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14. Supplementary Notes: This report has been prepared in cooperation with the coinvestigators <del>Dr. Bannert</del> and <del>M. Schönfeld</del> . Results of the investigations were presented at the Fall Meeting of the <u>German Geological Society</u> (Oct. 73), at the <u>ESRO-Symposium on European Earth Resources Experiments</u> (Frascati, Febr. 74) and at the <u>International Afar-Symposium</u> (Bad Bergzabern April 74, arranged by the German National Committee for Geodynamics). The papers presented at the above meetings will be published in the ESRO-Publication on the Frascati-Symposium and in the Afar-Monograph on the Afar-Symposium (to be published in spring, 1975).		
15. Abstract: ERTS 1-MSS-imagery covering the Afar-Triangle/Ethiopia and adjacent regions (the Ethiopian Plateau, the Somali-Plateau, now called the Western and Southeastern Plateau, and parts of Yemen and Saudi Arabia) has been applied to the mapping of lithologic and structural units of the test area (Fig. 1) at a scale 1:1 000 000. A photomosaic and the following thematic maps have been compiled for the test area covering about		

600 000 square kilometers: a map of surface drainage, a lithological map, a map of surface structures and a map of identified fault structures. These maps represent the first geological maps of the above scale covering all the Afar-Triangle and the adjacent regions. A comparison of these maps with the Geological Map of Ethiopia published in 1973 at a scale 1:2 000 000 reveals that the latter needs a considerable amount of updating. The results of the geological evaluation of the ERTS 1-imagery of the Afar have proven the usefulness of this type of satellite-data for regional geological mapping. The evaluation of the ERTS-images also resulted in new aspects of the structural setting and tectonic development of the Afar-Triangle, where 3 larger Rift-Systems, the oceanic Rifts of the Red Sea and the Gulf of Aden and the continental East African Rift System, seem to meet each other. Surface structures mapped by ERTS-imagery do not indicate that the oceanic Rift of the Gulf of Aden (Sheba Ridge) continues into the area of continental crust west of the Gulf of Tadjura. ERTS-data show, that the Wonj fault Belt of the African Rift System does not enter or cut through the Central Afar. The "Aysha-Horst" is not a Horst but an autochthonous spur of the Somali-Plateau. This leads to the conclusion that the SW-corner of the Arabian Plate could never have had its original position within the area of the present Afar-Triangle as has been supposed by several authors.

## 1. Objectives

Structural and lithologic mapping of the Afar-Triangle/Ethiopia, using multispectral MSS-imagery. Evaluation of the ERTS 1-data in consideration of the lithology and the tectonic setting and development of the Afar, which so far has been thought to be a possible triple junction with the oceanic Rifts of the Red Sea and the Gulf of Aden and the continental East African Rift System meeting each other.

## 2. Scope of Activities

The ERTS-material used has been multispectral scanner imagery in the four bands. The interpretational work has been carried out on pairs of single band prints or transparencies (mostly channels 6 and 7 or 5 and 7) using conventional photogeological techniques. The geological data obtained from the evaluation of the ERTS-imagery have been compiled on a base map 1:1 000 000, which was compared from ERTS 1-images using control points from the aeronautical chart as well as control points from photogrammetric triangulation and from field measurements. Correlations of the ERTS-data with data from photogeological mapping as well as from geological and geophysical field work and published data on parts of the Afar have been made.

## 3. Analysis, Findings and Techniques

### 3.1 Image Quality and Interpretability

From ERTS 1, MSS-imagery has been received in several sets taken at various times during the years 1972 and 1973. Generally, the imagery showed high planimetric accuracy. Images of bands 6 and 7 have proven to be especially useful for lithologic mapping because of better tonal contrast. No false color composites have been received for the test area from NASA.

### 3.2 Techniques

Conventional photogeological techniques applying the mirror stereoscope have been used for the geological evaluation of the ERTS-images. In an area such as the Afar-Triangle, where wide areas are still unmapped, only the experienced photogeologist can be expected to produce reliable mapping results. Our investigations represented the first relatively detailed mapping of all the Afar and the adjacent regions on a unified basis. The Geological Map of Ethiopia published in 1973 was compiled from the data resulting from mapping projects of limited and isolated parts of the country. It should be mentioned that the classification and identification of the lithological and stratigraphical units mapped on ERTS-images of the Afar could not have been realized without a certain amount of field knowledge and correlation of the ERTS-data with data from photogeological work and published data. Now the next step is to select representative lithologic units to test the application of more or less automatized interpretational techniques to find out if these techniques would be helpful for lithologic mapping of areas such as the Afar and the adjacent plateau regions. Further structural mapping will be done successfully by the experienced photointerpreter only.

### 3.3 Findings

#### 3.3.1 Background of The Investigations

Up to now, a major problem or handicap existed when interpretations of the geology of the Afar and its structural genesis were made which is the fact that only local and isolated regional geological observations had been made. The geological and tectonic history of the whole Afar was discussed in spite of the fact that only minor parts of the Afar and the adjacent regions had been investigated geologically. Here, ERTS 1 gave us a unique chance to get synoptical coverage of the whole area under discussion and to use it for lithological and structural mapping on a unified basis at an adequate scale (1:1 000 000). The Afar-Triangle represents a location, where 3 larger Pift-Systems seem to meet

each other within an area of continental crust: the oceanic Rifts of the Red Sea and the Gulf of Aden (Sheba Ridge) and the fault belt of the continental East African Rift. Spreading rates of 1-1.6 cm/year have been observed for the Red Sea Rift and rates of 1 cm/year for the Sheba Ridge. Accepting a drift of the Arabian Plate to the NE and comparing the morphological outlines of the Afar-Triangle on one side with the SW-corner of the Arabian Plate had its original position (pre-drift) where we now find the Afar-Triangle. This theory had been presented in the publications of several authors. To find out if this theory is true, numerous geological, geophysical and petrological investigations by teams from several nations have been undertaken in the Afar during the last years, in part within the International Upper Mantle Project. Our proposal was thought to be a contribution to the international geoscientific efforts by providing a complete mapping of the lithology and the structures of the Afar and adjacent areas. It should be mentioned, that the field investigations of the above mentioned teams had to be concentrated on observations of local areas and traverses because of climatic conditions, rough country and inaccessibility of wide areas.

