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THE UTILIZATION OF LANDSAT IMAGERY IN NUCLEAR POWER PLANT SITING

G-14

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ABSTRACT

Imagery derived from the Earth Resources Technology Satellite (LANDSAT) is being used to aid in the evaluation of sites for Nuclear Power Plants in the United States and foreign countries. This imagery has been used primarily to map geologic features such as lineaments, linears, faults, and other major geologic structures which affect site selection for a Nuclear Power Plant.

INTRODUCTION

The United States Nuclear Regulatory Commission (USNRC) has established regulations for seismic and geologic considerations which determine the suitability of proposed sites for nuclear power plants. The suitability of the plant design basis is established in consideration of the seismic and geologic characteristics of the proposed site in order to provide reasonable assurance that the nuclear power plant can be constructed and operated at a proposed site without undue risk to the health and safety of the public.[1] A great many of the governments outside the United States have adopted the USNRC reactor site criteria per se or the philosophy implied by these criteria. The design basis for the vibratory ground motion is determined through an evaluation of seismology, geology, and the seismic and geologic history of the site and the region surrounding the site.

The design basis for vibratory ground motion is the earthquake which could cause the maximum vibratory ground motion at the site and is designated as the Safe Shutdown Earthquake (SSE). The SSE is identified by a thorough evaluation of seismic and geologic information. The most severe earthquakes associated with tectonic structures or tectonic provinces in the site region are identified and if capable faults are in the site region, the most severe earthquakes associated with these faults are identified.

A tectonic province is defined as a region characterized by a relative consistency of the geologic features contained within and a tectonic structure is a large scale dislocation or distortion within the earth's crust and is usually measured in miles. Alternately, when earthquake epicenters cannot be reasonably correlated with tectonic structure or with known faults, they may be identified with a seismotectonic province. The seismotectonic province is a region characterized by like geologic structural features and equipotential seismicity. The seismotectonic province is identified by boundaries determined by an analysis of the geologic and tectonic environments and the seismic history. The assumption is made that any historical earthquakes which have occurred in the seismotectonic province can occur anywhere in the province. Figure 1 is an example of a tectonic map and Figure 2 is a seismotectonic map.[2]

existing in the technical literature. Similar studies are also being conducted in Asia to evaluate specific areas as to their desirability as a potential nuclear power plant site.

REGIONAL STUDY

Pakistan

The region of Pakistan is dominated by the tectonic activity associated with the Himalayan Mountains. This mountain system is considered by most to be the prototype area for continent-continent plate tectonic interaction where the two primary plates involved are the Indian Plate and the Eurasian Plate,[3] although some authors feel that the presence of additional, smaller plates are needed to satisfy small irregularities in relative motions indicated by focal mechanism solution. Generally, the Indian Plate is moving northward and colliding with the Eurasian Plate. Estimates of cumulative thrusting along this plate margin are 450 km for the area near Assam and 370 km in the Punjab-Hindu Kush region.[4] The plate tectonic configuration for this region is shown in Figure 3.

Studies of focal mechanism solutions for Himalayan earthquakes indicate that most earthquakes are being generated by horizontal compressive stresses that result in the formation of large scale, low angle thrust faults. It appears that most of the motion between these plates is taken up by movement along the Himalayan Thrust and the Hazara Thrust. Although these are the most prominent thrust faults in the region, it should be expected that movement along additional thrust faults would be likely. The rate of convergence has been estimated by LePichon to be approximately 5.6 cm/year.[5]

The eastern and western borders of the Indian Plate are not well defined. Very little research has been concentrated along the eastern region of the Indian Plate and no definite conclusions can be reached regarding the relationship of the Indian Plate to the Asian Plate and Burmese Arc.[6] The western border of the Indian Plate and The Baluchistan Arc, has been studied more extensively in terms of plate tectonics.[3,7] Focal mechanism solutions along the Kirthar-Sulaiman fault zone in Pakistan shows consistent left lateral strike-slip motion along a fault plane that strikes north-south. This type of movement agrees with field evidence, as well as observed displacements during earthquakes, and indicates a northward movement of the Indian subcontinent with respect to Afghanistan. The entire area can be considered to be moving northward, with the Indian Plate moving at a more rapid rate than the remainder of southwest Asia and the Middle East. The exact relationship of the Kirthar-Sulaiman fault zone to the spreading centers in the Indian Ocean has not been conclusively demonstrated.

The geology of the Baluchistan Arc is very complex. The area in general represents a bend, or syntaxis, of the east-west trend of the Himalayas to a north-south orientation. This north-south trend remains relatively consistent for a distance of approximately 1,000 km before taking another east-west bend in the Makran Mountains of southeastern Iran. Even the north-south segment is characterized by several smaller syntaxial bends, the largest of which is near the seismically active area of Quetta, another is west of the town of Mianwali, and a third is northwest of Tank in the Bhittani Mountains.

The structure of the Baluchistan Arc is dominated by thrust faults, mainly from the northwest and west toward the Indian Platform, and tight folds with axes essentially north-south, parallel to the general trend of the arc.[7] The pattern of mountain ranges, and the structural characteristics of each range, however, do not fit a simple model for the plate tectonic evolution of this region, nor does the pattern of thrust faults within the north-south or east-west oriented ranges fit into a simple model of the structural evolution of the region. A considerable amount of work is still needed to adequately define the tectonic setting as well as the tectonic evolution of this complex area.

Two areas in Pakistan have been studied in regard to utilization of LANDSAT Imagery to obtain geologic information. One area, as shown on Figures 4A, 5A and 6A, is dominated by the flood plain of the Indus River and the Thal desert of central Pakistan. It is bordered on the north by the Salt Ranges and on the west by the Khisor Range. The other area, along the Pakistan-Afghanistan border is within the Baluchistan Arc.

The first area is the region being considered for an industrial site. The Indus Valley and much of the Thal desert is covered by surficial deposits of Quaternary age which includes alluvium and sand dunes. The slopes of the ranges are generally covered by alluvial fans, bahadas, and unconsolidated detritus. Some older, possibly early Tertiary, terrace deposits are found in the foothills of the Sulaiman Range. Some of these are well cemented and attain thickness in excess of 250 feet.[8]

The Salt Range and the Khisor Range are dominated by thrust faults and salt tectonics. The Salt Range has apparently been formed by tectonic transport along a Precambrian-Cambrian formation composed of salt and gypsum. The range extends for several hundred kilometers in an east-west direction from Kalabagh to near the Kashmir border. The frontal area of this range has been mapped as a thrust fault along its entire length. There is, in addition, evidence for salt tectonics such as large salt domes near Kalabagh and small salt intrusions throughout the entire range.

The Khisor Range trends north-south and is perpendicular to the trend of the Salt Range. They are indirectly related by the poorly mapped Mianwali Re-entrant. This range is also dominated by thrust fault tectonics, however, there apparently has been no salt mapped as is the case with the Salt Range. The frontal region of this range has been mapped as a continuous thrust,[8,9] but it is nowhere exposed. Folding along this frontal range, however, may be indicative of drag folding associated with large scale thrusting.

The LANDSAT imagery is used in the analysis of this area to define areas where large linears are present in the mountain ranges, and to determine if they are traceable into the alluvial deposits adjacent the mountain ranges. Once these areas are identified they can be studied in more detail on conventional aerial photography and eventually by a team of field geologists. This, therefore, enables one to pinpoint areas of interest in regard to capable faults over an extensive area through a relatively inexpensive, but thorough analysis of linears. It has great advantages over conventional aerial photography in regard to man-hours as well as availability of imagery and cost. This is especially true for Pakistan since the military controls all aerial photographic coverage and it may take several months to get access to conventional aerial photography.

The area shown on Figures 4A, 5A and 6A was analyzed for linears prior to a brief field reconnaissance by one of the authors. It was, therefore, possible to define the areas of most significance to the site including the area of the Mianwali Re-entrant between the Salt Range and the Khisor Range, and the frontal regions of both the Salt Range and the Khisor Range. As seen on Figures 4B, 5B and 6B, the area of the Mianwali Re-entrant is dominated by several long linears, the longest of which crosses the Salt Range where it intersects the Indus River. This region (Figures 4A and 4B) was examined in the field and it was found that the linear corresponds to a fault of relatively large displacement that has been extensively eroded to form a major valley tributary to the Indus Valley. In addition, several other faults, with parallel orientations were found within a kilometer of the larger fault. This area has been chosen as one needing additional field work to determine the relationship between the faulting and the alluvial deposits.

The frontal portion of the Khisor Range was examined in some detail. The slopes, as well as the plain immediately below the slopes, are covered in most places by alluvial fans and river terrace deposits. All of the alluvial fans appear to end at the same distance from the range and several of the fans have sharp, steep scarps. It has been decided that these deposits should be studied in greater detail to determine if these features are a result of surface faulting, or if they are related to erosion of the alluvium by the meandering Indus River.

An additional area examined on the LANDSAT imagery and in the field, but not shown on the Figures is in the Bhittani Range, west of the Khisor Range. The structural style is similar to the Khisor and Salt Ranges. This range trends east-west and marks another small syntaxial bend in the mountain chain. The central portion of this range is marked by a large fault. It has been mapped as a strike-slip fault,[8] however, strike-slip movement appears to be inconsistent with the overall structure of the range. This fault may represent a large scale thrust along which there has been a considerable amount of erosion. Additional field work is planned to clarify the nature of this fault.

Much of the mountainous regions of Pakistan are inaccessible, especially the mountainous regions along the border with Afghanistan. It is, therefore, difficult to evaluate large scale geologic and tectonic maps or to assess the nature of faulting. This is again, complicated by the relative inavailability of conventional aerial photography, which is especially true along this disputed border region. We have found that LANDSAT Imagery is very valuable for this purpose, especially in areas of rugged relief and little vegetation. Figure 7A is the LANDSAT Imagery for a region along the Pakistan-Afghanistan border which clearly shows the major structural features. Figure 7B is a regional tectonic map derived from this LANDSAT Imagery. This area is being analyzed for evidence of large scale strike-slip displacement associated with the Kirthar-Sulaiman fault zone discussed earlier in this paper. Additional areas to the north, south, and east of this area are being examined to determine the distribution and interrelationships between faults along this suspected plate boundary. This LANDSAT analysis will aid the evaluation of available geologic and tectonic maps, as well as assisting in defining areas of capable faulting.

In general, analysis of LANDSAT Imagery has enabled the initiating of large scale tectonic and structural studies as well as helping to define areas of structural complexity and areas of potential surface faulting hazards to industrial sites in Pakistan.

RECONNAISSANCE STUDY

Huelva, Spain

LANDSAT Imagery has been used extensively in Spain to aid in the initial tectonic analysis of approximately 20 power plant sites. Most of Spain has been mapped in relatively good detail (1:50,000) and the LANDSAT analysis has been used primarily to check the location of large tectonic features and to determine the presence of other tectonic features that have not been identified by conventional geologic studies. In one instance, analysis of this nature has resulted in the recommendation to reject a site from any further consideration.

The LANDSAT Imagery for the region investigated is shown on Figure 8, and represents an area of southwest Spain along the Atlantic Ocean, and near the city of Sevilla. The geology of the region is relatively simple. A long prominent linear divides the imagery into two regions. North of the linear lies Hercynian metamorphic rocks, while to the south the area is composed of sediments of the Guadalquivir Basin, as shown on Figure 9. This linear has often been mapped as a fault, although recent evidence indicates that it is a monoclinal flexure within the Hercynian rocks of the basement complex. This linear is well known and was anticipated during the analysis. What was not expected, however, was a second long linear within the Guadalquivir Basin. This northeast-southwest linear passes through the city of Sevilla and continues to the coast. It passes very near to the town of Huelva, where the power plant site was being considered.

The Guadalquivir Basin is generally considered to be a downwarped section of the Hercynian Shield. Geologic evidence indicates that subsidence began during the Miocene and accumulated at least 3,310 meters of sediments. Basement faults have been identified beneath these sediments near the axis of the basin,[10] however, no faults have been mapped in the Tertiary deposits. There is some evidence that indicates that the basin subsidence may be continuing at present. Archeological evidence indicates at least several meters of subsidence during historic time. In addition, the area south of the recently identified linear is generally swampy, while the area to the north is well drained. In addition to subsidence, this last information may be indicative of normal faulting along this linear. Recent mapping along the Guadalquivir River, shown on Figure 10, near Sevilla indicates the presence of several small faults which either coincide with this linear or have similar trends. The interpretation of the linear features and the locations of faults are shown on Figure 11.

Although earthquake frequency is not high in this region of Spain, several earthquake epicenters are located along this linear. These include the 1504 Carmona Earthquake which had an estimated epicentral Intensity of XI (Modified Mercalli).

Using the combination of available literature, LANDSAT Imagery analysis, and earthquake data it was possible to perform a rapid analysis of this particular site. No definitive evidence was found for recent faulting, such as Quaternary offsets, however, sufficient information existed that indicates a probability of faulting. Since this was part of a multiple site selection study it was decided that large capital outlay would be required to prove the absence, or non capability of faulting in this region and the site was abandoned in favor of other sites.

