IMPERIAL GOVERNMENT of IRAN

PLAN & BUDGET ORGANIZATION

AN EVALUATION OF THE UTILITY OF ERTS-1 DATA FOR MAPPING AND DEVELOPING NATURAL RESOURCES OF IRAN

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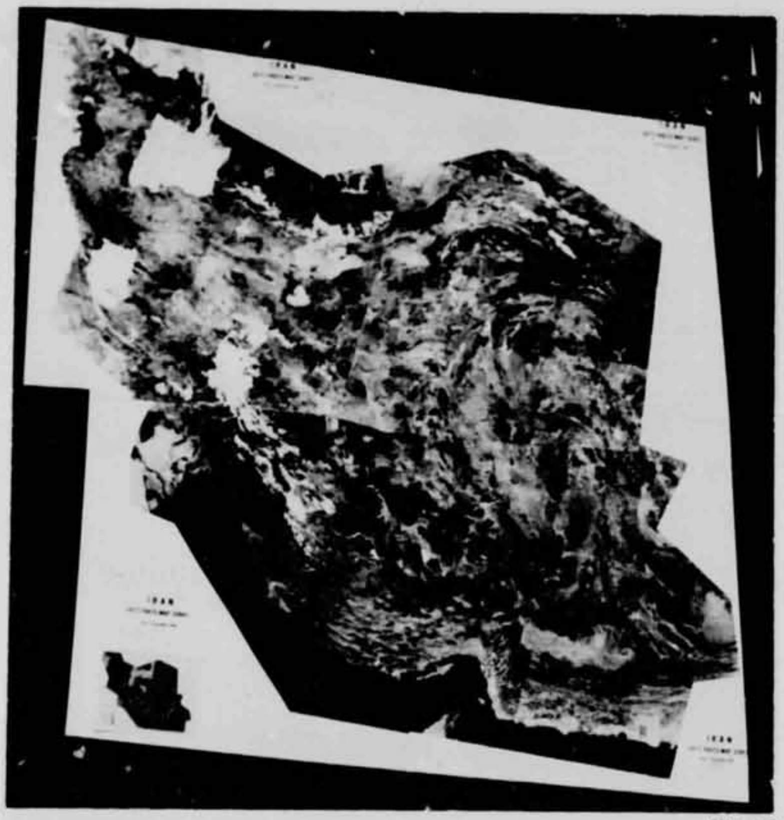

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15. Abstract

Significant result are reported in structural mapping leading to tectonic interpretation; in surficial deposits mapping; in analysis of salt diapirism in southwest Iran; in updating and correcting exsisting hydrological maps; in monitoring fluctuations of water in some intermittent lakes; in the delineation of wetland areas and the study of fluvial suspended load of the head of the Persian Gulf in relation to the fishing industry; in excercises in soil mapping; in range and agricultural surveys and inventory using multistage sampling methods, and in the computer analysis of ERTS-1 digital tapes for urban land use. The completion of a 1:1,000,000 false colour photomosaic of Iran is also reported.

PREFACE

SUMMARY OF PROJECT STATUS AND SIGNIFICANT RESULTS OBTAINED USING ERTS-1 DATA

ERTS-1 data are now being applied by the Government of Iran to the following projects :

- Geological interpretations
- Hydrological interpretations
- Oceanographical and Marine Resources studies
- Land Use Analysis
- Agriculture, Forestry and Range Management
- Soil type identification studies

Significant results obtained in the June 73 - June 74 reporting period using ERTS-1 data include :

- The completion of a colour photomosaic of Iran at a scale of 1:1,000,000. This project which involved the colour matching of 108 frames, and was produced in four seperate sheets, is believed to be a unique accomplishment in so far as if was the first product of its kind to be prepared using ERTS-1 imagery.

- Mapping of major tectonic, structural and stratigraphic features using various test sites in Central, South and Eastern Iran.
  It has beenconcluded that the greatest value of ERTS-1 imagery in geological applications is in the production of regional structural maps, especially where fracture patterns can be delineated.

AN EVALUATION OF THE UTILITY OF ERTS-1 DATA FOR MAPPING AND DEVELOPING NATURAL RESOURCES OF IRAN

color

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PLAN AND BUDGET ORGANIZATION
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- Compilation of a "Lineament Map" of Eastern Iran, and its use in the subdivision of this part of Iran into seperate tectonic provinces.

- Tectonic mapping and analysis of the Tabas Quadrangle in East - Central Iran.

- Continued updating and correction of exsisting hydrological maps, including the mapping of previously unrecorded lakes, reservoirs, playas, and drainage patterns.

- Monitoring of the seasonal fluctuations of the surface water in Darya-e-Namak.

- Continued use of ERTS-1 imagery in range and agricultural surveys by the Ministry of Agricltur and Natural Resources. Extensive multistage sampling methods are being used in this project.

- Delineation and evaluation of high potential fishing zones in the Persian Gulf. These projects involved the identification of wetland areas along the coastline, as well as the study of the offshore suspended sediment transport patterns.

- Evaluation of the utility of ERTS-1 data in Soil type identification and mapping in the Qazvin Test Site area.

- Further training of Iranian scientists in the United States and England, in both the interpretive techniques and the digital possibilities involved in using ERTS data.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION III :

SECTION I

Introduction

INTRODUCTION :

In June 1971, the Imperial Government of Iran, submitted its proposal for participation in NASA's Earth Resources Technology Satellite-1 program, entitled "To Evaluate the Utility of ERTS-A Data in Mapping and Developing Natural Resources in Iran" which was subsequently accepted in April 1972. As a result, an extensive multidisciplinary program was initiated in the Plan and Budget Organization with the active participation of several ministries.

Most of the work carried out on the ERTS-1 obtained data, between April 1972 and June 1973, has been already presented in our Type 1 and Type 2 Reports (Ebtehadj et.al 1973) and is here presented in review form only.

From June 1973 to the present time, the bulk of the work carried out has been addressed principally to the disciplines of geology, hydrology and oceanography.

In the field of geology the aim has been mainly confine attempts at analysing the general tectonic framework of the country, with special attention being paid to Eastern Iran. This preliminary work was carried out in two stages. Firstly the subdivision of East and South East Iran, into seperate tectonic provinces based principally on a study of ERTS - observed lineaments and associated trends, and culminated in a report entitled "Tectonic Analysis of East and South East Iran using ERTS-1 imagery", which was subsequently presented at NASA's Third ERTS Symposium in Washington D.C.

The second stage of the geological applications experiment involved an attempt at an intermediate level tectonic mapping of a small Test Site area, the Tabbas Quadrangle.

The hydrological studies carried out were effectively the continuation of the projects initiated at the beginning of the Earth Resources Program. These include locating previously unrecorded fresh water lakes, mapping of playas and associated surficial deposits, drainage network studies, and finally the monitoring of seasonal fluctuations of some intermittent lakes.

The oceanagraphical and marine resources projects involve hydrographical studies mainly in the form of coastal mapping with special attention being paid to wetland identification and the analysis of seasonal variations of the suspended load at the head of the Persian Gulf. These particular studies are considered to be very relevant to the identification of high potential fishing zones in the Persian Gulf.

In soil sciences a pilot project in the use of ERTS-1 imagery for the identification of soil types in the Qazvin area, has been conducted. this study, which is still in progress, is included in this report albeit its preliminary nature, to indicate the long-term potential of this imagery in large scales oil mapping of Iran. From the results obtained thus far, it would seem that digital techniques for mapping will be especially applicable in this project.

Several "ground check" programs, associated with the above studies, were undertaken to confirm the validity of the interpretations, and to establish the nature of some of the recognized but unidentified features as seen on the ERTS imagery. Care was taken to include personnel from as many disciplines as possible on these trips in order to maintain the essential multidisciplinary outlook of the program.

Finally, the project entitled "Range Land Evaluation in Iran", presently being carried out by the Ministry of Agriculture and Natural Resources, using multistage sampling methods in addition to

ERTS imagery, concludes the major activities in Iran using ERTS-1 data.

It should be pointed out that a false colour composite (bands 4,5, and 7) mosaic of Iran at a scale of 1:1,000,000 was also prepared during this period. This mosaic, consisting of 108 single ERTS-1 frames, most of which are totally cloud free, was the first of its kind to be prepared, and played an important role in the projects undertaken during this reporting period. (Plate - I)

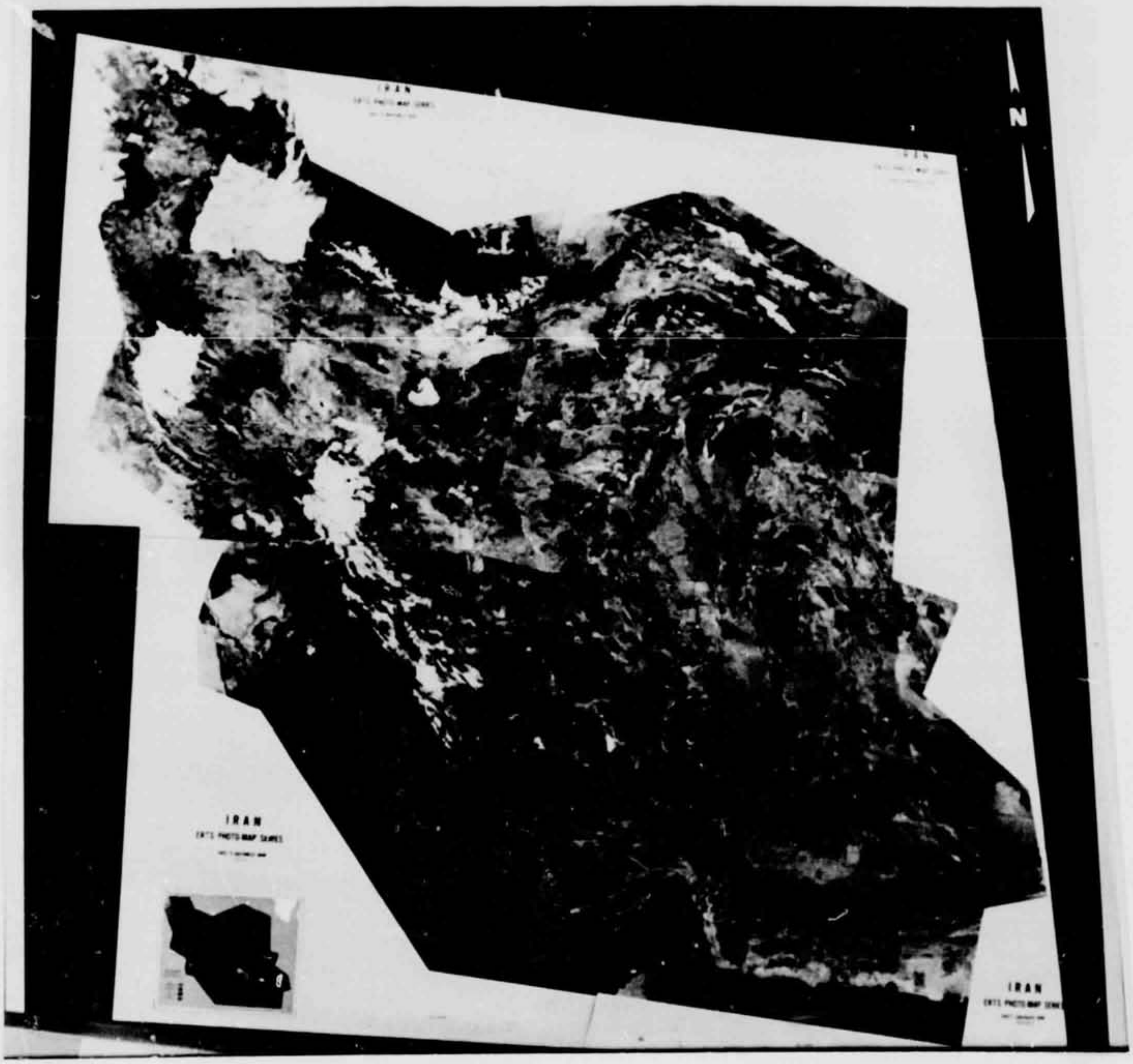

PLATE - I ERTS COLOUR MOSAIC OF IRAN

This is a reduced copy of the mosaic of Iran composed of infrared false colour composite of (bands 4, 5 and 7) ERTS-1 images. The mosaic of the entire country consists of 4 sheets at a scale of 1:1,000,000. This copy has a scale of approximately 1:10,000,000.