### 3.3.1 Lithology

The geological evaluation of the ERTS 1-imagery resulted in the compilation of the first lithological map of all the Afar and adjacent areas (covering about 600 000 square kilometers) at a scale 1:1 000 000. This map is based on ERTS-data, which have been correlated and checked, where data from ground observations, photogeological work or publications were available. In general, the ERTS-map is thought to be very accurate. In local smaller areas misinterpretations might have occurred.

For the mapping of lithologic units, pairs of single band prints or transparencies (mostly channels 5 and 7) were used under the mirror stereoscope. 31 lithologic units could be differentiated in the ERTS-images including: 3 units of basement rocks (Precambrian and Eocambrian), 16 units of sedimentary rocks

(Jurassic, Cretaceous, Tertiary, Quaternary), 12 units of basaltic and acid volcanics (Tertiary, Quaternary). It should be mentioned that the separation of individual rock types or units has been difficult in certain parts of the test area for certain rock types. Especially, the outlining and classification of basement rocks and the differentiation of basement rocks from the mesozoic sedimentary strata on top of them has proven to be difficult in places. In contrast, the differentiation and classification of sedimentary rocks and of the individual types and units of volcanic and igneous rocks is thought to be quite accurate. It should be mentioned that the differentiation of individual rock types in Skylab-photos, which we obtained for small parts of the test area, seems to be less problematic.

While detailed information can be taken from the lithological map (Fig. 3), the lithology of the larger regional units of the test area should be described here in brief. The Ethiopian highlands: mainly precambrian crystalline rocks, overlain by mesozoic sediments (limestones, marls, sandstones), tertiary basaltic and acid volcanics (Trapp-Series). The Somali- or SE-Plateau: predominating mesozoic sediments (sandstones, limestones, marls), locally basaltic and acid volcanics of tertiary age. The Danakil-Horst: basement rocks overlain by mesozoic sediments, tertiary and quaternary basaltic and acid volcanics. The Aysha-Spur: basement rocks, mesozoic sediments and tertiary volcanics. The Tadjura Uplift: basaltic and acid volcanics of tertiary age. The Danakil-Graben: marine and lacustrine sediments of tertiary age, basalt flows of the Aden-Group, acid volcanics in the southern part of the Graben. The Central Afar: flood basalts of the Aden-Group, acid lavas and intrusions, flood basalts of the Afar-Series, tertiary and younger sediments.

The results of the investigations should demonstrate the advantage of applying ERTS 1-type imagery in projects of regional lithological mapping. Applying conventional methods, the mapping of the test area (covering about 600 000 square kilometers) would have taken years. A team of 4 photointerpreters



completed the mapping of the ERTS 1-MSS-imagery within a few months. It should be emphasized, of course, that field knowledge or field checking is a must, if a reliable map is to be compiled from ERTS-data.

### 3.3.3 Tectonics

The structural evaluation of the ERTS 1-imagery resulted in the compilation of 2 structural maps of the Afar-Triangle and adjacent regions: the map of surface structures (Fig. 4) includes all photolineations visible on the ERTS-images related to jointing, fracturing and faulting; the second map (Fig. 5) shows identified fault structures only. These faults, mostly, are due to normal faulting and to graben-structures. It should be mentioned, that no strike slip faults could be identified in the ERTS-images of the test area.

The map of surface structures (Fig. 4) as compiled from ERTS-data only, represents the first more detailed structural map of the Afar-Triangle and the adjacent regions. It is thought to be a contribution to the investigations by geologists, geophysicists and petrologists from several nations working in specific parts of the test area. On the other hand our test area is only a part of the area covered by the ERTS 1-proposal of P.MOHR dealing with the structural pattern of the African Rift System as a whole. Therefore, P.MOHR has mapped the larger or more important structures of our test area, too. The high degree of agreement of the structural maps recently published by P.MOHR with the map of surface structures compiled by the Clausthal-group should demonstrate that reliable structural maps can be made from ERTS 1-imagery. Two groups working independently on structures of the same area came to very similar results as well as to similar questions referring to the origin, mechanism and age of certain structures (personal communication P.MOHR at the International Afar Symposium on Afar Problems, Bad Bergzabern April 74).

In the following, some of the essential results from our ERTS-investigations should be described. The distribution and orientation of the photolineations (Fig. 4) reveals the anomalous and complicated structural pattern of the Central Afar, characterized by curvilinear, bifurcating fault belts, grabens and intense fault belt virgations. The map of surface structures also shows that the fracture traces of the predominating trends do not continue into the area N and NE of Lake Abé. The predominating trends of fracture traces are: NNW/SSE (parallel to the Red Sea Rift), SW/NE or SSW/NNE, respectively, (following the trend of the East African Rift). To be observed all over the test area are ENE-striking fracture traces (about  $70^{\circ}$  E). Along the northern part of the Southeastern Escarpment, fracture traces of the above trend are caused by synthetic and antithetic faults. Within the Ethiopian Plateau the fracture traces striking  $70^{\circ}$  E are very common without much evidence of faulting. In the area N of Sardo ENE-striking fracture traces cross the southern end of the Danakil-Graben, representing normal faults, locally. Of special interest is the fact that the structures of ENE-trend can also be found within the corner of the Arabian Plate (Yemen Territory). Whereas the NNW/SSE- and the SW/NE-striking fractures and faults are believed to be related to oligocene/miocene and plio-pleistocene tectonic events, the ENE-striking structures are thought to follow premesozoic structures, which have been reactivated during the Tertiary and Quaternary.

