Paper G 8

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

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ABSTRACT

Linear anomalies dominate the new geological information derived from ERTS-I imagery, total lengths now exceeding 6000 km. Experimentation with a variety of viewing techniques suggests that conventional photogeologic analyses of band 7 results in the location of more than 97 percent of all linears found. Bedrock lithologic types are distinguishable only where they are topographically expressed or govern land-use signatures. The maxima on rose diagrams for ERTS-I anomalies correspond well with those for mapped faults and topographic lineaments, despite a difference in relative magnitudes of maxima thought due to solar illumination direction. A multi-scale analysis of linears showed that single topographic linears at 1:2,500,000 became segmented at 1:1,000,000, aligned zones of shorter parallel, en echelon, or conjugate linears at 1:500,000, and still shorter linears lacking obvious alignment at 1:250,000. Most circular features found were explained away by U-2 airphoto analysis but several remain as anomalies, the most notable being an elliptical "spoked wheel" anomaly which centers on Cranberry Lake. Neither shatter cones nor megabreccias have been found to date.

Visible glacial features include individual drumlins, best seen in winter imagery, drumlinoids, eskers, ice-marginal drainage channels, glacial lake shorelines and sand plains, and end moraines.

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INTRODUCTION

This paper presents accomplishments to date on a continuing project to utilize ERTS-I multispectral scanner imagery in a tectonic synthesis of New York State, and is a supplement to an earlier publication by Isachsen and others, 1973a.

New York provides a highly varied test area for evaluating ERTS-I imagery as a source of new geological information not readily seen at conventional mapping scales. The State covers a number of well defined physiographic provinces, and contains lithologic units ranging in age from Proterozoic to Pleistocene (Broughton and others, 1966). It stretches east-west

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across five tectonic provinces as follows (Fisher and others, 1971):
1) a continental platform (Platform I) consisting of Lower and Middle Paleozoic strata resting on a Proterozoic basement which covers all except the eastern part of the State; 2) the Adirondack Dome Mountains which are located on the eastern edge of this platform and expose Proterozoic basement of the Grenville Province, 3) the Appalachian Foldbelt with its several subdivisions including the Hudson Highlands (reactivated Proterozoic basement) and the Taconic allocthones, 4) the Triassic basin, and 5) Cretaceous coastal plain sediments on Paleozoic basement (Platform II).

For a general description of the geology and physiography of the State the reader is referred to Broughton and others (1966); the tectonic subdivisions are described in Fisher and others (1971).

INVESTIGATIVE PROCEDURE

The methods of handling and evaluating incoming ERTS-I multispectral imagery have been presented elsewhere (Isachsen, 1973), and are summarized by means of a flow diagram in Figure 1. Roman numerals signify the five stages of analysis which are as follows. I. photogeologic identification of suspected geological signatures in ERTS-I imagery; II. laboratory screening of these signatures in terms of existing data in order to identify new ERTS-I anomalies; III. field investigation of representative anomalies, IV. preparation and analysis of ERTS-enhanced tectonic maps; V. publication of results.

EXPERIMENTATION WITH VIEWING METHODS

In a search for effective methods of treating ERTS-I imagery for photogeologic analysis, experiments were conducted to compare the content of geological information in the following products (Isachsen and others, 1973b).

1. Positive transparencies and paper prints of each of the four spectral bands (4,5,6, and 7), as received from NASA.

2. Paper prints made from positive transparencies which were photogeologically reprocessed to increase density contrast.

3. Log E dodged prints. This processing subdues density contrast to permit more detail to be seen in shadowed areas, if such detail is present.

4. Multispectral color-additive viewing of 70 mm positives of bands 4, 5,6, and 7, both as received from NASA and after photographic reprocessing to produce higher contrast positives.

The experiments described above were intended not as rigorous investi-
gations, but rather as relatively rapid tests to help determine which
methods, beyond the more conventional approaches, would yield a suffi-
ciently greater amount of new geological information to justify the
additional time involved. From the results obtained, we conclude that,
for the region under study, the most advantageous method of photogeo-
logically analyzing ERTS-I imagery is to study bands 7 and 5 separately.
As for photogeologic linears, band 7 permitted detection of more than
97 percent of the total. A small additional increment of information
may be derived by color additive viewing of photographically reprocessed
imagery.

ERTS-I AND BEDROCK GEOLOGY

Introduction

ERTS-I imagery received through October 1973 totals 315 frames covering
34 scene areas over New York State and portions of adjacent states and
Canada. An inventory of this imagery in terms of geological usefulness
is as follows: useful (0-50 percent cloud cover), 55 percent; marginally
useful (50-70 percent cloud cover), 12 percent; virtually useless (70-100
percent cloud cover), 33 percent.

The 1:1,000,000 film positives of the usable imagery were analyzed in
transmitted white light (i.e. Stage I analysis) and the data were com-
bined into a statewide "spectral geological map" at 1:1,000,000 (Isachsen
and others, 1973a, Figure 2). For the late summer and fall imagery, it
was found that bands 5 and 7 compliment each other and contain all the
spectral signatures which appear to be geologically-linked; no additional
data were found on bands 4 and 6. The data referred to above have sub-
sequently received Stage II analysis, with a resultant ERTS-I anomaly
map which will be discussed later.

Capability of ERTS-I Imagery to Delineate Major Geological Provinces

The synoptic value of ERTS imagery is readily appreciated from a single
satellite image, but even more so from the mosaic of an entire State
(Figure 2) where, despite the loss in resolution due to photo-reduction
of the original mosaic, major physiographic, geologic and tectonic
provinces can be seen. The tectonic provinces visible in the mosaic
include Platform I which covers most of the State, the Adirondack Dome
Mountains which comprise the northern part of the State, the narrow belt
of upturned Silurian-Devonian rocks deformed during the Acadian Orogeny
which define the westernmost part of the Appalachian Foldbelt and adjoin
Platform I, the remainder of this Foldbelt, with the prominent Hudson
Highlands, the Triassic basin between the Highlands and the Hudson River,
and Platform II (Long Island). Two physiographic provinces within Plat-
form I are clearly delineated in the imagery, namely the Tug Hill Plateau
located between Lake Ontario and the Adirondacks, and the Catskill Moun-
tains at the eastern end of the Allegheny Plateau of Platform I. (Both
of these provinces are composed of erosionally-resistant deltaic rocks,
one Ordovician, the other Devonian.)

Outlining the Adirondacks can be seen the major unconformity between the Grenville basement and the onlapping Paleozoic section which has at its base the Potsdam Sandstone of Upper Cambrian age. The contact is accentuated by a topographically-induced land use boundary, namely forest versus farmland, but it is also well delineated geologically, particularly along the southwestern, southern and eastern Adirondacks, by the abrupt termination of the east-west arcuate pattern in the basement at the Potsdam contact. This arcuate pattern results from differential erosion of the basement lithologies.

Along its northern, western, and southwestern borders, the crystalline Adirondack basement is expressed on ERTS-I imagery as a slightly dissected planar surface which dips gently away from the central part of the Adirondack Dome (Figures 2 and 3). This surface is exposed in a belt ranging in width from 10 km in the north to about 20 km along the western perimeter and corresponds closely to the physiographic section designated as the "Fall Zone Belt" by Buddington and Leonard (1968, p.8). It is doubtless a tilted erosion surface from which the Paleozoic units have been stripped by erosion. A striking feature of this paleoplane in the northern Adirondacks is its abrupt termination to the southeast, along a topographic lineament which had not previously been mapped, to produce a pseudo-cuesta. Along the northern border of the Adirondacks, the contact between this erosion surface and the Potsdam Sandstone is well displayed as a boundary between forest and cultivated farmlands. About 10 km to the north, is the contact between the Potsdam Sandstone and the Theresa sandy dolostone, again marked by a change in land use influenced by bedrock.

Along the southwestern border of the Adirondacks, the basement-Potsdam contact is accentuated by the Black River. In the intervening section, basement exposures are continuous from the Central Highlands, across the Frontenac Arch of the Northwest Lowlands, into the main Grenville Province of Canada. Potsdam occurrences are here limited to scattered, relict patches.

Within the Adirondacks, many geological structures can be identified. These include the major east-west arcuate folds extending across the southern Adirondacks (Figures 2 and 3) and a number of domical structures, plunging folds, refolds, and other structures which have topographic expression (Figure 3). More pronounced than these structural elements, however, is the strong expression of NNE-trending linear features. These will be discussed in a later section.

Within the Appalachian Foldbelt, major subdivisions can be seen in the ERTS-I imagery at the original 1:1,000,000 scale (albeit notably better at 1:500,000). In Figure 4, the Allegheny Plateau with the Catskill Mountains as its eastern projection, is readily identified by its dendritic drainage pattern. The straight eastern edge of the Catskill Mountains, which has long been referred to as the "Wall of Manitou", is prominently displayed. A major insight into its cause has been provided by ERTS-I imagery, as will be discussed later.

About 20 km south of the Catskills, the Shawangunk Mountains begin, and extend southwestward into New Jersey where they are known as the Kittatinny Mountains. They represent a belt of upturned Silurian and Devonian rocks, dominated by the Shawangunk conglomerate which marks the western boundary of the Appalachian Foldbelt.

