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EVALUATION OF ERTS-1 IMAGERY FOR SPECTRAL
GEOLOGICAL MAPPING IN DIVERSE TERRANES OF
NEW YORK STATE

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Geological Survey - New York State Museum
and Science Service

October 20, 1972
Type II Report for Period June - October, 1972

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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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(E72-10302) EVALUATION OF ERTS IMAGERY
FOR SPECTRAL GEOLOGICAL MAPPING IN
DIVERSE TERRANES OF NEW YORK STATE
by Y.W. Isachsen,
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16. Abstract <p>Preliminary visual examination of film positives of thirty ERTS-1 scenes obtained over New York State and adjacent areas from 28 July 72 to 5 September 72 indicates the following: 1) sixty percent of the imagery has a cloud cover of 70-100 percent, twenty five percent has a cloud cover of 0-30 percent, and the remainder has a cover of 40-65 percent, 2) on the useable imagery, the spectral lines which may turn out to be geologically-linked totals as follows: Spectral linears, 5200 km; broadly curved lines (spectral "curvilinears"), 700 km; major forest boundaries, 3100 km; areas with spectral geological fabric, 3100 km². In the central and northwest Adirondacks, known lineaments and faults were "subtracted" from the spectral linears leaving a "residue" which totals 160 km in the Central Adirondacks and 230 km in the northwest Adirondacks. It must be emphasized in this preliminary announcement that these are <u>spectral</u> linears which have not yet been checked out against any ground truth except geological.</p>					
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1. PREFACE

This reports presents a summary of accomplishments to date on a project to evaluate the usefulness of ERTS imagery in the preparation of a spectral geological map. The study concentrates on the geologically useable (i.e., sufficiently cloud-free) imagery obtained over New York State, although major new structural elements will be studied where they extend into adjacent regions. Work to date indicates that ERTS imagery is particularly well suited to detect linear and curvilinear structural elements. Twelve hundred miles of U-2 under-flight coverage are recommended.

2. INTRODUCTION

2.1

Prior to the launch of the ERTS I orbital satellite, the success of the terrain photography experiments conducted during the Gemini and Apollo missions had demonstrated the potential value of orbital photography for geological mapping and regional tectonic studies. This demonstration was of particular interest to three of the investigators (Y.W. Isachsen, D.W. Fisher, and L.V. Rickard) who had recently published a Geologic Map of New York State (Fisher and others, 1970) and are currently working on a Tectonic Atlas of the State. The potential of ERTS imagery to provide new regional geological data, particularly large scale linear and curvilinear elements, made the ERTS program especially attractive. The fourth co-investigator, R. Fakundiny, is concerned with the potential usefulness of ERTS imagery for mineral resource inventories and environmental geology. The geologically useable imagery received to date has been of interest primarily to Isachen and Rickard, authors of this report.

2.2.

The major objectives of this study are to evaluate the usefulness of ERTS imagery as a spectral-geological mapping tool in the highly diverse geological terraines of New York State, utilizing a vast store of ground truth, ground checking, and supplementary aircraft sensor data; to test spectral extrapolation of geology from well known into poorly known areas; to identify and analyze new geological anomalies certain to appear in ERTS imagery, using ground checking, underflights, and small aircraft as required.

2.3

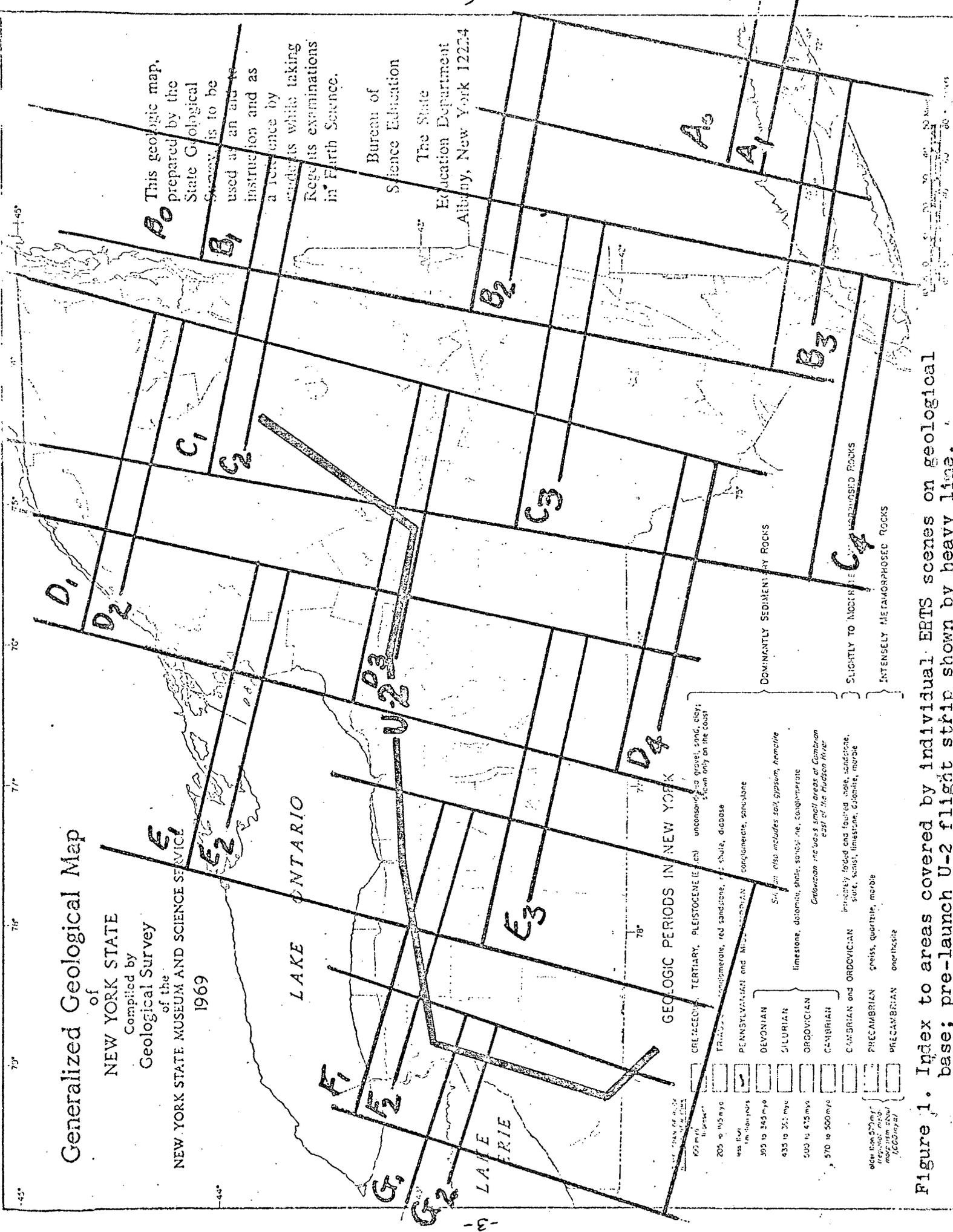
The logistic activities connected with establishing a working ERTSLAB have been essentially completed, and the laboratory is now fully functioning. A large (22' x 32') air-conditioned room has been rewired as needed and equipped with NASA-funded items as follows: Bausch and Lomb Zoom 240 Stereoscope mounted on a Richards Light Table MIM # 3, a Spectral Data Corporation Model 64 Multispectral Viewer-Projector, a Bruning Engineering Copier, a Paulin Surveying Microbarograph, and a heavy duty camera tripod. A large map case is yet to be delivered. The Department has furnished a drafting table, light table, map rack, small map file, and required office furniture. Standard filing cases are being ordered.