Also of interest are ESE-striking fracture traces, which so far have been known only from the area south of the Lake Abé, where they are cut off by the Wonji-Fault Belt. In ERTS-images, fracture traces of the  $100^{\circ}$  E trend have been found along the Southeastern Escarpment within Yemen Territory (Arabian Plate) and in the northern parts of the Ethiopian Plateau, NW and E of Asmara. The ESE-striking structures are thought to be of Tertiary/Quaternary age. Their geomechanical function in the overall structural pattern of the Afar is not yet understood.

The ERTS-map of surface structures is the first to give synoptical information on the width of the fault belts forming the Western and Southeastern Escarpments. Intensive faulting (with synthetic and

antithetic faults predominating) can be observed over a zone of 10-50 kilometers in width along the above escarpments. The frequency of fracture traces decreases rapidly into the plateau areas.

In the tectonic maps published so far, the Danakil-Graben is shown to end at about 13° N. This can be observed on ERTS-imagery, too. But the evaluation of ERTS-images has shown that NNW/SSE-striking fault structures (normal faults and grabens) also exist within the Southeastern Plateau, extending from the area between Harar and Jijiga to the SE over a length of 120 kilometers. The type of faulting observed in the ERTS-images and the SE-trend of the fault zone, being more than 20 kilometers wide, could indicate a so far unknown prolongation of the Red Sea Rift or Fault System into the Southeastern Plateau.

Also new and in contrast to the opinion of papers published previously, is the fact that the surface structures mapped on ERTS-images do not indicate that the Sheba Ridge structures (which could be followed by aeromagnetics into the Gulf of Tadjura) continue into the Central Afar, that is into an area of continental crust.

Also in contrast with the opinion expressed in several papers is the fact that according to the data obtained from ERTS, the Wonji Fault Belt (as part of the East African Rift) does not enter or cut through the Central Afar. In the area SW of Lake Abé, the Wonji-Graben is obviously cut off by the SE-trending curvilinear grabens and faults of the Central Afar fault system. Within the fault belt of the Wonji Zone, the ERTS-data indicate the existence of transform faults, which according to some authors have been thought to offset laterally, northern parts of the Wonji-Graben at several locations.

The geological evaluation of ERTS-images resulted in other findings of high interest and importance under the consideration of the overall structural setting of the Afar and its geological development. According to the lithological and structural data obtained from the

ERTS-imagery covering the area of what has been called the Aysha-Horst, this "Horst" does not exist. Lithologically and structurally, this area is an autochthonous part of the South-eastern Plateau or -Escarpment, respectively. Therefore the generally accepted theory has to be revised, that the Aysha-"Horst" (as an isolated block) originally had its position further westward near the Ethiopian Plateau from where it drifted NE-ward like the Danakil-Horst and the Arabian Plate. This leads to the conclusion, that the SW-corner of the Arabian Plate never could have had its original position within the area of the present Afar-Triangle as has been supposed by several authors. This result of the geological evaluation of the ERTS-imagery of the Afar alone is an essential contribution to the international discussion on the structural development of the Afar in time and the amount of drift of the Arabian Plate, since seafloor-spreading started along the present Red Sea and the Gulf of Aden Rift Systems.

To find out if the surface structures we mapped from ERTS-images could somehow be correlated with lithological and structural patterns or settings at some depth, the ERTS-data of the Afar were compared with known results from geophysical investigations within the test area (GIRDLER a.o. 1972).

The positive magnetic anomalies obtained along the Danakil-Graben disappear at its southern end at about 13°N. That is the area where the structural pattern of the surface structures changes more or less abruptly. It is the area where the linear expressions of the Graben structure pass into or are replaced by the curvilinear complicated fault pattern of the Central Afar. It is also an area where ENE-striking fracture traces, partly identified as normal faults, are very frequent.

Along the Wonji-Fault Belt, NE-trending positive gravity anomalies are the geophysical expression of this part of the East African Rift System. The gravimetric anomalies of NE-trend can be followed into the area just SW of Lake Abé, where they are met by SE trending

gravimetric isolines: here, the NE-striking Wonji-Fault Belt is cut off by the SE-trending curvilinear fault-sets of the Central Afar as shown on ERTS-images.

Also within the area of the Gulf of Tadjura (from which a broad discussion has been going on, if the oceanic Sheba Ridge Structure crosses into the Central Afar, that is an area of continental crust) a good correlation of ERTS-surface data and data from aeromagnetic surveys could be found. The evaluation of the ERTS-images has not given evidence for a continuation of the Gulf of Aden- or Sheba Ridge Structures into the area west of the Gulf of Tadjura. Here, NW/SE-striking surface structures have been mapped. Accordingly, the aeromagnetic map of GIRDLER shows that the E/W-trend of the aeromagnetic anomalies within the Gulf of Tadjura is turning into a NW-trend right from the western end of the Gulf of Tadjura. Even if GIRDLER has given another interpretation, to the author it indicates a good correlation of ERTS-surface structural data and the data from aeromagnetics.

It should be mentioned, that the SE-trending fault zone detected in ERTS-images from the Southeastern Plateau in the area of Harar and Jijiga is also indicated in the gravity map of the area by a strong SE-ward distortion of the lines of equal gravity.

Further investigations, of course, will be necessary to verify or to find out the reasons for apparent agreements of surface and subsurface data.

#### 4. Conclusions

The above results of the geological evaluation of ERTS 1-imagery of the Afar have shown, that the main objectives of our proposal could be met: the use of ERTS 1-MSS-imagery for the compilation of lithological and structural maps of all the Afar-Triangle and the adjacent regions at a scale 1:1 000 000. Those maps are seen as a major contribution to the international studies of this area, which is of so much interest with relation to problems of plate tectonics.