An angular unconformity between the titled Shawangunk conglomerate and isoclinally-folded Ordovician shale and graywacke beds is seen on the imagery as the eastern edge of the Shawangunk Mountains. These beveled Ordovician rocks extend eastward to the resistant Proterozoic basement rocks of the Hudson Highlands, north of the wide portion of the Hudson River. Northwest of the Hudson Highlands a synclinal belt of down-faulted Silurian and Ordovician strata occurs. This belt is marked by the elongate Greenwood Lake at is southern end, and by the isolated Schunemunk Mountain mass at its northern end about 10 km southwest of the point at which the Hudson River enters the narrow gorge (fiord) through the Hudson Highlands. The Highlands extend northeastward, where they appear to merge, in the 1:1,000,000 imagery with the more highly-metamorphosed Paleozoic rocks of New England. (In the 1:500,000 imagery, the northern boundary of the Hudson Highlands is better delineated.) The elongate Housatonic Highlands, a separate Proterozoic mass, can be seen northeast of the Hudson Highlands. The belt of Taconic allocthones north of the Hudson Highlands is not well defined in the 1:1,000,000 print, but can be seen at the 1:500,000 scale.

The Triassic Basin borders the Hudson-New Jersey Highlands along the Ramapo normal fault, and is bounded on the east by the Hudson River. The Palisades diabase sill forms a vertical escarpment along the west shore of the river. It can be seen in the imagery as a faint line parallel to and within 500 meters of the shoreline. The Hudson flows along the onlapping contact between the Triassic red beds and the high-grade Appalachian basement rocks to the east. This basement, in turn, forms the substrate for the Cretaceous and Pleistocene formations of Long Island.

ERTS-I Linears in New York State

In this report the word "linear" is used in the sense of Dennis (1967, p. 103) to designate lines of uncertain origin on aerial photographs or imagery. The term "lineament" on the other hand, is reserved for a naturally occurring linear feature (e.g. Hobbs, 1904, Lattman, 1958), i.e. one that has been confirmed to exist on the ground.

Without question, the most significant geological contribution of ERTS-I imagery to date in New York State has been the location of more than 500 Stage II linears which had not previously been recognized. This linear detecting capability of ERTS-I imagery was the most frequently cited geological application at a recent Symposium of Significant Results from the Earth Satellite, ERTS-I (Short, 1973).

A work map of Stage II linears observed on ERTS-I imagery at 1:1,000,000 is shown in Figure 5. The linears represent those remaining from a Stage I work map (Isachsen and others, 1973a, Figure 2) after the removal of such "cultural linears" as transmission lines, railroads, abandoned railroad

beds, and highway segments. The Stage II linears range from strongly-developed topographic lineaments to very subtle linears which are defined by faint tonal, rather than topographic signatures. They range in length from 5 to 200 km, and the majority are straight. The combined lengths of these ERTS-I linear anomalies exceeds 6000 km, not including linear portions of the Hudson River and the Finger Lakes. It has been learned subsequent to the preparation of Figure 5 that topographic lineaments as short as 1.5 km are mappable on the 1:1,000,000 imagery. Hence additional linears can be extracted in the future.

ERTS-I Linears in the Adirondack Region

The most spectacular area of linear display in the State, if not in the entire northeast, is the Adirondack Mountain region (Figures 2 and 3). The linear features seen in the imagery include the majority of the major faults and topographic lineaments shown on the Geologic Map of New York at 1:250,000 (Fisher and others, 1971; Isachsen, 1973). Of those not visible in the imagery at 1:1,000,000 (Isachsen, 1973), most are short, and may turn out to be discernible at larger scales. The easternmost group occur in the Champlain Valley, an area of low relief, and are less likely to be expressed in the imagery.

A numerical summary of the Adirondack linear information obtained as of May 1973 is tabulated below:

Category	Number	Combined length, km
Previosuly mapped faults and topographic lineaments seen on ERTS-I imagery	232	1890
ERTS-I linear anomalies which have survived Stage II investigation	364	3131
Total linears seen on ERTS-I imagery	596	5021
Previously mapped faults and topographic lineaments not discernible on ERTS-I imagery	297	1750

The linear data shown in Figure 3 has had all obvious lithologically-controlled and "cultural" linears removed. Subsequent to this, each of the remaining linears in the Adirondacks were located by inspection on 1:62,500 airfoto index mosaics. They were thereupon classified as to photogeologic character (see Isachsen and others, 1973b for details). A summary of the photogeological classification follows:

Cultural linears	20
Linears parallel to lithological trends	51
Straight segments of stream courses	96

Straight stream valleys	27
Winding streams	7
Elongate lakes or straight shorelines	7
Ridge crests	3
Edge of topographic high or aligned segments of same	5
Alignments of vegetation:	
a. dark vegetation strips (may be valleys)	30
b. vegetation border	7
Combinations of one or more of the above	57
Unexplained	<u>125</u>
TOTAL	435
Total, less cultural and lithological linears above	364

The ERTS-I linear anomaly data for the Adirondack region are summarized in the two rose diagrams of Figure 6. The upper diagram is an unweighted plot of the total number of linears, whereas the lower diagram takes the lengths of linears into account. The generally similar appearance of the two diagrams holds up well under closer scrutiny. The maxima appearing in the weighted diagram can also be seen in the unweighted one, namely: N75W, N45W, N20W, N-S, N25E, N40E, N50E, N60-70E, N85-90E. This close correspondence indicates that, in general, the lengths of the anomalous linears are proportional to their frequency for any give azimuth.

When the above diagrams are compared with analagous plots of previously mapped faults and topographic lineaments (Figure 7), both differences and similarities appear. The most notable difference is that the major concentration of ERTS-I linear anomalies occurs in the 30° sector N40E to N70E, whereas previously-mapped linear structures fall in the 35° span between N15E and N50E. This may reflect differences in the geological control and expression of these newly discovered linears. More likely, however, to the extent that they are topographic linears, they are so well expressed in this sector because it is essentially orthogonal to the azimuth of solar illumination in October (153°, 34° elevation). Consistent with this interpretation is the low incidence of linears parallel to the direction of illumination (N20-40W), despite the fact that linears in this direction are fairly abundant on the ground (Figure 7). Wise (1969) has demonstrated experimentally the critical effect of direction of illumination on the display of linears, although he used considerably lower elevations (5 to 20 degrees). The interpretation presented above is consistent with the conclusions reached by MacDonald and others (1969) from a look-direction study of side-looking radar images.

Despite the difference in relative magnitudes of the maxima, a very close correspondence exists for their directions, except for two. The maxima of Figure 7, which also appear as prominent directions (within 5 degrees) on the imagery, are as follows: N70W, N45W, N20W, N-S, N40E, N50E, N70E, and N80E. On the ERTS-I linear diagram, however, a N25E set is prominent rather than the N15E set mapped on the ground. The most prominent ERTS-I set (N60E) is very subordinate among the known ground linear features. However, its trend comes within 3° of being perpendicular to the direction of solar illumination, and this probably explains its prominence.

Stage III Investigation of ERTS-I Linear Anomalies in the Adirondack Mountains

A major problem associated with field checking of ERTS-I anomalies is

locating them on the ground. This is greatly facilitated by visually trans-
ferring data from the ERTS-I photographic product to another photographic
product at a more useful field scale, namely airfoto index sheets at
1:62,500. It is then relatively easy to plot the feature in the approx-
imately correct location on 1:62,500 topographic maps, particularly if it
is topographic. The most economical and effective way to locate the feature
on the ground is by viewing and photographing it from low level aircraft.
Photographs taken on such a flight can be seen in Figures 8 and 9. They
show an ERTS-I anomaly which is located entirely within a single geolo-
gical unit, the Marcy Massif metanorthosite. The linear, a confirmed topo-
graphic lineament, turns out to be a 16 km-long southward extension of a
previously mapped lineament. It extends both north and south of the por-
tion shown in the photograph.

The contrast in relief between this new lineament and a previously mapped
one (which has of course, a stronger expression in the imagery) can be
seen by comparing Figures 8 and 10.

A far more subtle topographic lineament found in the ERTS-I imagery is
shown in Figure 11. This broad, relatively short (6 km) linear valley
extends WNW, transecting at nearly right angles the North River-Mt. Marcy
range. The northern edge of the North River Mountains appears in the left
middleground. The linear is terminated to the west by a major NNE linear
which passes just east of Popple Hill, the dark mountain in the middle of
the valley. It reappears to the west, as can be seen in Figure 3.

Geological Identification and Origin of ERTS-I Linears in the Adirondacks

Although data gathering and collation must continue to dominate our activ-
ity for some time before extensive synthesis and interpretation can be
made, there is good reason to suspect that the NNE topographic lineaments
will prove to be traces of high-angle faults and fracture zones. This is
based on detailed geological mapping by Walton (unpublished) of four
contiguous 15 minute quadrangles in the eastern Adirondacks where these
linear fractures are so abundant. Walton (oral communication) found that
fault breccias and/or stratigraphic displacement could generally be demon-
strated for these structures.

Stage I Multi-scale Analysis of an ERTS-I Scene Covering Southeastern New York

A Stage I multi-scale photogeologic analysis was made of linears in south-
eastern New York (Figure 4) to determine their characteristics at various
scales. ERTS-I data products at 1:1,000,000, 1:500,000, and 1:250,000, as
well as a mosaic at approximately 1.2,500,000 (Figure 4) were used. Details
of this study are given in Isachsen and others, 1973b. Selected results of
the study are as follows:

1) Of the total number of linears visible on bands 5 and 7, and on
   a false color composite, more than 97 percent were visible on the
   band 7 image;

2) The features recorded as linears were simply lines having "sufficient
   length" to determine that they are straight. Following this criterion,
   the shortest lines classified as linears were 5 km at 1:2,500,000,
   2 km at 1:1,000,000, 1 km at 1:500,000, and 0.5 km at 1:250,000. This

amounted to an unconscious selection of 2 mm as the shortest "reliable" straight line, whatever the scale.