Generalized Geological Map

of
NEW YORK STATE
Compiled by
Geological Survey
of the
NEW YORK STATE MUSEUM AND SCIENCE SERVICE
1969

B₀ This geologic map, prepared by the State Geological Survey, is to be used as an aid to instruction and as a reference by students while taking Regents examinations in Earth Science.

Bureau of
Science Education
The State
Education Department
Albany, New York 12224



GEOLOGIC PERIODS IN NEW YORK

CRETACEOUS	TERTIARY, PLEISTOCENE (E ₁)	unconsolidated gravel, sand, clay; 500 m to 100 m thick
TRIASSIC	Triassic, Permian and Mississippian	conglomerate, sandstone, shale, diabase
PENNSYLVANIAN	Devonian	limestone, dolomite, shale, sandy shale, conglomerate
SILURIAN	Ordovician	limestone, dolomite, shale, sandy shale, conglomerate
ORDOVICIAN	Cambrian	limestone, dolomite, shale, sandy shale, conglomerate
CAMBRIAN	Pre-Cambrian	gneiss, quartzite, marble
PRE-CAMBRIAN	Pre-Cambrian	gneiss, quartzite, marble

Other units:

- 600 m to 100 m thick
- 200 to 100 m thick
- less than 100 m thick
- 300 to 345 m thick
- 435 to 755 m thick
- 500 to 475 m thick
- 570 to 500 m thick

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- 570 to 500 m thick

Figure 1. Index to areas covered by individual ERTS scenes on geological base; pre-launch U-2 flight strip shown by heavy line.

Orbit	Date	Product I.D.	Usable Imagery %				Locations of Usable Area	Photographs	Keypoints	Annotations	Useful Bands, in Decreasing Order	Examined via:	Geological Content				Remarks
			1	2	3	4							5	6	7	8	
A0	68	28Jul 72 1005-15005	30			4, 7	NO	NO	NA	NA	NA	SDC Settings	NA	NA	NA	NA	So. New England, tip of L.I.
A1	68	28Jul 72 1005-15011	10			1	NO	YES	✓	NONE							E. Long Island, LUC
B0	333	16Aug 72 1024-15055	25			1, 2, 5	NO	YES	✓	7, 5			150	100	250	-	Vermont and Canada
B1	333	16Aug 72 1024-15062	15			3, 6	NO	NO	NA	NA	NA	NA	NA	NA	NA	NA	Clear only in Vermont
B2	333	16Aug 72 1024-15064	20			4, 6, 8	NO	YES	✓	5, 7			80	80	200	-	
B3	333	16Aug 72 1024-15071	30			1, 2, 3, 4, 7	?	YES									To be done
C0	347	17Aug 72 1025-15112	15			2, 3	NO	NO	NA		NA	NA	NA	NA	NA	NA	Canada; orthogonal joint systems
C3	598	4 Sep 72 1043-15123	30			2, 5, 7, 8	NO	YES	✓	5, 7			450	90	250	-	
C4	598	4 Sep 72 1043-15130	35			1, 2, 3, 6	NO	YES	✓	7, 5			130	80	350	1800	Clear only in New Jersey and Pa.
D1	612	5 Sep 72 1044-15171	100			ALL	NO	YES	✓	5			180	-	550	-	LUC
D2	612	5 Sep 72 1044-15173	50			1, 2, 4, 5, 6, 9	?	YES	✓	7, 5			720	40	270	1300	
D3	612	5 Sep 72 1044-15180	20			3, 9	NO	YES	✓	7, 5			680	20	100	-	
D4	612	5 Sep 72 1044-15182	20			3, 5, 7	NO	YES	✓	6, 5 (7 not recd)			600	-	550	-	

fb = forest boundary
 Cf = area showing geological fabric
 LUC = Land use camouflage
 FOLDOUT FRAME 1
 FOLDOUT FRAME 2

Orbit	Date	Product I.D.	Imagery Quality %	Locations of Useable Area				Photogrammetry	Reprocessing	MORT annotation	Annotation on Master	Useful Bands, in Decreasing Order	Examined via:	Spectral Content			Remarks
				4	5	6	7							8	9	L, K, Cl, Km	
D4	18Aug 72	1026-15182	<10	5			NO	NO	NO	NA		NA	NA	NA	NA		
D5	18Aug 72	1026-15182	<5	8			NO	NO	NO	NA		NA	NA	NA	NA		
E0	1Aug 72	1009-15223	0	-			NO	NO	NO	NA		NA	NA	NA	NA		
E0	19Aug 72	1027-15224	>90	ALL			NO	NO	NO	NA		NA	NA	NA	NA	Canada only	
E1	1Aug 72	1009-15230	0	-			NO	NO	NO	NA		NA	NA	NA	NA		
E1	19Aug 72	1027-15231	90	ALL			YES	YES	YES	✓	5, 7	NA	540	120	-		
E2	1Aug 72	1009-15232	30	5, 6, 7, 8, 9			NO	NO	NO	NA		NA	NA	NA	NA	LUC	
E2	19Aug 72	1027-15233	70	ALL			YES	YES	YES	✓	5, 7		280	100		+160 Km Helderberg Contacts +Finger Lake Trends LUC	
E3	1Aug 72	1009-15235	45	2, 3, 5, 6, 8, 9												To be done	
E3	19Aug 72	1027-15240	70	1, 2, 3, 4, 5, 6			NO	YES	YES	✓	5, 7		1100	-	550		
E4	1Aug 72	1009-15241	55	2, 3, 5, 6, 9			NO	NO	NO	NA		NA	NA	NA	NA	Pa. only	
E4	19Aug 72	1027-15242	15	6, 9			NO	NO	NO	NA		NA	NA	NA	NA	Pa. only	
F2	2Aug 72	1010-15292	0	-			NO	NO	NO	NA		NA	NA	NA	NA	NA	