SECTION II

Geological Applications

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INTRODUCTION

The geological portion of the Iran ERTS-1 project experiment is in effect seperated into two parts. Part I of the geologic experiment involved examining all of the imagery, in the form of 1:1,000,000 black and white, band 7, and false colour mosaics, single frame prints and transparencies, as well as 1:500,000 and 1:250,000 enhancements of "special interest" frames. This preliminary analysis was carried out mainly to obtain an idea of the different types of geological information, and the level of detail that could be extracted from the imagery: in general to evaluate ERTS-1 data in terms of its potential in geological applications in Irar

For this purpose, several test sites were selected and analysed in detail. Special care was taken over the choice of these sites, so that they would exhibit as many geological features as possible and to be generally representative of the country, as a whole (Figure 1).

Part II of the geological portion consists of the projects undertaken as a result of the studies carried out on the above mentioned Test Sites. Since the preliminary analysis in Part I, indicated that the principle use of ERTS-1 imagery for geological studies in Iran, is in the definition of structural features, the second portion of the report is almost wholly involved with structural and tectonic interpretations. Nevertheless, geological mapping and lithological identification studies have not been totally neglected, and at present several studies looking into the feasability of geological mapping in Iran, using ERTS-1 imagery, have been initiated and are presently in progress.

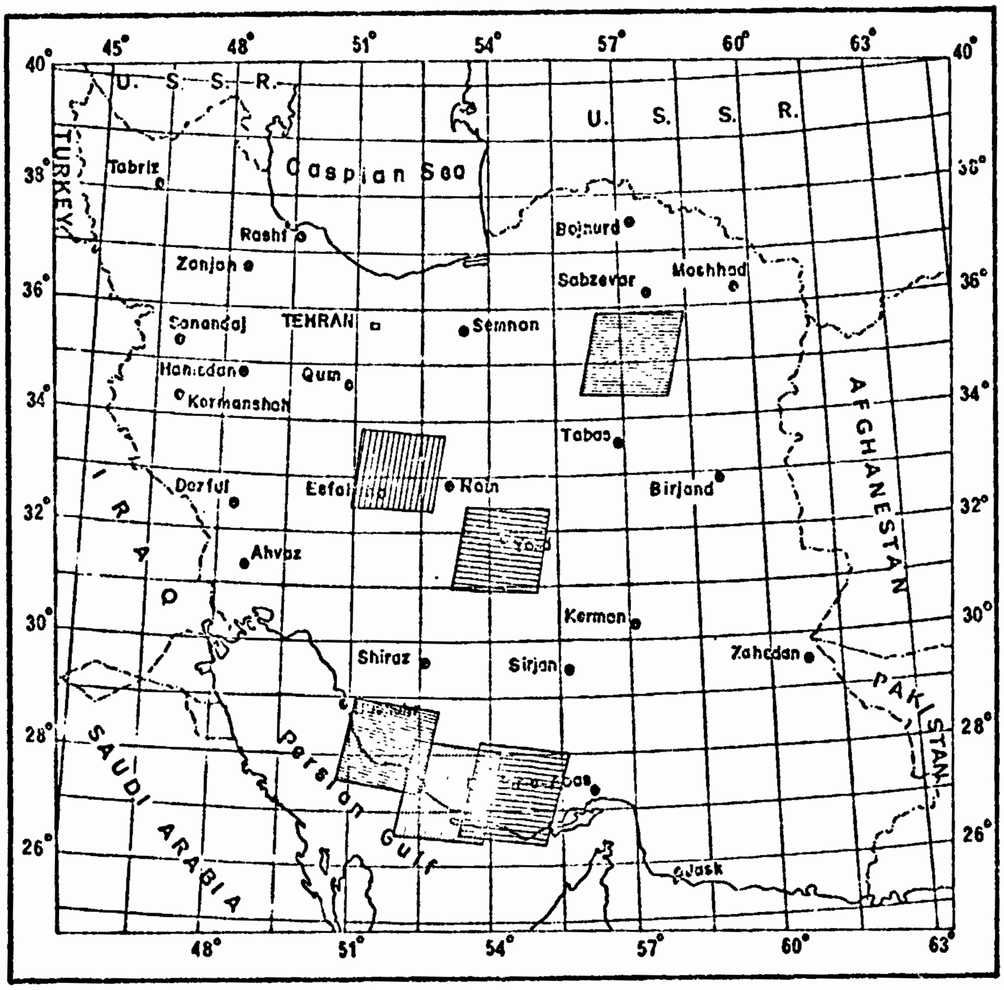


Figure 1 - Test Site Locations

HISTORY AND BACKGROUND

Iran is that section of the Tethyan Geosyncline that was compressed between the Russian and Arabian Shields, with the resulting formation of major geomorphological features apparent today such as the Zagros and Alburz mountain chains.

In term of depositional history Iran is thought to have exsisted in relatively stable platform conditions throughout the entire Paleozoic era, with the exception of the emergence of southwest Iran during late Cambrian times, and gentle epirogenic movements mainly in pre-Devonian and pre-Permian times, probably coinciding with the Caledonian and Variscan orogenies.

The quiet platform conditions of the Paleozoic gave way in late Triassic times to intense folding and faulting in the central Iranian region. This orogonic phase did not however affect southwest Iran, where a comformable sedimentary sequence, several thousands of meters thick was deposited ranging in age from Cambrian to late Tertiary. The whole sequence was folded only by the latest Alpine movements (Plio-Pliestocene) into long paralell asymmetric folds, occasionally pierced by Infracambrian aged salt diapirs. There are no metamorphic or igneous rocks in this fold belt.

The Zagros Fold Belt is bounded northeastwards by a zone of intense thrusting culminating in the main Zagros Thrust. This major geofeature may be considered as the surface expression of the fundamental break between the once coherent Arabian and Iranian Platform, resulting in the under thrusting of the Arabian Shield below the Iranian Platform.

The Zagros Thrust Zone also represents the deepest part of the former Zagros Trough, as shown by the presence of radiolarian shales, and flysch-type deposits, locally accompanied by ophiolitic intrusions, forming typical "Coloured Melange" sequences.

The Alpine Orogeny also brought into being the Alburz mountain chain. These ranges which are stratigraphically and structurally related to Central Iran are considered to have commenced rising in early Pliocene times with renewed movements in late Pliestocene. These later movements are thought to have been responsible for the folding of the molasse-type erosional material from the surrounding mountains, which had accumulated in nearby depressions during the Neogene.

The general area bounded by the Alburz and Zagros fold belts to the north and south west respectively, and by the Lut Block to the east is perhaps one of the most geologically complicated regions in Iran, if not the world.

This region was previously considered to be of a stable platform character and often referred to as a stable "Median Mass". However recent work (J. Stocklin 1968), clearly indicates that only the Lut Block is of this particular character. The remaining regions were found to consist of intensely folded and faulted Mesozoic and Tertiary rocks, exhibiting many of the trends and characteristics of its surrounding structural styles, but in general bearing the most affinity to the Alburz mountains.

To the east of this central region, there exists a large desert region known as Dasht-e-Lut. This is generally an area of random faulting and insignificant folding.

Three main types of surface lithology are noted in this area. Mesozoic sedimentary rocks, forming the extensive table-mountains in the western part, tabular volcanic rocks of Paleogene age covering older sedimentary rocks in the north and finally Pleistocene-Recent deposits filling young depressions.

The Dasht-e-Lut, or more accurately the Lut Block itself in bounded to the south and east with extensive developments of Eocene flysch. These manifest themselves as gentle undulating structures in the Makran Ranges to the south and as tight linear folds, locally metamorphosed, in the East Iranian Mountains bordering and passing into Pakistan. In both cases the flysch is occasionally associated with "Coloured Melange" developments especially along the junction with the Lut Block.

This concludes a very general review of the geology of Iran, and is included in this section to give the reader a general background that may be necessary for a fuller understanding of the discussions in the coming forth pages.

REVIEW OF PREVIOUS FINDINGS :

Before commencing on the results obtained in the single Test Site interpretations, regarding the value of ERTS-1 imagery in geological applications, it is perhaps in place to review some of the previous major findings using ERTS-1 imagery. These have been more fully reported in Types I and II (Ebtehadj et.al 1973). These results relate firstly to the detection of major previously unrecorded tectonic features of Iran, that have been identified using ERTS imagery and are shown schematically in Figure - 2 . and secondly to some very general observations concerning surficial deposits and their possible identification using ERTS-1 data.

Major Tectonic Features as shown by ERTS-1 Imagery

A regional tectonic interpretation of the entire country, using black and white ERTS-1 MSS, band 7 data as well false colour composites (bands 4,5, and 7) was carried out with the following results :-

(a) A major northwest - southeast trending fault, passing through Rezaiyeh and Esfandagheh, almost 2000 kilometers in length and roughly parallel to the Zagros thrust, was recognized. This fault which had not been previously recorded in its entirety and thus does not appear on any geological map as such, was found to be intersected by a series of northeast - southwest trending faults in the vicinity of the city of Nain. There have been tentalively named the "Nain-Kashmar" fault series, (Figure 2). This new observation indicates that previous tectonic interpretation of this region (compilation map NIOC 1959) which showed these two series of faults being continous and hence belonging to one generation is probably erroneous.

(b) Another large lineament, previously unrecorded, extending from Khairabad (Kerman Province) to southwest Teheran, and about 800 kilometers in length was recognized.(Figure 2). This lineament, although not very conspicuous in some sections of its length, is best noted by the sharp boundaries it has created in some playas, as well as possible displacements of volcanic material near the town of Anar. In addition, the presence of Quaternary volcanic activity near or on the lineament may indicate recent movements along its length.

Surficial Deposits as seen on ERTS-1 Imagery

The following are a few general observations concerning surficial deposits as seen on ERTS-1 black and white as well as false colour composite prints :-

- The aerial extent, and the boundary between alluvial fans and other types of unconsolidated sediments are easily observable on the ERTS-1 images. The delineation of these fans are particularly significant for hydrological investigations, since most wells or Qanats* in Iran are drilled or dug in these alluvial deposits.

* Qanat is a horizontal interceptor to the ground water table, which is linked through a series of interconnected wells. (Wulff, 1968).

- Sediments in playas and some river channels being predominantly evaporitic in nature are visible as white patches. As a result the playa is probably the most easily recognizable feature on the ERTS-1 imagery. Playas are furthur discussed in the Hydrological section of this report.

- An important feature of ERTS-1 imagery regarding surficial deposits is the possibility that these images offer in the detection of previously unrecorded Recent faulting in alluvial deposits. These lineament/faults are seen on the imagery as narrow linear bands contrasting in tone or colour with the immediately adjacent areas. The ability to conduct rapid and inexpensive reconnaissance of Recent faulting has important applications to land use planning, ground water exploration, geological hazard studies and the siting and design of engineering projects in general.

- Areas covered by weathered and eroded by-products of nearby igneous and metamorphic source rocks, exhibit themselves with different tonal signatures. In general the by-products of acidic igneous rocks tent to have a lighter tone, compared with those derived from basic massifs.

- Unconsolidated sand dune developments are clearly noted on the ERTS-1 imagery in several previously unrecorded locations. This detectibility of loose sand coupled with the repetitive ERTS coverage, has great potential in aiding investigations presently being carried out near urban areas such as Sabzevar, in attemps to monitor and control unconsolidated sand movement.