3) Linears are abundantly expressed in the region, and, in general extend across physiographic, geologic, and tectonic boundaries.

4) What appear as continuous linears at the smaller scales, are zones of aligned segments at the larger scales. Furthermore, the segments may strike parallel to the zone of alignment, en echelon to it, or in conjugate relationship. As one example, the N65E trending set of linear segments near the northeast corner of Figure 4 produces at 1:2,500,000 what appears to be a single linear several hundred kilometers long, at 1:1,000,000 a dashed line (Figure 4), and at 1:500,000 a series of two sets of en echelon segment lying in a N65E zone. At 1:250,000 the individual linears are no longer recognizable as part of a major through-going structure. This study illustrates the value of multi-scale viewing in lineament analysis.

Stage III Investigations in the Catskill Mountains

General

Field work to date in the Catskill region indicates a direct relationship between the long axes of straight valley segments and the strike of major joint sets. If subsequent field investigations across the Allegheny Plateau confirm this relationship, ERTS-I imagery will prove to be the most economical method available for mapping major joint sets over large regions.

Field Study of the N20E Linear Set

The eastern edge of the Catskill Mountains is a notably straight steep escarpment (Figure 4) along which the Mountains rise abruptly for 800 m from the broad Hudson River Valley to adjacent summits which exceed 1000 m in height. This escarpment, long known as the "Wall of Manitou" extends south from the latitude of Catskill for a distance of 20 km.

West of the "Wall", the Catskill Mountains are eroded to produce prominent, northwest trending, ranges and valleys. Crossing these ranges at a high angle are numerous topographic lineaments which trend about N15E, and parallel the Wall of Manitou. The pervasive nature of this set, extending westward for at least 25 km, was never recognized before, and its geologic origin has only received brief mention. Chadwick (1944, p. 17) interpreted the two prominent valleys which occur 10 km west of the Wall of Manitou as being controlled by closely spaced joints along which "the internal settling known as 'keystone' faulting (Crosby, 1925)" might have occurred, although "as yet actual faulting has been demonstrated in only the easternmost of these lines, namely that which is tangent to the east end of North Lake." The fault referred to is located at the northern end of the "Wall" at the upper break in slope on Chadwick's geological map.

A vertical aerial photograph recently taken by NASA at 24,000 feet altitude of an area 12 km west of the Wall of Manitou (Figure 12) provides a useful

calibration device to determine how short a linear may be mapped on the ERTS-I imagery with confidence. As expected, the relatively long N20E linears are readily confirmed, a particularly good example being the Stony Clove linear. More imppressive, however, is the fact that the two short N75E linears, spaced only 1 km apart, with the shorter one being less than 2 km long, can be discerned on the imagery.

Low level aerial reconnaissance of the Stony Clove linear confirms it as a well defined topographic lineament (Figure 13). A closer view of the Stony Clove drainage divide (Figure 14) suggests that vertical displacement may have taken place. Field altimetry, however, was inconclusive, inasmuch as an elevation difference of only 5 m across a valley width of 100 m in continental sediments can be explained without resort to faulting. Of interest, however, is the fact that the valley is developed along a steeply dipping conjugate joint sets. On the west side of the valley, east-dipping joints are dominant. On the east side, westward dips predominate (Figure 15). The orientation of the 32° acute angle is compatible with the interpretation that this set of conjugate joints, and the valley itself, are reflected basement structures such as might be produced by minor dip-slip reactivation along a basement fault such as those exposed along strike in the Adirondacks (Figure 5).

Circular Features on ERTS-I Imagery

A number of circular features appearing on the ERTS-I imagery covering New York State have been described and illustrated in some detail by Isachsen and others (1973b), and will be only briefly referred to here. Those which have survived Stage II analysis (i.e. are not fortuitous arrangements of urban signatures) are shown in Figure 5. A cluster of three occur southeast of Rochester, one north of Oneida Lake, and three in the Adirondacks. Of the three near Rochester, only the central one is well defined in a U-2 photograph covering the area. It results from a combination of a scalloped drainage pattern which forms the upper and lower parts of the circle, and elongate fields paralleling drumlins which define the sides. The drainage pattern is probably of glacial origin. The circular feature north of Oneida Lake is not visible on airfoto index sheets, and so remains unexplained. That located to the NNE across the Black River is formed in the main by a possibly fortuitous arrangement of two stream courses.

The most striking of the "circular" features is an elliptical "spoked wheel" centering on Cranberry Lake and here termed the Cranberry Lake anomaly (see Figures 3 and 5). Seven of the radial valleys are arms of Cranberry Lake, at least in part. The long axis of the feature measures about 30 km, the short axis about 22 km. In a very general way it has a central domal high surrounded by a ring depression, with a lake basin at the center of the feature. The maximum topographic relief measured from lake bottom to the higher mountains within the feature is about 830 m. In the eastern and southern parts of the feature, a suggestion of concentric rings can be seen in the imagery (Figures 2 and 3). A recently published gravity map of the Adirondacks (Simmons and others, 1973) shows a two milligal simple Bouguer negative gravity anomaly over the Lake basin. Taken together, the above observations suggest the possiblity that the Cranberry Lake anomaly may be a cryptoexplosion structure.

The relationship between the topography of the anomaly and bedrock geology
(Isachsen and others, 1973b) may be summarized by stating that the rim
valley parallels bedrock foliation trends along part of its course, tran-
sects it along others, and fails to develop at all across an antiform of
quartzofeldspathic units to the northeast.

Aeromagnetic trends in the Cranberry Lake anomaly area (unpublished map
of Zietz) show no anomalous deviation from the mapped lithologic trends.
Field work in the area to date has failed to disclose any criteria indica-
tive of cryptoexplosion structures (e.g. Short and Bunch, 1968), particularly
shatter cones, megabreccias, injection veins, or other anomalous fracturing.
Thin section search for cryptoexplosion features remains to be made.

Beginning 15 km north of Childwold is a roughly circular feature 30 km in
diameter which is bounded by a narrow valley (Figure 2, 3 and 5).   This
feature forms the major part of an irregularly-shaped area which has a
northeasterly elongation. The topography and tone are clearly different
in appearance from any other part of the Adirondacks. The area appears
in the imagery as a broad depression with sparse, irregularly-scattered
hills, suggestive of "broken ground" on a very large scale. The area is,
in regional terms, a terrace (The Childwold Terrace of Buddington and
Leonard, 1962, p. 8) with valley bottoms having elevations of 1200-1300
feet on the northwest and 1600 feet on the southeast. The scattered hills
rise up to a maximum 400 feet above the valley floor. This physiographic
belt has an anomalously high percentage of sand plains and swamps, and the
lowest density of bedrock outcrops of any large area in the Adirondacks
(see Fisher and others, 1971). The reason for this is not known. The
area does not show any gravity anomaly (Simmons and others, 1972).

ERTS-I AND GLACIAL GEOLOGY

Numerous previously-mapped glacial features can be seen on ERTS-I imagery
at 1:1,000,000. These include more than ten drumlin fields, drumlinoid
glacial streamline forms, glacial lake sand plains and deltaic deposits,
segments of glacial lake shorelines, ice-marginal drainage channels, and
end moraines (Figure 16). No new glacial features have been identified
to date. The search for mapped glacial features on ERTS imagery is greatly
facilitated by using a scale-changing device such as the Bausch and Lomb
Zoom Transferscope model ZT-4.

Several drumlin fields can be located on the summer and fall imagery due
to the topographic effect of drumlin topography on land use pattern, but
most are obscured. However, when snow cover obliterates land use patterns
and the low sun angle of winter months highlights their relief, drumlin
fields, and even individual drumlins, can readily be identified. Indeed,
the stoss and lee sides of drumlins can be distinguished in some cases.
Good examples can be seen south of the Mohawk River (1169-15123, 1170-15182)
and in the Finger Lakes region (1243-15244). In the later area, however,
snow cover is less complete, and field patterns tend to camouflage the
topography. For this reason only portions of the extensive drumlin fields
of the Finger Lakes region can be identified, and of an estimated 10,000
drumlins in central New York State (Flint, 1957) only 228 could be recognized.
South of the Mohawk River, 316 drumlins were counted. On the ground, the
drumlins measure 2 km in length, 400 m in width and 25 m in height.   It

appears likely that optimum winter imagery could be "calibrated" using topographic map information, and then used to make a rapid, relatively accurate, inexpensive inventory of the drumlins in any region of the State.

Numerous glacial features are visible east of Lake Ontario. On the Tug Hill Plateau, glacial streamline forms or drumlinoids with northwest axes are extensively developed. In contrast to the drumlin fields mentioned above, these are best shown on the fall imagery (1080-15180). This is understandable because the Plateau is evenly forested, rather than being camouflaged by agricultural patterns. On a topographic map, the drumlinoids average 2-4 km in length, about 80 m in width, and 15 m in height. No published data are available to indicate to what extent they are depositional landforms or erosional bedrock features.

