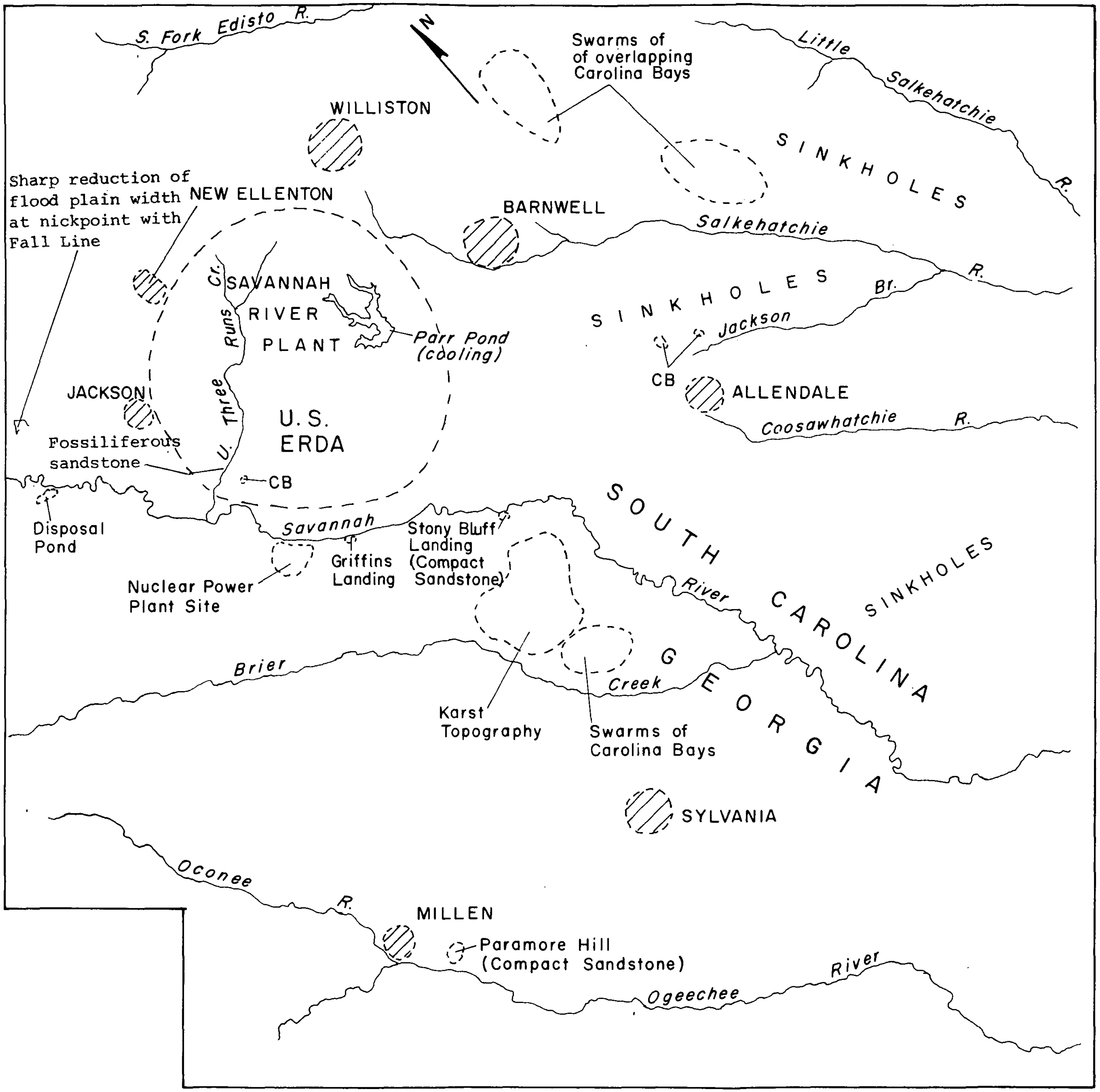


Figure 11. Overlay to NASA SL-4 frame 049, magazine 90, ground track 19, EREP pass 54 (descending). S190B enlarged (2x) color transparency, scale 1:500,000. Central Savannah River Area, South Carolina and Georgia. CB: Carolina bays. Karst topography and sinkholes are synonymous.

More extensive field work is needed to verify the causes for deflection of some major and minor streams in the SRP - Allendale area. Known faulting occurs in rock units of Triassic age there. Discontinuities on the aeromagnetic map of the area (Petty and others, 1965) suggest additional faults in younger rocks of the area.