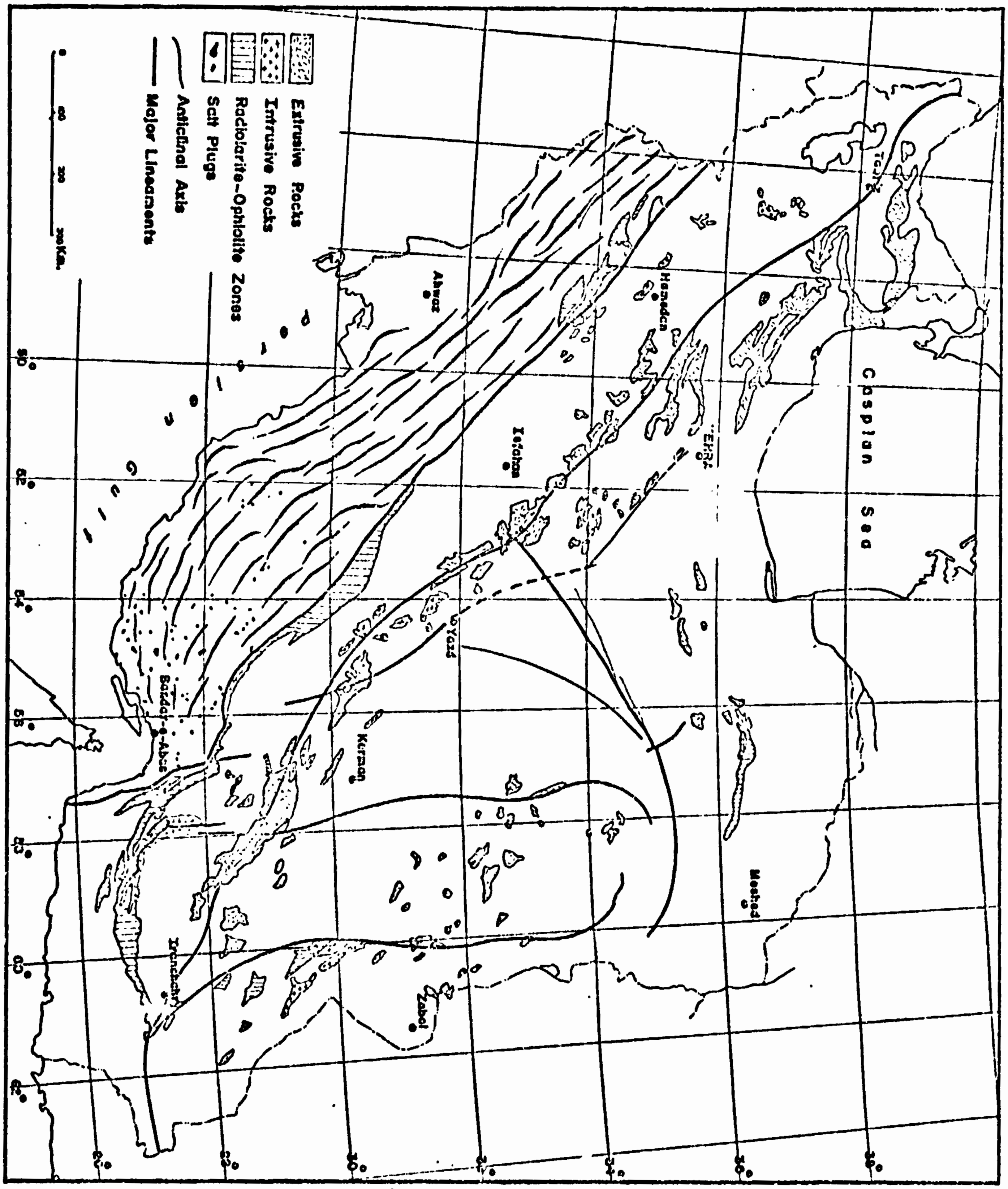


Figure-2 Schematic map showing major tectonic features of Iran.

PART I

SINGLE FRAME TEST SITE ANALYSIS OF ERTS-1 IMAGERY IN IRAN

In order to fully evaluate the applicability of ERTS data to geological studies, the following test sites were chosen and analysed is detail:-

TEST SITES IN CENTRAL IRAN

(a) Isfahan Region Frame No. 1169-06391

The analysis and interpretation of this image taken on 8, Jan, 1973 may be split up into two major portions, those related to structural studies and those in surficial deposit investigations. These are fully described below:-

- Structural Interpretations

The structural information gained from this image is expectedly in the form of identification of lineaments and associated trends. In this context the main Rezaiyeh-Esfandagheh fault is observed as an extending fault zone, partially covered by snow, running from the northwest corner of the image to the southeast, in addition, a series of lineaments, also with a northwest-southeast trend, and passing to the south of the city of Isfahan were noted.

Several of the latter lineaments were confirmed to be surface manifestations of previously unrecorded faults, during "ground check" programs carried out in the Isfahan area.

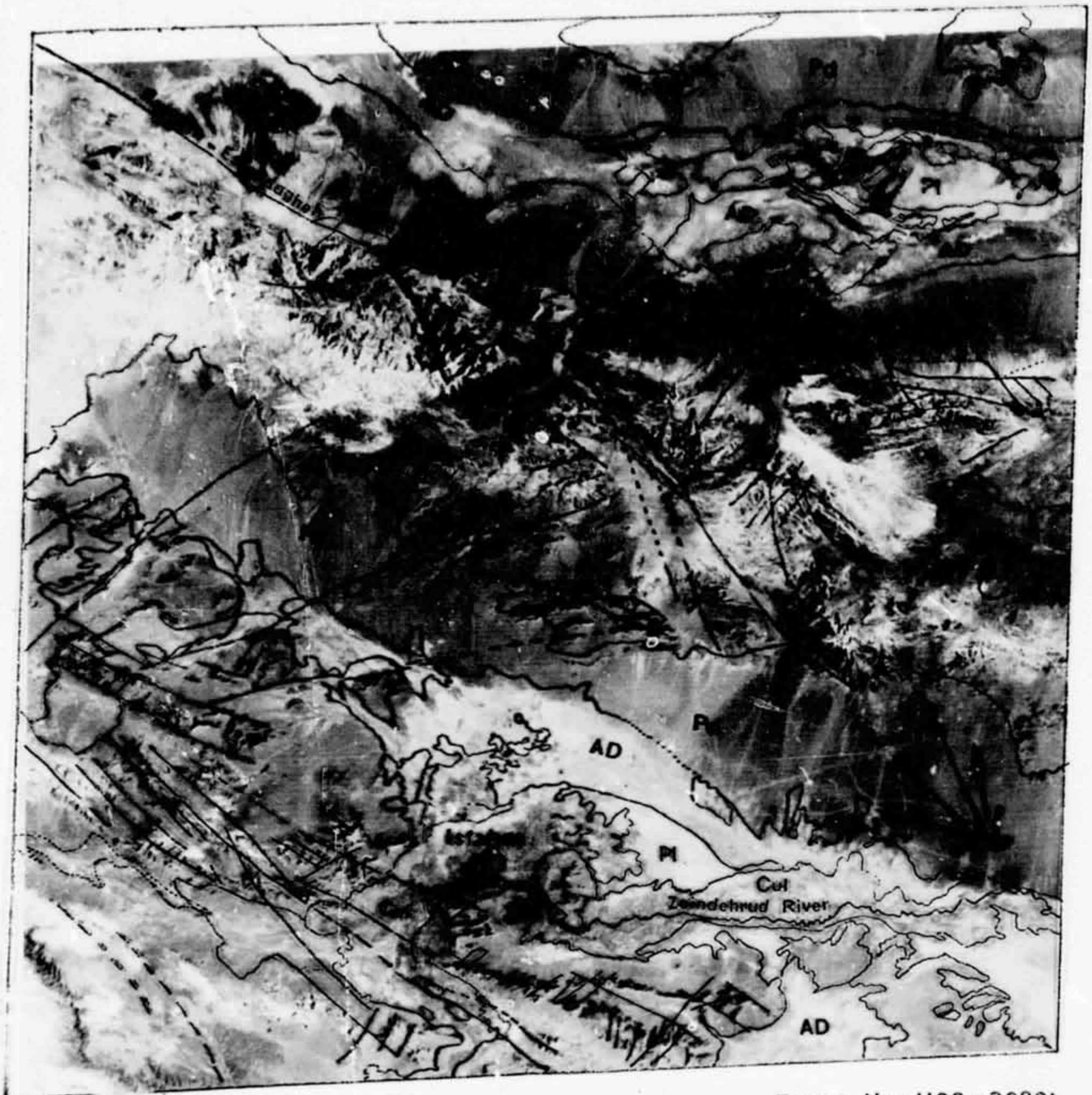
In addition to the above parallel fault zones, a zone of northeast-southwest lineaments to the north of Isfahan was recognized. These lineaments are of particular interest since this trend as a whole, has not been previously recorded in this region.

- Surficial deposits:

A preliminary study into the possibility of detection and recording of the different types of surficial deposits was carried out. As a result several major types, such as alluvial deposits (AD), piedmont (Pd), playa (PL) in addition to other features such as cultivaled areas (Cul), and springs (Sp), were differentiated. These are shown on figure 3.

Of the above surface deposits, the most readily distinguishable are playas and piedmont deposits. The playas which generally show on the imagery as clear light-grey to white patches, due to their evaporitic content, were noted to be mainly to the east of Isfahan as well as in the upper most right hand corner of the image. The tonal differences noted within the playas themselves, are attributed to probable variations in the evaporitic and/or moisture contents.

Piedmont deposits, on the other hand, appear as rather more extensive and "smoother" appearing areas, their colour generally reflecting their source. In other words, the piedmont deposits of intermediate or basic volcanic rock units, which comprise the greater part of the outcrops of the upper portion of the image, tend



Frame No: 1169-06391

AD	Alluvial Deposit	(symbol)	City
Cul	Cultivation	——	Lineament
Pd	Piedmont	(symbol)	Unit boundary
Pl	Playa		
SP	Spring		

N

Figure 3 : Isfahan Test Site
Scale 1:1,000,000

to be darker than the deposits derived from the predominantly sedimentary sequences in the lower portion of the image .

In the southeast of the image and to a lesser extent in the north, several scattered circular patches of vegetation were noted within the darker piedmont deposits. These are believed to be surface manifestation of near surface ground water accumulations. The interconnecting road system between these springs, which are clearly visible on the ERTS imagery indicate that these "oasis" are either inhabited or frequently used for the water supply of nearby settlements.

Perhaps the most difficult surface material to differentiate on the image are alluvial deposits. While some areas are clearly alluvial such as the area immediately to the north of Isfahan, other areas, due to partial cultivation, are not so clearly differentiable. Also, as in the case of piedmont deposits, the colour and tone of the alluvial deposits to the north of the imagery are generally darker than those in the south. This is again a source influenced phenomena.

Finally the image clearly shows the city of Isfahan, and the major river of this region the Zaindehrud, along which extensive cultivation is undertaken.

Yazd Region from No. 1149-06282

This image , take on 19 Dec. 1972 covers the region surrounding the city of Yazd in Central Iran.