A small drumlin field not apparent in earlier imagery can be seen in the winter imagery on the northwest slope of the Tug Hill Plateau (1170-15182, 1170-15175). Also visible in the winter image are several glacial lake drainage channels which roughly parallel the contours around the north slope of the Plateau. Although these could be seen to some extent in the fall imagery (1080-15180) they are enhanced in the winter imagery due to the contrast between shadowed channels (accentuated by low sun angle) and surrounding snow. On the ground they are 2-17 km long, 200-700 m wide, and 20-30 m deep.

Comparison of the imagery with existing glacial maps of the Tug Hill region (Stewart, 1958; Forster, 1971) revealed no correlation. Farther north, in the St. Lawrence Lowland, image 1080-15174 was compared with the maps of MacClintoch and Stewart, 1965, and a rough correlation was noted between the extensive areas of intermediate gray density located west of Malone, and areas mapped as peat and muck (swamp). An even better correlation was found when the imagery was compared with the woodland overprint on the 1:250,000 topographic map of the USGS (N118-11, 1961)--another example of a geological signature linked to land use.

In the Central Highlands of the Adirondacks, numerous segments of eskers show up in the imagery as narrow ridges bounded by bodies of water. On the ground these are 200-400 m wide and 15-25 m high.

At the northernmost part of the State, the Covey Hill drainage channels for glacial Lake Iroquois can be recognized on image 1079-15115. On the ground, these channels are 2-4 km long, approximately 300 m wide, and 20 m deep. On the same image can be seen an area south of Plattsburg which has a distinct, uniform, tonal density. This area was found to correspond quite closely with that of a sand plain mapped by Denny (1967) as a deposit formed in glacial Lake Vermont.

Farther south, two thirds of the distance to Albany, is a tonally distinct gray area whose borders were found to have a fair to excellent correspondence with the boundary of stratified drift and deltaic deposits associated with glacial Lake Albany, as shown on an unpublished 1:250,000 glacial map of the area prepared by R. Dineen.

In the southeastern part of the State, a series of moraines mapped by Connally and Sirkin (1967) in the Wallkill and Hudson Valleys were searched for on both fall (1079-15124) and winter (1205-15132) imagery. On neither image was any indication seen for these moraines.

Imagery of Long Island (1096-15074) was compared with a map of the Harbor Hill and Rankankama moraines using a direct overlay. A few short segments of these moraines were detected because of different land use on the moraine compared with surrounding areas.

Using a 1:1,000,000 enlargement of the Glacial Map of the United States east of the Rocky Mountains (Flint, et al, 1959) imagery for New Jersey and Pennsylvania (1205-15135, 1170-15184, 1243-15251) was searched for end moraines and other glacial features. As shown on Figure 16, only a few short segments of moraines are visible.

For the western part of New York State the imagery (1243-15244, 1243-15251, 1244-15303, 1046-15292, 1244-15305) was compared with a compilation of moraines and beach ridges (Muller, 1972). Perhaps because of land use camouflage and low relief of these ridges (10 m), only small sections of a limited number of each was seen. Moraines searched for include the Valley Heads, Olean, Almond, Arkport, Clymer, Findley Lake, Gowanda, Hamburg, Marilla, Alden, Buffalo, Niagara Falls, Batavia, Barre, Albion, Colton, Geneva, and Waterloo. Those sections seen are shown on Figure 16. Glacial lake shorelines of the following lakes were also searched for: Whittlesey, Warren, and Iroquois; only two sections of the Iroquois beach ridge were found (Figure 16).

CONCLUSIONS

The overwhelming majority of bedrock features which can be seen in ERTS-I imagery are identifiable either by their direct topographic expression or by differences in land use patterns governed by topography. Variations in bedrock lithology which lack topographic expression are only seen where they strongly influence land use.

By far, the greatest geological contribution of ERTS-I imagery is in the delineation of hundreds of hitherto unknown linear features, both topographic and tonal, long (up to 200 km) and short (less than 1.5 km). The new linear information will, in the short run, be incorporated into a regional tectonic synthesis now in progress. In the long run, because of its sheer magnitude it will doubtless occupy the attention of numerous field geologists for some time to come.

A comparison of ERTS-I linears with ground structures indicates that some linears parallel known major fault trends while others parallel regional joint sets. There are doubtless a number of other genetic categories represented.

It is anticipated that the ERTS-enhanced fracture map of the State now in preparation will prove to be invaluable in seismic studies now underway by Lamont-Doherty Geological Observatory and the New York State Geological

Survey. At present, virtually nothing is known about the relationship
between seismicity and tectonics in New York. Both theoretical questions
relating to seismicity within the North American Plate, and practical
questions concerning seismic hazard are involved.

A number of potentially anomalous circular features seen in the imagery
were explained through the use of U-2 aerial photography. An elliptical
anomaly with a radial system of valleys, the Cranberry Lake anomaly, however,
will require additional investigation.