liners Fb = forest boundary
curvilinear GF = area showing geological fabric

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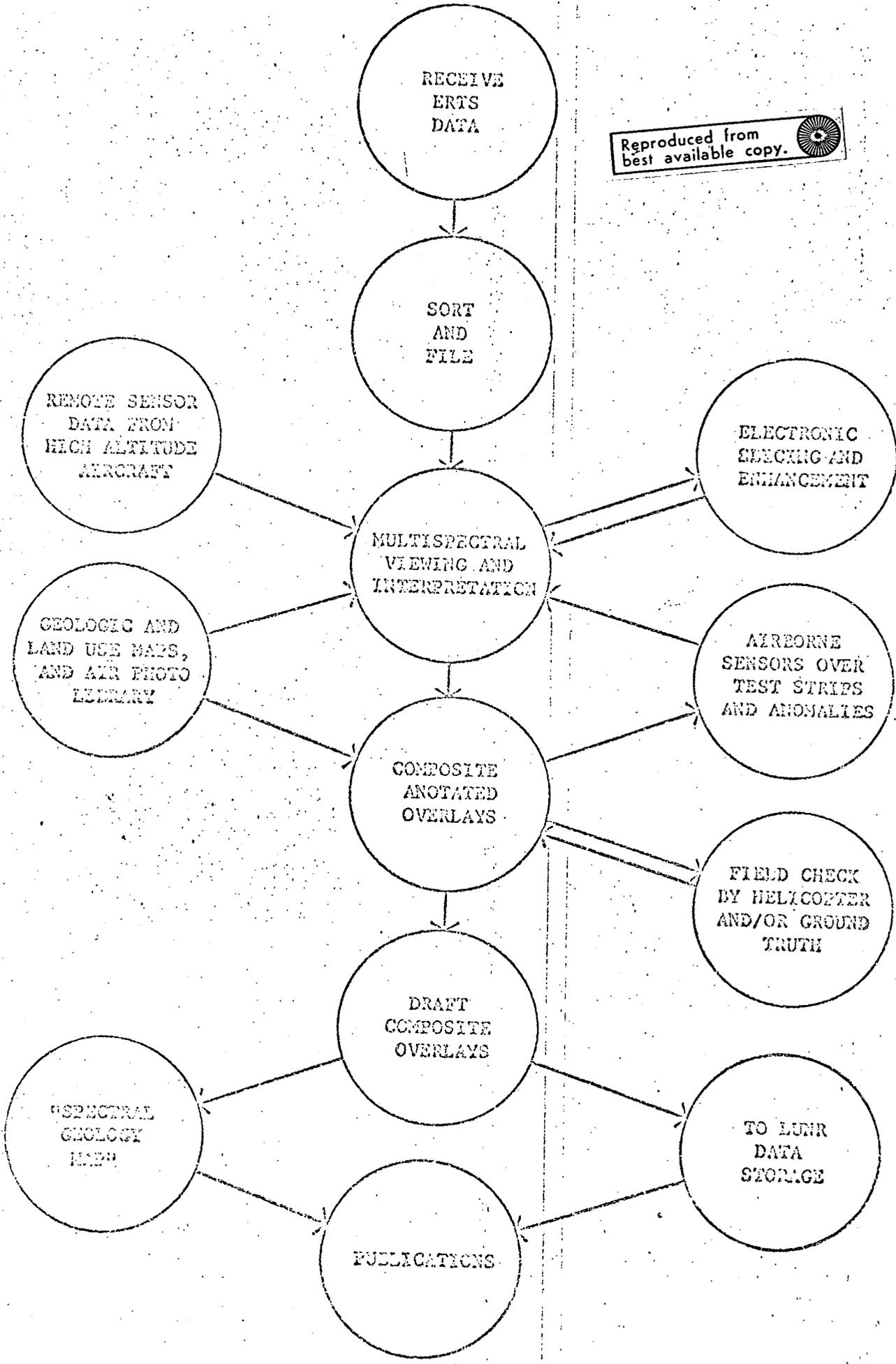


Figure 2. Flow chart of imagery analysis

- 2.4 At this writing, thirty ERTS scenes have been received covering the area of interest (Table I, Figure 1). Of these, fifteen are geologically useful in terms of cloud cover (percent and distribution) and geographic location. The procedures developed for handling these data are summarized in the next section.

3. DATA HANDLING

3.1 Introduction

- 3.1.1 The overall data handling plan is shown by flow chart in figure 2. In terms of goals, the data handling may be subdivided into three stages as follows:

Stage I: Recognition of all spectral signatures which may be geologically-linked.

Stage II: Evaluation of these signatures in terms of existing information (unpublished and published) in order to identify them as either:

- a. clearly non-geological (e.g., highways, power transmission lines, forest fire burn areas).
- b. clearly geological (e.g., known faults, topographic lineaments, formational boundaries), or
- c. Unexplained (spectral anomalies).

Stage III: Field investigation of the spectral anomalies identified above.

3.2 Data-handling procedures for ERTS imagery:

Stage I procedures routinely include steps 1, 2, and 3 and apply to all imagery received. Steps 4, 5 and 6 may be applied to both stage I and Stage II investigations. Step 7 applies to Stage III investigation of spectral anomalies.

3.2.1 Stage I

1. Cataloging of incoming imagery, and identification of sub-areas which are geologically useable in terms of cloud cover, (Table 1 columns 1 - 6)
2. Tracing from 9" positive transparencies onto clear mylar overlays all spectral signatures which may be geologically linked. These data are color-coded according to spectral band in which they are best displayed (Table 1, column 10). The overlays are also assembled at 1:1,000,000 to produce a working, preliminary "spectral-geologic" map of New York State and adjoining areas. (Column 9 of Table I). A companion "underlay" map of this area is also assembled for each season using Bruning paper prints of

band 5 to make a working copy "orthofoto map".

3. Preliminary classification of the spectral geological content into five categories; four standard, and one "open" (Table I columns 15 and 16). At this stage, image descriptor forms are done and mailed to NASA.

3.2.2 Stages I and II

4. Stereo-viewing of selected imagery as deemed useful for corroboration or examination of above spectral data (Table I, columns 12 and 16). (Lacking useable stereo pairs to date, we have thus far used only monoscopic magnification. Preliminary observation suggests that optimum magnification ranges between 7x and 11.5x, depending upon sharpness of spectral contact, and spectral band.
5. Experimental photo-reprocessing of selected 70 mm NASA negatives to produce 70 mm positive transparencies with a maximum spread of the gray scale over land areas (at the expense of water areas). These products will be used for color enhancement experimentation using the SDC 64 multispectral viewer.
6. Multiband color viewing of selected NASA 70 mm positive transparencies, mainly at 1:250,000, as may be required to corroborate or expand the above spectral signatures.

3.2.3 Stage III

7. Evaluation of the identified spectral signatures, and annotation of the overlays. This will involve:
 - a. Comparison with existing ground truth to explain as many signatures as possible.
 - b. Intensive study of unexplained signatures by:
 - 1) stereo and multispectral viewing of original, (and, where necessary, reprocessed) NASA 70 mm chips for multispectral projection at large scales (experimentally, up to 1:62,500) for study and comparison with topographic and geologic maps.
 - 2) Comparison with available conventional aerial photography, other existing remote sensor products made available by the Rome Air Development Center, and aircraft remote sensor data (U-2 and NC 130B) to be provided by NASA in support of this study. (Pre-launch U-2 data are of very limited usefulness due to either cloud cover over desired areas or failure to fly the course requested; see figure 1.

- 3) Field investigation, using conventional geological methods supplemented as needed by observation and hand photography from small aircraft at suitable sun angles.
- 4) For unusually enigmatic anomalies, possible use of Spectral Data Systems RS 10 Playback Console at the Rome Air Development Center. This instrument has capabilities for electronic edge enhancement, spectral level splicing, density level slicing, and hard-copy readout in black and white or color film.
- 5) Combining all annotated spectral geologic data onto a single spectral - geologic map of New York State and adjacent areas.

4. RESULTS

The geologically useful ERTS imagery received thus far covers the period of late summer, principally the month of August (Table I). A brief analysis of cloud cover in thirty scenes received (Table I) indicates that more than half (60 percent) have 70 - 100 percent cloud cover, 15 percent have 40 - 65 percent cover and remainder have 0 -30 percent cloud cover.

Thirteen scenes have received Stage I study, with the following designations assigned to spectral lines and areas considered to have possible geological linkage: linear elements (linears), curvilinear elements (curvilinear), forest boundaries, (topographically-and hence geologically-linked), areas having a recognizable fabric, and formational boundaries (along the Helderberg escarpment). Figures 3 and 4 illustrate these categories adequately despite the fact that they are "instant" Bruning paper prints of ERTS film positives rather than photographic prints. An examination of figures 3 through 7 illustrates the power of ERTS imagery to define major linears. The majority of the linears in the central Adirondacks (eastern part of these figures) are well expressed topographically on 1:62,500 quadrangle maps and, in areas which have received detailed mapping, almost all are recognized as faults. The "mapping" of these features on ERTS imagery required only about one-half hour, whereas assembling the same data from topographic maps for the 1961 Geologic Map of New York (Fisher and others, 1961) required about two man days of work.