Further work will be necessary to evaluate the individual sets of fracture traces, their age and geomechanical meaning. This work will be part of a project to study continental fracture patterns in various parts of Europe of large geological units of varying age and varying structural development in time. These investigations, too, will be based on ERTS 1-imagery. Finally, the ERTS 1-results on the Afar-geology will have to be compared with the results of the evaluation of Skylab-photography, which has been obtained for parts of the Afar.

Enclosed

- Fig. 1 Location Map of the Test Area Proposal Sr. No. 351
- Fig. 2 Map of the Regional Geological Units of the Afar-Triangle and Adjacent Regions
- Fig. 3 Lithological Map of the Afar and Adjacent Regions  
(Scale 1:1 000 000)
- Fig. 4 Map of Surface Structures of the Afar and Adjacent Regions (1:1 000 000)
- Fig. 5 Map of identified Faults of the Afar and Adjacent Regions (1:1 000 000)
- Fig. 6 Map of Surface Drainage of the Afar and Adjacent Regions (1:1 000 000)

Literature on the Test Area: see attached list

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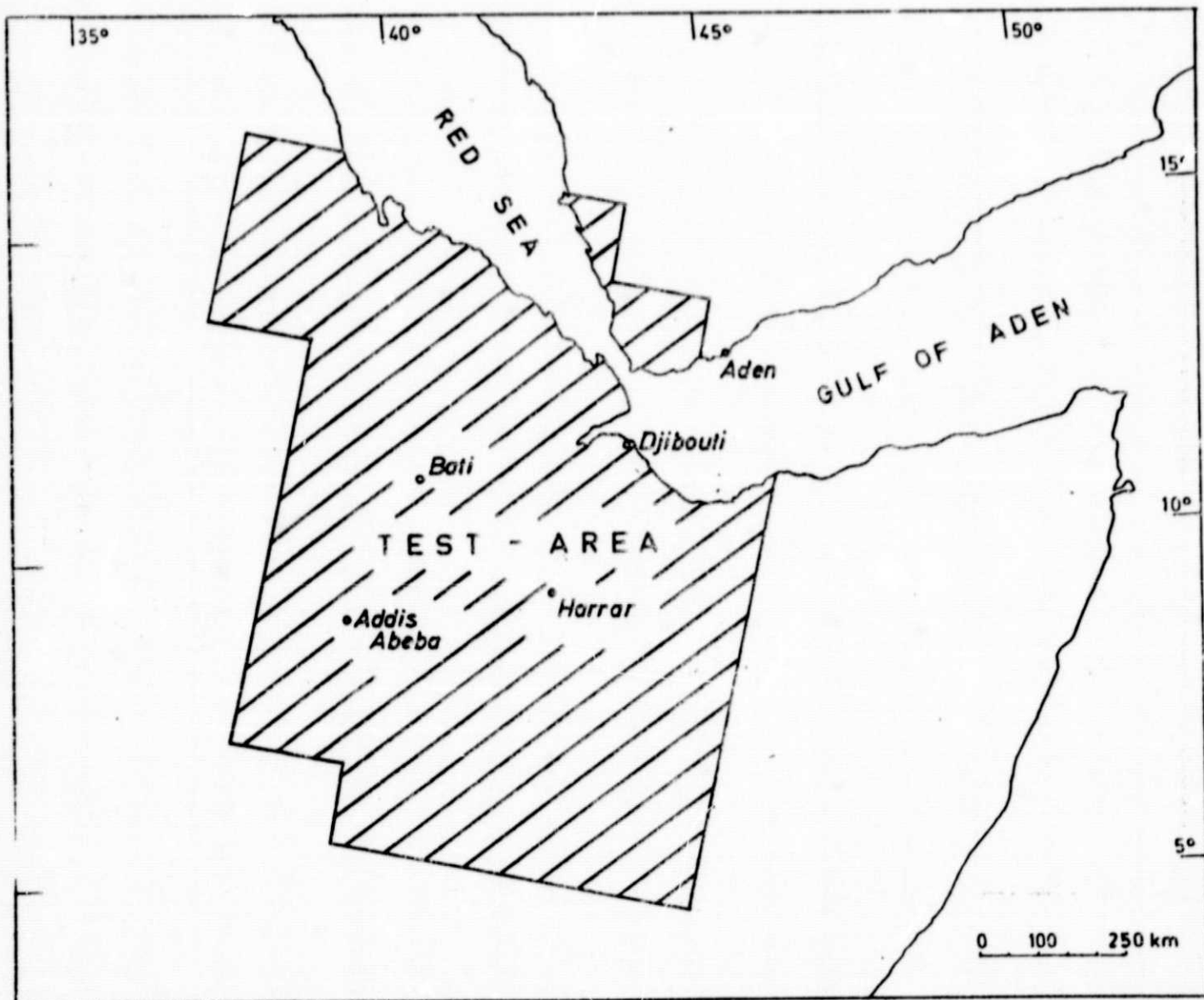
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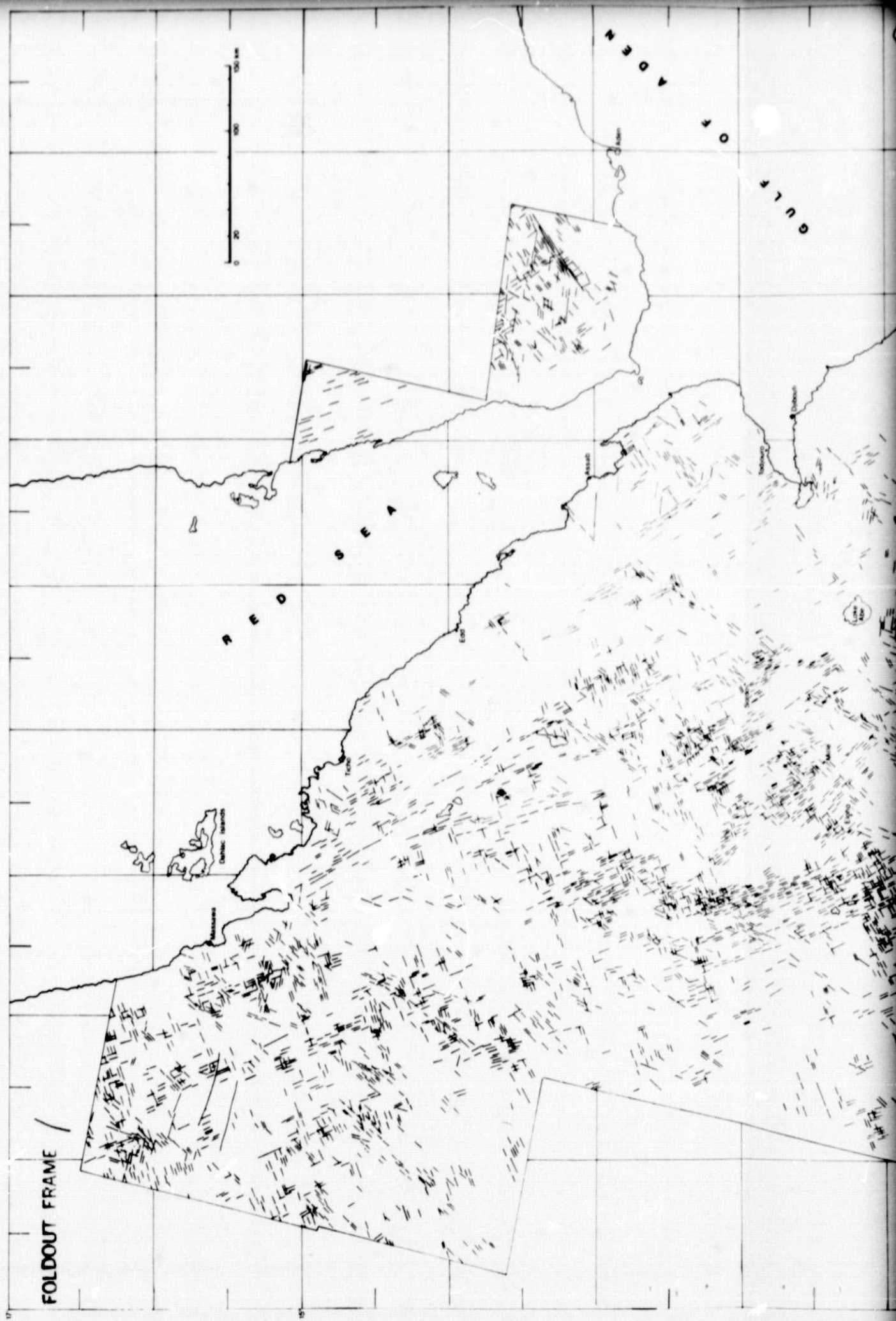