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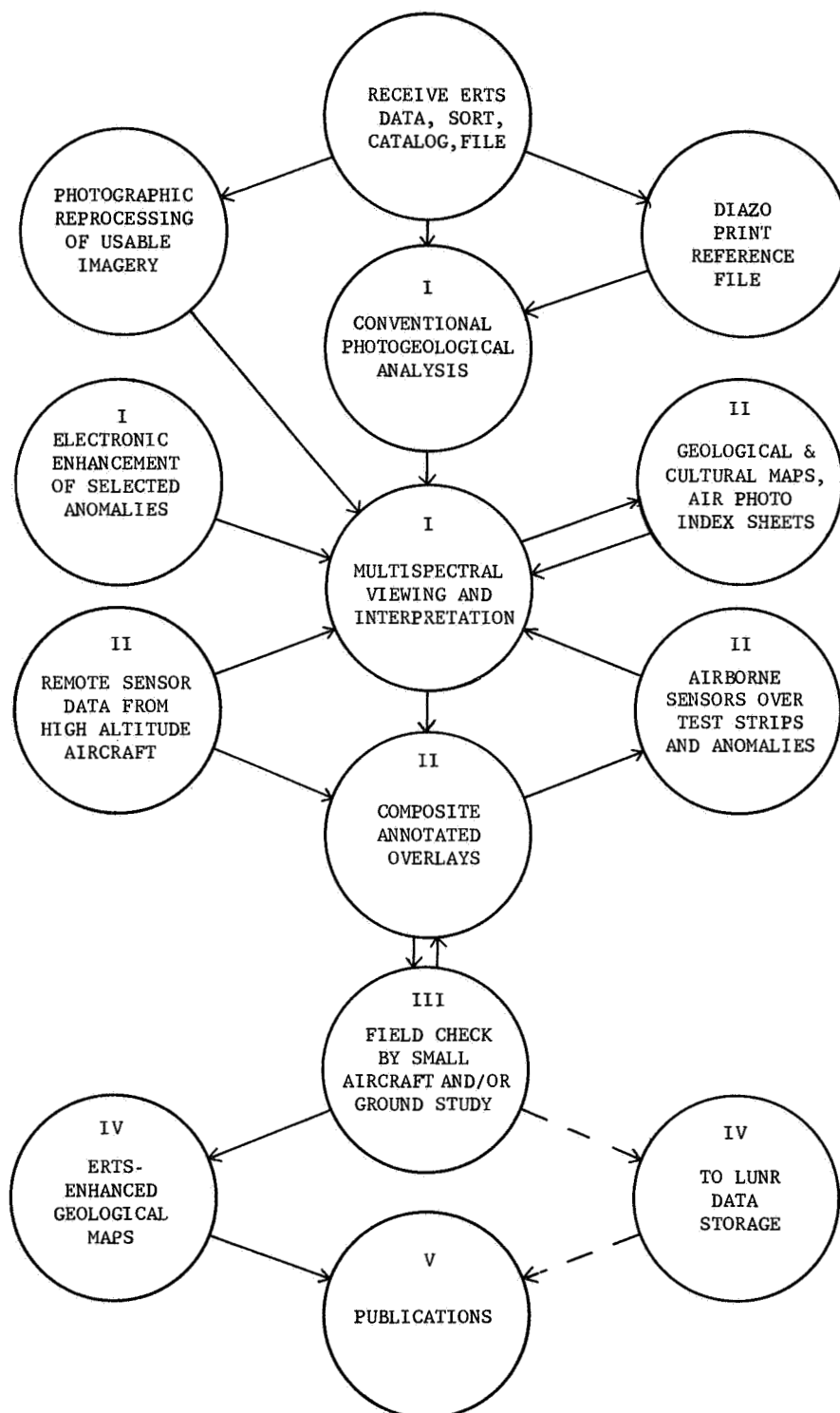
Figure 1. Flow chart of data handling and imagery analysis for ERTS-1
products. Roman numerals signify stage of study as discussed in text.
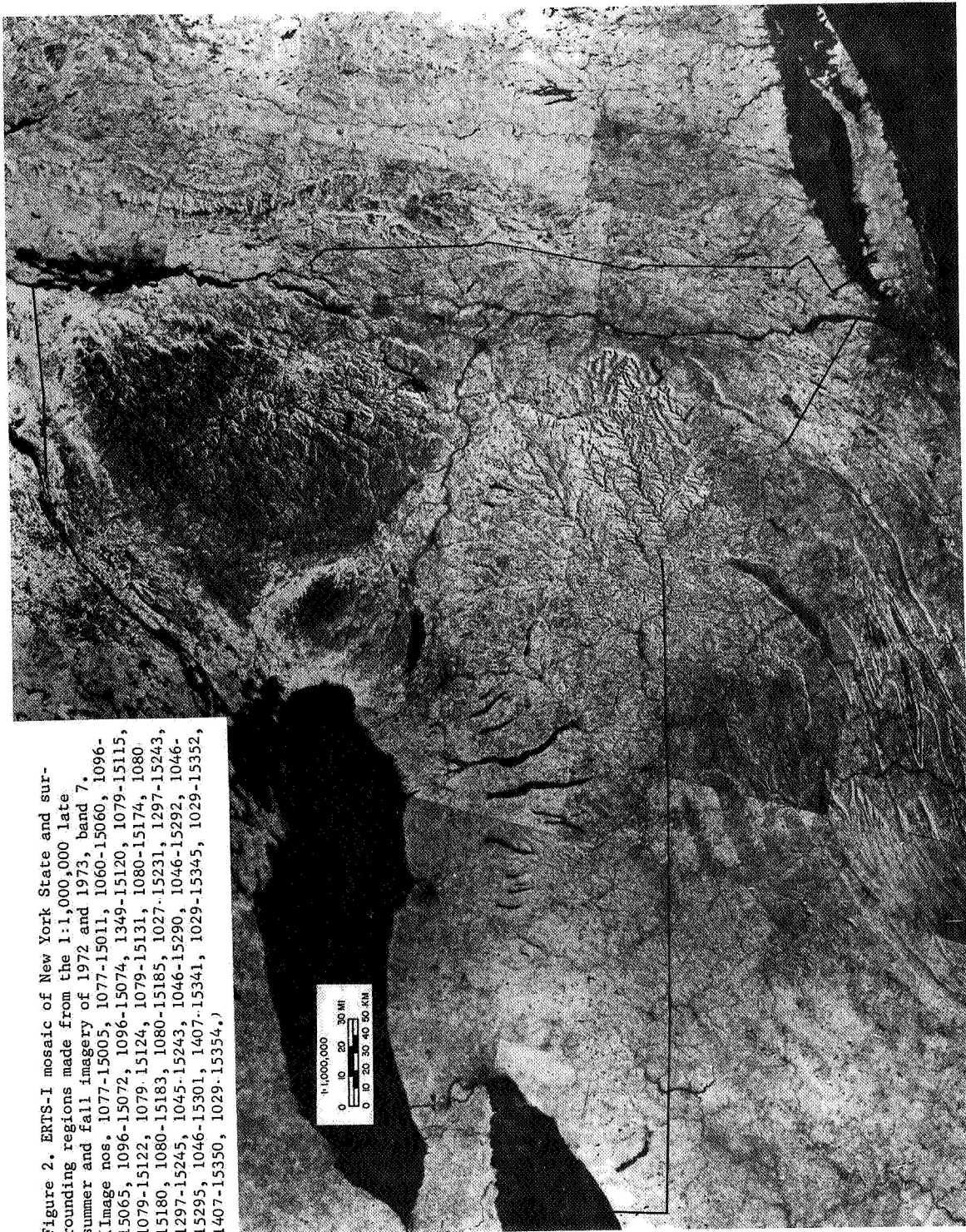
Figure 2. ERTS-I mosaic of New York State and sur-
rounding regions made from the 1:1,000,000 late
summer and fall imagery of 1972 and 1973, band 7.
(Image nos. 1077-15005, 1077-15011, 1060-15060, 1096-
15065, 1096-15072, 1096-15074, 1349-15120, 1079-15115,
1079-15122, 1079-15124, 1079-15131, 1080-15174, 1080
15180, 1080-15183, 1080-15185, 1027-15231, 1297-15243,
1297-15245, 1045-15243, 1046-15290, 1046-15292, 1046-
15295, 1046-15301, 1407-15341, 1029-15345, 1029-15352,
1407-15350, 1029-15354.)
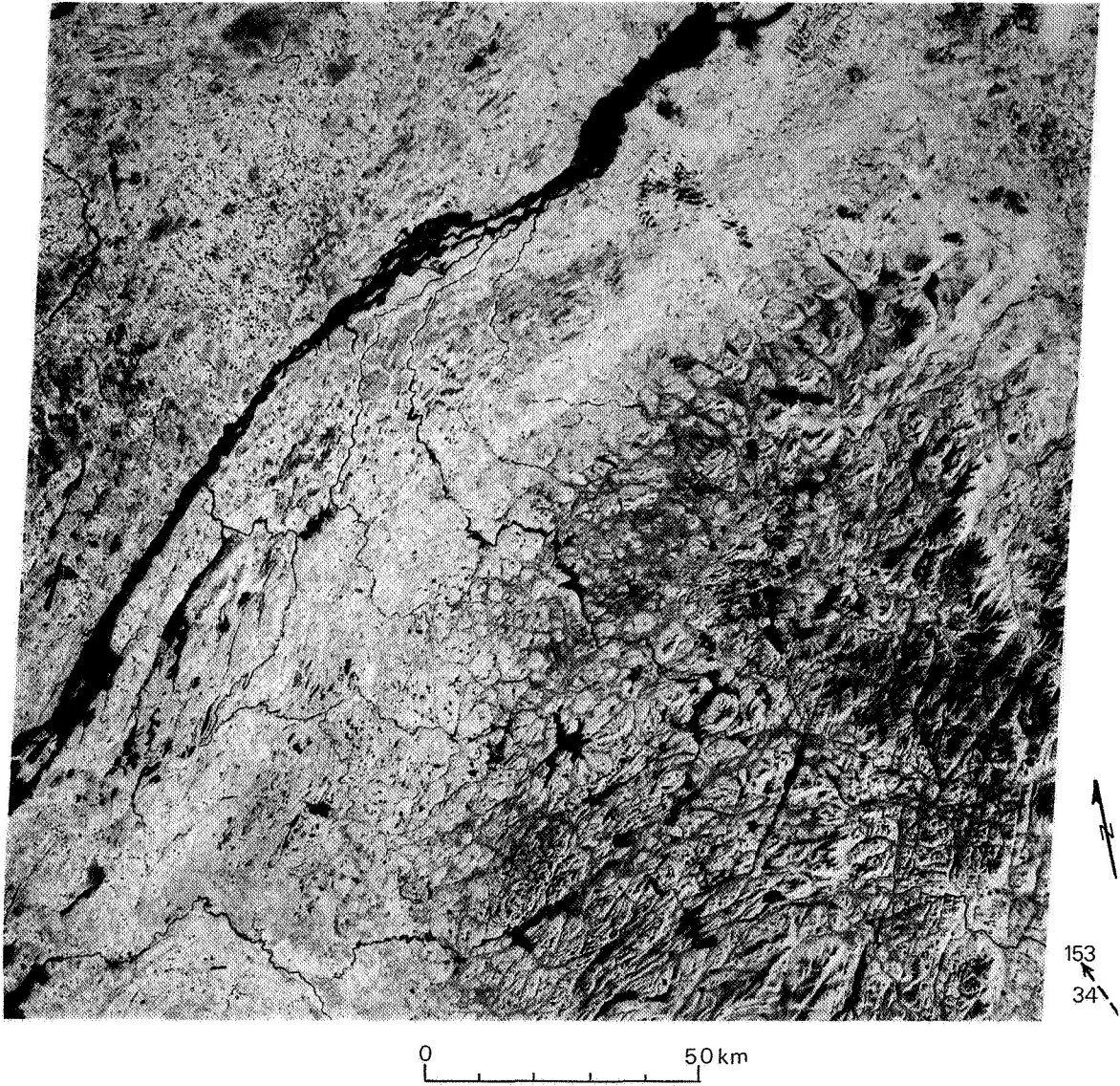
Figure 3. ERTS-I image of Adirondack area, band 7, taken 11 Oct 72 over the northern Adirondack region (image no. 1080-15174). Dashed arrow indicates sun azimuth and angle. From east to west, the dots in the high peaks region indicate sites from which were taken the photographs of Figures 8, 11, and 10 respectively.