DETAILED STUDY

South Carolina Piedmont

A detailed analysis of LANDSAT linears was conducted for a nuclear facility in South Carolina in 1973. This study included a statistical analysis of LANDSAT linears and their relationship to geologic features, both major and minor, in a part of the Piedmont Province of the Appalachian Orogenic Belt, as shown on Figure 12. Although the imagery includes a portion of the Blue Ridge Province, no detailed field work was done in the Blue Ridge, and hence it will not be treated in this paper.

The Piedmont Province lies between the Coastal Plain to the southeast and the Brevard Zone to the west and extends for the entire length of the Appalachians. Typically the Piedmont Province is a broad plateau sloping gently seaward from the front of the Brevard Zone and the Blue Ridge to the Coastal Plain. Bedrock exposures in the province are scant and poor since rock is covered with a residua mantle of thoroughly weathered material (saprolite) of varying thickness. Because rock exposure is poor, the geology of the province has not been fully investigate and the regional interpretation is inferred from a few locations where details are known.

The Piedmont in North Carolina, South Carolina and Georgia consists mainly of a complex of contorted gneisses, schists, phyllites and slates, containing granite plutons and small ultrabasic intrusives. The metamorphic grade generally increases toward the west and then decreases again in the Blue Ridge. The last high temperature metamorphism and plutonic emplacement is thought to have been at the end of the Paleozoic era.

The Piedmont Province can be divided into five zones as shown on Figure 12, which are elongated parallel to the Appalachian structural trends. These belts are: the Chauga Belt, the Mobilized Inner Piedmont, the Charlotte Belt, the Kings Mountain (Lowndesville) Belt and the Carolina Slate Belt.(11)

The Chauga Belt forms the westernmost subdivision of the Piedmont Province, and is bounded on the northwest by the Brevard Zone. The belt contains two formations, the Chauga River Formation, consisting primarily of phyllites with some impure marble and the quartzo-feldspathic Henderson Gneiss.

The Mobilized Inner Piedmont Belt contains rocks of the highest metamorphic grade formed in the Southern Appalachian Piedmont. These rocks include both volcanic and sedimentary series that have been metamorphosed to the staurolite-kyanite and sillimanite-almandine subfacies of the almandine-amphibolite facies.(11) Griffin(12) states that the rocks in the core of the Inner Piedmont are of a higher grade than either the northwest or southeast flanks. Griffin(12) has also observed that the Inner Piedmont is marked by undulatory foliation with a predominance of very gentle dips that are most likely the result of a gentle folding of a previously deformed foliation.

The Kings Mountain Belt (Lowndesville Belt) of South Carolina and North Carolina has been studied extensively by Overstreet and Bell,[13] Overstreet,[14] Butler,[15] and Griffin.[12] Overstreet and Bell[13] believe that field evidence indicates that the Kings Mountain Belt represents a metamorphosed sedimentary sequence which is in part the age equivalent of similar lithologies in the Inner Piedmont, Charlotte Belt and Carolina Slate Belt. They also indicate that the apparent physical differentiation between the Kings Mountain Belt and other belts in the Piedmont is a result of a change in metamorphic grade rather than the result of faulting. More recently Griffin[16] and Hatcher[11] indicate that the northwest boundary of the Kings Mountain Belt is a fault contact.

The Carolina Slate Belt, the easternmost belt in the Piedmont and the one with the lowest grade of metamorphic rocks, can be followed almost continuously from Virginia, 30 kilometers north of the North Carolina border, well into Georgia. The stratigraphic section within the Slate Belt is composed of metasedimentary and metavolcanic rocks. The metasediments are mudstones, argillites and greywackes, which are poorly sorted and contain bedding that ranges from fine laminations to thick, graded beds. All of the fine grained rocks in the section show slaty cleavage. Quartzites, conglomerates and carbonates occur in this belt but are not major constituents. The interbedded metavolcanic rocks are tuff, breccia and mafic and felsic volcanic flows.

The Charlotte Belt extends from eastern Alabama through South and North Carolina and into Virginia. Rocks similar to those found in the Charlotte Belt also crop out in the eastern area of the Carolina Slate Belt. The rocks of the Charlotte Belt are predominantly medium grade gneiss, schist and amphibolite that were intruded by many pre-metamorphic and post-metamorphic plutons. Overstreet and Bell[13] found that granitic textures are common in the rocks of the Piedmont and that the belt includes a large number of plutons. They found that the granitic rock has strong compositional banding resulting from the metamorphism of sedimentary and volcanic rocks. This granitic rock is often a fine-grained gneiss and migmatite of the albite-epidote-amphibolite subfacies, the highest of temperature subfacies of the green-schist facies. In places, metamorphic grade rises to staurolite-kyanite subfacies and near plutons, it even rises to sillimanite-almandine subfacies; both subfacies of the almandine-amphibolite facies. Thus the Charlotte Belt represents an area of moderate grade metamorphism between two areas of lower grade metamorphism.

The LANDSAT Imagery used for this study is presented in Figure 13 and a map of linears on this imagery is presented as Figure 14. Visual comparison of the linear map and LANDSAT Imagery to the map of geologic subdivision shows only two features common to both. These are the Blue Ridge Province and the Brevard Zone, which separates the Blue Ridge from the Piedmont.

The most prominent linear feature, which is sufficiently long to be considered a lineament, is associated with the Brevard Zone. This zone is characterized throughout its length by both faulting (possibly several periods of movement) and a distinctive stratigraphy consisting of the Chauga River Formation[11] and the Henderson Gneiss. With the exception of the Brevard Zone and the Chauga Belt with which it is associated, no other geologic subdivision within the Piedmont can be discerned on the imagery.

Considering the regional lithologic and structural variations within these subdivisions it would be expected that at least the northwest boundary of the Kings

Mountain Belt (Lowndesville Belt) would be represented by a pronounced photo linear, especially since it is considered to be bounded by a fault that extends well into Georgia.[11,16] This lack of a distinct linear feature may indicate that the northwest border of the Kings Mountain Belt is not fault controlled, or that faulting along this boundary may be of only minor importance in the regional tectonic setting.

The most interesting of the remaining linears that have been detected in this study is located north of the Greenville-Spartanburg area of South Carolina and passes near the town of Tigerville. This east-west oriented linear extends from the Brevard Zone in the west, to within 20-30 miles of the North Carolina state line in the east. This linear has not been studied in detail, however, it is tentatively suggested that this may represent a large fault within the Piedmont Province. However, no faults have been mapped along this trend. This linear appears to be marked by a distinct change in topography, with the northern area having a rugged topography more similar to the Blue Ridge than to the gentle topography of the remaining portion of the South Carolina and North Carolina Piedmont.

It is difficult and time consuming to field check each linear mapped on LANDSAT Imagery. It was decided that the most efficient way to analyze the results of a large areal linear study was to perform a statistical analysis of linear orientations and determine their relationship to minor geologic structures. The area of the LANDSAT Imagery was subdivided into two domains based on gross geologic features; the Blue Ridge, and the Piedmont. The Blue Ridge was not of immediate concern in regard to the site being evaluated and subsequently no additional work was conducted there. The orientations of the LANDSAT linears within the Piedmont Province were then measured and plotted on a rose diagram, shown on Figure 15. The orientations are listed in Table I.

In order to evaluate these orientations in terms of geologic structure, a reconnaissance level joint study was undertaken. Three areas were defined for collection of data based on geologic and geographic distribution. The area near Lake Hartwell (Area 1 on Figure 16) was chosen because of its proximity to the proposed site. The area near Hendersonville, North Carolina (Area 2) was chosen because of the differences in topographic character with the remaining portion of the piedmont being studied. The area northwest of Columbia, South Carolina (Area 3) was chosen because of the difference in geologic features between the Slate Belt and the Inner Piedmont. Joints were measured in each of these areas and plotted on rose diagrams. These are shown on Figure 17, and presented in tabular form in Table I.

It is evident from the comparison of orientation data in Table I that most of the LANDSAT linears correspond quite well with the orientations of joints distributed throughout the Piedmont. This is particularly the case with the N2E, N43W, and N68W orientations, which may represent primary fracture trends in the Piedmont Province. Wielchowsky and Drakovsal[17] have indicated that a N47W orientation is one of the dominant LANDSAT linear trends in the Dora-Sylvan Springs Area of Alabama. Comparison with other areas cannot be made because there is very little published information on joint orientations within the Piedmont Province.

Each of the other LANDSAT linear orientations has at least one area within the study region that has joint orientations with similar, or identical trends. The only exception to this is the N53W trend on the LANDSAT Imagery. Additional work is in progress to determine the relationship of this trend to the regional structural setting. It is tentatively suggested however, that this trend corresponds with one of the predominant northwest trends of Triassic diabase dikes which are distributed throughout the Piedmont.

This study has shown the usefulness of LANDSAT analysis to the study of major and minor linear geologic structures within the Piedmont Province of the Appalachians. Large scale geologic features such as the Brevard Zone are very evident and easy to distinguish on this type of Imagery. The statistical treatment of small linears on LANDSAT Imagery coupled with reconnaissance studies of minor geologic structures such as joints has proven to be a valuable technique in the evaluation of geologic hazards for power plant siting.

CONCLUSIONS

This study emphasizes the usefulness of LANDSAT Imagery interpretation in the selection processes for industrial and power plant sites. It has proved useful for the delineation of linear geologic or geographic features that may represent traces of faults. These areas can then be examined in more detail by conventional aerial photography and eventually by geologic field mapping. LANDSAT Imagery has also been of particular use in the analysis of regional tectonics as a check on maps that are currently available and as a base on which to begin tectonic studies in areas that have insufficient geologic control.