The new spectral linears in this region are seen in figure 7. Their total length is about 160 km in the Central Adirondacks and 230 km in the Northwest Adirondacks. For what it is worth at this very preliminary stage, the spectral "geological contents" of Table I total approximately as follows:

<u>FEATURE</u>	<u>TOTAL LENGTHS</u>
spectral linears	5200 km
Spectral curvilinears	700 km

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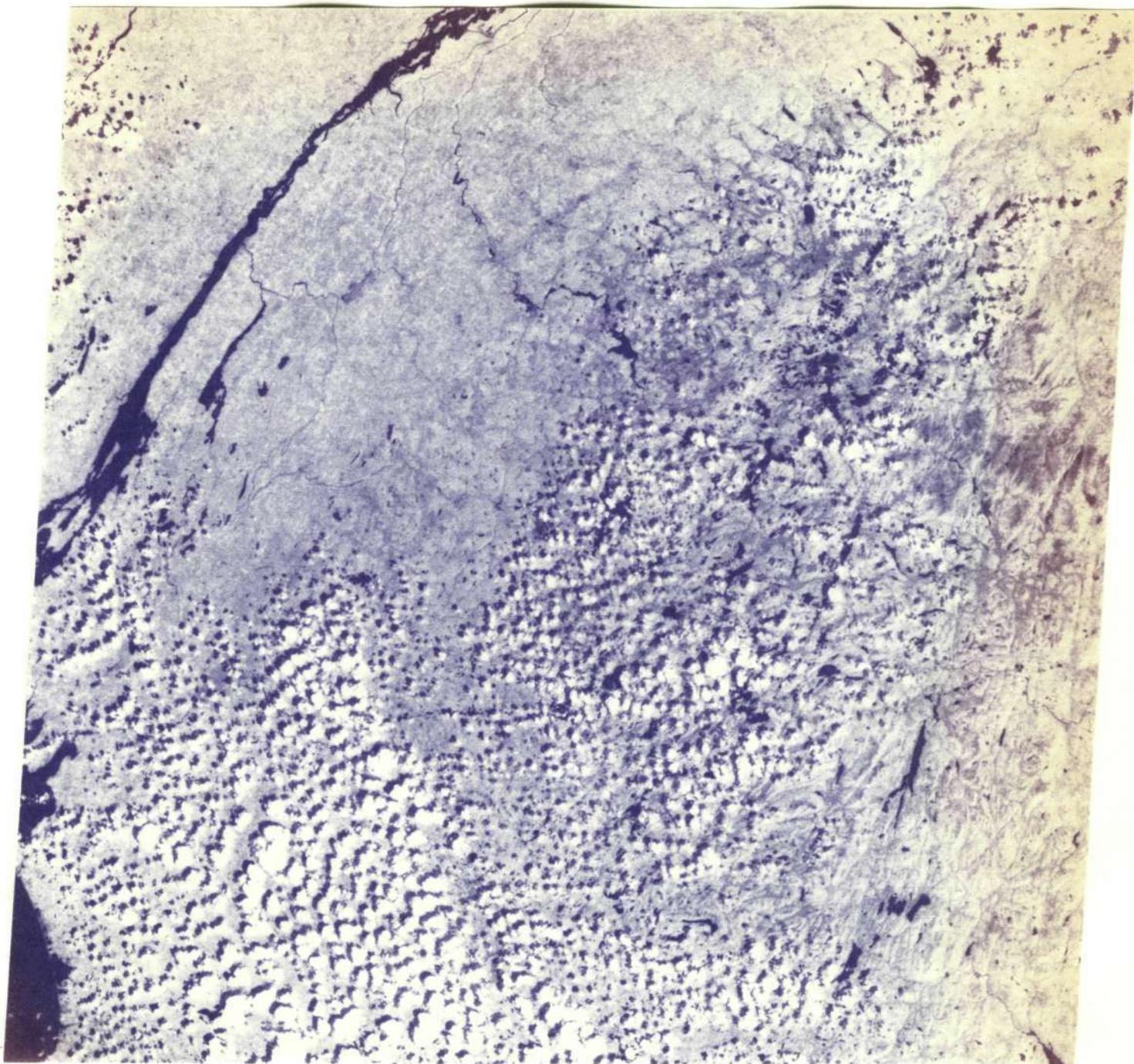


Figure 3. ERTS scene over central and western
Adirondacks, at 1:1,000,000 , 5 Sep 72,
band 7, scene 1044-15173.

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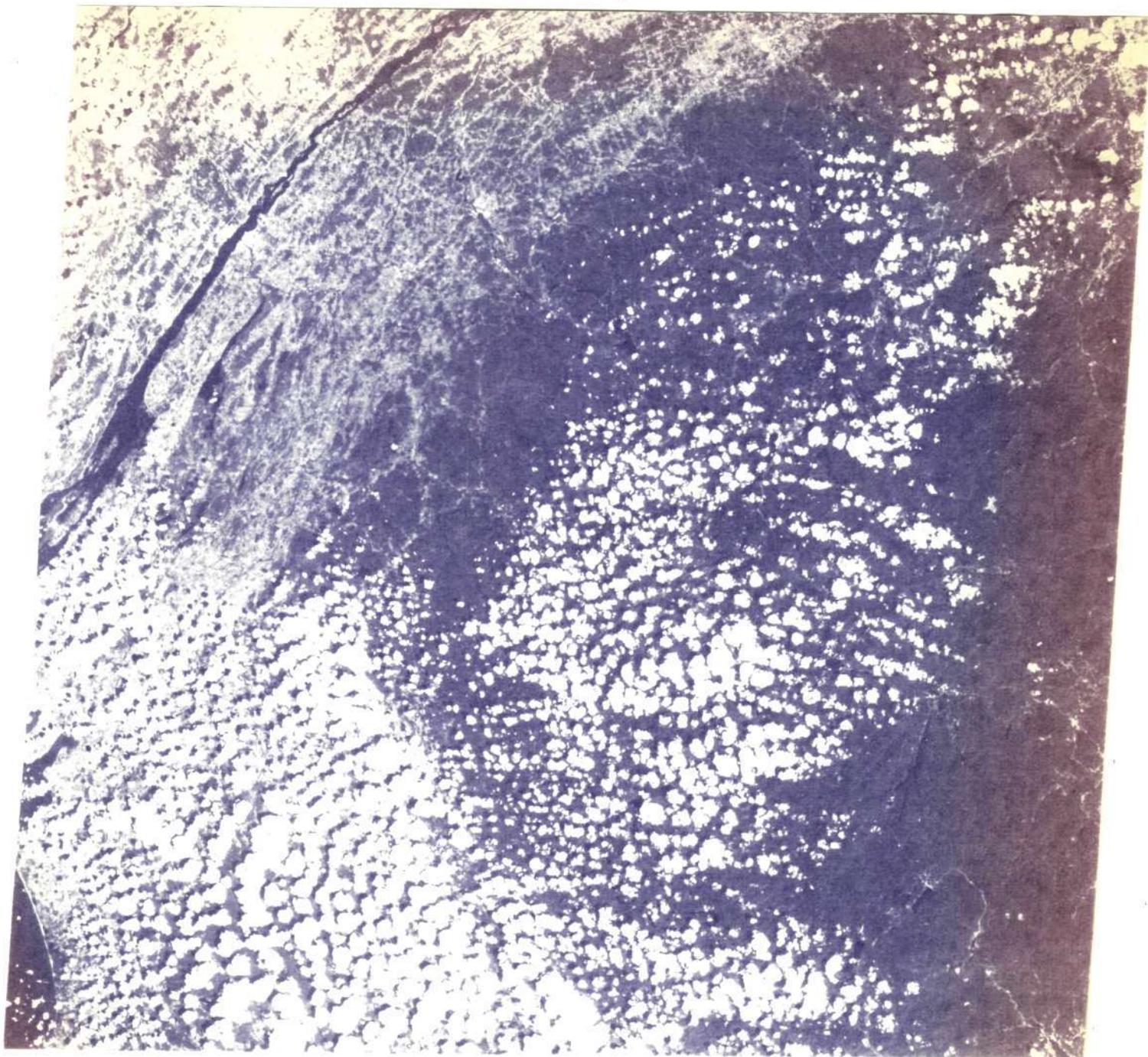


Figure 4. ERTS scene over central and western Adirondacks, at 1:1,000,000 , 5 Sep 72, band 5, scene 1044-15173.