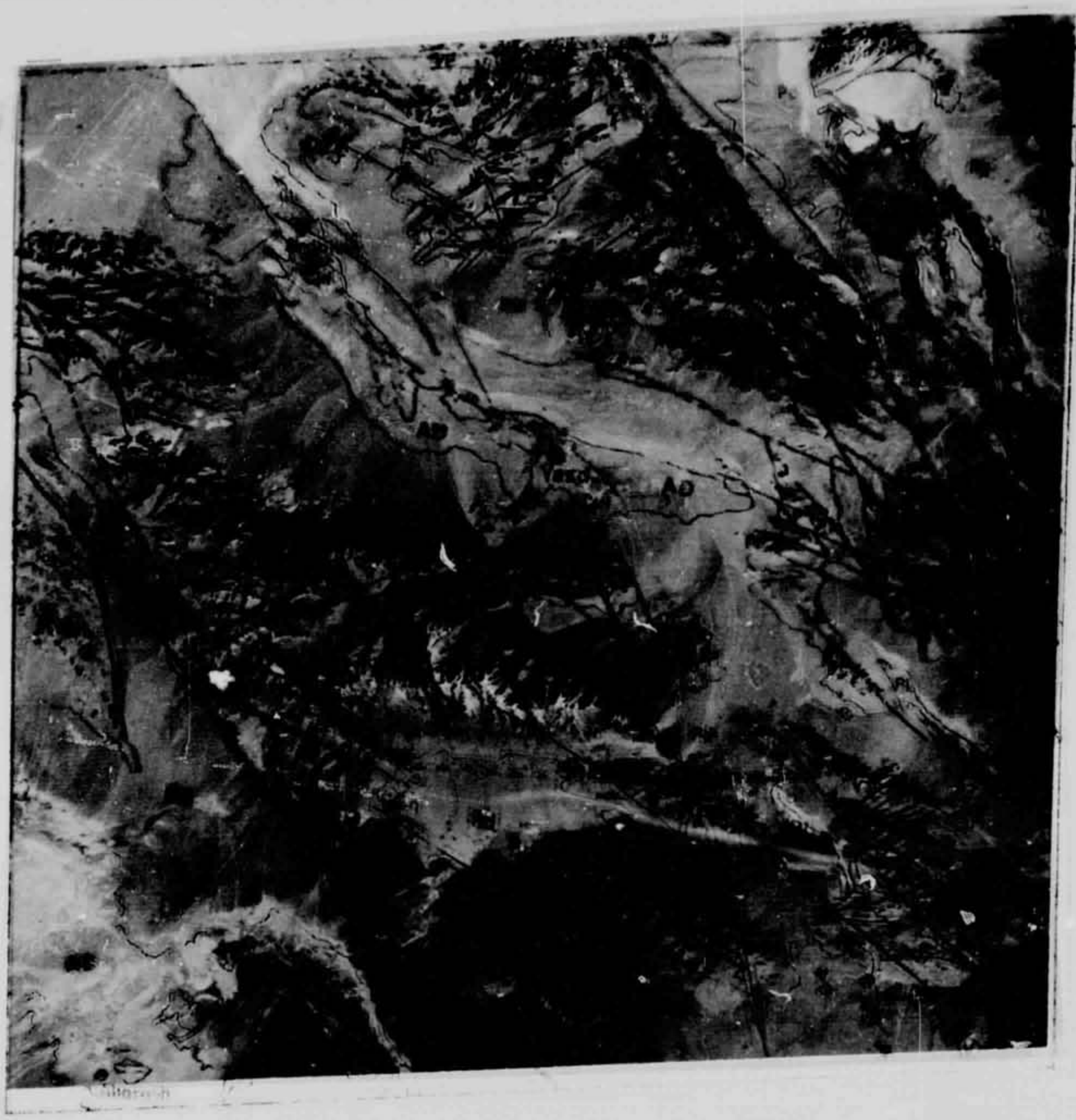
Sturctural Consideration :

Structurally this area can be divided into two part. Firstly in the lower left of the image a portion of Rezaiyeh- Esfandagheh limeament can be clearly seen running in a northwest-southeast direction . this lineament, which can be seen in its entirety on Figure 4 is noted to truncate some recent piedmont deposits, indicating probable recent reactivations along an older fracture. This is further corroborated by reports of recent earthquake activity along this belt in inhabited areas.

To the north of the R-E fault network of minor northeast-soutwest and northwest-southeast lineaments.have been recorded . It is of interest to note that the density of lineaments recorded is higher in the igneous bodies to the west and southeast of the city of Yazd than those noted on the Cretaceous outcrop directly to the south of the city . The origin of this minor lineaments is presently under investigation and ground checking programs to this site are planned.

To the northeast paralled of this network a system of larger lineaments some exceeding 200 Kilometers are noted to occure . The rocktypes in which most of these occur is Jurassic and Cretaceous aged limestones.

In the lower right region of this Test Site evidence for recent volcanism in noted . The trend of these small cones,



Frame No 11[illegible]-0828

AD	Alluvial Deposit	⊙	City
Pd	Piedmont	——	Lineament
Pl	Playa	- - -	Unit boundary
Cul	Cultivation		
V	Recent Volcanism		

N

Figure 4 : Yazd Test Site ,
Scale 1:1,000,000

is roughly parallel to the R-E fault (Figure 4).

Surficial deposits

A trial mapping of the surficial deposits of this frame using tonal and textural contrasts was also carried out . These units are shown in figure 4 .

Nayshabur Region Frame No. E-1111-06154

This image taken on 11 November 1972 covers a substantial part of the Khorasan Province in northeast Iran.

As in the previous test site , the image has been interpreted from the point of view of obtainable structural information and possible identification and delineation of surficial deposits within the area . These considerations are discussed below :-

Structural Considerations

The primary structural information derived from this image may be summarized as follows :

The Duruneh Fault , is clearly seen in the lower portion of the image , as an east-west trending major lineament that begins to swing to a southwest-northeast trend with approach towards central Iran . This fault , which can be considered as one of the major tectonic features of eastern Iran , is in all probability still active , as indicated by recent earthquake activity along its length as well as its transection of Quaternary alluvial fans to its south . Immediately to the north of the Duruneh Fault , there is a network of northeast-southwest and southeast-northwest trending , minor lineaments , that are seen to occur almost exclusively in Eocene aged volcanics . Further " ground truth " studies are planned to ascertain the reason for this prefrential jointing of these volcanic rocks .

Further to the north of this network of minor lineaments a previously unrecorded major lineament has been recognized . This lineament , which trends in an almost eastwest direction is of particular significance , since it is bordered along portions of its length by extensive " Coloured Melange " developments, which in turn are considered to have important implications regarding

AD Alluvial Deposit

Cul Cultivation

Pd Piedmont

Pl Playa

Figure 5 : Nayshabur Test Site ,
Scale 1:1,000,000

plate boundaries in Eastern Iran.

Also of interest is the detectibility of intricate folding in Miocene and Eocene rocks to the west of the image .

Surficial Deposits :

A preliminary mapping excercise concerning surficial deposits was carried out using ERTS imagery . As in the previous test sites the surficial deposits were divided into several catagories , depending on their tonal and textural contrasts . These include alluvial deposits (AD) , piedmont (Pd) , playas (Pl) and cultivated areas (cul). These are shown on Figure 5 .

The alluvial deposits mapped on the image occur for the most part to the south of the Duruneh Fault in the lower portion of the image. It is interesting to note that almost all of the cultivation seems to be concentrated within these deposits.

From the imagery , it will be noted that the supply point of most of the alluvial/piedmont fans seem to fall on the Duruneh Fault, indicating that recent movements along this fault line may have had a direct bearing on the formation of these fans .

Piedmont deposits are mostly located to the north of the Duruneh Fault , and appear on the imagery as extensive " smooth " areas with tonal variations that are apparently source controlled.

TEST SITES IN THE ZAGROS FOLD BELT, Southwest Iran

The economic importance of the Zagros Fold Belt with respect to its vast oil and gas accumulations makes it natural that several Test Sites should be chosen in this region for evaluating the potential of ERTS-1 imagery with view to a better understanding of the geology of this area, especially its tectonic evolution. In addition to the above mentioned commercial aspect, it should be pointed out that this fold belt lends itself particularly well to satellite orientated analyses due to its exceptionally well exposed, double plunging anticlinal structures. There is also the added advantage that a high quality Gemini photograph of this region is available, offering the interpreter a different perspective of this fold belt from that which is attained using ERTS-1 imagery.

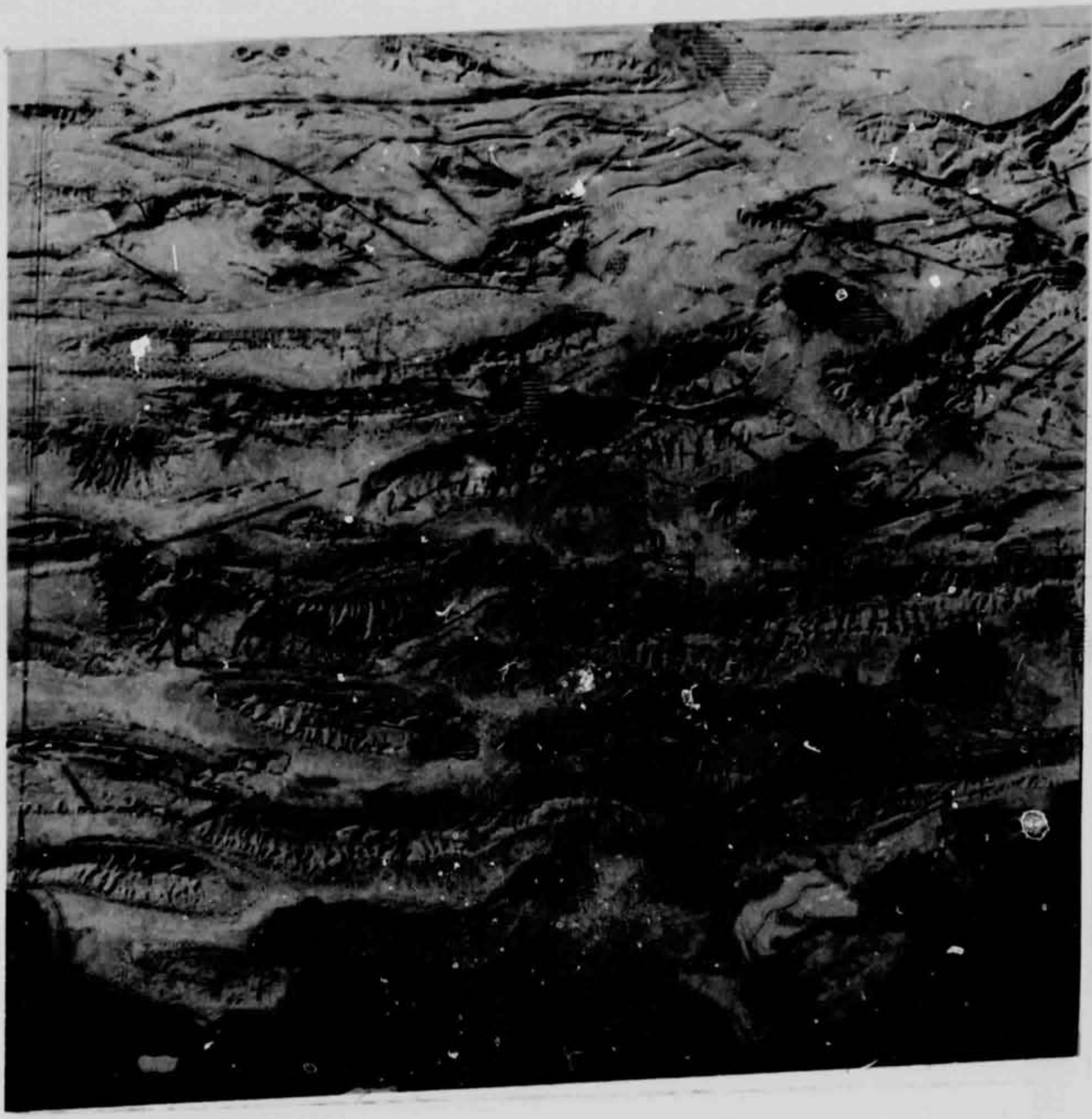
For geological evaluation, two test sites, consisting of two single frames (I.D. 1149-06294 and I.D. 1149-06235) and a third, composed of a mosaic of two frames (I.D. 1168-06344) and I.D. 1168-06350), were selected, with the following results:

Bandar-e-Lengeh Region Frame No. 1148-06235

This image taken on 18 December 1972 spectacularly shows numerous almost equally spaced, east-west trending, doubly plunging carbonate anticlines, typical of the Zagros Fold Belt. Abundant, previously undetected lineaments are also noted, most of which tend to follow two principle trends of northwest-southeast and northeast-southwest. The relative importance of these lineaments are discussed later in this section, (Figure 6) .