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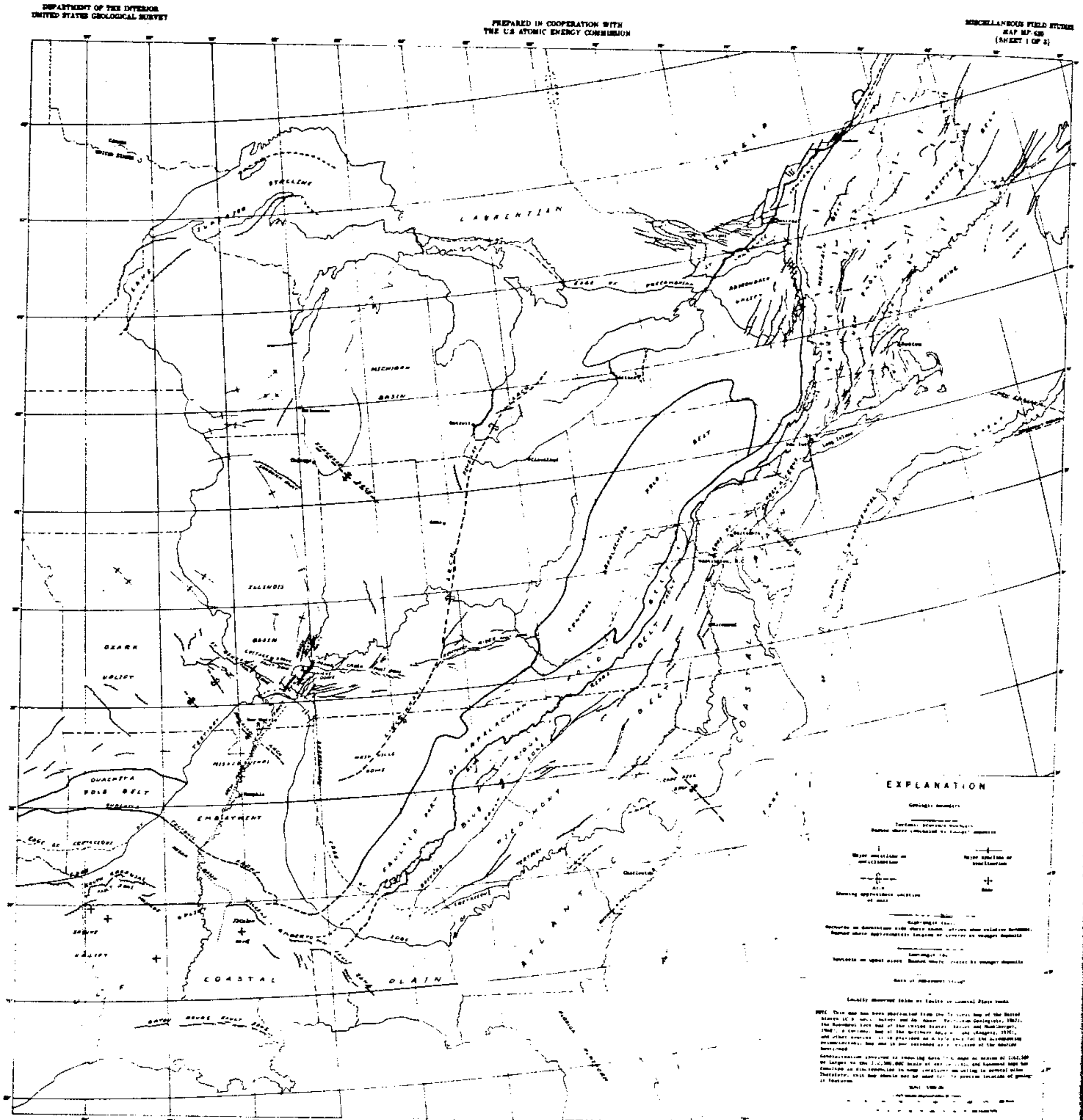
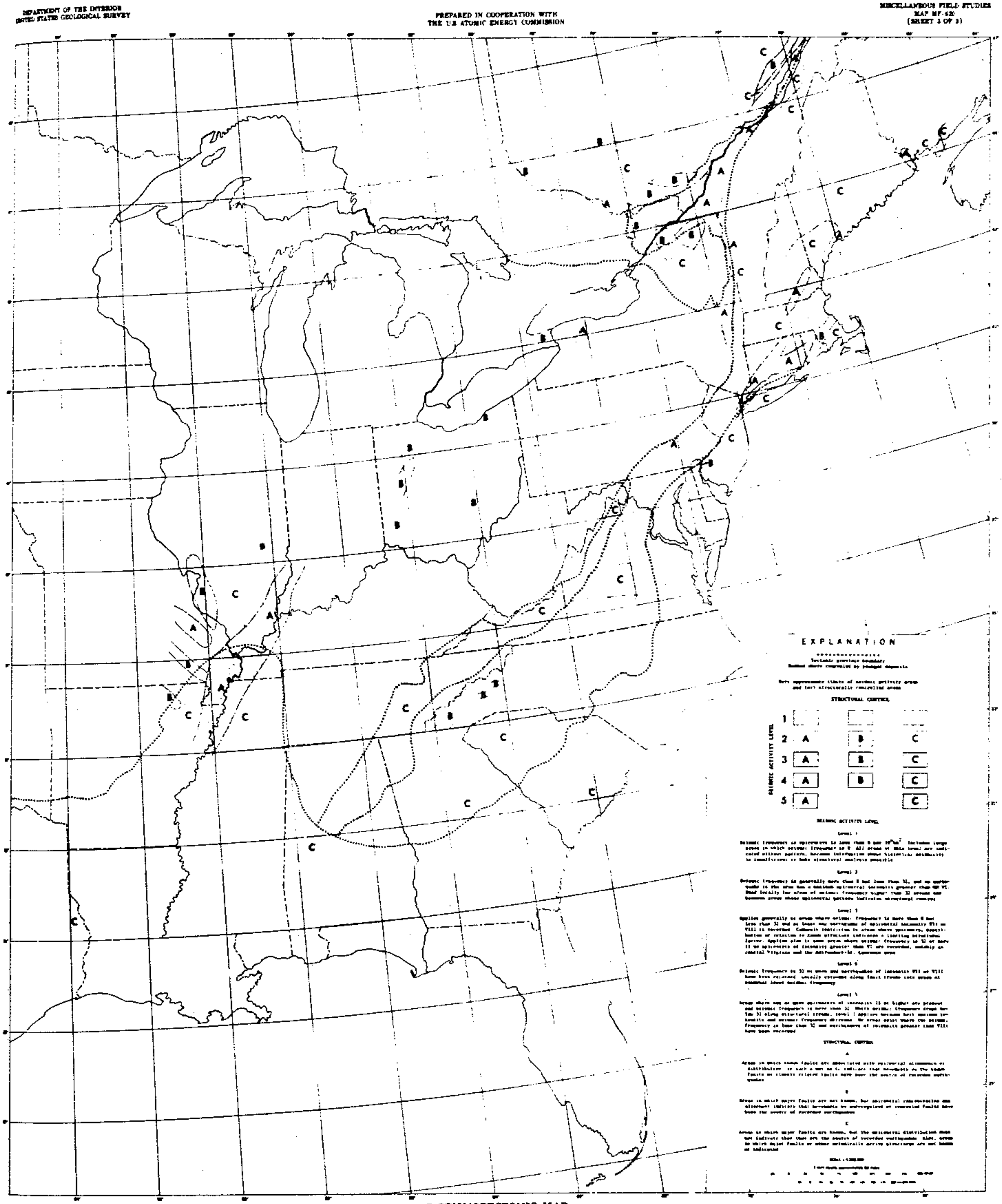
TABLE I. - SUMMARY OF ORIENTATION DATA

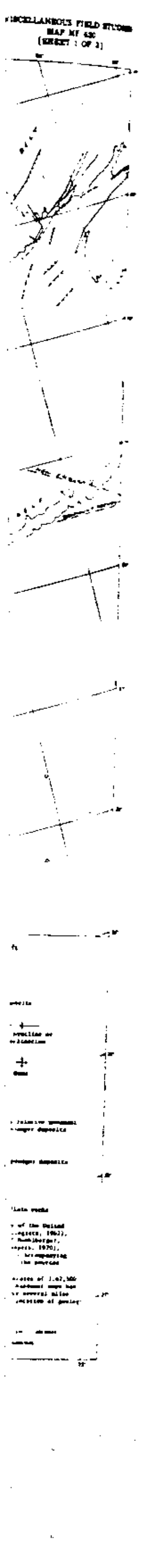
LANDSAT Linears (Piedmont Area)	Joints Anderson Area, S. C.	Joints Hendersonville Area, N. C.	Joints Columbia Area, S. C.
N63E		N62E	
N52E	N52E		N57E
N32E	N37E	N30E	
N16E	N15E	N17E	
N2 E	N2 E	N2 E	N8 E
N8 W			N12W
N22W	N17W		
N43W	N42W	N47W	N42W
N53W			
N68W	N62W	N62W	N68W
N82W	N82W	N88W	
	N82E	N80E	
		N42E	
	N32W		N32W
	N72W		



A. TECTONIC MAP
SEISMOTECTONIC MAP OF THE EASTERN UNITED STATES
By
Jarvis B. Hadley and James F. Devine
1974

FIG. I EXAMPLE OF A TECTONIC MAP





C, SEISMOTECTONIC MAP

SEISMOTECTONIC MAP OF THE EASTERN UNITED STATES

By

Jarvis B. Hadley and James F. Devine

1974

FIG. 2 EXAMPLE OF A SEISMOTECTONIC MAP

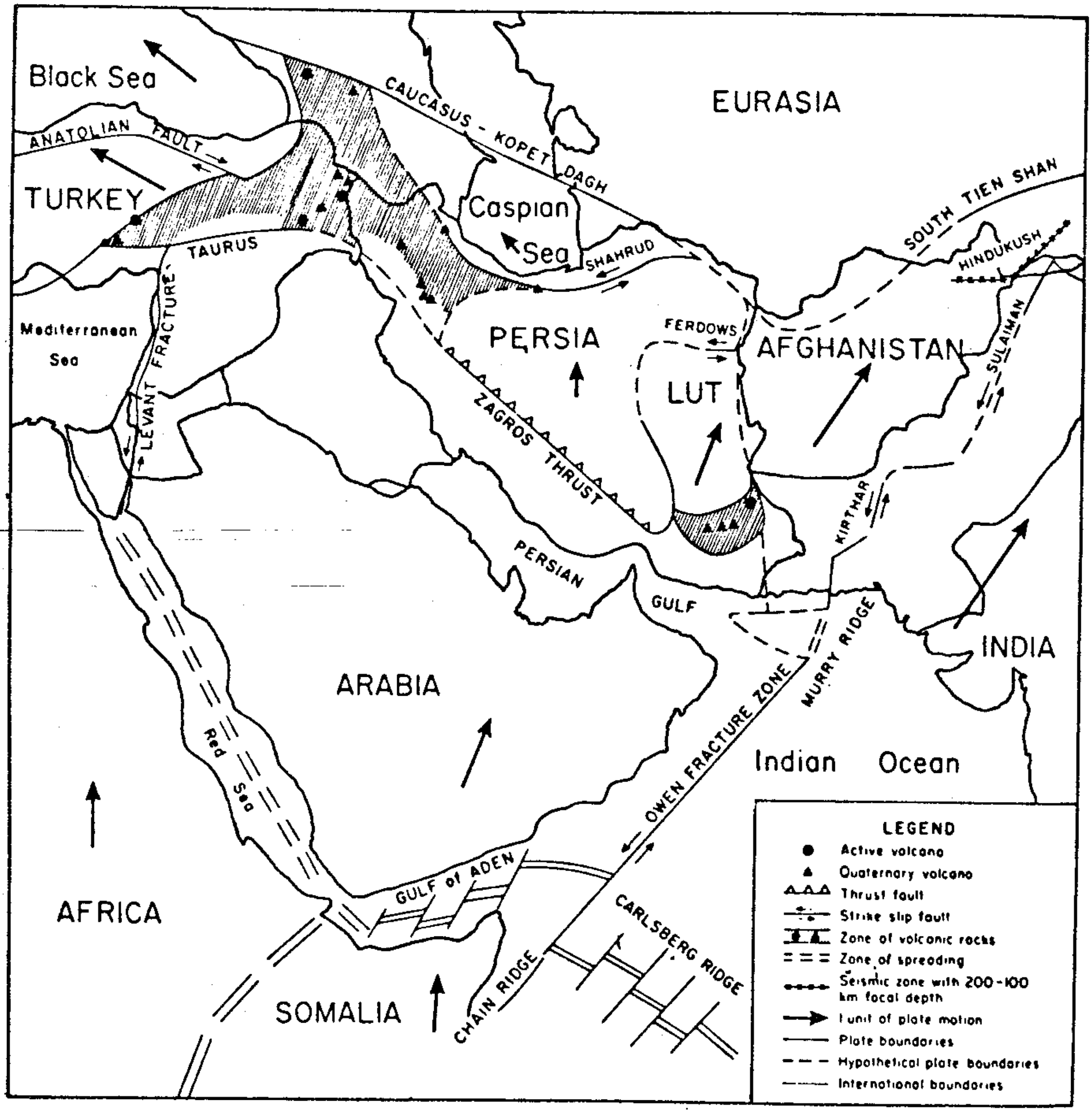


FIG. 3 PLATE TECTONIC CONFIGURATION OF THE MIDDLE EAST (FROM NOWROOZI, 1972)