Land-use patterns

Development of roads and housing in the Piedmont is taking place along ridge tops and higher areas, whereas in the Blue Ridge and Valley and Ridge development follows the valleys for the most parts.

The overall drainage pattern developed in the mobilized Inner Piedmont is random but somewhat fracture controlled. Fracture control of drainage is particularly evident in the Chauga belt along the Georgia-South Carolina border (Frame 90-044). Drainages in the Blue Ridge are more or less random with some fracture control and local control by less resistant rock units, as in the Murphy belt (Frame 90-042). The Valley and Ridge of East Tennessee has strong structural control of drainage with trellis patterns produced on subsequent streams by the tilted rocks and contrasting resistance to weathering.

APPLICATIONS

Mineral Resources

Within the South Carolina areas of the ground tracks covered by Skylab missions SL-3 and SL-4 several important mineral resources (known and potential) occur. Sandstone, granitic stone (dimension and crushed), silica sand (construction, glass), marble, sillimanite, kaolin, fuller's earth, common clays and possibly limestone are among the most important ones.

Skylab photography gives a synoptic view in color, black-and-white, and combinations of these in infrared like no other sensors available to us. This ability to view stream patterns, structural lineaments and other surface geologic features is a more useful tool in the planning and beginning stages of mineral exploration. Ore-forming fluids (Piedmont and Blue Ridge) and many stratiform ore deposits (Coastal Plain) are localized by structural control such as joints, fractures and related features. Detection of fracture traces, faults, and other lineaments is one of the major uses of Skylab and other satellite photography and imagery by geologists.

Land Resources

Basic data for the main land resource application of this investigation came from the high altitude color infrared photography furnished by the NASA U-2 flight along the South Carolina coast (fig. 2). The U-2 color IR transparencies and the enlarged prints, already described, were used along with the 1968 U.S. Department of Agriculture black-and-white photo index to delineate land-use patterns in the Myrtle Beach area (fig. 7).

The U-2 transparencies were the first known color IR scenes available for the South Carolina coastline. Future flights should verify this limitation because of the details required for land-use mapping. Furthermore, "ground truth" determination of level II land-use classification of Anderson and others (1972)--not conducted by our EREP team--is necessary in preparing any detailed land-use map.

Skylab photography is useful for showing large areas of river floodplains, Carolina bays, karst terrain, beach ridges, marshlands, and hilly or mountainous topography--all natural land resources which must be considered in effective land-use planning and management. Skylab and associated aircraft photography provide unique combinations of sensors not available anywhere else, particularly in preparing a statewide land-use map.

CONCLUSIONS

Any visual interpretation of satellite photography in the southeastern United States is aided greatly by color films. Decomposition of rock units in the Piedmont and the resulting iron oxides produces a reddish tint to most of the soils. Variations in the degree of oxidation of the iron-bearing minerals can be seen in the larger bare soil areas, as in the nuclear power plant site of the South Carolina Electric and Gas Company.

We have had good results from using Skylab photography in conjunction with LANDSAT imagery for visual interpretation of various geologic features, particularly lineaments. Our team feels that visual interpretation alone of Skylab photographs is quite limited, and much of this is because of the low-contrast, heavily vegetated terrain in our part of the United States. Lineaments of major structural features are detectable but subtle. One actually has to have an intimate knowledge of the geologic field relationships before a meaningful analysis is feasible using current satellite photography alone. However, it is possible that a geologist initiating a mapping study in the South Carolina Piedmont could find this photography helpful as he maps the rock units, because it will point out some lineaments of potential major structural importance which could be checked out very early in the project.

S190B enlargements (2x) from both SL-3 and SL-4 provided some excellent frames at a good working scale (1:500,000) for visual interpretation. Skylab photography should be used in conjunction with similar data products, at varying scales, from conventional aircraft.

Our team from the beginning of the proposal wanted to participate in the NASA Skylab/EREP program as a unique learning experience. We stated as an original objective some land use applications but it later developed that we were very limited in both manpower and expertise. Work of better quality should have been accomplished. Although we have many techniques yet to learn we now can apply the information and skills gained from our many months as South Carolina investigators in the Skylab program.

REFERENCES

Acker, L. L., and Hatcher, R. D., Jr., 1970, Relationships between structure and topography in northwest South Carolina: South Carolina State Devel. Board, Div. Geology Geol. Notes, v. 14, p. 35-38.