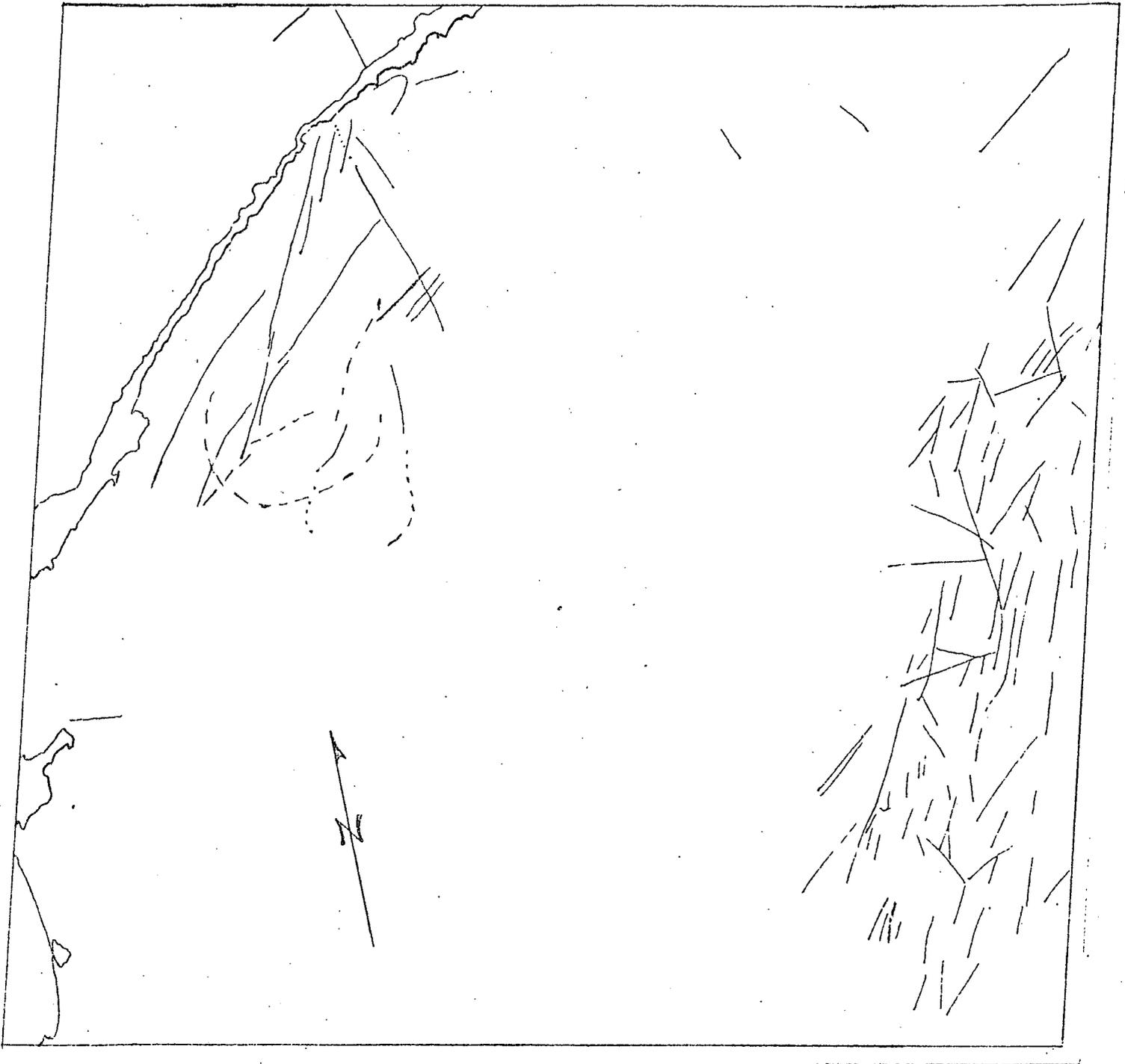


Figure 5. Spectral linears seen on Figures 3 and 4 (copy of overlay); dashed and dotted where less well defined.

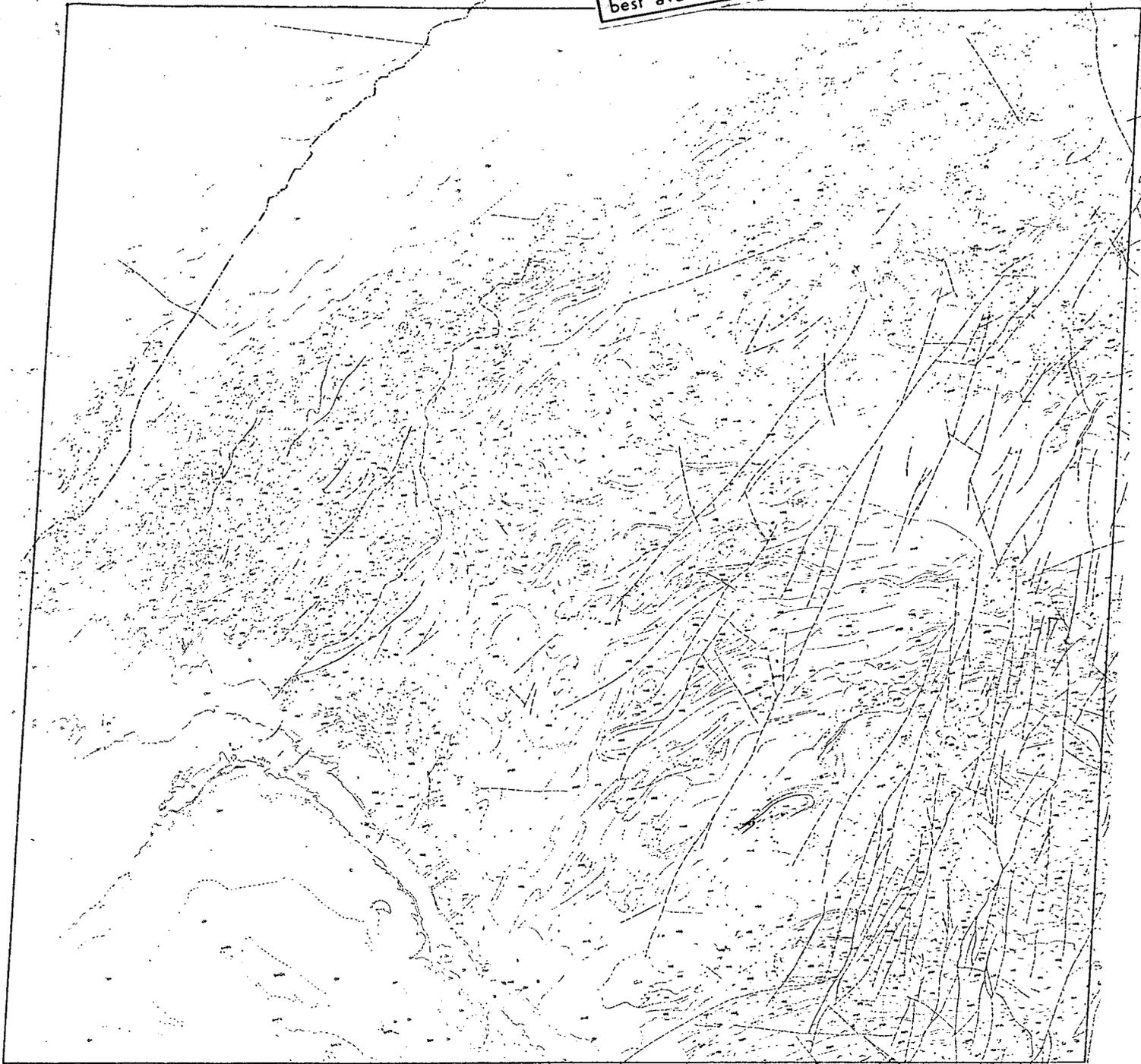


Figure 6. Geologic map of area in Figures 3 and 4, at same scale, reduced from Fisher and others (1970), for comparison with the spectral linears of Figure 5.