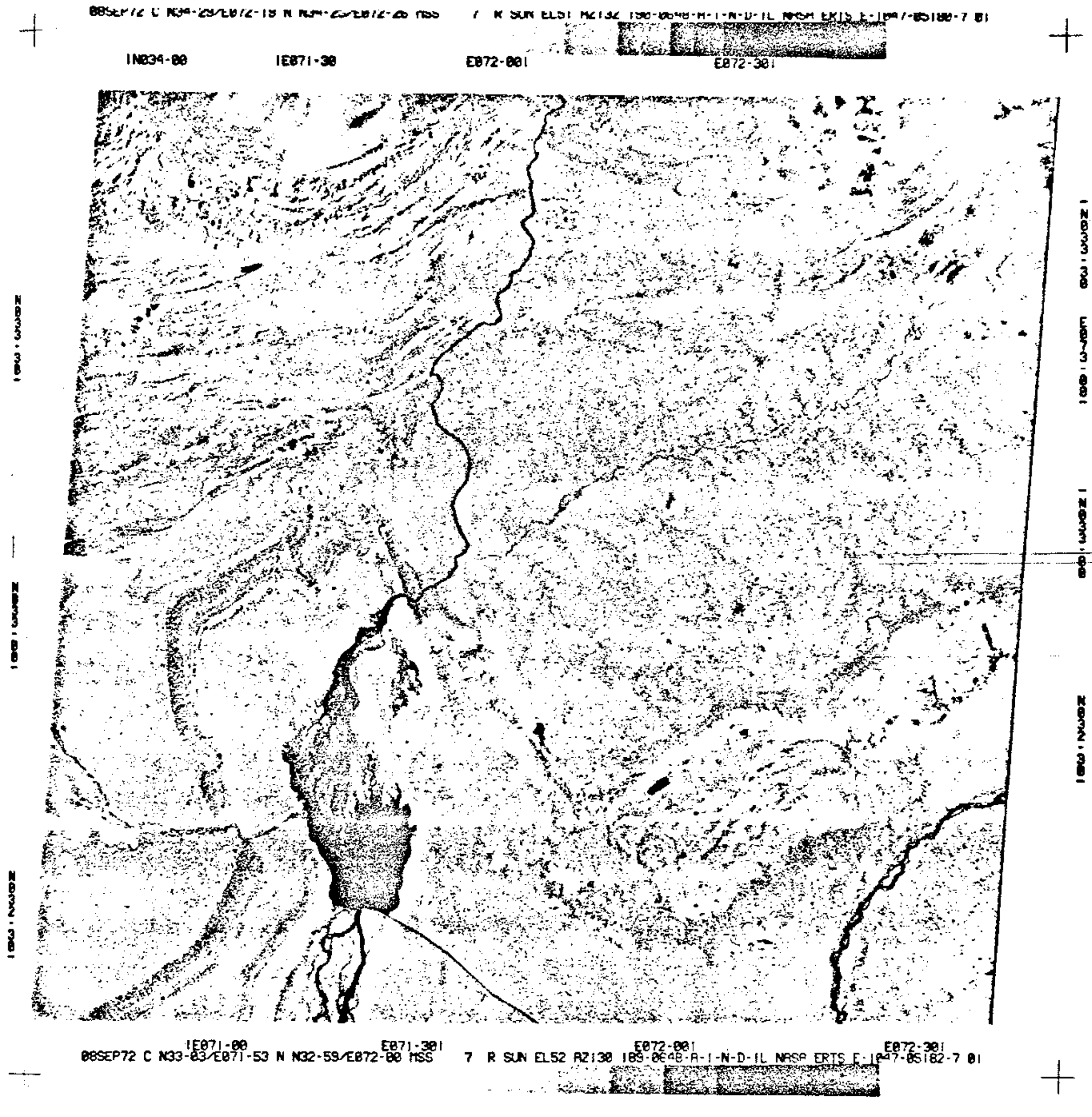


FIG. 4A LANDSAT IMAGERY OF A PART OF THE INDUS RIVER VALLEY, SALT RANGE, KHISOR RANGE, AND MIANWALI RE-ENTRANT

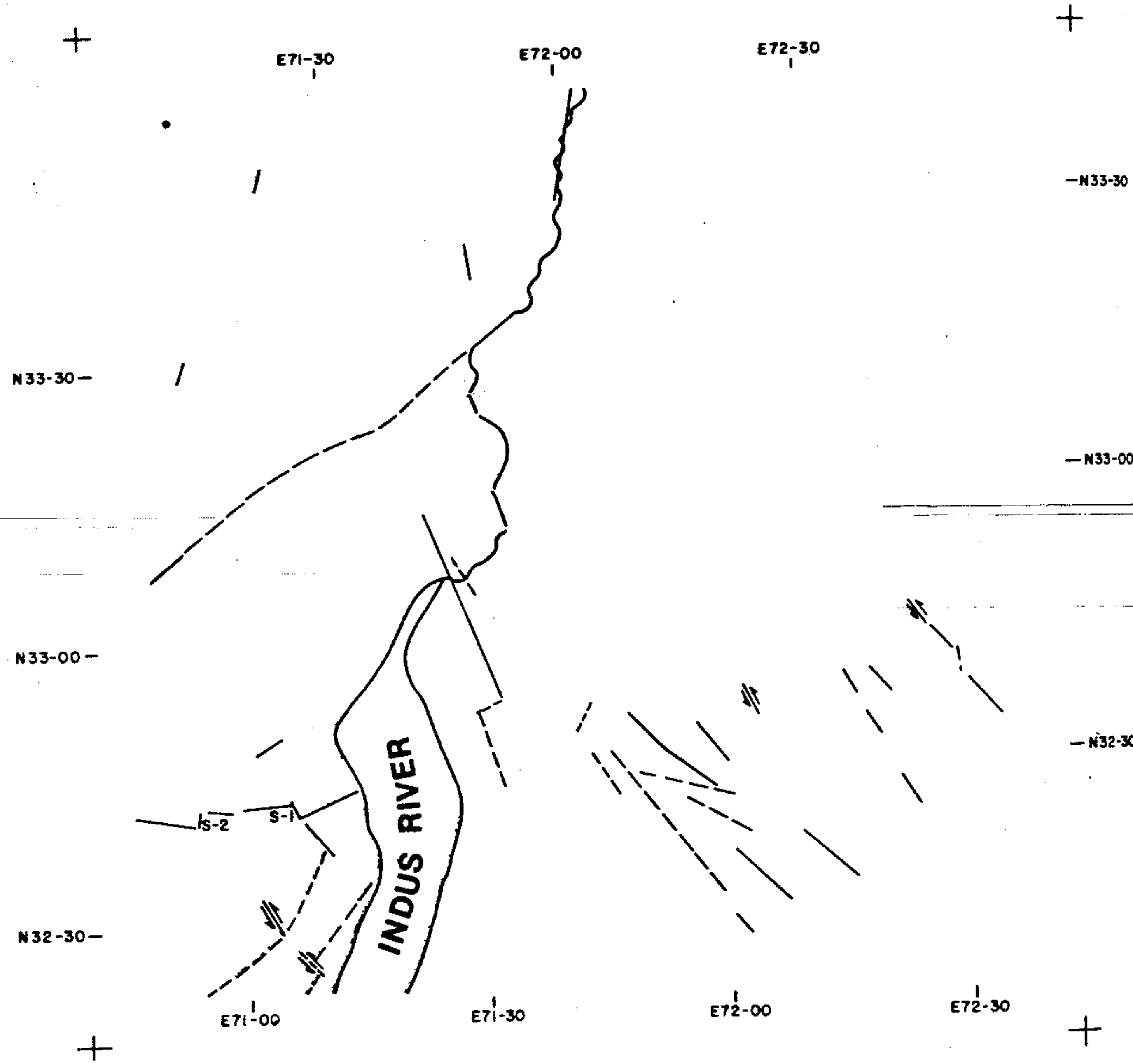


FIG. 4B INTERPRETATION OF LINEAR FEATURES ON FIGURE 4A

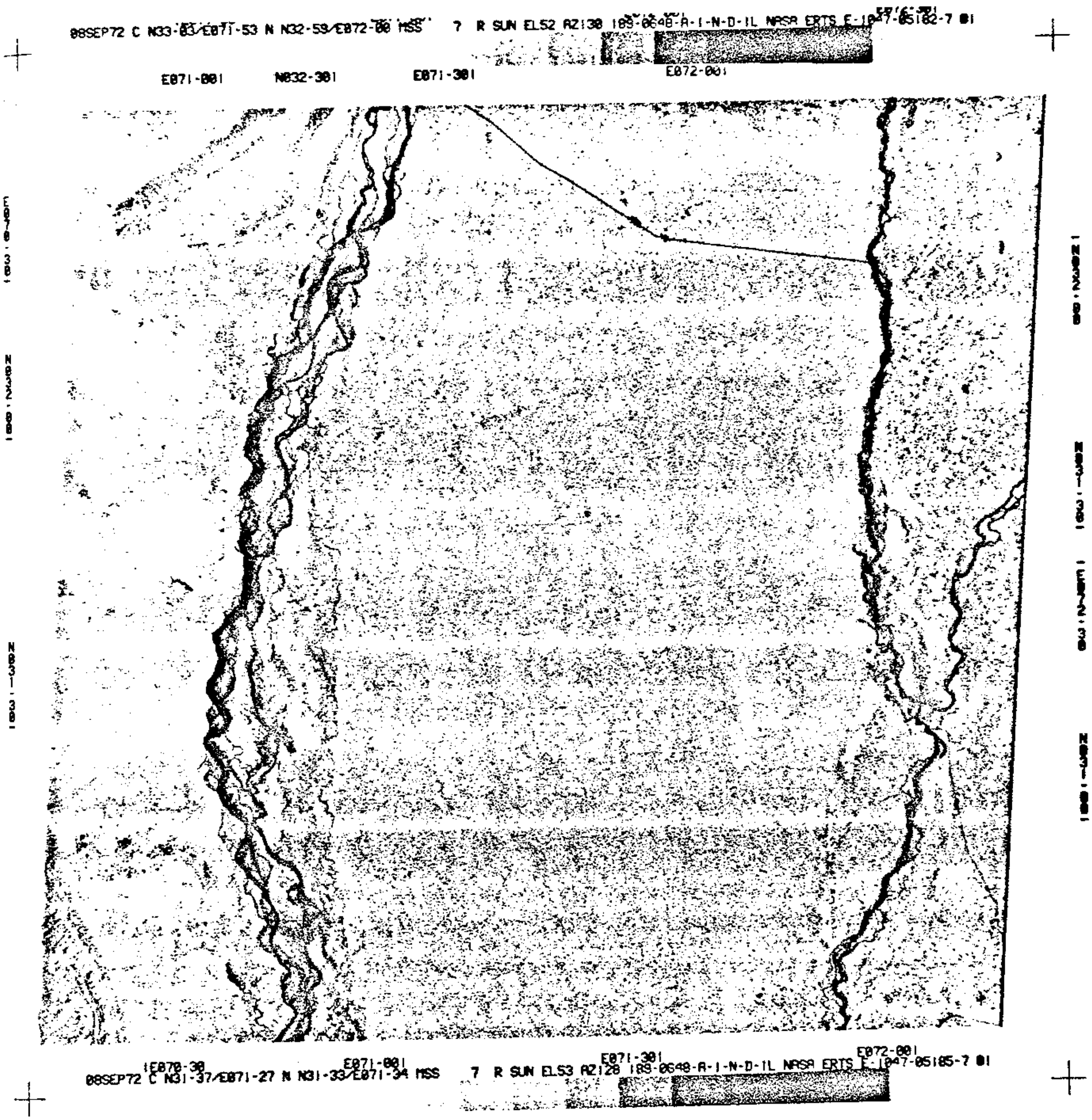


FIG. 5A LANDSAT IMAGERY OF THE INDUS RIVER VALLEY SOUTH OF FIGURE 4A

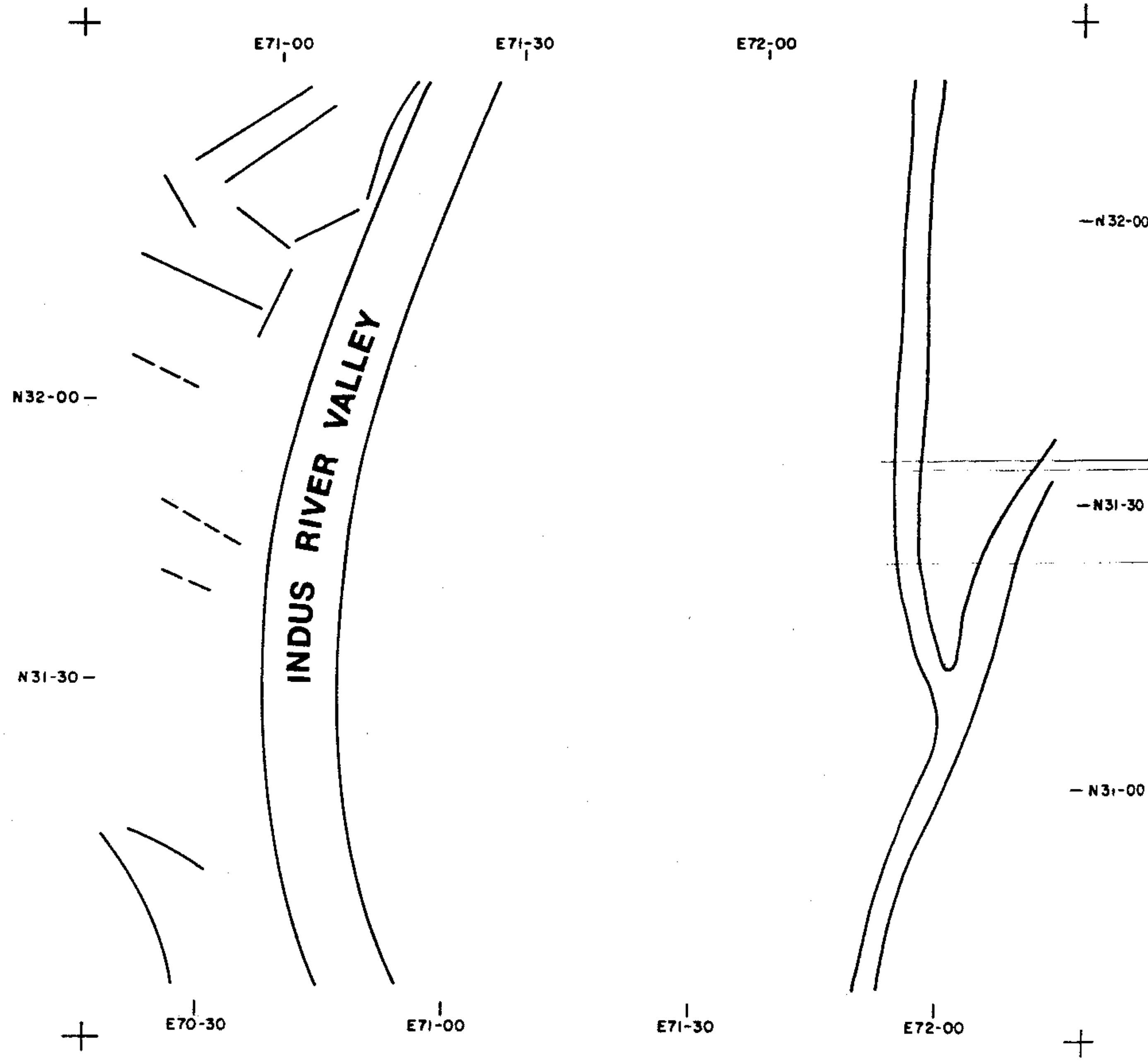


FIG. 5B INTERPRETATION OF LINEAR FEATURES ON FIG. 5A