Anderson, J. R., Hardy, E. E., and Roach, J. T., 1972, A land-use classification system for use with remote-sensor data: U. S. Geol. Survey Circ. 671, 16 p.

Birkhead, P. K., 1973, Some flinty crush rock exposures in northwest South Carolina and adjoining areas of North Carolina: South Carolina State Devel. Board, Div. Geology Geol. Notes, v. 17, p. 19-25.

Butler, J. R., 1966, Geology and mineral resources of York County, South Carolina: South Carolina State Devel. Board, Div. Geology Bull. 33, 65 p.

Conley, J. F., and Drummond, K. M., 1965, Ultramylonite zones in the western Carolinas: Southeastern Geology, v. 6, p. 201-211.

Crickmay, G. W., 1952, Geology of the crystalline rocks of Georgia: Georgia Geol. Survey Bull. 58, 54 p.

Daniels, D. L., 1974, Geologic interpretation of geophysical maps, central Savannah River area, South Carolina and Georgia: U. S. Geol. Survey Map GP-893 (with text + three maps), scales 1:250,000 and 1:500,000.

Griffin, V. S., Jr., 1972, Progress report on a geologic study in Abbeville and McCormick Counties, South Carolina: South Carolina State Devel. Board, Div. Geology Geol. Notes, v. 16, n. 3, p. 59-78.

Hatcher, R. D., Jr., 1974, An introduction to the Blue Ridge tectonic history of northeast Georgia: Georgia Geol. Survey Guidebook 13-A, 60 p.

Keith, Arthur, and Sterrett, D. B., 1931, Description of the Gaffney and Kings Mountain quadrangles (South Carolina-North Carolina): U. S. Geol. Survey Geol. Atlas, Folio 222, 13 p.

McCauley, J. F., 1961, Relationships between the Carolina slate belt and the Charlotte belt in Newberry County, South Carolina: South Carolina State Devel. Board, Div. Geology Geol. Notes, v. 5, p. 59-66.

Morgan, B. A., 1972, Metamorphic map of the Appalachians: U. S. Geol. Survey Map I-724 (with text), scale 1:2,500,000.

Overstreet, W. C., Yates, R. G., and Griffitts, W. R., 1963a, Geology of the Shelby quadrangle, North Carolina: U. S. Geol. Survey Misc. Inv. Map I-384, scale 1:62,500.

Overstreet, W. C., Whitlow, J. W., White, A. M., and Griffitts, W. R., 1963b, Geologic map of the southern part of the Casar quadrangle, Cleveland, Lincoln and Burke Counties, North Carolina, showing areas mined for monazite and mica: U. S. Geol. Survey, Misc. Inv. field studies map MF-257, scale 1:24,000.

Overstreet, W. C., and Bell, Henry, III, Geologic map of the crystalline rocks of South Carolina: U. S. Geol. Survey Misc. Geol. Inv. Map I-413 scale 1:250,000.

______, 1965, The crystalline rocks of South Carolina: U. S. Geol. Survey Bull. 1183, 126p.

Petty, A. J., Petrafeso, F. A., and Moore, F. C., Jr., 1965, Aeromagnetic map of the Savannah River Plant area, South Carolina and Georgia: U. S. Geol. Survey Geophys. Inv. Map GP-489.

Tewhey, J. D., 1973, The transition between metamorphic belts on the southeastern edge of the Carolina slate belt (Abs.): Geol. Soc. America Abstracts with Programs, S. E. Section, p. 443.

APPENDIX

Distribution

NASA-MSFC
Marshall Space Flight Center, AL 34812
A&PS-PR-RS
A&PS-MS-D
A&PS-TU
EFO 2

NASA Scientific & Technical Information Facility, Code KS
Washington, D. C. 20546

EREP Principal Investigations Office, Code TF 6
Lyndon B. Johnson Space Center
Houston, TX 77058

NASA-Lyndon B. Johnson Space Center
Houston, TX 77058
EREP Principal Investigations Office
Code TF 6

Earth Resources Program Office
Attn: R. K. Stewart, Mail Code HD

Regional Planning and Development/Cartography
Code TF-6-75-5-38

Facility and Laboratory Support Branch

Technical Library Branch, Mail Code JM6

Management Services Division, Mail Code JM7

Co-Investigators and Advisors, South Carolina EPN 507