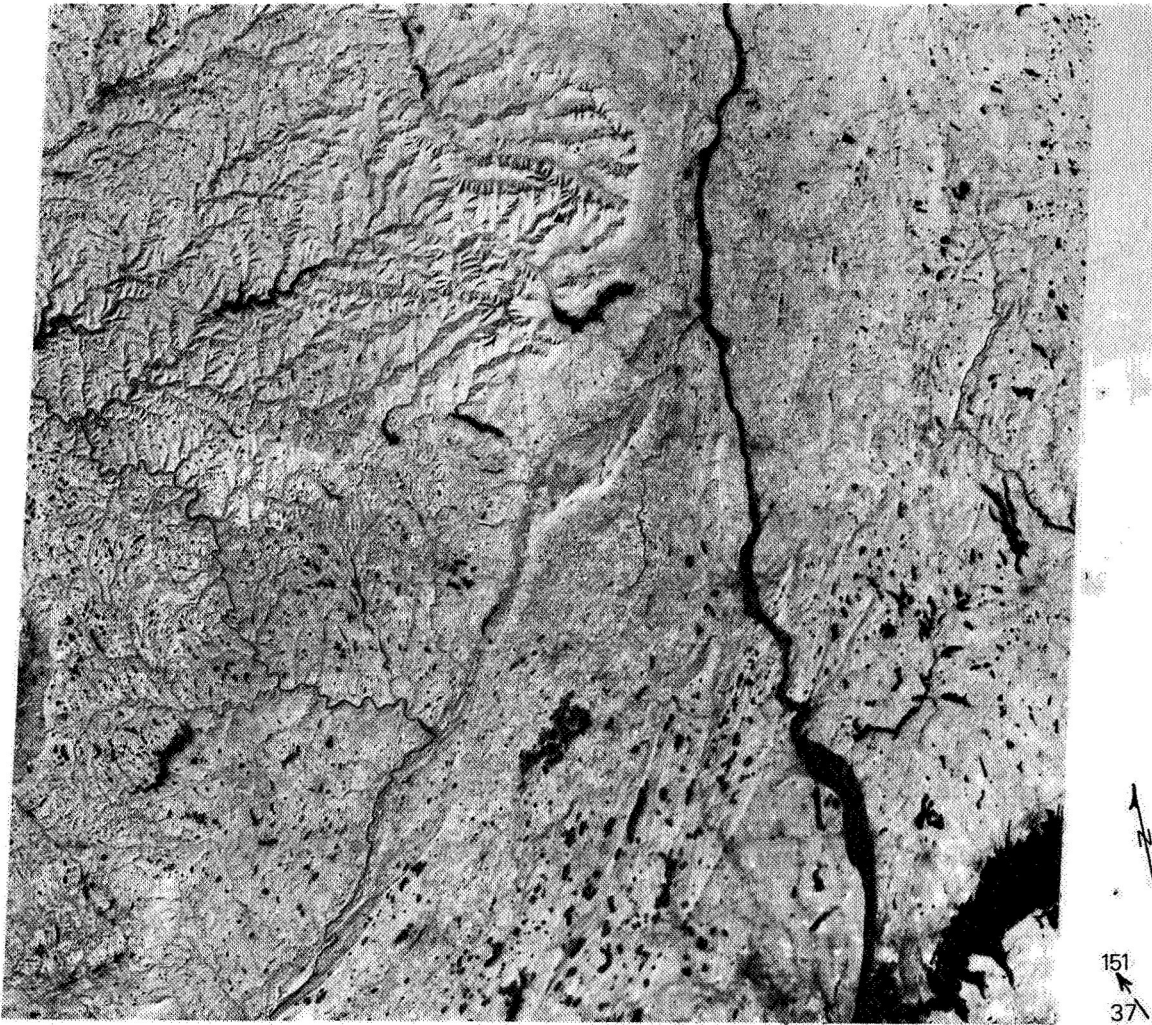
Figure 4. ERTS-I image over southeastern New York State, band 7 of 10 Oct 72 (image no. 1079-15124). Dashed arrow indicates sun azimuth and angle. Triangle in Catskill Mountains indicates site from which photograph of Stony Clove (Figure 13) was taken.
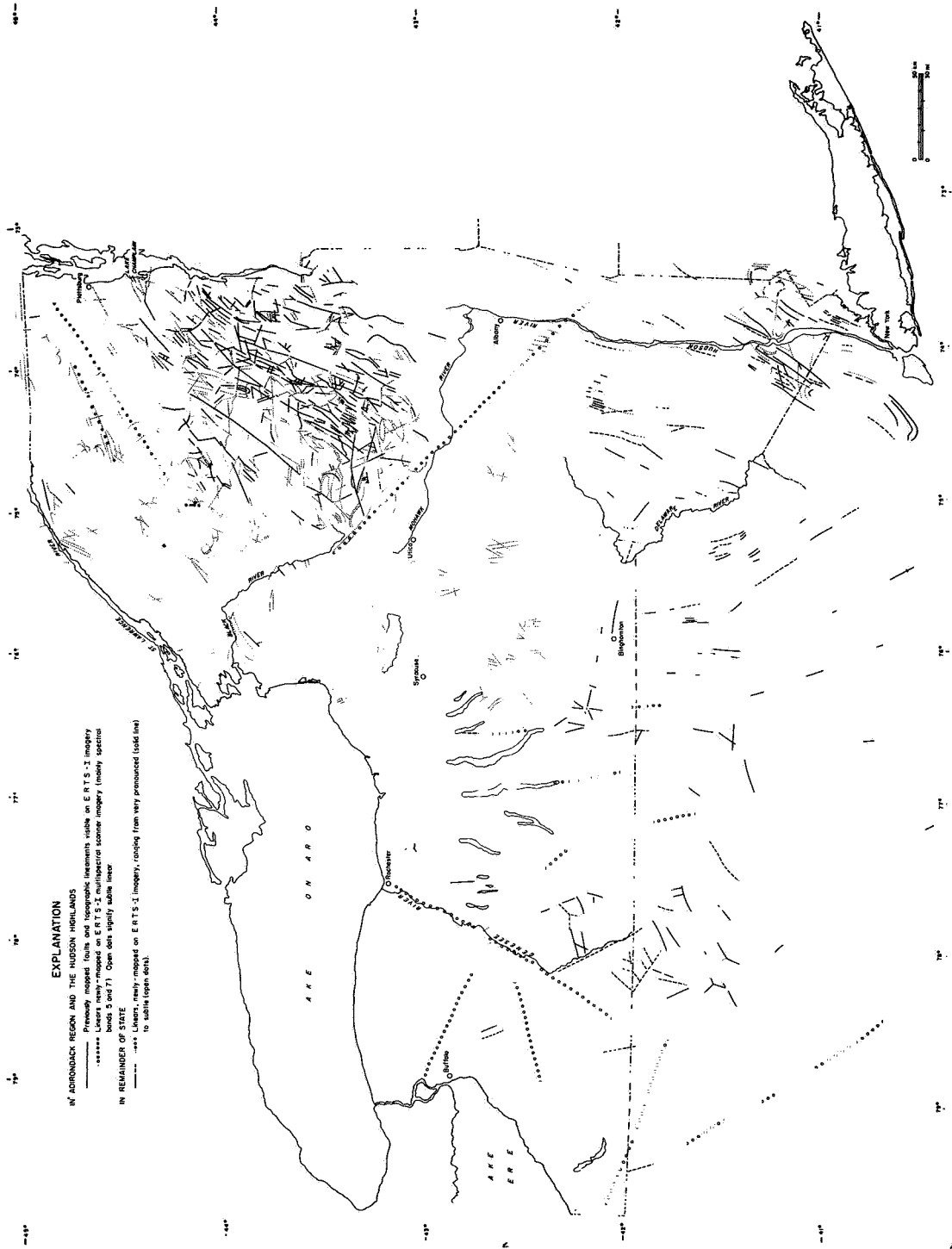
Figure 5. Stage II work map of ERTS-I anomalies mapped at 1:1,000,000.
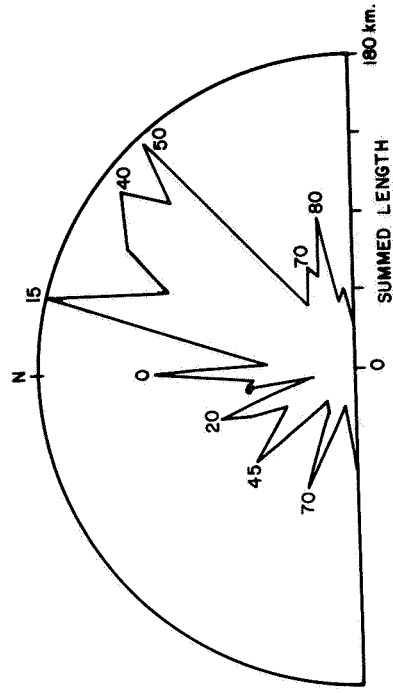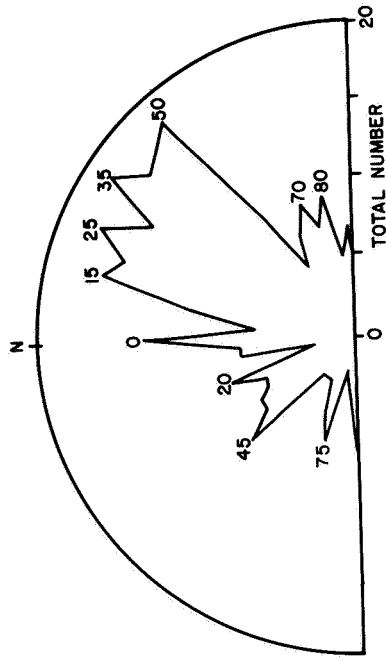
Figure 7. Rose diagram of previously mapped faults and topographic lineaments in the Adirondack region with data lumped into 5 degree intervals. Upper diagram is a plot of total number of linear features (335), whereas lower diagram sums total lengths. Curved lines were arbitrarily excluded.
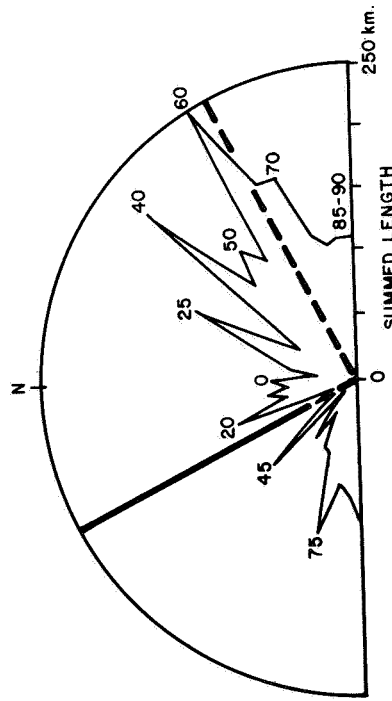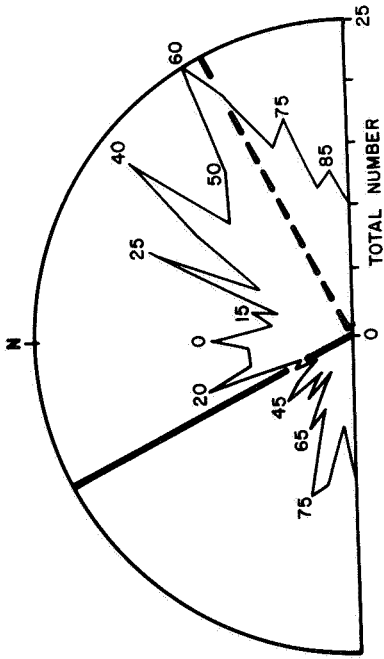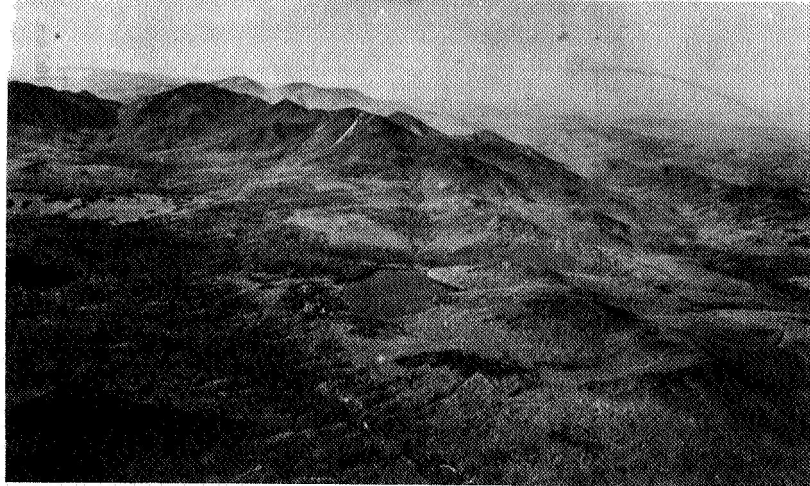