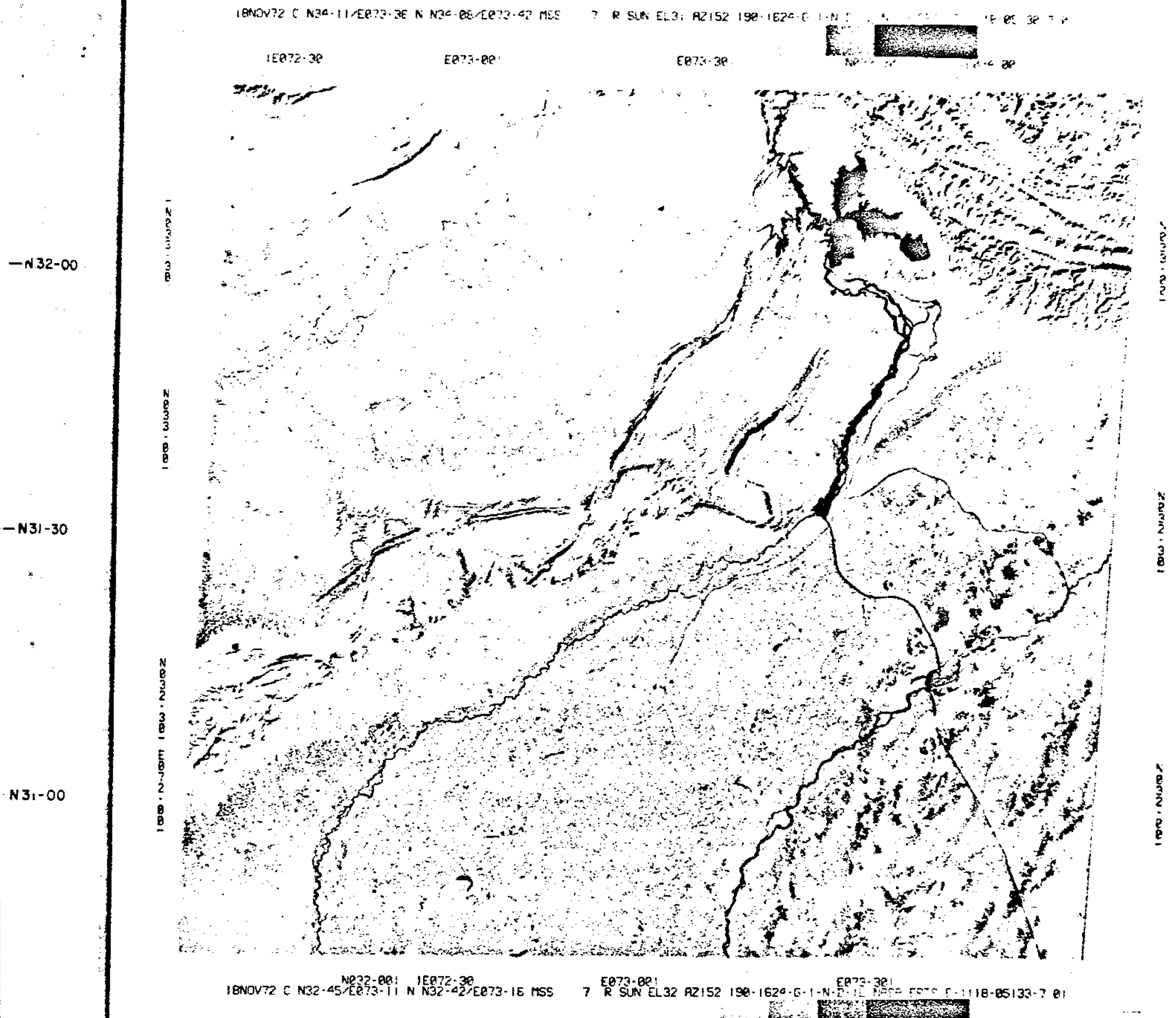


FIG. 6A LANDSAT IMAGERY OF THE INDUS RIVER EAST OF FIGURE 4A SHOWING THE TOPOGRAPHY OF THE SALT RANGE

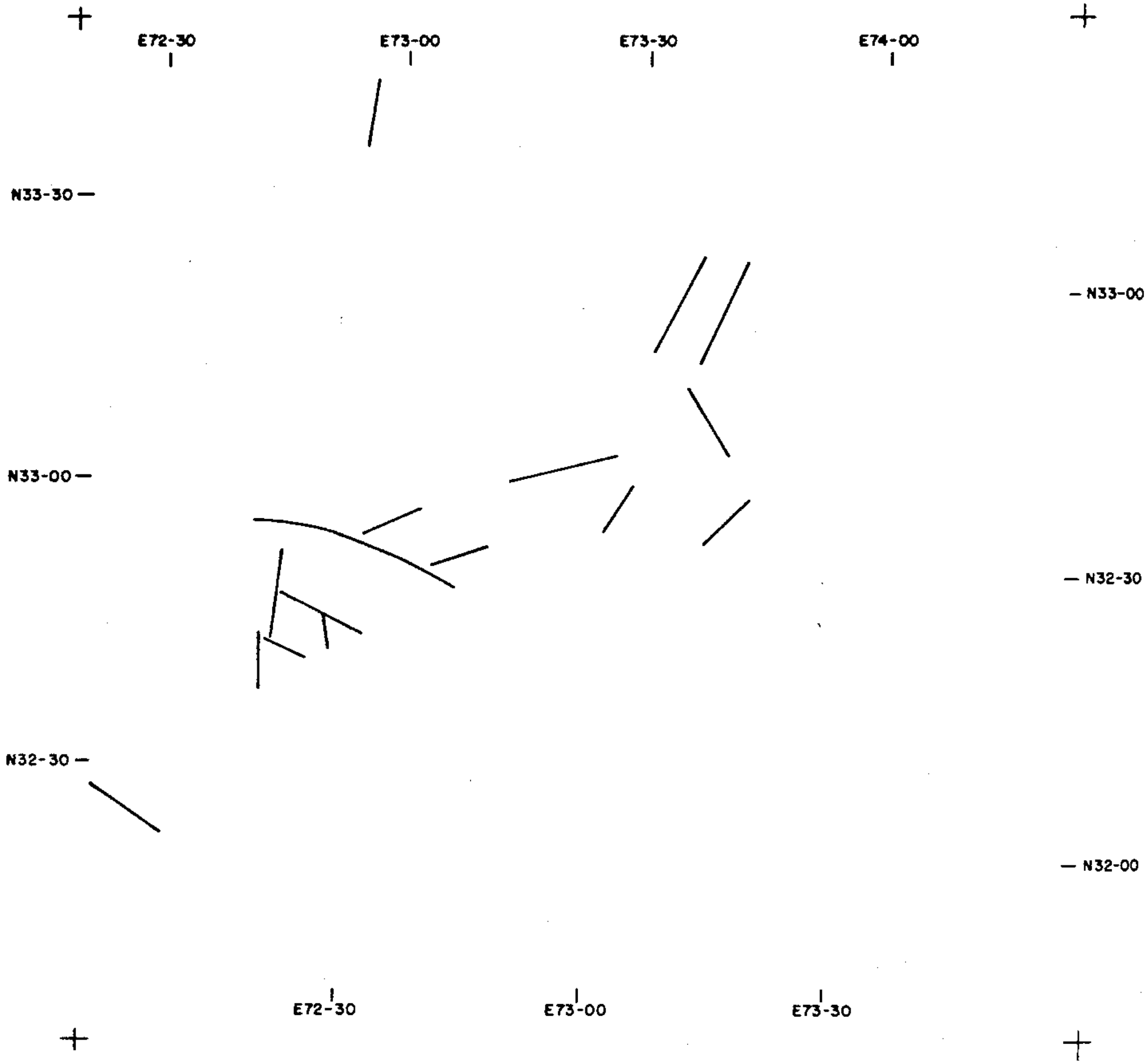


FIG. 6B INTERPRETATION OF LINEAR FEATURES ON FIGURE 6A

N33-00

N32-30

N32-00

FIG. 7A LANDSAT IMAGERY OF PART OF THE BALUCHISTAN ARC ALONG THE PAKISTAN-AFGHANISTAN BORDER

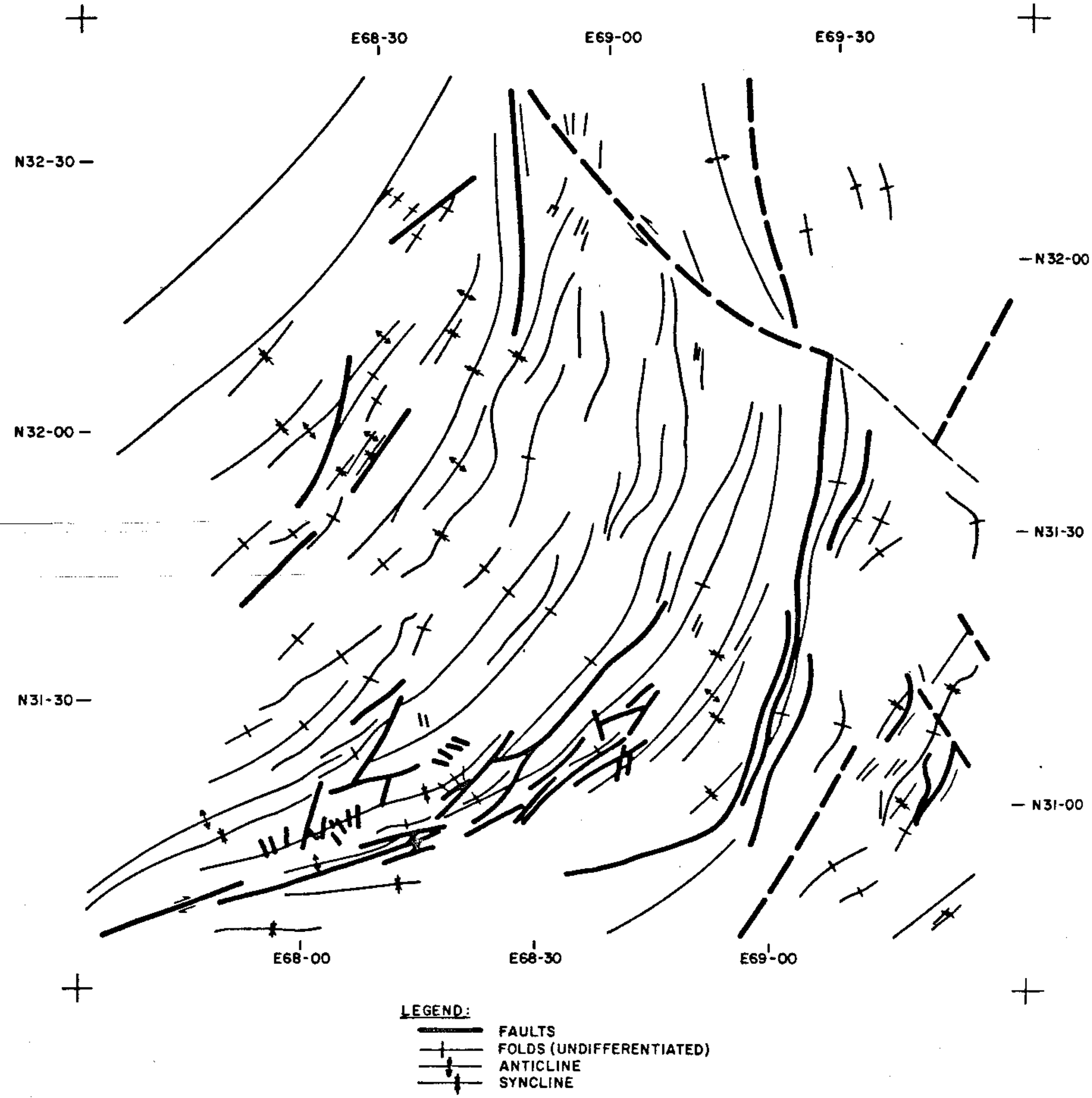