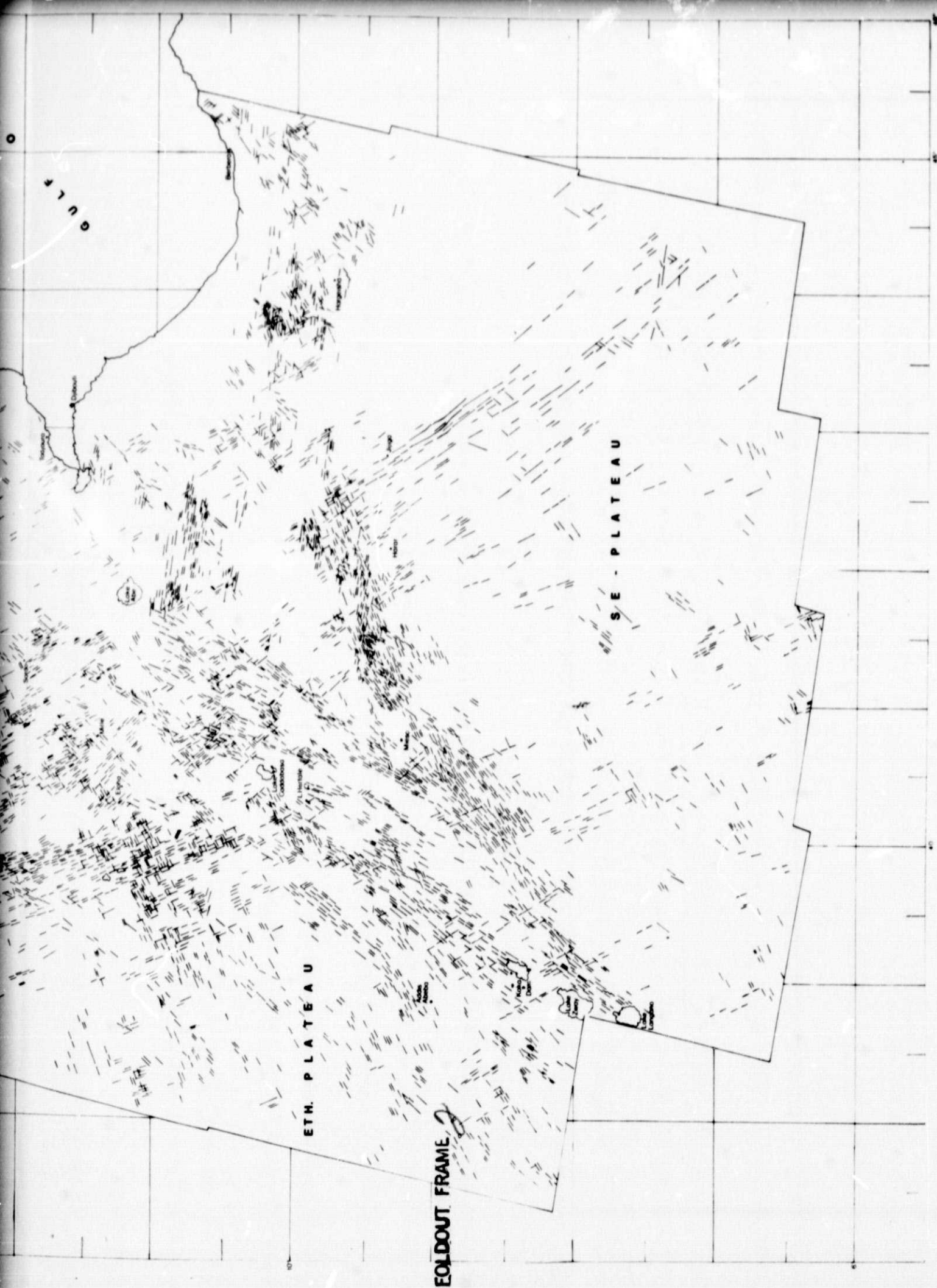


**Location Map Test Area ERTS 1-Proposal Sr. No 351**

# Main Trends of Faulting and Jointing of the Afar/Ethiopia and Adjacent Regions as Mapped From ERTS 1-Imagery (ERTS 1 Proposal Sr. No 351)

principal investigator: P. Kromberg, co-investigators: D. Bannert, M. Schönfeld, co-workers: R. Gläntzer, P. Teonbo, drawn by: H. Polyzos