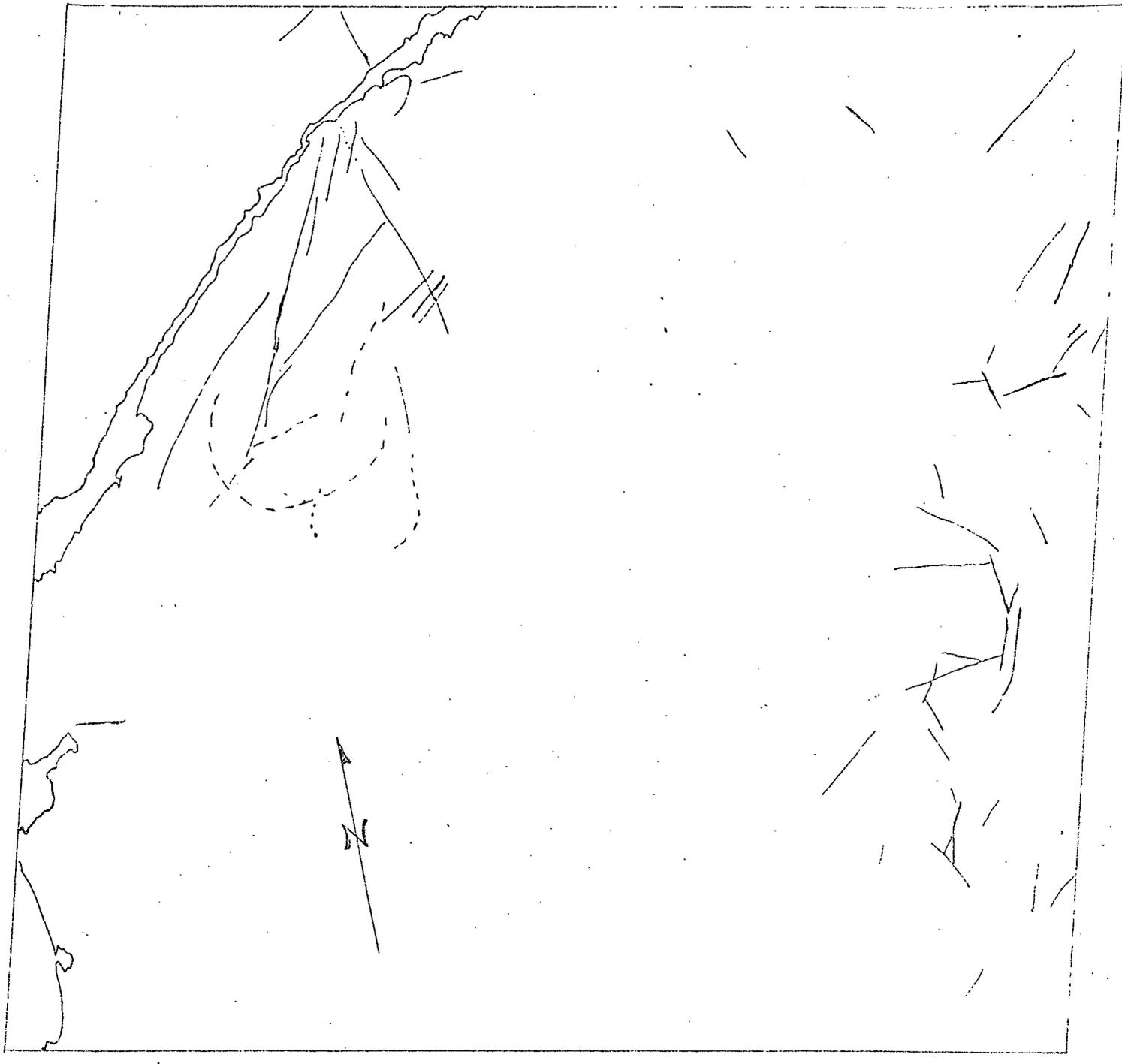


Figure 7. Anomolous spectral linears in area covered by Figures 3 and 4, obtained by subtracting known topographic lineaments and faults of Figure 6 from the spectral linears of Figure 5.

GEOLOGIC MAP OF NEW YORK STATE
 SHOWING 15' QUADRANGLES
 COMPILED BY
GEOLOGICAL SURVEY
 OF THE
 NEW YORK STATE MUSEUM AND SCIENCE SERVICE
 1964