FIG. 7B TECTONIC MAP DERIVED FROM AN ANALYSIS OF GEOLOGIC FEATURES SHOWN ON FIGURE 7A

— N32-00

— N31-30

— N31-00

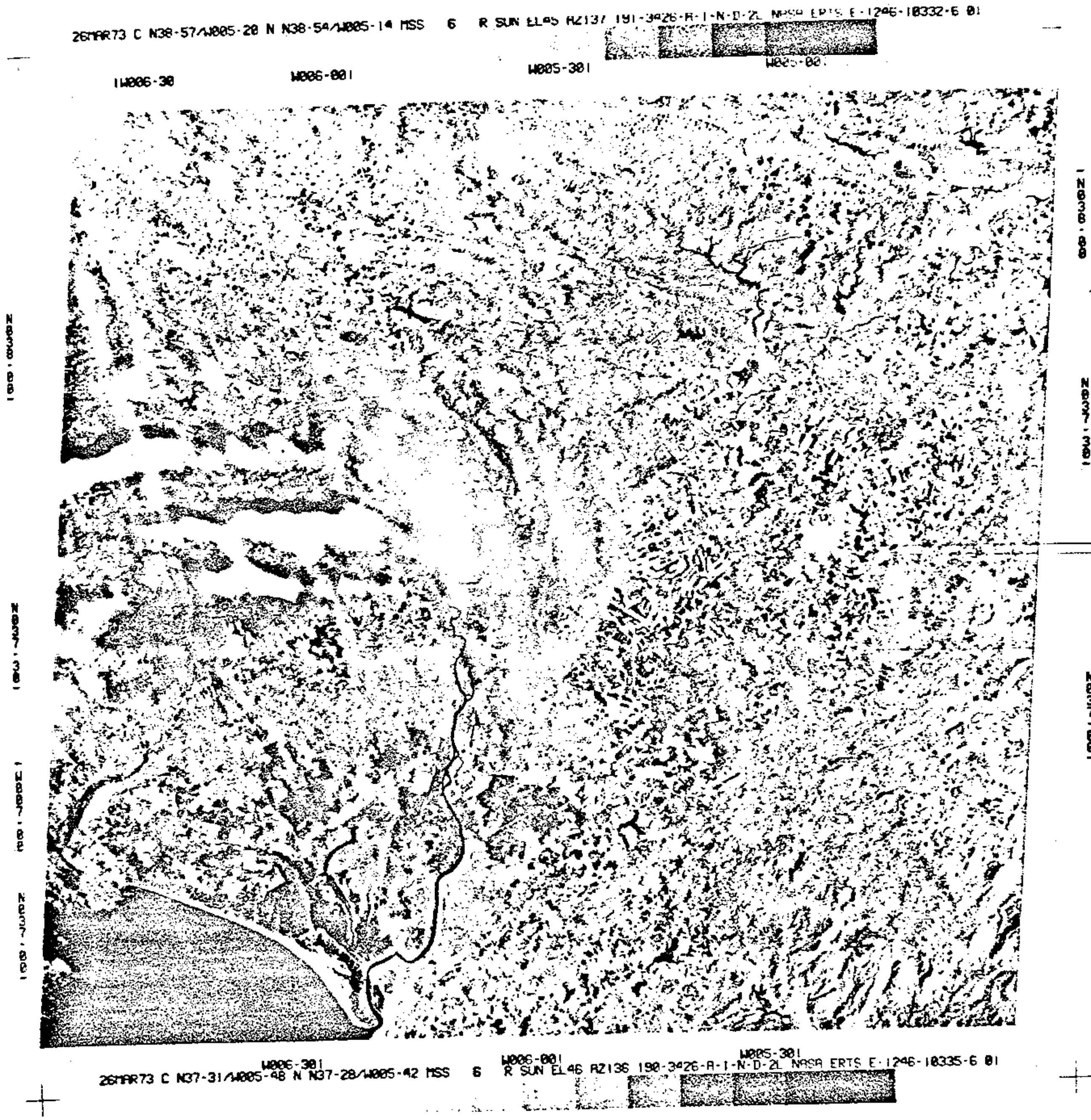
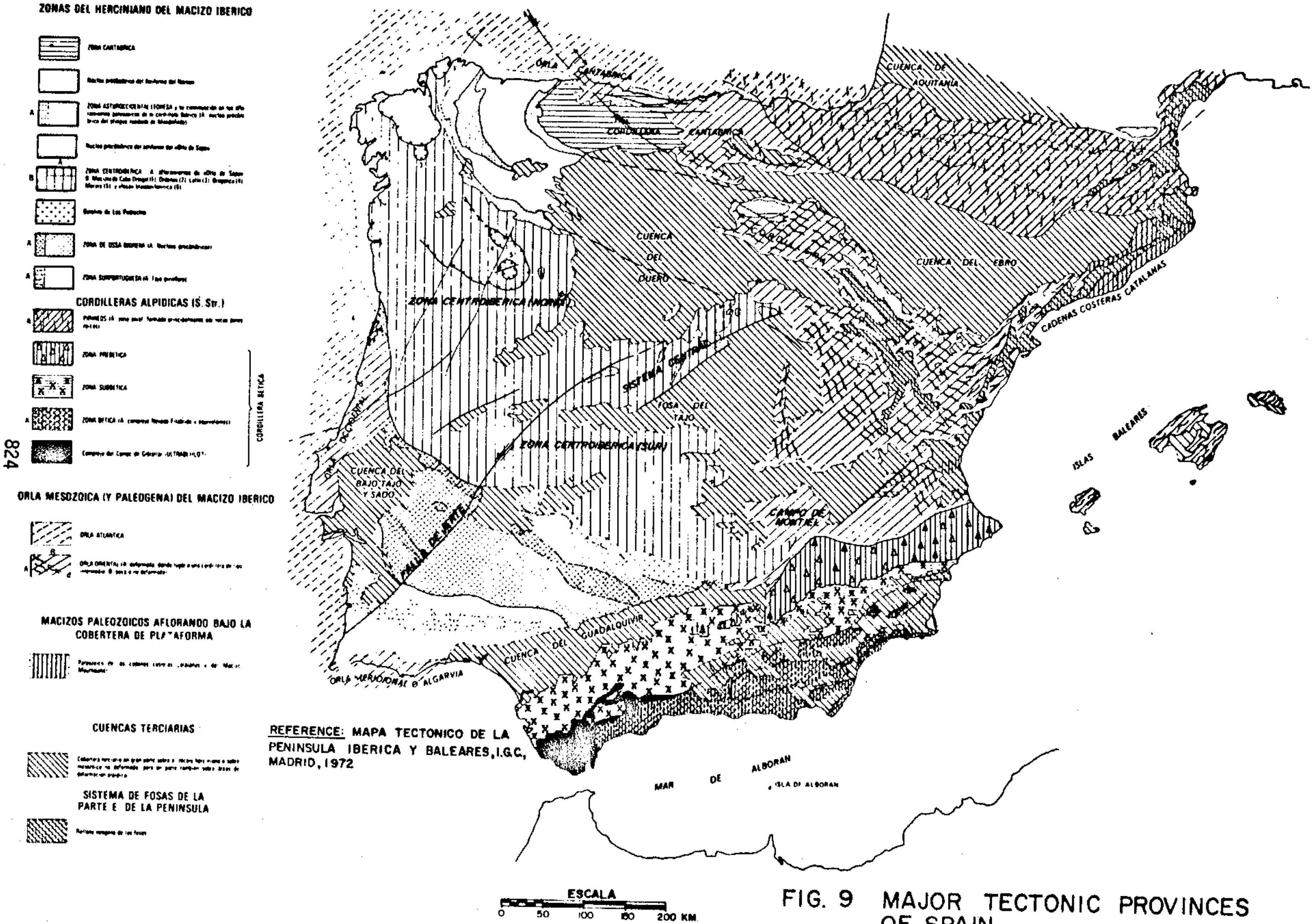


FIG. 8 LANDSAT IMAGERY OF THE NORTHWEST PORTION OF THE GUADALQUIVIR BASIN, SPAIN



REFERENCE: MAPA TECTONICO DE LA PENINSULA IBERICA Y BALEARES, I.G.C., MADRID, 1972

FIG. 9 MAJOR TECTONIC PROVINCES OF SPAIN

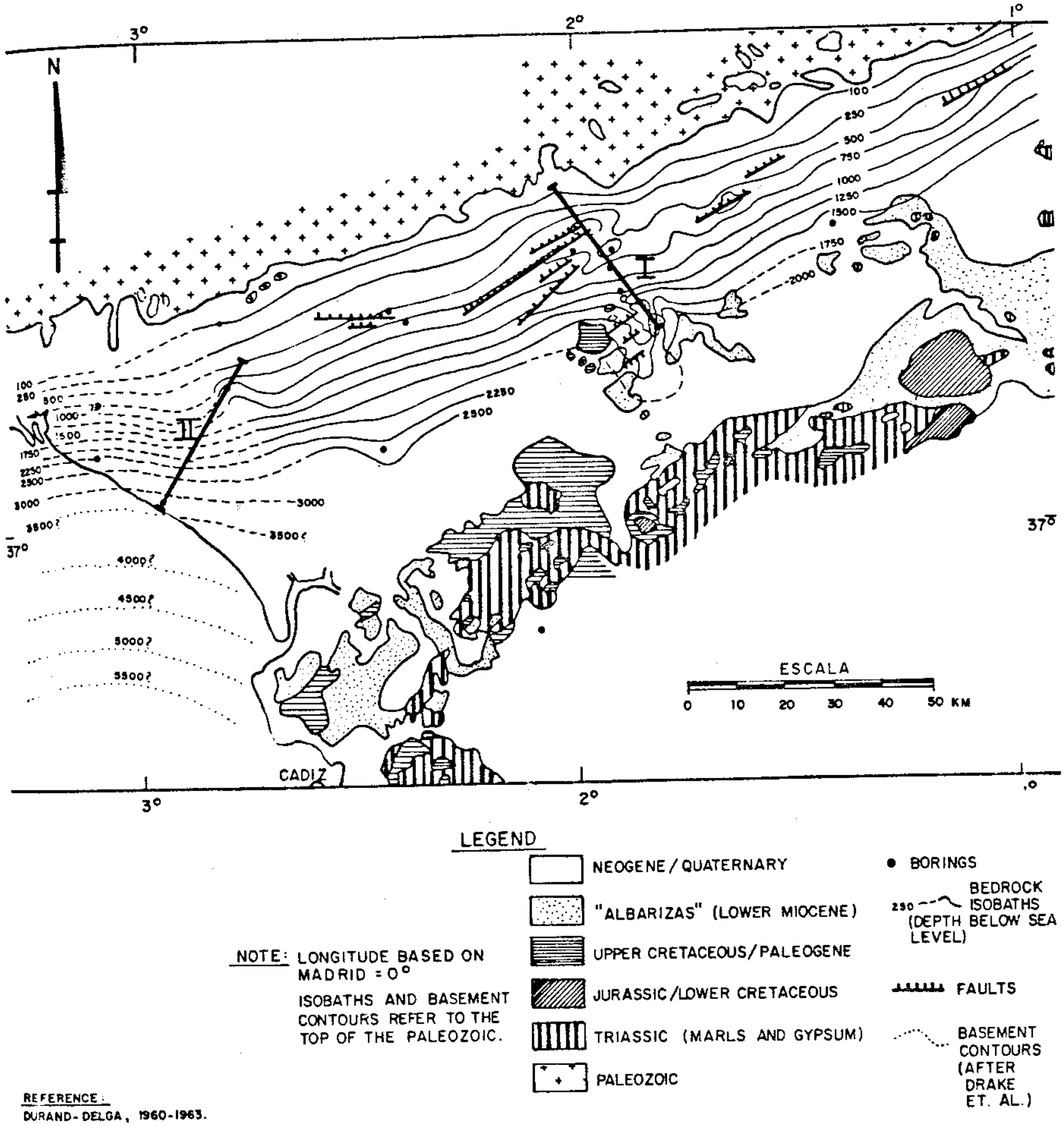
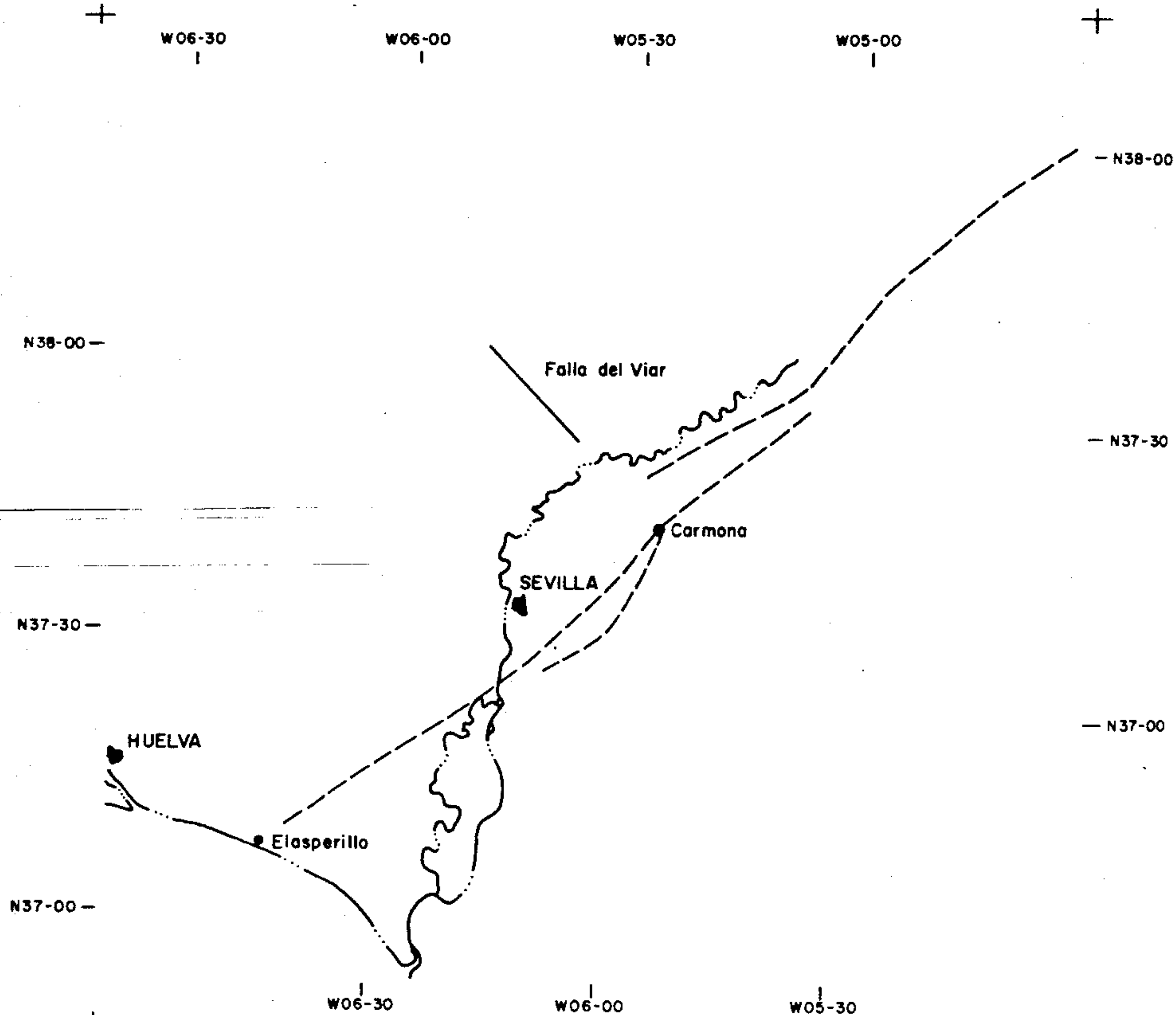