ETH. PLATEAU

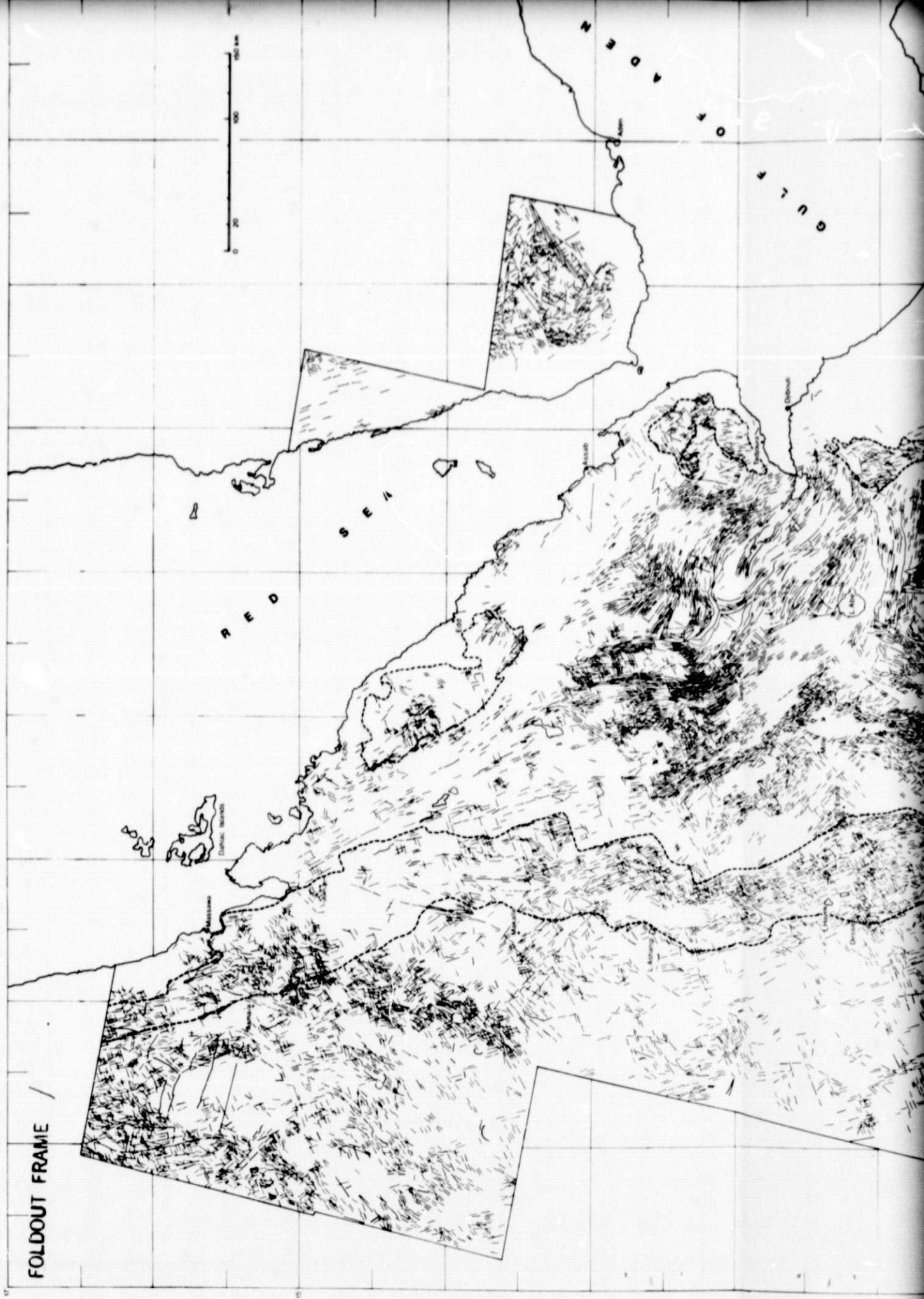
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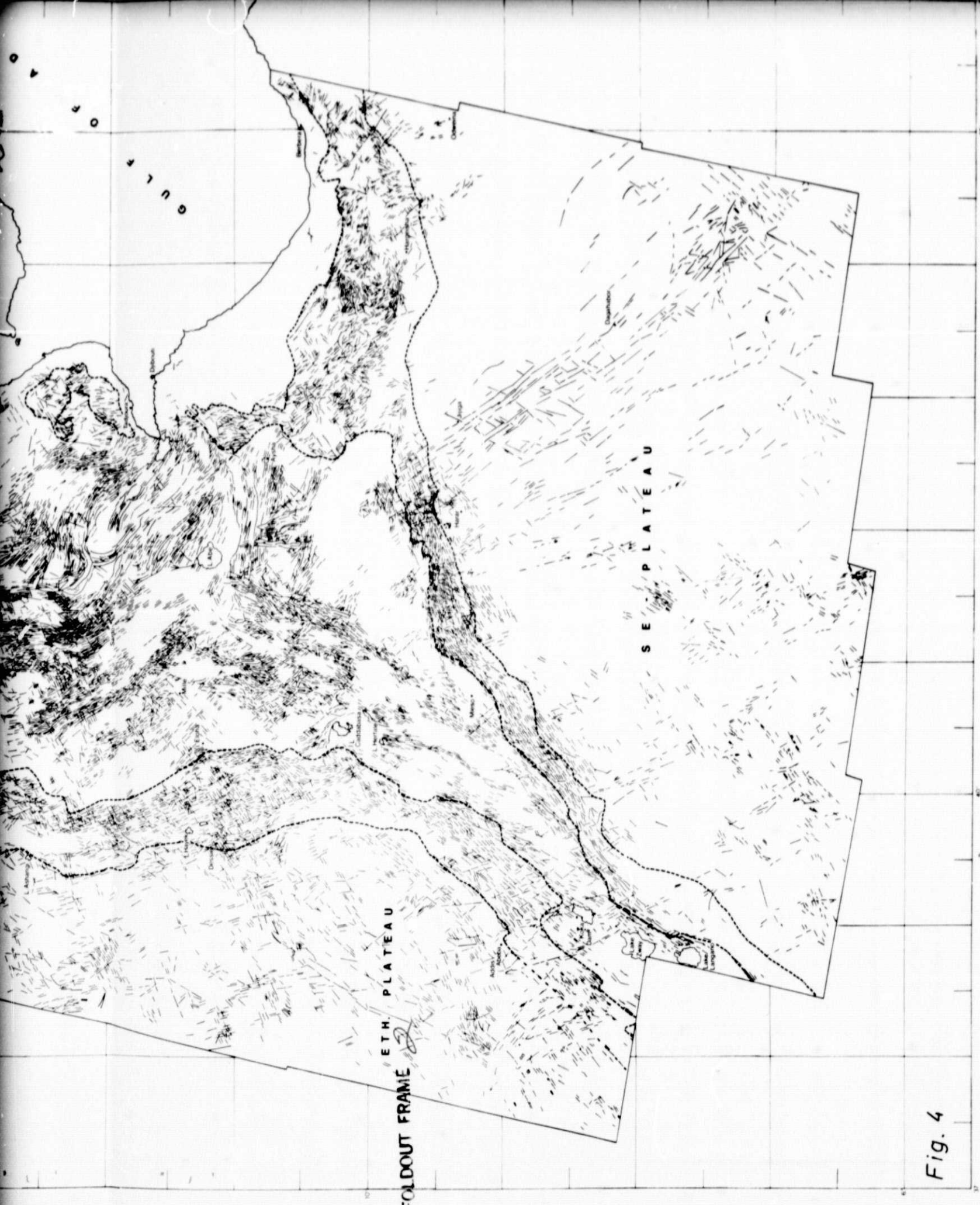
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# Surface Structures of the Afar / Ethiopia and Adjacent Regions as Mapped From ERTS 1-Imagery (ERTS 1-Proposal Sr. No 351)