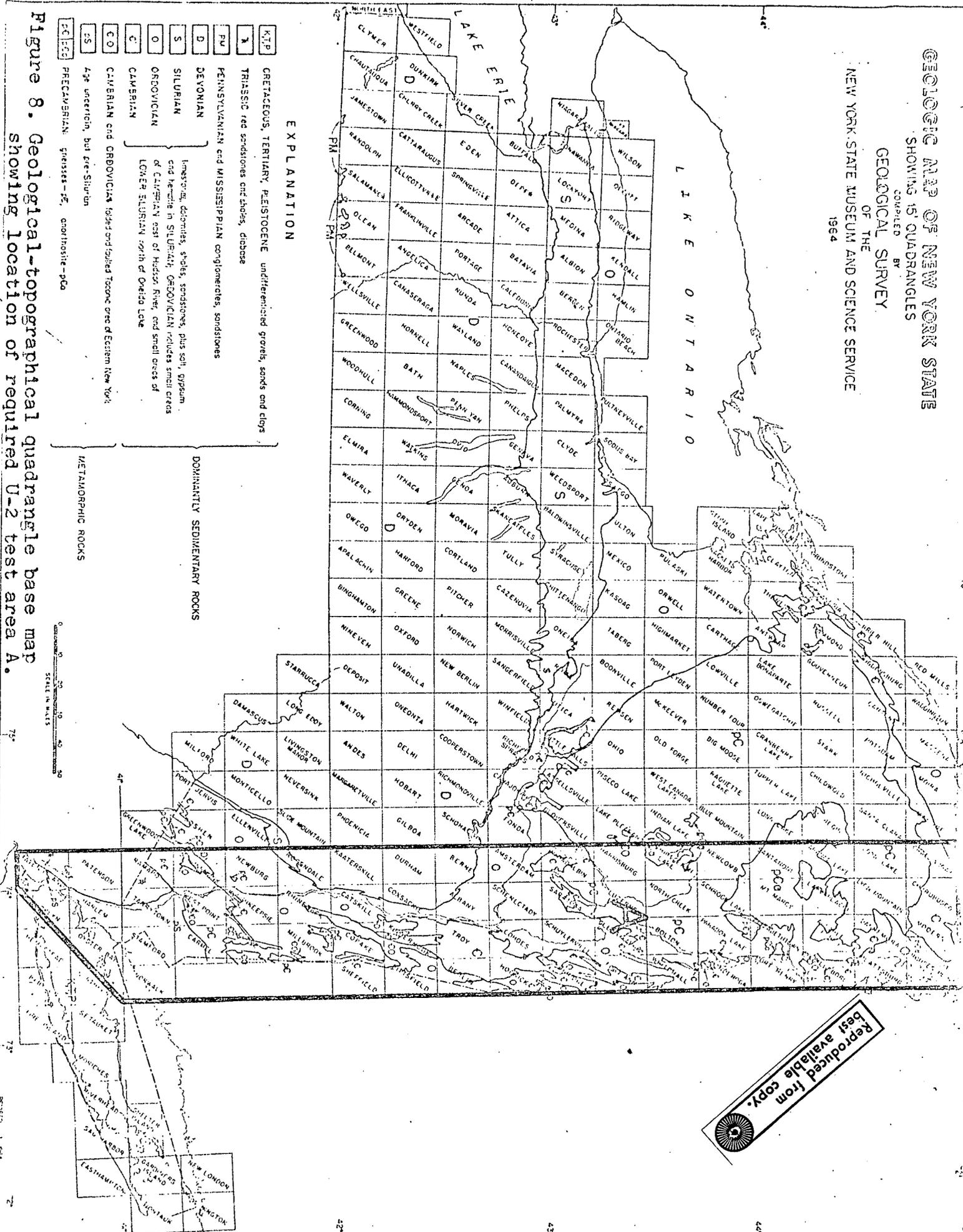


Figure 8. Geological-topographical quadrangle base map showing location of required U-2 test area A.

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 best available copy.

<u>FEATURE (con't)</u>	<u>TOTAL LENGTHS</u>
spectral forest boundaries	3100 km
areas of spectral geological fabric	3100 km

It must be emphasized that the preceding are raw spectral data, not yet evaluated by Stage II procedures.

For the late summer imagery, spectral bands 5 and 7 together contain all the spectral signatures which appear to be geologically linked. Bands 4 and 6 were not found to be additionally useful.

5. CONCLUSIONS

As anticipated in our original research proposal, ERTS imagery has revealed a number of hitherto unknown spectral linears which may turn out to be geologically - linked. It is certain that ERTS imagery will prove very useful in regional fracture analysis. Initial field-checking in the St. Lawrence Lowland, northwest Adirondacks is scheduled for early November. Incoming "imagery for all seasons" is eagerly awaited to compare with that of late summer. Of the numerous specific questions we had originally planned to "ask" the ERTS products, the following remain to be tested:

1. Is there evidence that any of the large map areas of granitic and charnockitic gneisses, all of which appear to be conformable at mapping scales, are actually cross-cutting on a regional scale?
2. Can the wide belts or relatively well exposed, undifferentiated marbles in the northwest Adirondacks be subdivided into calcitic and dolomitic facies? Rowen and others (1970) found pre-dawn IR imagery in the Arbuckle Mountains, Oklahoma, to be useful in distinguishing limestone and dolostone.
3. Are recognizable signatures, botanical or otherwise, produced by sedimentary lithologies which have subtle geochemical differences? Two examples would be continental versus marine clastics of the Devonian in the Catskills and southwestern New York, and organic-rich versus organic-poor marine shales of the Middle Devonian in western New York.
4. Can regional cross-cutting be demonstrated for the Marcy massif metanorthosite?
5. Can the NNE-trending faults which extend southward from the Adirondacks into the Mohawk Valley and hinge out to the south (figure 5), be dated using ERTS synoptic imagery or airborne sensors? Do these faults pass beneath the Devonian Helderberg escarpment cutting only the Ordovician and Silurian strata? If

airborne sensors are used, what would be the most advantageous time of day (Rowen and others, 1970, Wolfe, 1971)?

6. Are there more faults and lineaments crossing the Adirondack dome than are now known (figure 5)? The answer appears to be yes (figure 7). Can relative ages be determined from orbital imagery? From high altitude remote sensor?
7. What is the isolated and ambiguous Clarendon-Linden structure which passes through Batavia in western New York? What is its geometry and extent? It is marked by a diminished amount of rock exposure and has been alternately interpreted as a fault and as a monocline. The late summer imagery is too badly camouflaged by land use patterns (LUC in Table I, Remarks column) to be useful in answering these questions. Perhaps imagery obtained after the growing season (during early winter with snow enhancement or in the spring before field cultivation) will be useful.
8. What is the explanation of the several N.E. and NW-trending topographic lineaments some as long as 80 miles, in the Appalachian Uplands in the central and western part of the state.
9. Can ERTS imagery provide any new insights into the character and extent of the enigmatic "Cameron's Line" in New York and western Connecticut? This line may be the contact between two tectonic plates. Increased understanding of this structure would greatly facilitate reconstruction of the geological history of a vast area.
10. What is the configuration and extent of the Carthage-Colton Line, a zone of cataclasis separating the Adirondack Highlands from the Northwest Lowlands (figure 5)? Is this Proterozoic scar part of an extensive crustal feature, one explainable in terms of plate tectonic theory?
11. What is the geometry of the contact between the Hudson Highlands and the Fordham-Inwood-Manhattan terrane to the south? Fault? Unconformity?
12. There are sections of the Appalachian Uplands from which large quantities of Silurian salt has been mined by room and pillar methods and by solution (brine wells). Is subsidence of the overlying strata detectable in the imagery?
13. To what extent will it be possible to determine the form, distribution and possible thickness (via ground water or botanical signatures) of surficial deposits? For this investigation, the imagery will be compared with surficial maps (1:62,500) in a rectangular area in the Hudson River Valley measuring 100 miles by 20 miles.
14. Will the resolution of imagery be sufficient for making a useful surveys of the changing configurations of wetlands and tidal areas? Will it permit the policing of dumping in wetlands?

6. RECOMMENDATIONS AND AIRCRAFT REQUIREMENTS

Our original request for aircraft underflights by NASA (Isachsen, 1971b) have been tentatively modified on the basis of ERTS imagery received to date, to exclude the areas in the western part of the State. The reason for this is the extensive land use patterns, both urban and rural which appear on the late summer imagery. The effect of this cultural overprint is to camouflage most of the geological features we had hoped to find and evaluate. It is of course possible that upcoming imagery obtained outside the growing season may change this appraisal.

Figure 8 shows the required U-2 test site. The purpose of the aircraft sensor data is to replicate ERTS coverage at higher resolution in areas selected to provide adequate sampling of diverse lithologic, tectonic, and physiographic units of the State to provide calibration for analysis of ERTS imagery. This will apply particularly to major anomalies and to numerous subtle geological features which might otherwise be missed on the ERTS imagery. Appendix I provides many of the geological reasons for site selection (from Isachsen, 1971b)

Flights should be made in the spring during the interval between snow disappearance and leaf budding generally in mid to late April. It will be necessary to keep in contact with flight coordinator as to timing, beginning April 1. It is mandatory that the flying be done this spring (1973) to permit achievement of research objectives.

Sensor and other requirements are unchanged from the original request. The same applies to the request for NC 130B coverage over sites to be determined as ERTS spectral anomalies discovered which require high resolution remote sensor data.

7. REFERENCES

Fisher, D.W., Isachsen, Y.W., Rickard, L.V., Broughton, J.G. and Offield, T.W., 1961, Geologic Map of New York State. N.Y. State Museum and Science Service Map and Chart Series 5.

Fisher, D.W., Isachsen, Y.W., and Rickard, L.V. (1970) Geologic Map of New York State, N.Y. State Museum and Science Service Map and Chart Series 15.