Another interesting feature of this image is the detectability of abundant salt diapirs, showing as dark coloured, almost circular features, many with characteristic weathering halos that appear on the imagery with a slightly lighter tone than the plug itself. Several points of interest are noted on the imagery regarding these salt diapirs. These include the relationship between salt plugs and major lineaments in the area, and the identification of the various stages of development of the salt plug in general (i.e. domal features at the plunge point of some large anticlines probably denote unexposed salt plugs), as well as the different stages of weathering of the plugs at the surface. These points are all further discussed below.

In addition, the Mehregan playa, which is covered by a layer of salt crust throughout the year is clearly seen as a white patch in the southeast corner of the image. The high reflectivity of this area on the imagery is no doubt due to the high salt content of the playa, resulting from the leaching of the surrounding salt plugs by perennial stream action.



Frame No: 1148-06232

L	Intermittent Lake		Salt Plug
PL	Playa		Lineament
	Anticlinal Axis		Dip & Strike
	Unit Boundary		

Figure 6 : Bandar-e-Lengeh Test Site,
Scale 1:1,000,000

Furthermore, the extremely high temperatures of the region result in quick evaporation of the already saline waters in this depression, leaving a relatively thick salt crust.

North Of Lavan Island   Frame No. 1149-06294

This image taken on 19 December 1972, and located immediately to the west of the Bandar-e-Lengeh frame, again shows typical "Zagros type" gently folded Tertiary and Cretaceous carbonate rocks in the form of long linear almost equally spaced, en echelon, anticlinal and synclin- structures. Again as in the previous test site, several major as well as minor previously undetected lineaments, were noted on the imagery. Of these lineaments of particular interest is the one trending northeast-southwest and terminating at an intermittent lake, located to the top right corner of the image. This feature here termed the "Kowareh Lineament" passes very close to the town of Qir, which was recently devastated by a major earthquake. The possible relationship between these lineaments and deep seated fractures and earthquake activity will be discussed later.

It should be noted that while salt diapirism decreases as one moves from the Bandar-e-Lengeh area to the area covered by this frame, there is a corresponding increase in the number of recorded lineaments. These two phenomena and their possible relationship are being presently investigated.

The Lavan (larger) and Hendurabi (smaller) islands are also clearly visible on the imagery. (Figure 7)

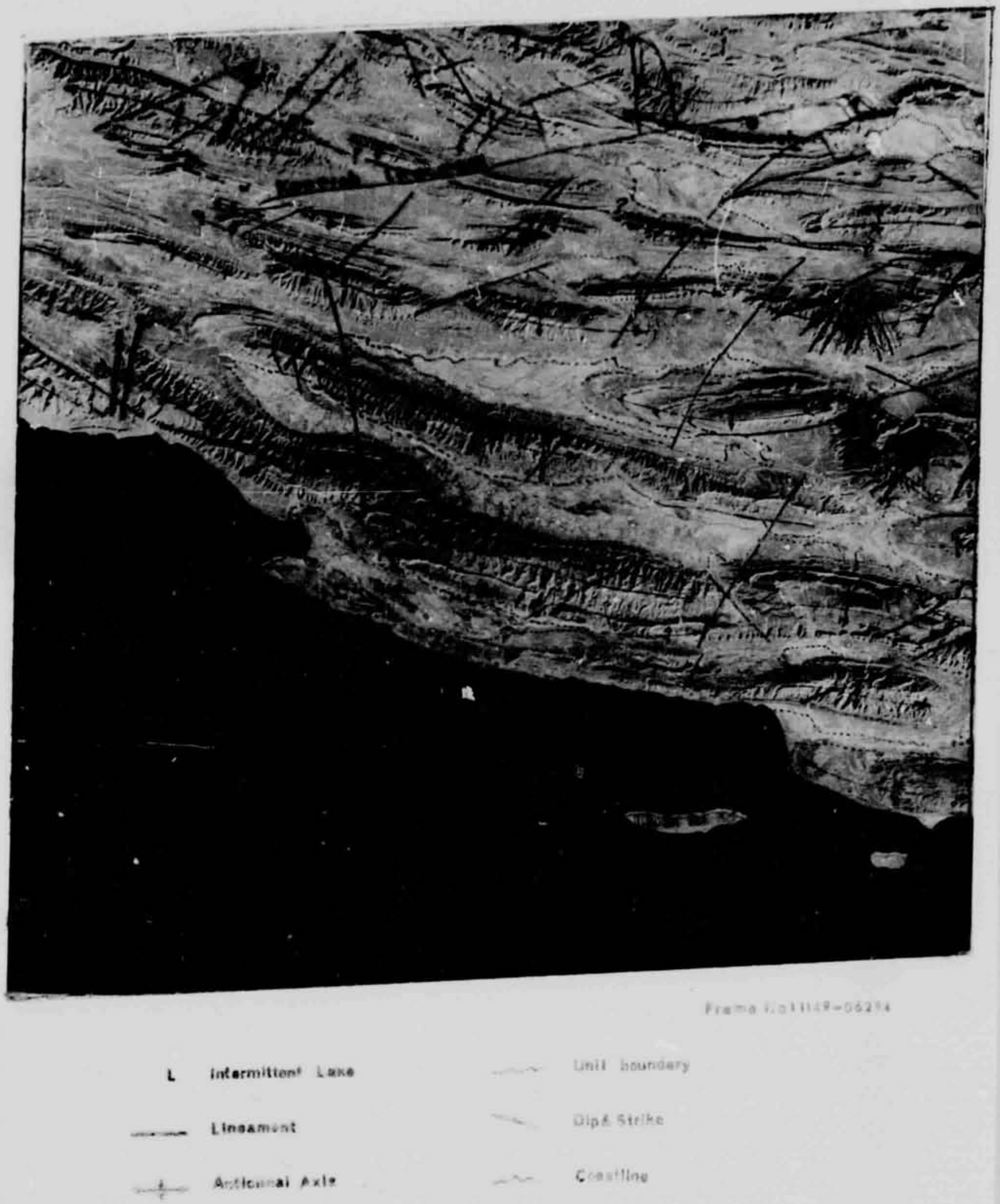


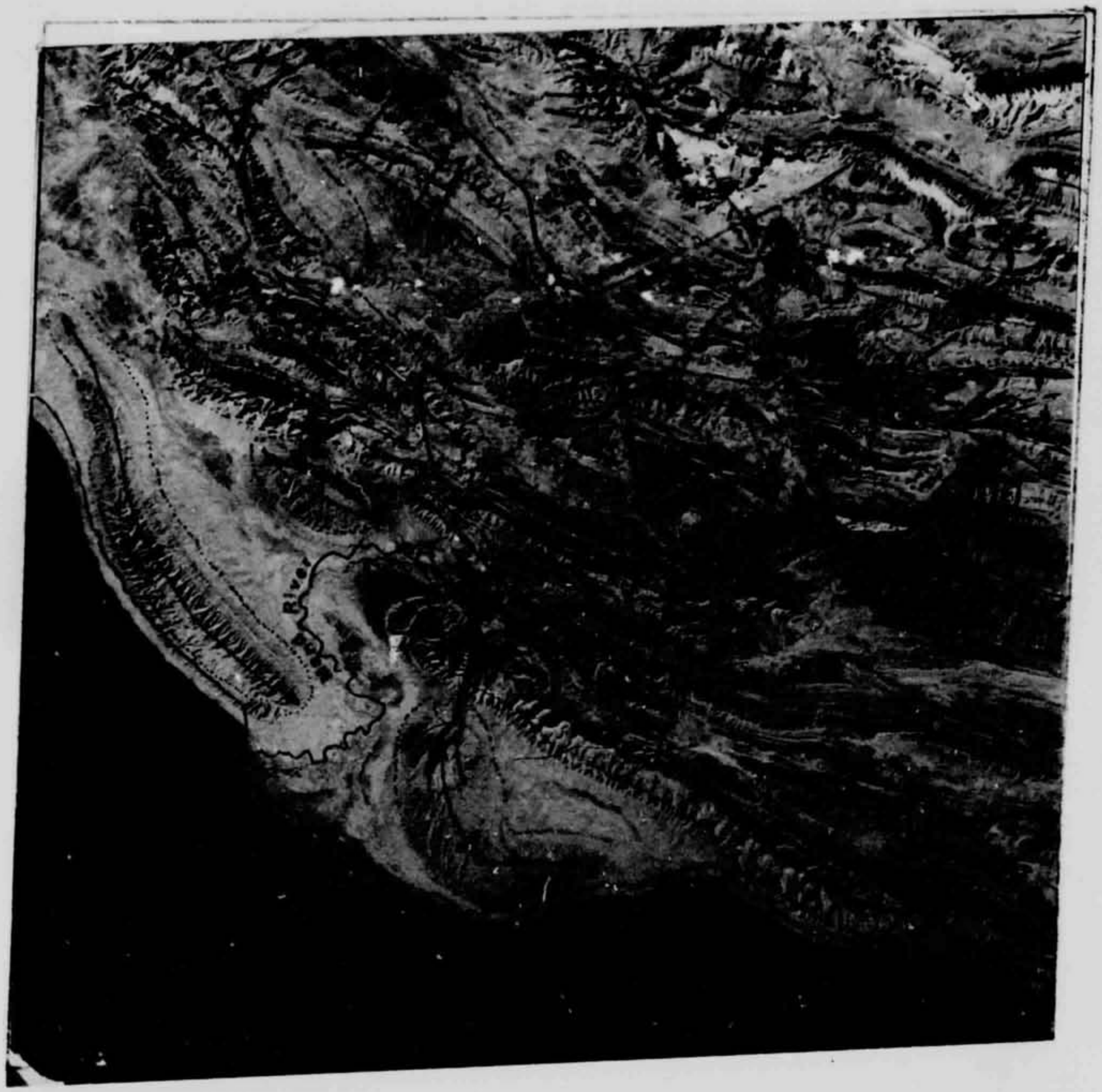
Figure 7 : North of Lavan Island Test Site,
Scale 1:1,000,000

Kangan Area Frame Nos. :- 1168-06344 And 1168-06350

In terms of location, this is a composite image of two frames, taken on 7 January 1973, of the region immediately to the west of the area covered by image 1149-06295. By and large the image covers typical northwest-southeast trending Zagros folds, with an abundance of associated faulting, both previously and newly observed. (Figure 8)

The most outstanding feature of this area is a major lineament running in a northeast-southwest direction, here named the "Firuzabad Lineament". The almost total absence of lateral movement at the surface, coupled with the presence of salt plugs along its length may suggest basement control. This is further corroborated by the fact that extensive earthquake activities have been recorded in this region (Firuzabad Earthquake).

In addition to the above investigations, using false colour imagery, single band analysis of this frame was also carried out. From this analysis, bands 4 and 5 clearly indicated that a great deal of fine grained sedimentary material is being carried into the Persian Gulf via the Mand River. This load is then being carried southeastwards by a coastal current which in conjunction with wave action, has resulted in the formation of several offshore bars near the coastline.