Figure 6. Rose diagram of ERTS-I anomalies, i.e. features which have survived Stage II analysis, in the Adirondack region, with data lumped into 5 degree intervals. Upper diagram is a plot of total number of linears (364), whereas lower diagram sums total lengths.

Figure 8. ERTS-I linear (no. 291), shown here to be a topographic lineament.
It strikes N43E and extends in both directions across Clear Pond
in the foreground. View is northerly. The mountain peaks west of
the linear are McComb (with slide), Hough (sharp peak), Dix, and the
valley of Hunters Pass. Hunters Pass is part of a previously-mapped
topographic lineament 25 km in length which extends across Elk Lake
in the middleground. All bedrock in clear view is metamorphosed
anorthosite. Mt. Marcy 15' quadrangle. See Figure 3 for site of
photograph on ERTS-I imagery.

Figure 9. Central and upper portion of linear shown in Figure 8 . Topographic
expression is slightly enhanced by the contrast between deciduous
trees in the valley and conifers plus rock outcrop along the ridge.

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Figure 10. View of Avalanche Lake topographic lineament, a previously-mapped
            feature, looking south. Avalanche Lake is in shadow at the base
            of Mt. Calden. Entire terrane except hazy background is located
            within Marcy Massif metanorthosite; Mt. Marcy 15' quadrangle. See
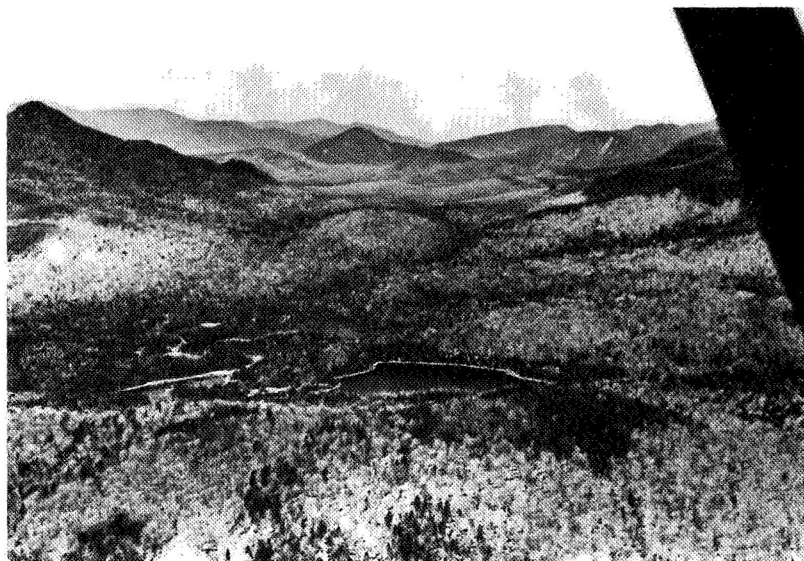   Figure 3 for location on ERTS-I image.

Figure 11. ERTS-I linear no. 287, extending N52W from White Lily Pond;
            entirely within Marcy Massif metanorthosite; Mt. Marcy and
            Santanoni 15' quadrangles.

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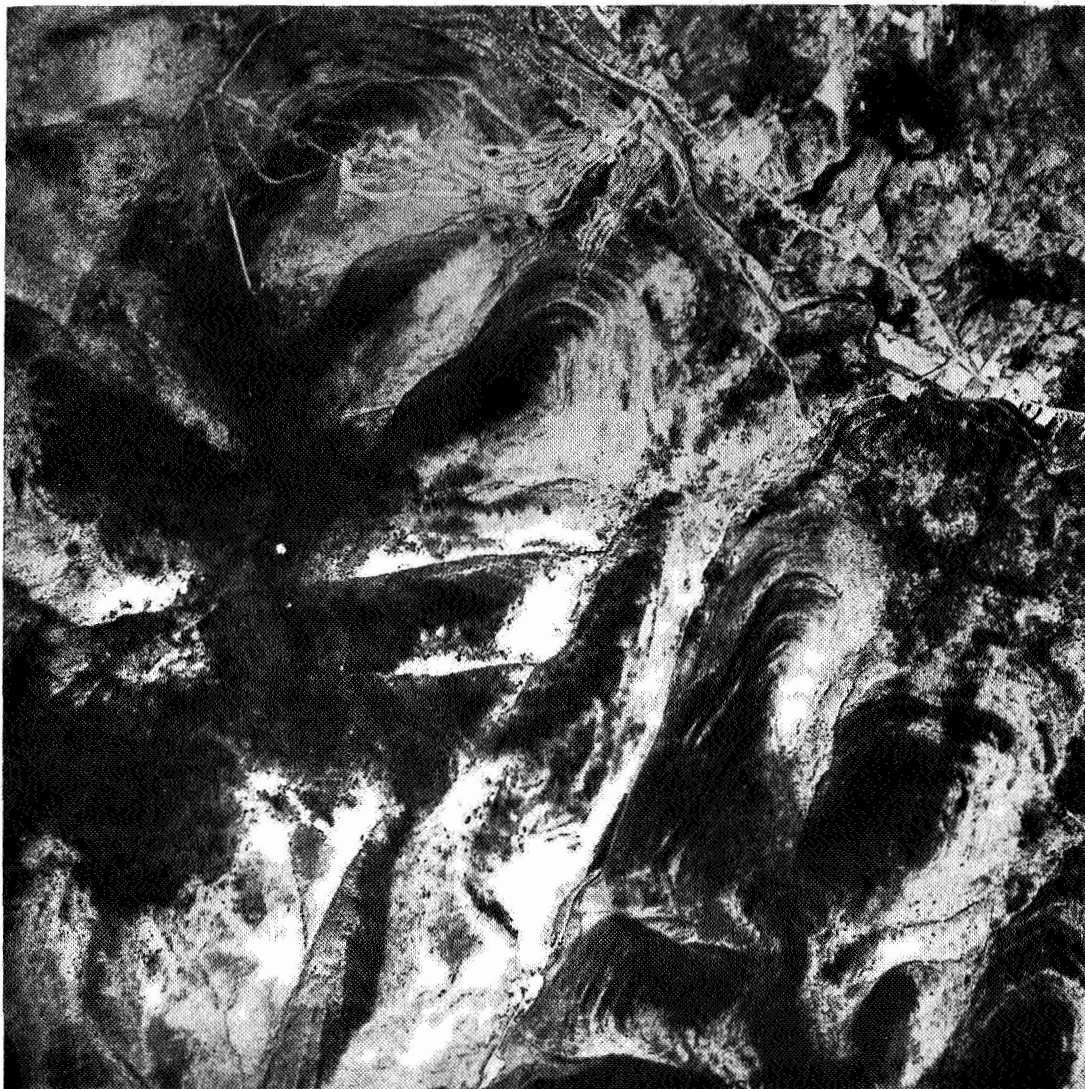
Figure 12. Print from color transparency aerial photograph over the eastern Catskill Mountains. Stony Clove topographic lineament extends about N15E from south center of photo; Hunter Mountain ski area is near north edge of photo. Note pair of N75E topographic linears. Photo by NASA, 30 Apr 73. For site of Stony Clove lineament on ERTS-I imagery, see Figure 4.
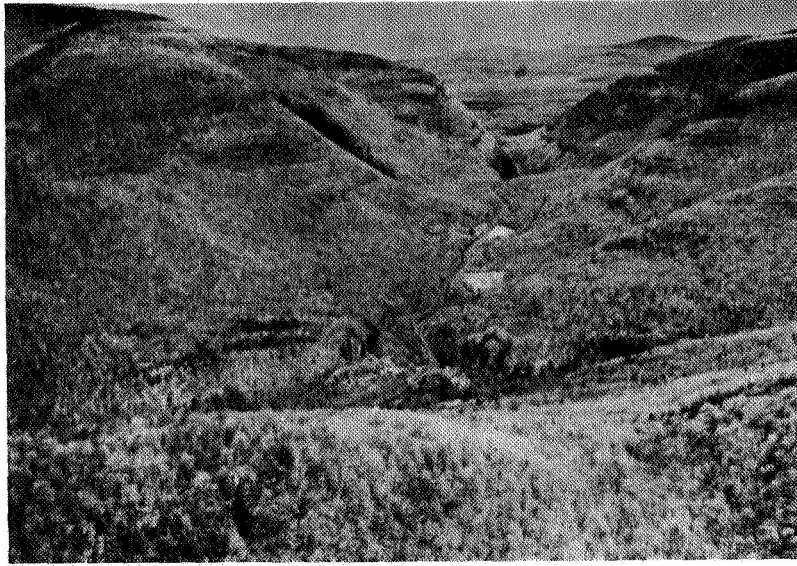
Figure 13. Stony Clove topographic lineament, looking N15E over
Edgewood (hidden behind hill in foreground), with drainage
divide at Clove in middleground; Hunter 7½' quadrangle.
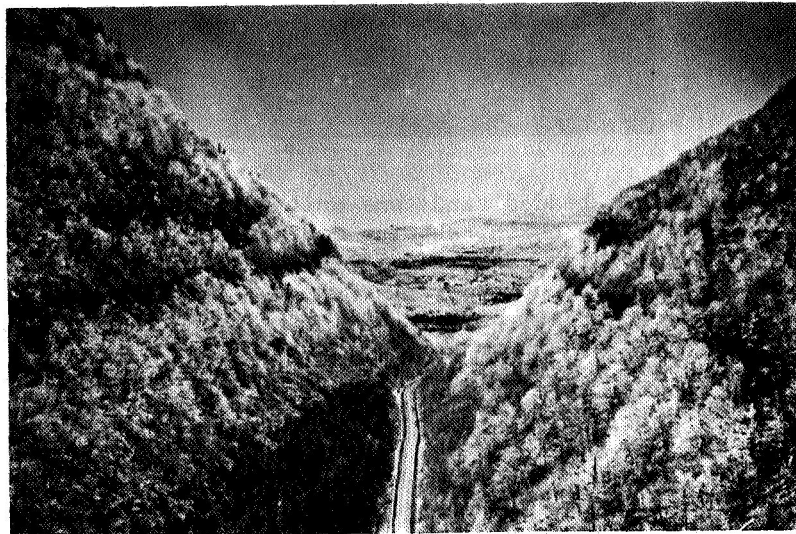From color-infrared photo. See Figure 4 for location on
ERTS-I image.