FIG. 10 GEOLOGIC MAP OF THE GUADALQUIVIR BASIN



LEGEND:
— — — — FAULTS

FIG. 11 INTERPRETATION OF LINEAR FEATURES SHOWN ON FIGURE 8

N37-00 N37-30 N38-00

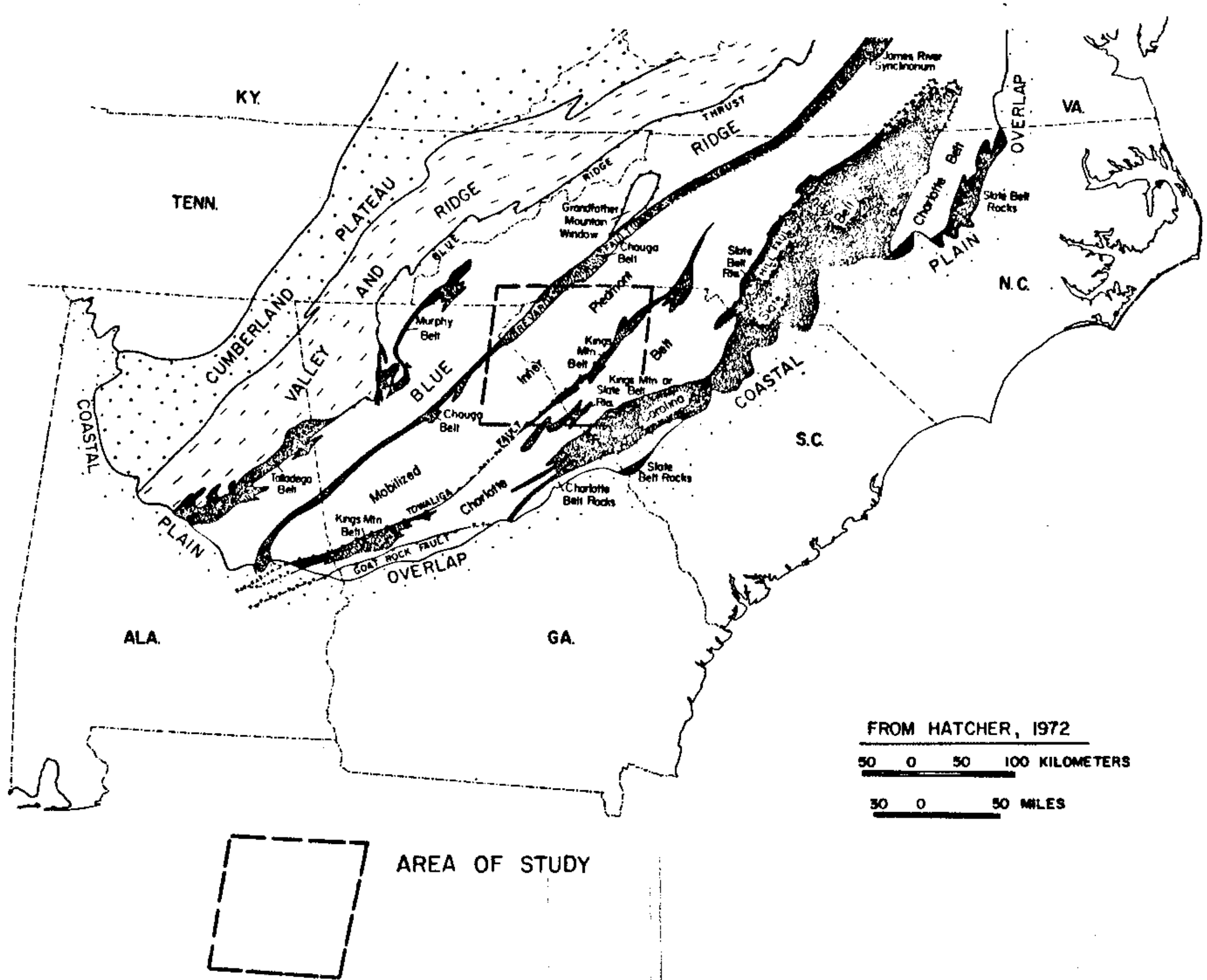


FIG. 12 GENERALIZED GEOLOGIC MAP OF SOUTHERN APPLACHIANS SHOWING AREA OF STUDY

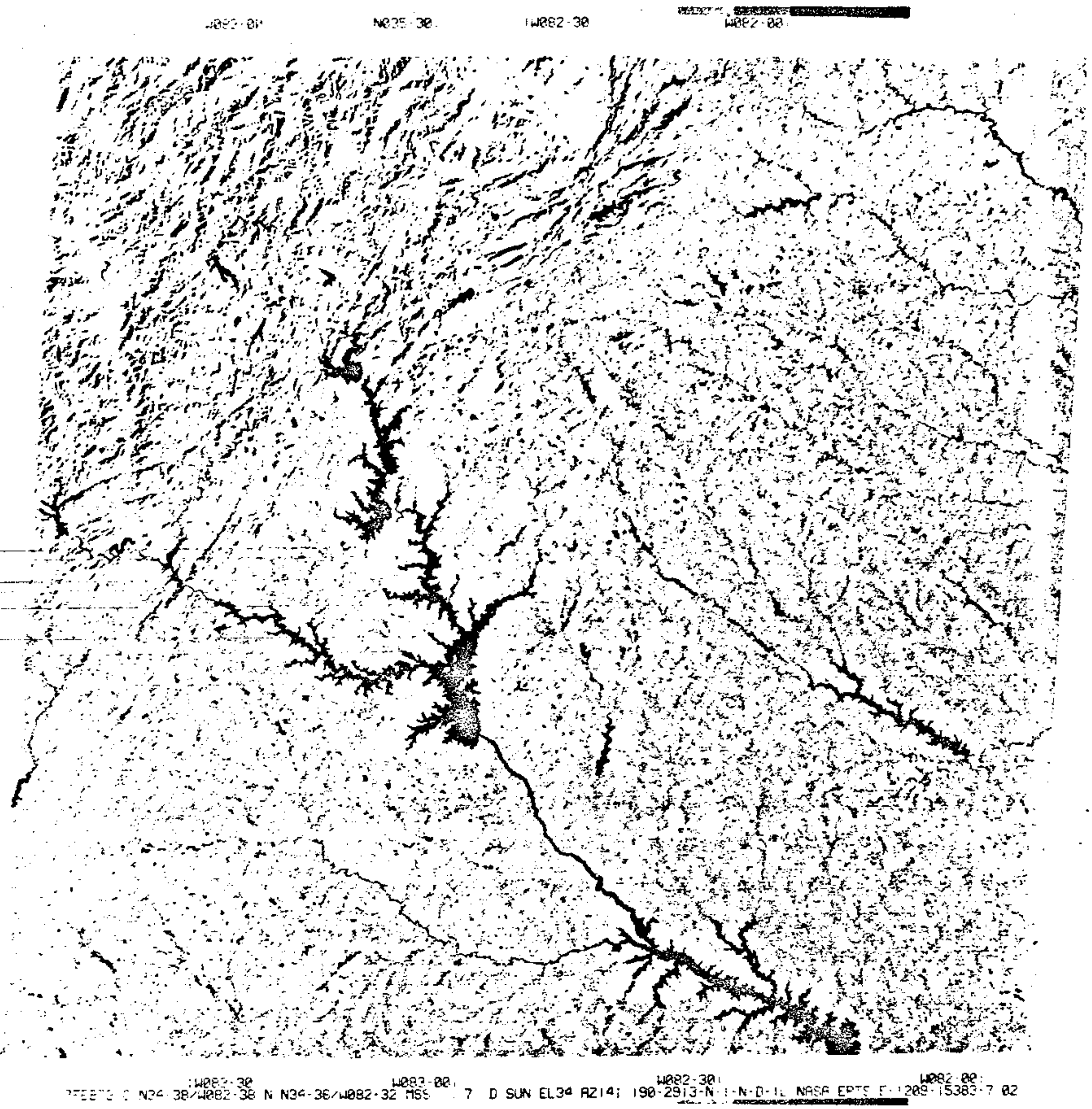


FIG. 13 LANDSAT IMAGERY OF THE PIEDMONT AND BLUE RIDGE PROVINCES OF SOUTH CAROLINA, NORTH CAROLINA AND GEORGIA

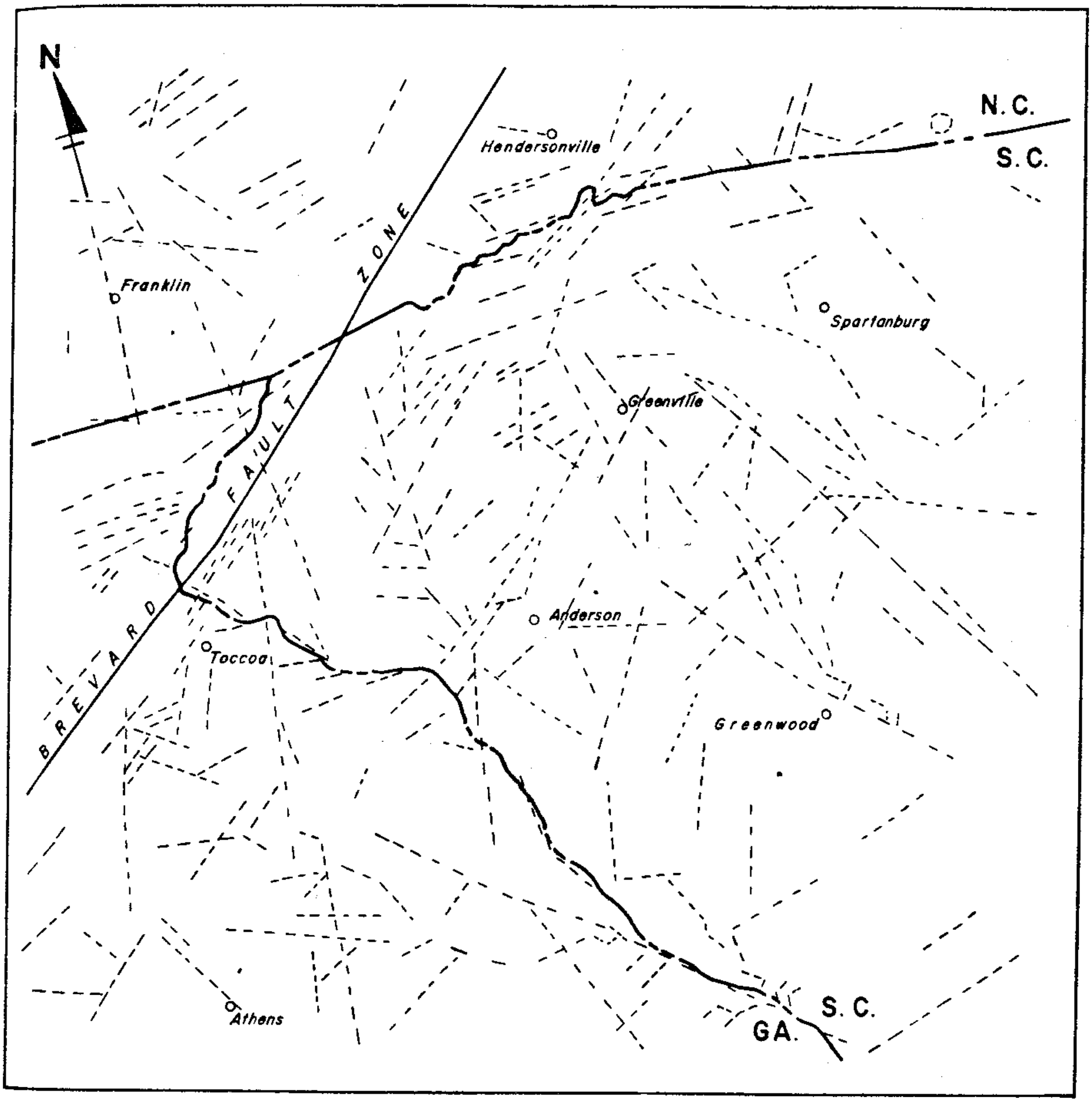