Frame No: 1168-06344 & 1168-06350

Lineament

Anticlinal Axis

Dip & Strike

Salt Plug

Unit boundary

Coastline

Figure 8 : Kangan area Test Site ,
Scale 1:1,000,000

RESULTS OF THE ZAGROS TEST SITE ANALYSIS

The main spheres of interpretation activity and subsequent conclusions concerning the analysis of the selected Test Sites in the Zagros Fold Belt, can be considered to fall in three distinct categories. Firstly, structural information especially the identification of previously unrecorded lineaments; secondly the observation and analysis of salt diapirism in the Fars region, and finally considerations regarding lithological identifications within the Test Sites, using ERTS-1 imagery. These catageries are seperately discussed below:

- Structural Considerations

The most conspicuous contribution of ERTS-1 imagery in the field of structural geology in this region (as indeed is the case for most other areas) is the identification of a great many hitherto unrecognized lineaments. The particular significance and overall importance of these newly recorded lineaments in this region cannot be overemphasised for two fundemental reasons. Firstly it must be borne in mind that the Zagros Fold Belt, due to its extremely valuable hydrocarbon deposits has been mapped in great detail, the quality of the maps produced competing with any in the world. Thus the observation of so many new lineaments cannot be attributed to poor mapping or lack of geological knowledge of this area, but to the inherent value of ERTS-1 imagery itself, without which many of these features would have remained undetected. Secondly and more important is the fact that whereas in other parts of Iran with less sediment cover of the basement, the observed lineaments mainly tend to coincide with known surface trends (although the number of lineaments observed tends to increase using ERTS-1 imagery), in the Zagros Fold Belt, due to its extensive and relatively undisturbed sedimentary cover in places purported to be over 30,000 feet thick the presence of these lineaments may indicate previously unrecognized fundemental deep-seated structural trends, in all probability relating to the basement itself. This re-evaluation of basement trends will no doubt promote a great many new ideas concerning the related sedimentary history of this fold belt, leading to major revisions of the present theories of its tectonic evolution.

Salt Dome Analysis

The southern portion of the Zagros Fold Belt is an ideal region for the study of salt diapirism and its associated phenomena. In the area over 50 salt plugs, of varying sizes are found to occur between two major structural trends, the "Oman-Lut High" to the east and the "Kazerun Fault Zone" to the west. The Zagros thrust zone limits the northern part of this region.

As can be seen on image 1148-06235, salt diapirs which are found to occur in various stages of development, are very conspicuous on the ERTS imagery. These include unexposed non-piercement salt plugs, that have caused doming of the overlying carbonate beds (Inset A), exposed piercement diapirs in different stages of weathering showing characteristic halos (insets B and C), and finally plugs that seem to have been totally weathered out and subsequently covered by alluvial deposits (Inset D).(Figure 6)

It should be here mentioned that not all previously recorded salt plugs are visible on the ERTS-1 imagery. The reasons for this are not yet quite apparent, but at a glance, it would seem that the plugs that are more difficult to discern fall in the more recently exposed, smaller sized, category. To find out in more detail the reason for the difficulties in discerning some of these salt plugs on the imagery, field checking programs have been planned.

Another major feature of the ERTS-1 imagery when studying salt diapirism in the Fars Region is the clear identification of major lineaments along which these salt plugs seem to occur. There is no doubt that ERTS imagery offers by far the best mode of analysing the relationship between salt diapirism and these deep seated fractures that either facilitated the rise of the salt or indeed acted as conduits for the diapirs. Considering the fact that the horizon from which these salt diapirs originated (Hormuz Salt Series) is of early Cambrian or late Precambrian age, the detection of these particular lineaments, which are very probably connected in some manner with basement trends, or indeed reflect actual major breaks in the basement, will greatly aid our understanding of the mode of formation of the Zagros Fold Belt.

- <u>Lithologic Considerations</u>

In the general evaluation of the Zagros lest Sites, a certain amount of preliminary effort was channeld into studies concerning possible geological mapping of this region.

The sedimentary pile of the Z.gros Fold Belt being dominantly caronate in nature makes the task of differentiating lithologies much more difficult, especially when taking into account the abundant facies changes that occur across the region within these carbonates. However these difficulties are more or less offset by the advantage of dealing with a sedimentary sequence of interbedded competent and incompetent lithologies (i.e. limestone/marl sequences). This variation in lithology has produced the preferentially weathered geomorphology of the present Zagros landscape, i.e. the major positive features tend to be limestone while the weathered out areas indicate marly sequences.

This variation in weathering style, in conjunction with different erosional patterns within the limestone sequences themselves, seems to be the best parameter to be used in the mapping of the region. It is also noted that certain lithologies seem to have particular characteristic tonal signatures, but again as in the case of weathering style, the mapping of these units tends to take on a more or less subjective character which is not particularly desirable.

In conclusion, it would seem that at present geological mapping per se is not a feasable proposition in this region. However it should be pointed out that exsisting maps can be quite safely checked against ERTS-1 imagery of this region for the purpose of correcting mislocated lithologies or adding omitted rock units.

PART II

PART II

As has been partly discussed in Part 1, it is concluded that in Iran, where the nature of rock deformation at the surface is so well exposed the geological data immediately obtainable from ERTS-1 imagery is most likely to be of a structural character and therefore readily applicable to tectonic interpretations. It is for this reason that the Geological Applications part of this report is primarily involved with tectonic interpretation rather than attemps at geological mapping. This does not however mean that geological mapping, especially at reconnaissance level, is not a viable proposition using ERTS imagery, but just to indicate that taking into account the present state of the art, lithological identifications, except for the most generalized rock type categories, still tend to be primarily of a subjective nature, requiring considerably more judgement, experience and field work.

The tectonic interpretations that have been undertaken are here presented as in two seperate projects. The first is a large scale lineament study, dividing Eastern Iran, into recognizable tectonic provinces, entitled "Tectonic Analysis of East and Southeast Iran Using ERTS-1 Imagery", while the second is involved in a trial intermediate level tectonic mapping of the Tabas Quadrangle.

TECTONIC ANALYSIS OF EAST AND SOUTHEAST IRAN

General:

The cloud free nature and the excellent ground exposure of Iran, coupled with the synoptic view offered by satellite photography has given us a unique opportunity to note the presence of several major, as well as many minor, hitherto unrecognized linear transgressive features, here termed "lineaments". For the most part, these lineaments are considered to be the surface expressions of faults and thrusts.

It is noteworthy that many years of field-work, as well as extensive areal photographic analysis, had failed to reveal many of these major tectonic features. In fact the ratio of the number of lineaments recognized using ERTS-1 imagery to the number of those already recorded, well exceeds 10:1. As an explanation, it must be realized that the large scale synthesis, or integration of geological data, such as field mapping, however painstaking and exact, does not necessarily mean that a large feature within that area will become apparent from a smaller scale map generated. Hence the absence of many of these features on present day geological maps. In the case of areal photography, this deficiency is evidently due to inconsistent conditions, such as variable sun angle and seasonal changes of the nature of the ground, i.e. vegetation and snow cover.

ERTS-1 data, on the other hand, have inherently none of the above disadvantages and are therefore an excellent tool for the identification of these major lineaments, the recognition of which is essential for unravelling the very complicated tectonic history of Eastern Iran.

AREA OF STUDY

An area of over 500,000 square kilometers, covering East and South East Iran, bounded by longitudes E54^0 and E62^0 and latitudes N25^0 and N30^0, has been chosen as the "springboard" study area (Fig. - 9). The main reasons for the choice of this particular area are outlined below:-

(I) The general ambiguous nature of present-day knowledge of tectonism in this region.

(II) The desert climate, coupled with enormous communication problems, has resulted in almost impossible field work conditions, making areal reconnaisance, and especially ERTS-1 imagery, ideal for this region.

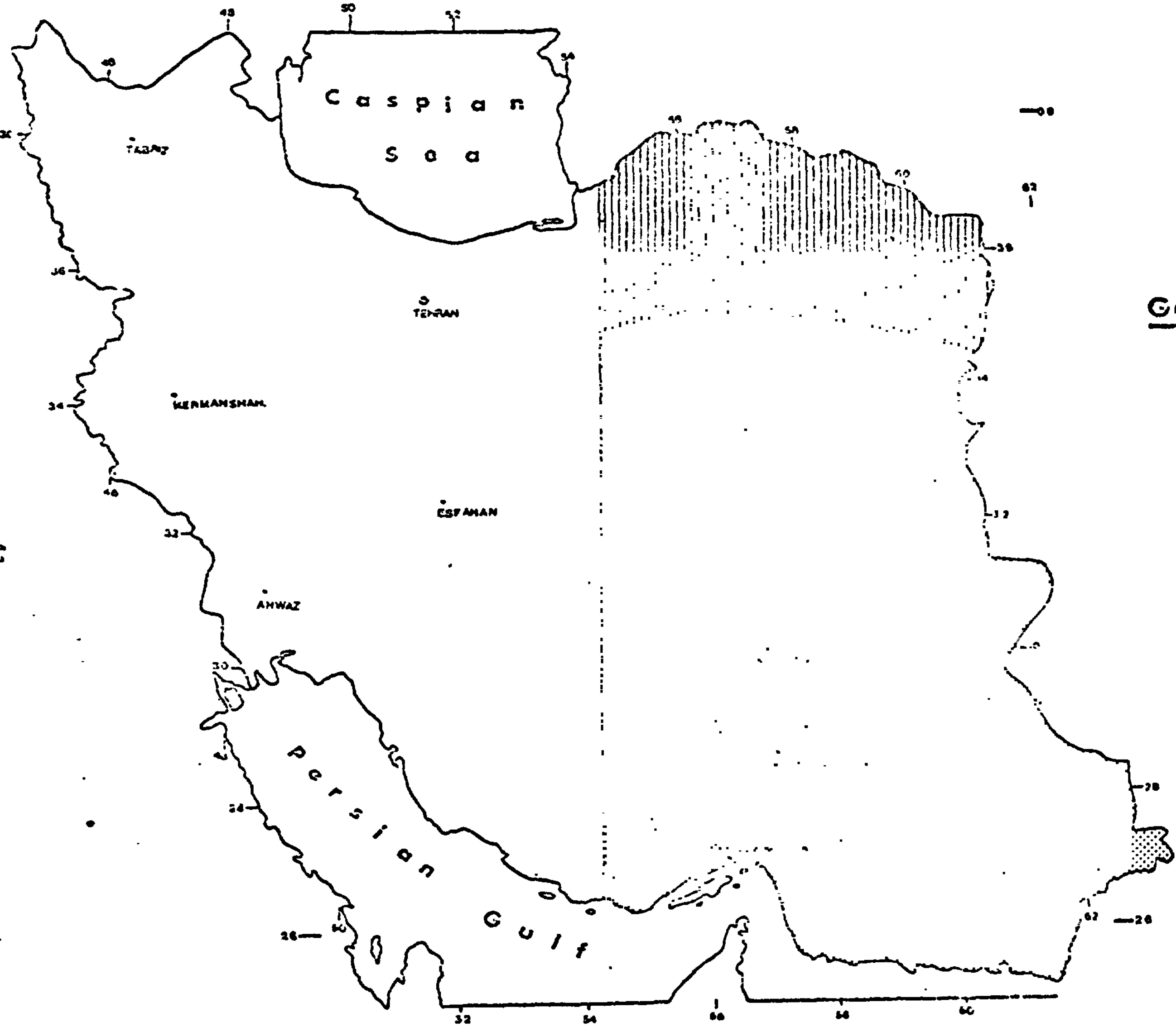
(III) The scale of lineaments in this area is such that the satellite synoptic view is the only means possible for their detection.

(IV) This is a very important area when considering the overall tectonic evolution of the Arabia-Iran-Pakistan province.

(V) The presence of mineralization associated with intrusive and extrusive materials in this area, offers the possibility of a direct economic "pay-off" by means of detecting relationships between these lineaments and previously undetected "mineralization trends".

General Boundaries of Study Area

Approximate Scale 1:12,000,000



Area covered in report

Area under investigation

Figure 9

METHODS AND PROCEDURE

The bulk of the work presented here is based on the analysis of ERTS-1, MSS, band 7 black and white, as well as, false colour composite photomosaics.