Principal Investigator: P. Kronberg, co-investigators: D. Bannert, M. Schönfeld, co-workers: R. Günther, P. Teombos, drawn by: M. Polyzos





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Fig. 4

# Fault Tectonics of the Afar / Ethiopia and Adjacent Regions as Mapped From ERTS 1- Imagery (ERTS 1-Proposal Sr.No 351)

Principal investigator: P.Kronberg, co-investigators: D.Bannert, M.Schubert, co-workers: R.Günther, Tsomboe, drawn by: N.Polyzos



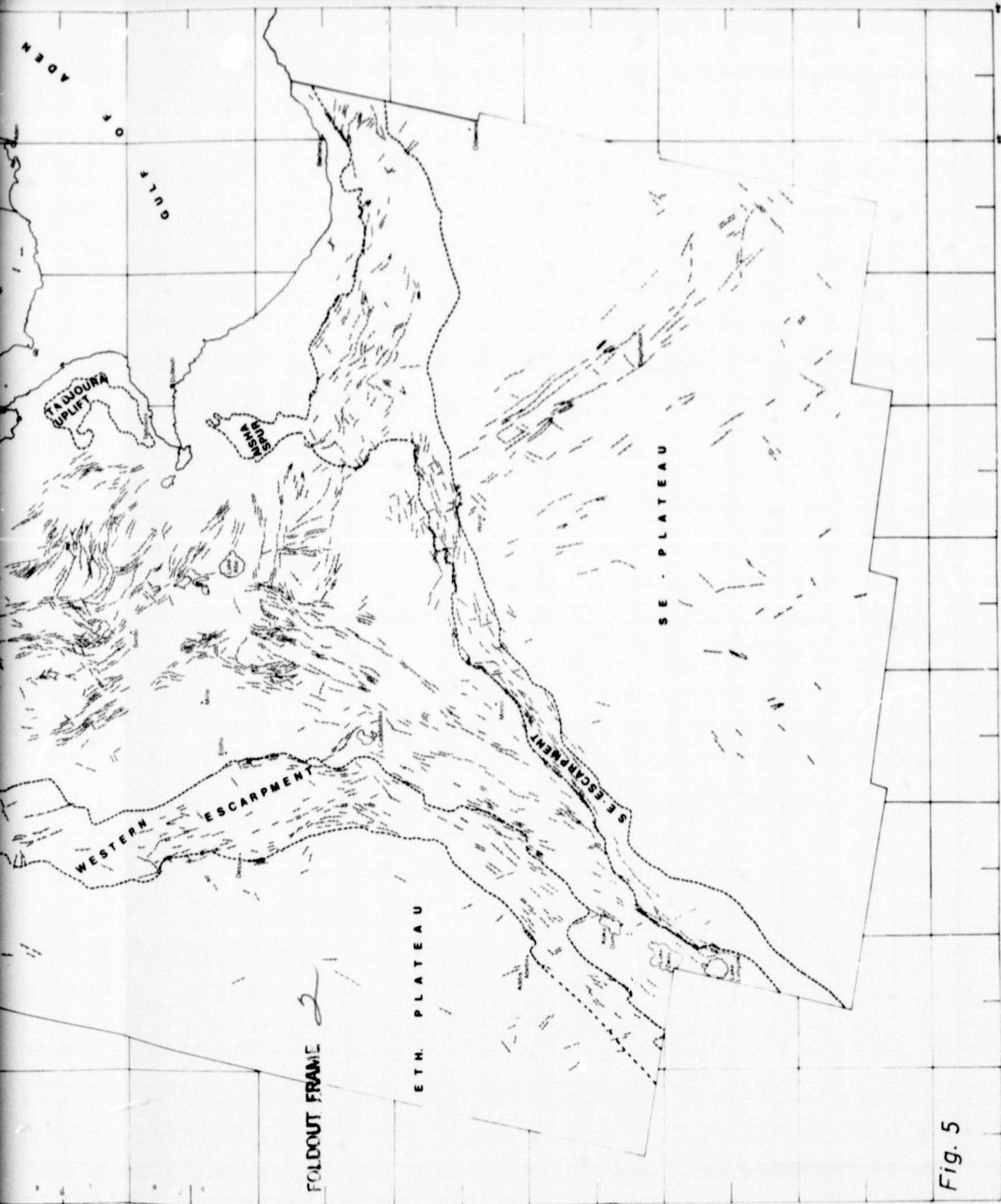


Fig. 5

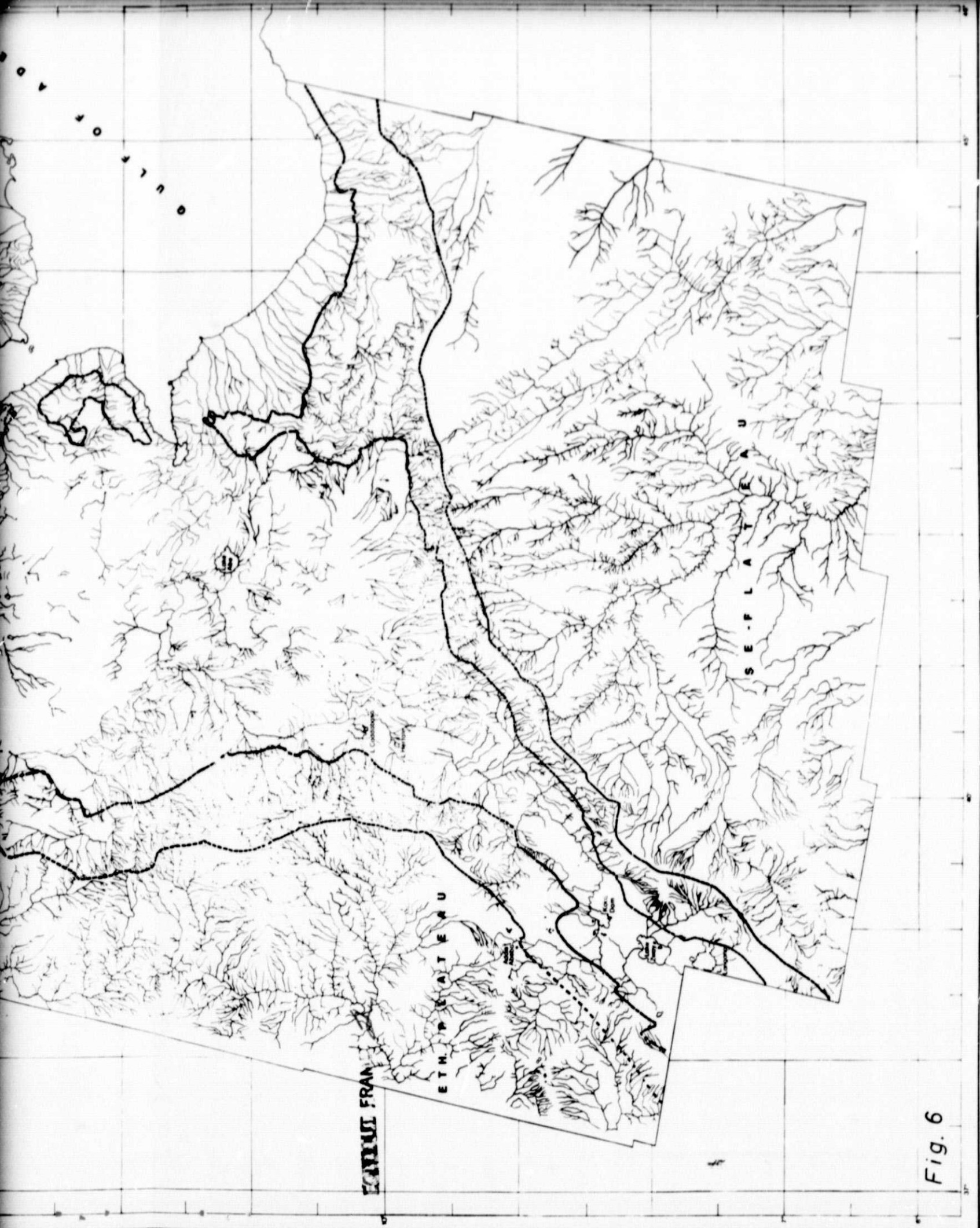
# Surface Drainage of the Afar / Ethiopia

and Adjacent Regions  
as Mapped From ERTS 1-Imagery  
(ERTS 1-Proposal Sr. No 351)

Principal Investigator: P. Krombholz, co-investigators: D. Benner, M. Schönfeld, co-workers: R. Günther, P. Teasdale, drawn by: A. Gundlach







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Fig. 6