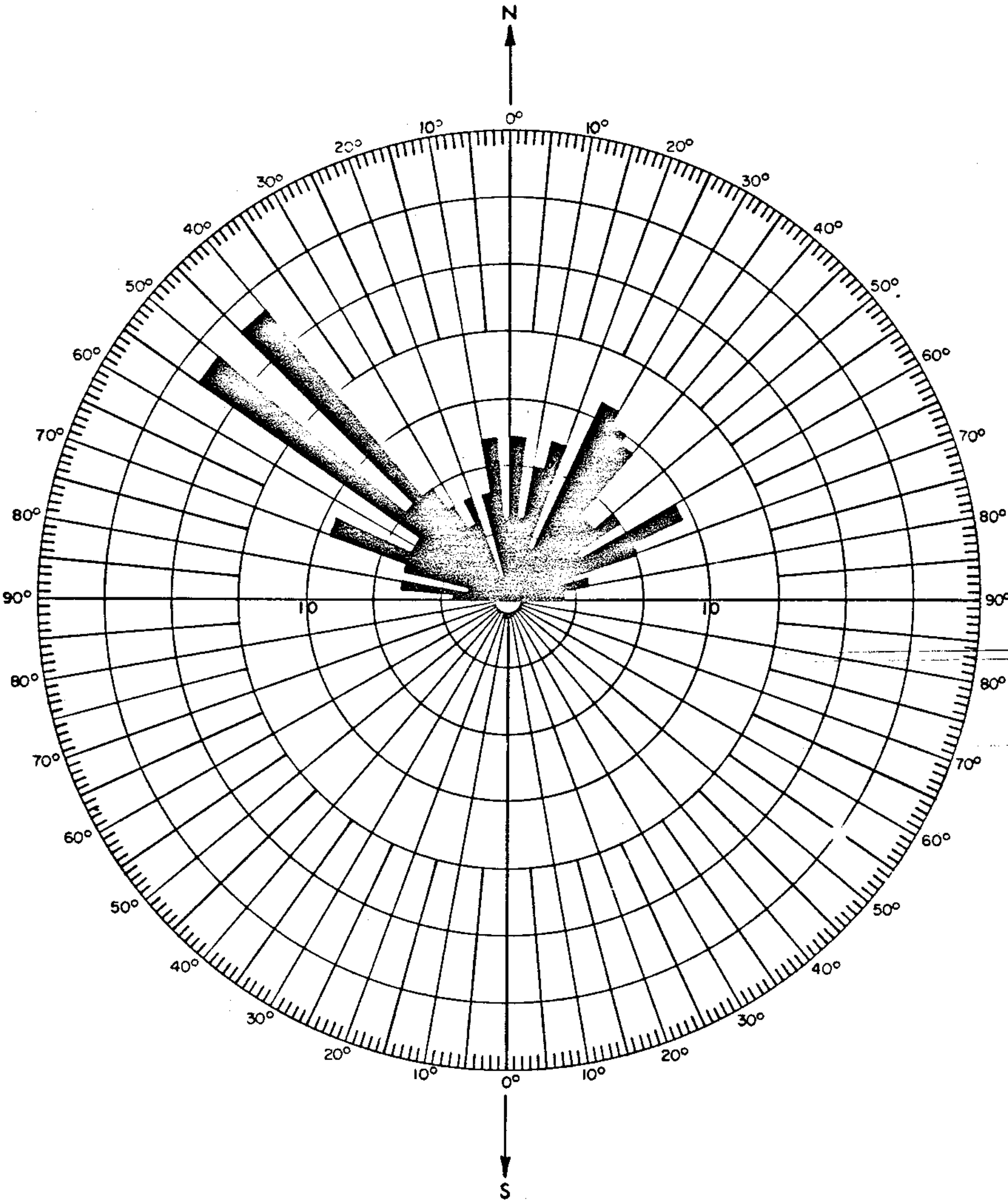


FIG. 14 MAP OF LINEAR FEATURES IN THE AREA OF FIGURE 13

SCALE
0 10 20 30 MILES



178 LINEARS
LANDSAT PHOTO
PIEDMONT-ANDERSON
NORTH CAROLINA

FIG. 15 DIAGRAM SHOWING DISTRIBUTION OF LINEARS MAPPED FROM FIGURE 11

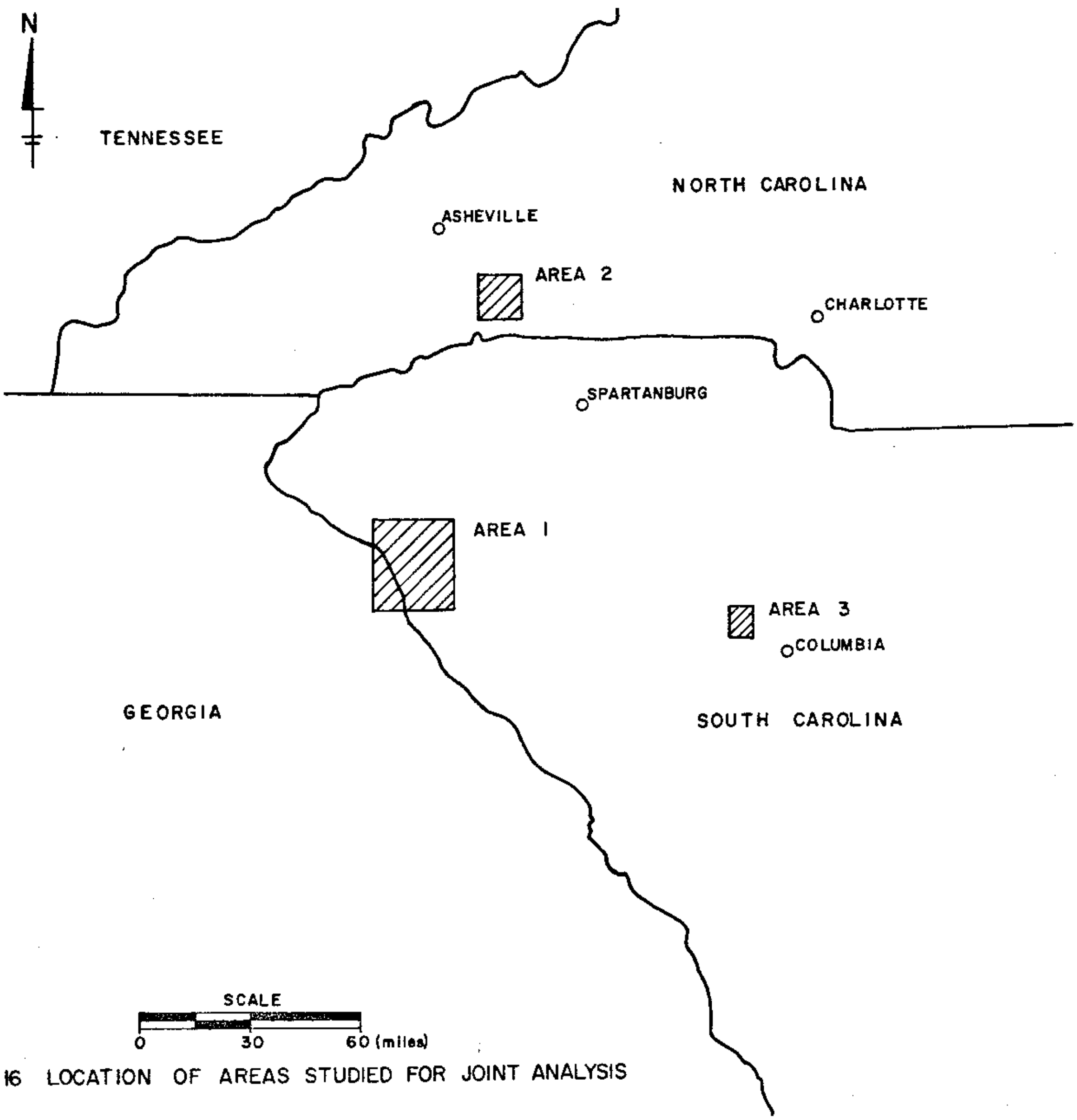


FIG. 16 LOCATION OF AREAS STUDIED FOR JOINT ANALYSIS

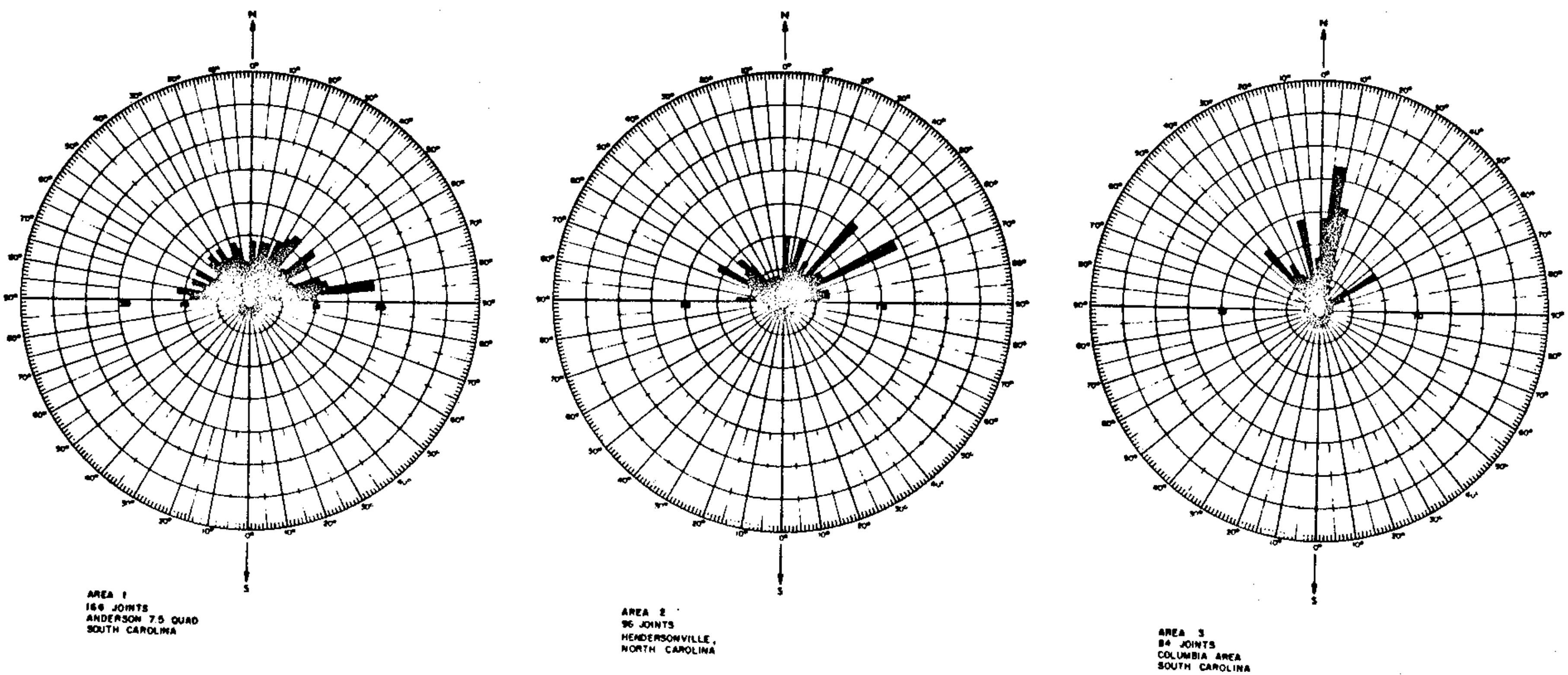


FIG. 17 DISTRIBUTION OF JOINTS IN THREE AREAS STUDIED