Figure 14. Stony Clove drainage divide of Figure 13, showing possible
vertical offset of the resistant Stony Clove sandstones of
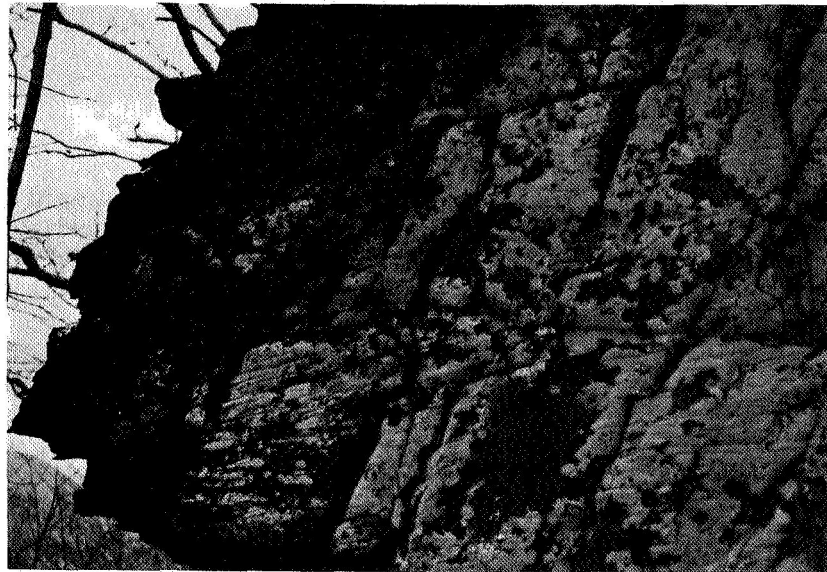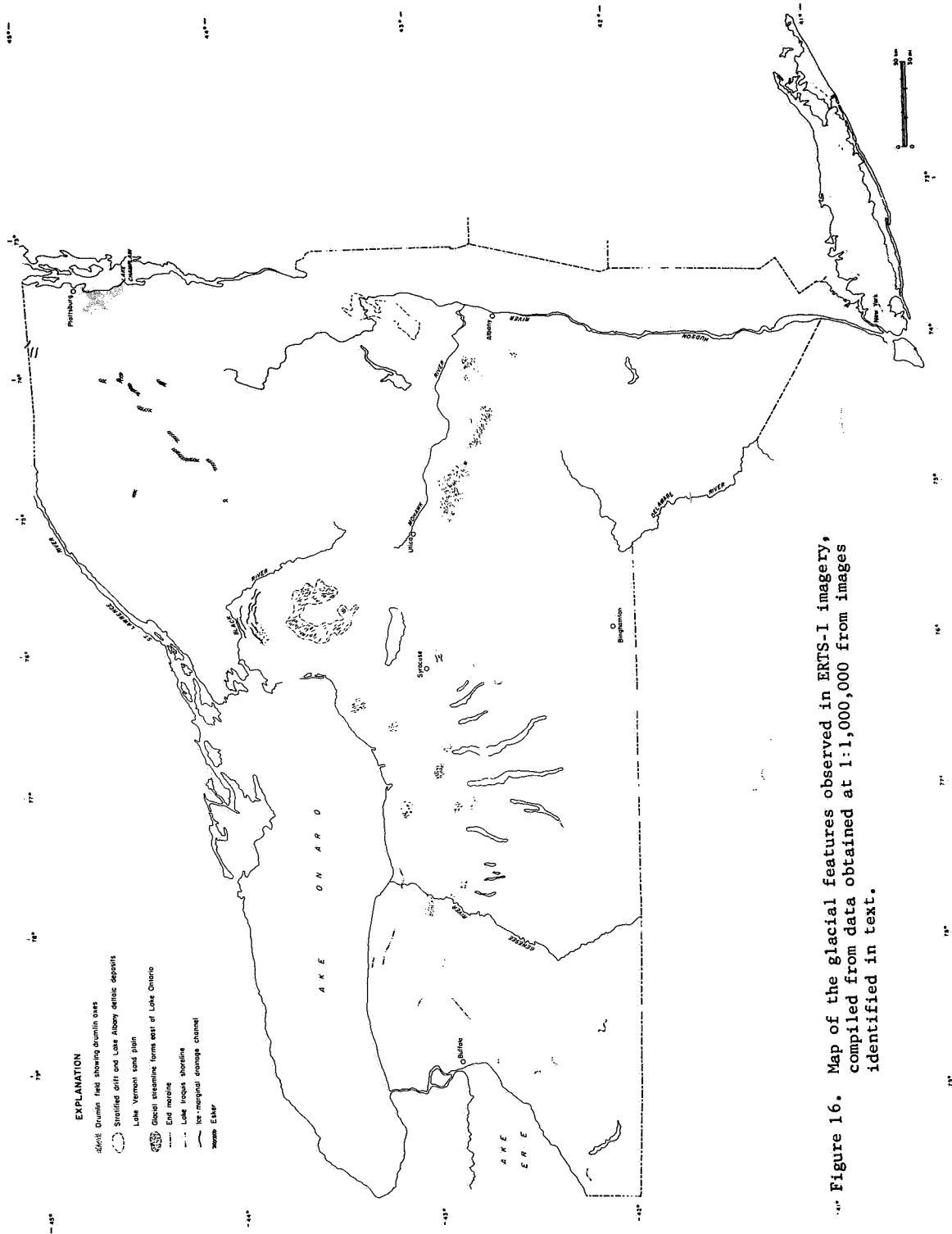of the Upper Devonian Lower Walton Formation.

Figure 15. Cross-bedded sandstone unit along east wall of Stony Clove, looking north, showing dominance of westward-dipping joint set which parallels valley. Note conjugate joints at east side of outcrop; dips are 75° east and 73° west, making an acute angle of 32°.

EXPLANATION

Drumlin field showing drumlin axes

Stratified drift and Lake Albany deltaic deposits

Lake Vermont sand plain

Glacial streamline forms east of Lake Ontario

End moraine

Lake Iroquois shoreline

Ice-marginal drainage channel

Esker

LAKE ONTARIO

LAKE ERIE

Buffalo

Syracuse

Binghamton

Albany

New York

Plattsburg

HUDSON RIVER

MOHAWK RIVER

GENESEE RIVER

BLACK RIVER

DELAWARE RIVER

UNADILLA RIVER

LAWRENCE RIVER

50 km
50 mi

Figure 16. Map of the glacial features observed in ERTS-1 imagery, compiled from data obtained at 1:1,000,000 from images identified in text.