Isachsen, Y.W., 1971a, Technical proposal to the National Aeronautics and Space Agency for Geological Participation in the ERTS A program, 47pp., Unpublished, document.

Isachsen, Y.W., 1971b Flight requirements for earth observatories airport support of ERTS investigation: Evaluation of ERTS A data for usefulness as a geological sensor. Unpublished document, 15pp.

Rowan, L.C., Offield, T.W., Watson, K., Cannon, P.J. and Watson, R.D., 1970, Thermal Infrared Investigations, Arbuckle Mountains, Oklahoma, Geol. Soc. America Bull. V. 81, no. 12, p. 3549-3562, 7 figs.

Wolfe, Edward W., 1971, Thermal IR for geology: Photogrammetric Engineering, V. 37, no. 1, p. 43-52.

APPENDIX I GEOLOGICAL BASIS FOR UNDERFLIGHT SITE SELECTION

The geological reasons for site selection are more numerous and complex than can be stated briefly. Nevertheless, the items listed below serve to illustrate the geological diversity referred to under "objectives." The quality of ground truth, in terms of both bedrock and surface material, ranges from excellent to fair.

We believe that ERTS and high altitude aircraft imagery, owing to its synoptic character, will suggest answers to numerous regional geological questions which were raised during and subsequent to our preparation of a new Geological Map of New York State (in press). The questions asked below are not, however, restricted to problems of regional scope.

The most complex and varied part of the State lithologically and tectonically, is the eastern portion (Area A on attached map). It has been arbitrarily divided, without drawing lines, into the southern, central, and northern portions in the listing which follows, and each listing proceeds from south to north.

AREA A, SOUTHERN PORTION

Juncture of three tectonic provinces (Manhattan Prong, Triassic Basin, Coastal Plain): serpentinite body intruded into Manhattan

schist, unconformably overlain by Triassic red beds which are intruded by Palisade diabase, partially buried by Cretaceous Platform; Wisconsin age terminal moraine; structural control of the Hudson, East, and Harlem Rivers; does "Camerons Line" (structural discontinuity) extend into New York City region? How are Paleozoic nappes (Taconic? Acadian?) of Westchester County imaged? What is the configuration and relationship of the Bedford Augen Gneiss to surrounding rocks? Are the Manhattan and Waramog Formations correlative around the eastern end of the Hudson Highlands?

Is the contact between the Hudson Highlands and the Fordham-Manhattan-Inwood terrane of Paleozoic nappes a major fault or is the Fordham gneiss an intact extension of the Highlands? What is the character and extent of the enigmatic "Cameron's Line" in New York and western Connecticut? (It may be the welded contact of two crustal plates!). What spectral distinction exists between the varied Hudson Highlands and Housatonic Highlands gneisses? What are the relative ages of faults in the Hudson Highlands, and what is their relationship to Triassic faults? What are the northern extensions of the Highlands and Triassic gravity faults? To what extent do fault patterns control the course of the Hudson River through the Highlands gorge (fiord)?

Are the known large-scale refolds of the Hudson Highlands spectrally imaged? Do others occur? Are spectra distinct for the mafic vs. ultramafic rocks of the Cortlandt Complex and for isolated ultramafic plutons in the Hudson Highlands? for the Peekskill Pluton granite and granodiorite? In Dutchess County, will spectral signatures help solve the problem of distinguishing, above the garnet isograd, between the autochthonous and allochthonous metapelites which are so easily separated at lower metamorphic grades? What is the spectral character of the chaotic mix of huge carbonate and gneiss blocks-in-shale at Stissing Mt.

Will imagery distinguish Taconic gravity slides from Taconic thrust sheets? Can the relative ages of emplacement ("shingling") of these thrusts be inferred? What is the pattern of lineaments in the Shawangunk ridge? Does the Marlboro Syncline predate (pass under) the Devonian escarpment? Are the rootless, isolated Proterozoic hills west of the Schunnamunk graben, and at Newburgh, remnants of a thrust sheet?

AREA A, CENTRAL PORTION

Why is the Catskill front so pronounced north of Kingston? Is it lineament-controlled? What are the spectral signatures of Beecraft

Mt. carbonates compared with those of the surrounding Taconic sequence? How does the imagery record the narrow belt of transition from the Alleghany Plateau Province to the Ridge and Valley Province, a belt marked by the abrupt development of Acadian folding and thrust-faulting? The nearby juxtaposition of Acadian and Taconic structural trends across the Ordovician-Silurian unconformity? What is the spectral signature of the Canaan area - Lebanon warm spring and associated fault (the only thermal spring in New York)? Is the "Knob" near Queechy Lake a basic plug or flow with distinct spectral signature? Ditto for Stark's Knob pillow basalt near Schuylerville. How does "spectral geology" compare with samples of well-mapped surficial geology in the Hudson-Mohawk Valley region? Is there any evidence of faulted Pleistocene deposits, possibly associated with glacial rebound?

AREA A, NORTHERN PORTION

Can cross-cutting on a regional scale be demonstrated for the Marcy metanorthosite massif anywhere along its contact? For any of the large, apparently concordant, belts of charnockitic or granitic gneiss? Does any spectral evidence exist for a major unconformity separating Adirondack metasediments from an older anorthosite-

charnockite "infracrustal" terrane? Are large scale compositional variations spectrally discernible within the metanorthosite (known varieties range from metanorthosite to anorthosite metagabbro, and locally to saturated metagabbro)? Do charnockite, granitic gneisses, augen granitic gneisses, and leucogranite have identical signatures? Can para-amphibolite be distinguished from ortho-amphibolite from olivine metagabbro? Dolomite from calcitic marble, from quartzite, from paragneisses? Can xenoliths of calcsilicate (including commercial wollastonite-andradite deposits be spotted spectrally in the metanorthosite?

Are hook-shaped and domal refold patterns apparent in the imagery? What are the spectral representations of domal structures cored by charnockite (e.g. Piseco Lake, Pharaoh, Ticonderoga and Snowy Mt.) and nappes cored by charnockite (Wakely Mt. and Huckleberry Mt.)? East of the Lake George graben, what is the relationship of the EW fault system in the Paleozoic carbonates to the juncture of the Adirondack, Valley and Ridge, and Taconic Provinces? Are the Taconic slide and associated mélnage spectrally distinguishable? How are the numerous NNE-trending fault and graben systems in the Adirondacks and Mohawk Valley imaged? Do they extend as far south as the Silurian-Devonian unconformity, and if so, do they cut the Devonian or pass beneath it? Do they show strike-slip component? Can relative ages

be inferred at fault intersections? Are the faults actually, or only apparently, restricted to the eastern half of the Adirondacks? How sensitive is ERTS imagery to the fault control of Adirondack drainage.

In the Plattsburg region, what are the spectral signatures of the Cumberland Head thrust plate, three distinct fault systems in the carbonates, a carbonate block terrane, the Champlain Fault on the Vermont side of Lake Champlain? Can any spectral expression of the subsurface "Montergian Hills" be inferred from gravity anomalies?

Can the shoreline features of Pleistocene Lake and the post-Pleistocene Sea be recognized spectrally? Any recent faults cutting Pleistocene deposits (accompanying Post-glacial rebound)?

What is the delineation of the Carthage-Colton Line of Proterozoic cataclasis? Is it part of an extensive crustal feature explainable in terms of Plate Tectonic theory: has reactivation along this zone influenced configuration of Paleozoic limestones under which it passes, as suggested from regional map pattern? Does the imagery suggest any subtle expression of post-Pleistocene faulting in the St. Lawrence River valley (a seismically active area)? What is the configuration and extent of the open folds in Paleozoic rocks parallel to the St. Lawrence River near the Frontenac Axis (Thousand Islands?)