In addition, single frame analysis has been carried out for the more complex and interesting areas.

The main stages of analysis have been:-

(I) Primary correlation with available "ground-truth" data in the form of geological maps, and their correction when necessary.

(II) Recognition and recording of tectonic linear features-"lineaments".

OBJECTIVES

The objectives of the present project may be divided into two seperate parts. First, the short-term objective, which was to prepare a detailed "lineament" map of Eastern Iran, using 1:1,000,000, MSS, band-7, ERTS-1 imagery. This has been successfully completed, and here presented in two forms, a 1:1,000,000 detailed Structural "Lineament" Map (enclosure A), and a reduced form of that map, showing only the major and intermediate lineaments (Fig. 10). Using the above mentioned maps, several structural provinces have been recognized in this region. Similar projects will be undertaken for other parts of Iran, with the final view of producing a 1:1,000,000 "lineament" map for the whole country.

Second, and more important, is the long term objective, which is to produce a 1:1,000,000 Tectonic Map of Iran. To attain this aim, the above mentioned "lineament" maps will provide the framework on which future data, obtained from detailed interpretation of 1:500,000 colour images, and relevant "ground truth" studies will be based.

GENERAL ASSESSMENT OF LINEAMENTS

(I) Recognition and characteristics

Perhaps the most spectacular and unexpected feature of ERTS-1 imagery of Eastern Iran, is the number and distribution of hitherto unrecognized linear features. These transgressive features are either of a near straight-line character or slightly curved, and exhibit themselves on the ERTS-1 images as characteristic narrow bands, contrasting in "Grey Scale" with surrounding areas or displacing areas of like pattern. Sudden reversals in dip and changes in strike direction, as well as morphological features such as gaps in ridges, gully developments and abrupt changes in valley alignments, are also indicative of the presence of lineament.

The length of these features varies from tens to hundreds of kilometers (occasionally exceeding a thousand), and have been here classified as follows:-

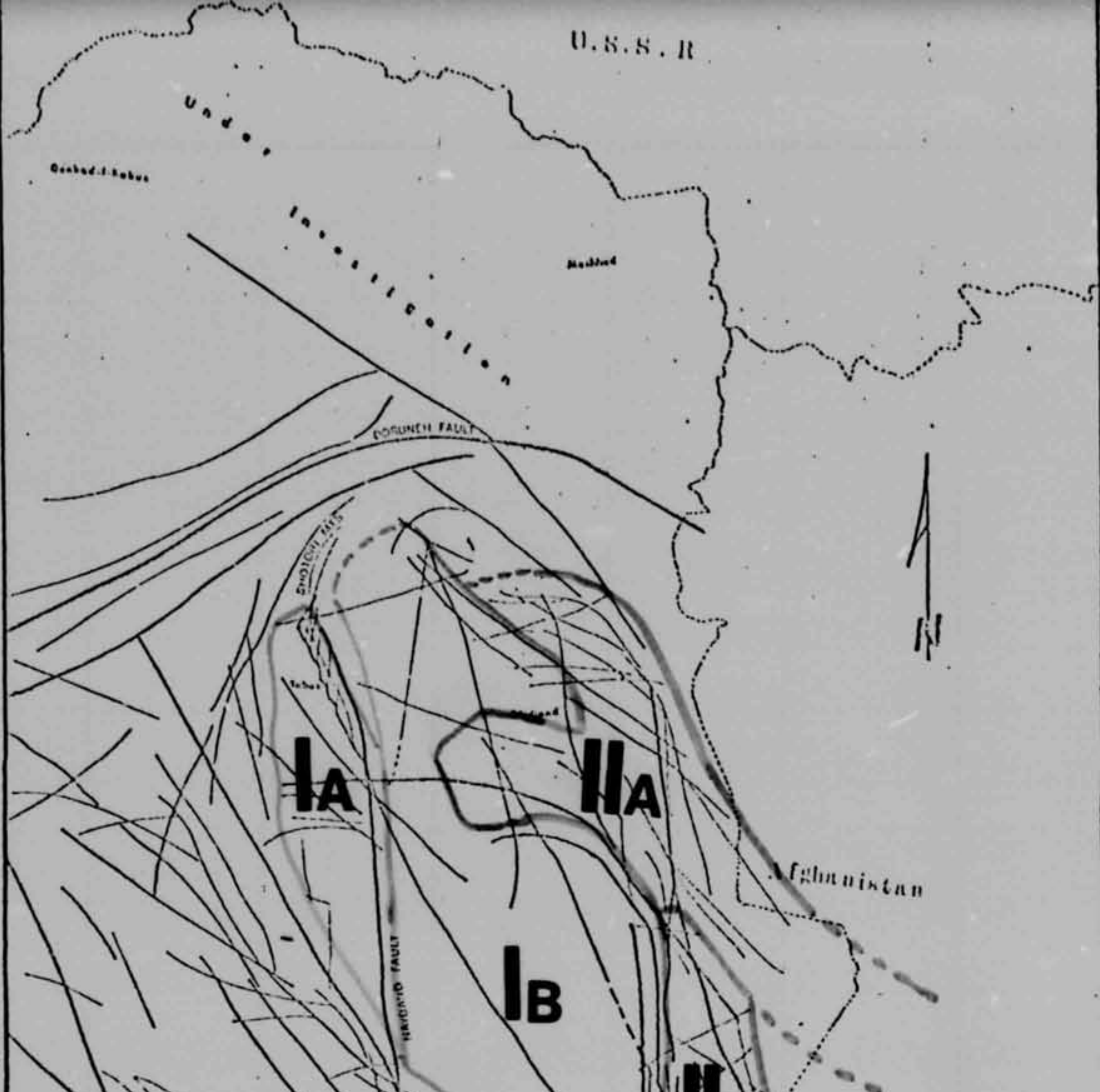
Minor lineaments	:10-100 kms
Intermediate lineaments	:100-350 kms
Major lineaments	:250 kms and above

The Dorouneh fault (800 kms) to the north and the Nayband fault (500 kms) to the west of the area of study, are two classical examples of major lineaments with important geological consequences (Fig. 10). Altogether, about 20 major lineaments have been recognized in Eastern Iran.

(II) Structural consideration

With the exception of lineaments coincident with known faults, when they can be taken as surface manifestation of near vertical movements, the physical nature of these features in three dimensions is not known, although there can be little doubt, that they have a subsurface control similar to that of fracture traces. It is also most probable that a zone of deformation such as movements between major blocks or units, underlays the larger lineaments. Gold (Gold et. al. 1972) has suggested considering these major lineaments as "crustal joints", a term we believe to be very applicable for some of the features in this part of Iran.

In conclusion, it seems that these major lineaments are not controlled by local structure, but rather, by regional structural trends, both recent and ancient.



PLAN & BUDGET ORGANIZATION

Structural "Lineament" Map of Eastern Iran

Based on ERTS-1 Imagery, MSS, band-7 Interpretation

Figure-10

TECTONIC PROVINCES OF EASTERN IRAN BASED ON STRUCTURAL STYLE

One of the main purposes of this project has been to outline and asses the significance of the main simila:ities and differences in "tectonic style" of the major tectonic provinces of Eastern Iran.

Each of these provinces is a discrete area set apart from all others by salient characteristics of orogenic deformation which has stamped it with a distinct inprint. The "tectonic style" of each region is the aggregate expression of a whole array of distinctive but interelated "tectonic parameters", each of which provides an indication of some aspect of its tectonic evolution. The most important parameters used in this study include:

(1) Lineaments: their scale, distribution and direction

(2) Shape and physical dimensions of each province

(3) Crustal stability

(4) Nature and intensity of folding

(5) Relationship of one unit with adjoining units.

(6) Patterns of sedimentary deposition

(7) Presence of "Coloured Melange". This is a term used particularly in Iran, to define a structurally chaotic mixture of flysch and volcanic rocks with diabasic and ultrabasic components.

(8) Volcanicity

(9) Metamorphism, its character, distribution and timing.

Based on the above parameters, and a great deal of additional information from previously published data, (especially J. Stocklin 1968, and the N.I.O.C compilation Map), several tectonic provinces (overlay of Fig. 10) have been recognized and are described below:-

1. LUT BLOCK

General

The most conspicuous tectonic feature of Eastern Iran, as seen on the ERTS-1, MSS, band 7, photomosaic, is an elongated, north-south trending, irregular shaped, lineament bounded unit, about 900 Kilometers long and 200-300 Kilometers wide, covering an area of approximately 200,000 square Kilometers, termed the Lut Block.

Tertiary volcanic rocks cover most of the northern part of this province while to the south the block dips below one of the major morphological features of Eastern Iran, known as the Lut Depression, which is presently covered by unfolded continental deposits and recent sand accumulations, the whole often referred to as the Lut Desert (Fig. 11). Further south the Lut Depression is seperated from that of the Djaz-Murian by the Bazman Massif, which is composed of Tertiary and Quaternary volcanic rocks and granites (Fig.12).

Structure

The term "Block" has been applied to this region simply to define it as an aeea of relatively low intensity of deformation of post-Jurassic rock, while its inferred pre-jurassic rigidity is assumed to be a consequence of consolidation and

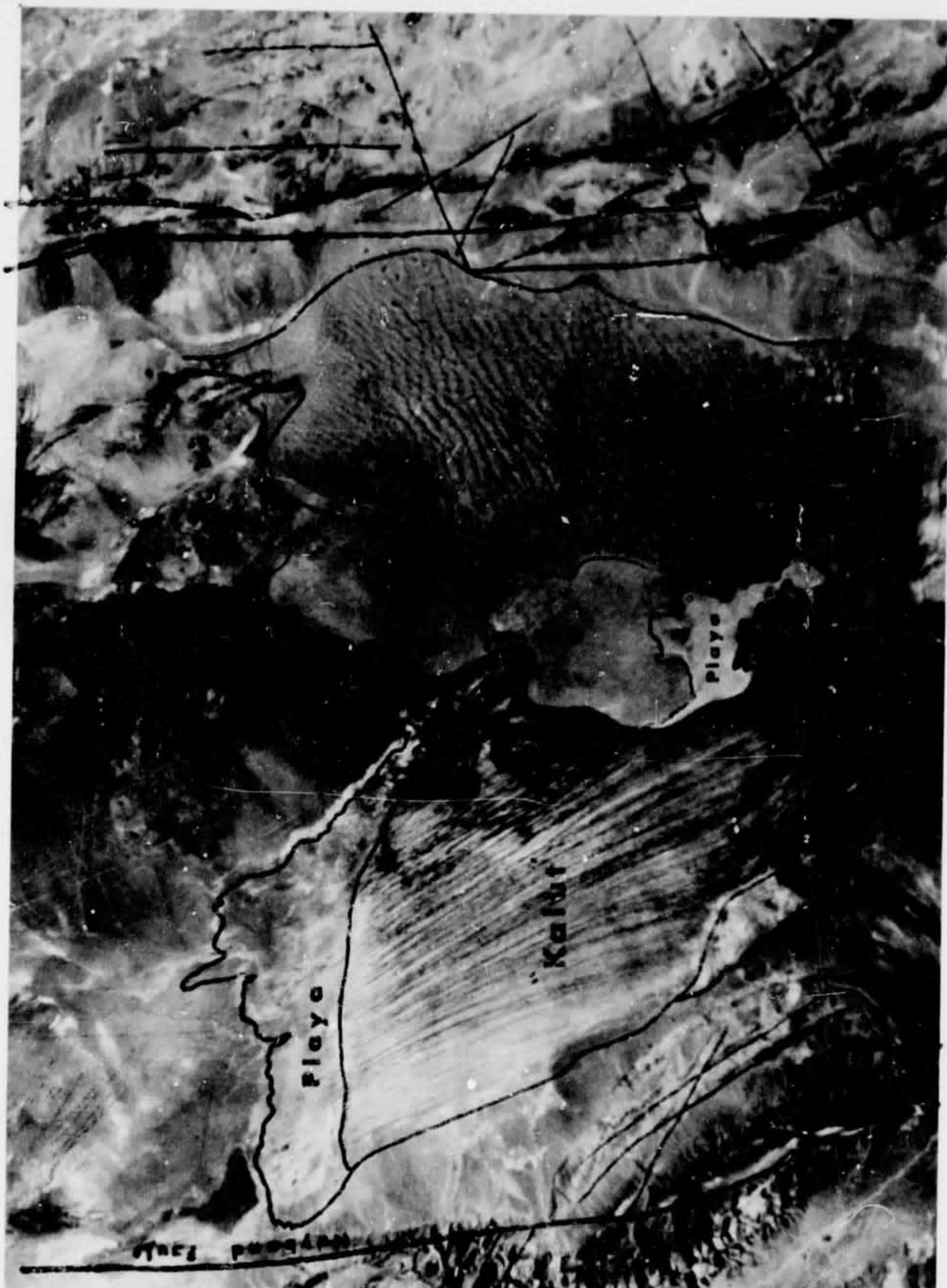


Figure 11 Central Lut Depression, showing the "Kalut" wind channels and the "Lut" sand dunes.
Approx. scale 1:1,250,000

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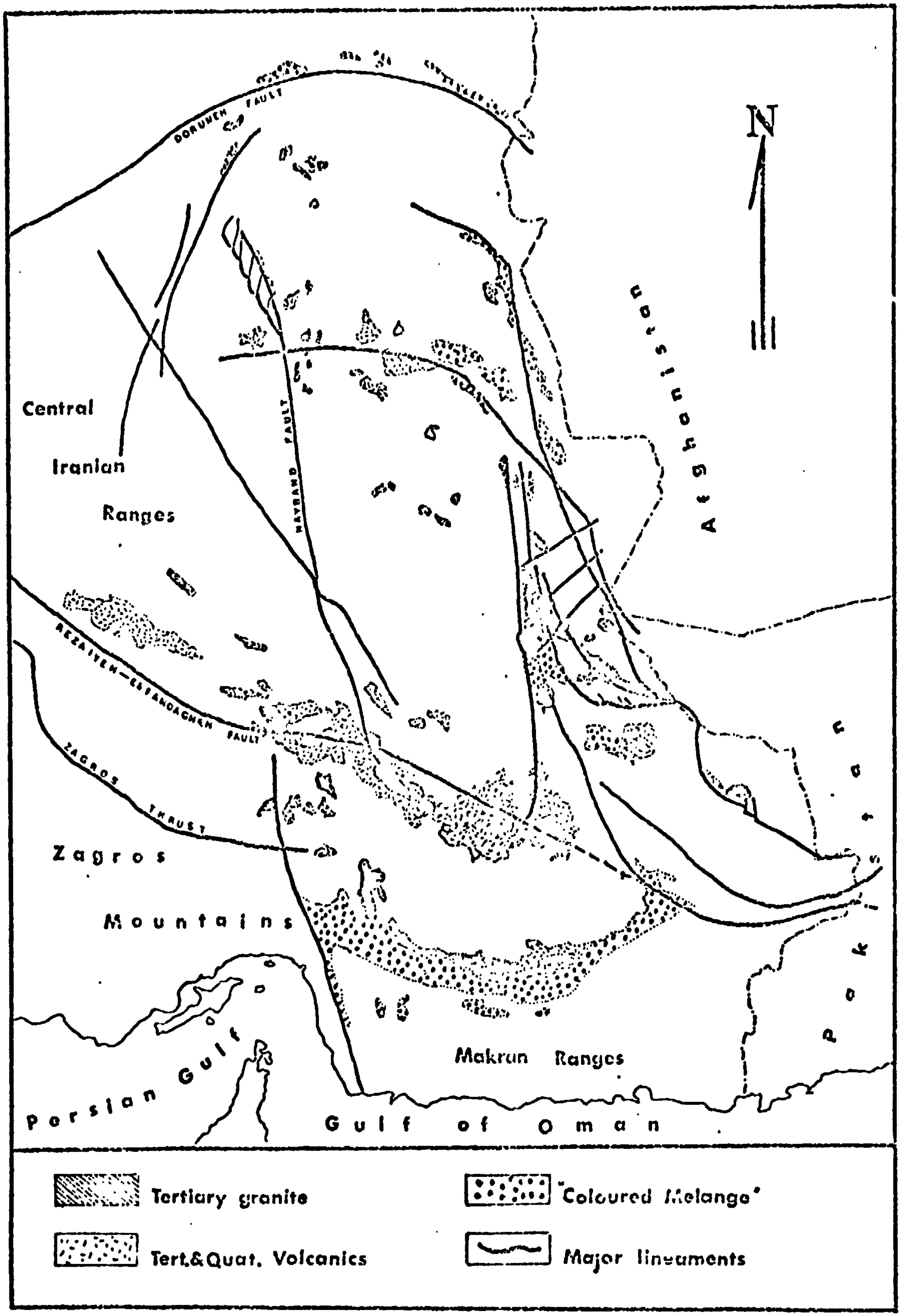


Figure 12: Diagram showing major lineaments of Eastern Iran and their relationship with, igneous, volcanic, and "Coloured Melange" sequences.

metamorphism, by a strong folding phase in late Triassic times (Reyre and Mohafez, 1970).

The post Jurassic rocks exhibit a relatively simple tectonism which includes both block faulting and gentle folding, neither showing any preferred orientation, with the exception of the South Tabas area, where an east-west direction is noted on some lineaments.

The "Lineament Map" of Eastern Iran (Fig. 10) clearly illustrates this decrease in intensity of tectonism by a corresponding decrease, or in some instances, total absence, of lineaments, such as faults, thrusts, and fold trends. Of those lineaments that are recognized the majority are small in scale, with random directions. Two major, sub-parallel, poorly defined, northwest - southeast features, and a north-south running lineament in the southeast, are the exceptions to the above, and are believed to be following important Precambrian trends.

Boundaries

The southern boundary of the Lut Block with the Makran Ranges, and its eastern contact with the East Iranian Ranges, are very sharp and can easily be distinguished (Fig. 13). Both these boundaries are associated with the presence of a chaotic sequence of flysch deposits, often mixed with blocks

Figure 13 The southern boundaries of the Lut Block.
Approx. scale 1:2,500,000

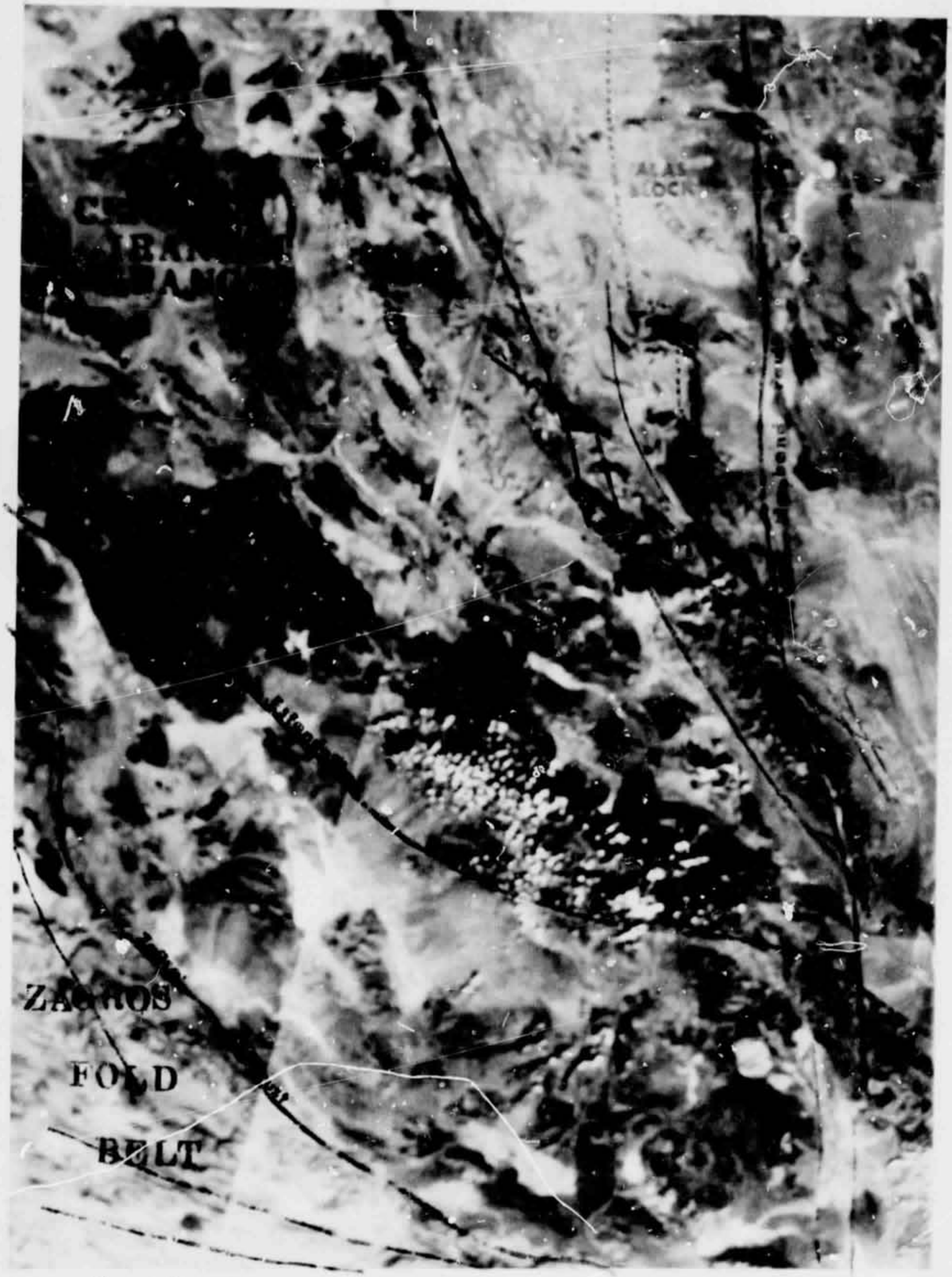


Figure 14 South-Central Iran , showing the western boundary of the Lut Block.
Approx. scale 1:2,600,000

of serpentinized ultrabasic materials. The whole rock jumble is usually referred to as the "Coloured Melange" series. To the west the boundary is a major continuous north-south running lineament, the Nayband Fault. Further south, the western margin is less clear but in general follows a north-south trending lineament system (Fig. 14).

In the northwestern portion of this province, a near north-south trending sequence of tightly folded rocks with associated intense faulting and thrusting known as the Shotori Ranges, are recognized, (Fig. 15). With the previously mentioned definition of a "Block" as a unit of relative stability, this folded region is clearly anomolous. It has become therefore necessary to split the block into two portions, the Lut Block proper on the east, and the smaller Tabas Block on the west (Fig. 16). It is believed that late Triassic movements acting on a north-south Precambrian "Oman-Lut" trend, created a horst feature which was subsequently tightly folded into this north-south trending mountain belt (J. Stocklin 1968).

In the south, the Bazman volcanic massif seperates the Djaz-Murian and Lut Depressions (Fig. 17) and appears as the most southerly termination of a distinct northwest trending volcanic belt running from northwest Iran to the southeast corner (Fig. 12). With this in mind, it is suggested that the Rezayieh-Esfandagheh fault, which approximately follows this volcanic belt, also continues across the Lut Block and joins the major east-west trending lineaments of the flysch deposits of South East Iran.

Figure 15 The Shotori Ranges of northern Lut Block. Approx. scale 1:650,000

Figure 16 The separation of the Lut and Tabas Blocks by the Shotori Ranges.
Approx. scale 1:1,115,000

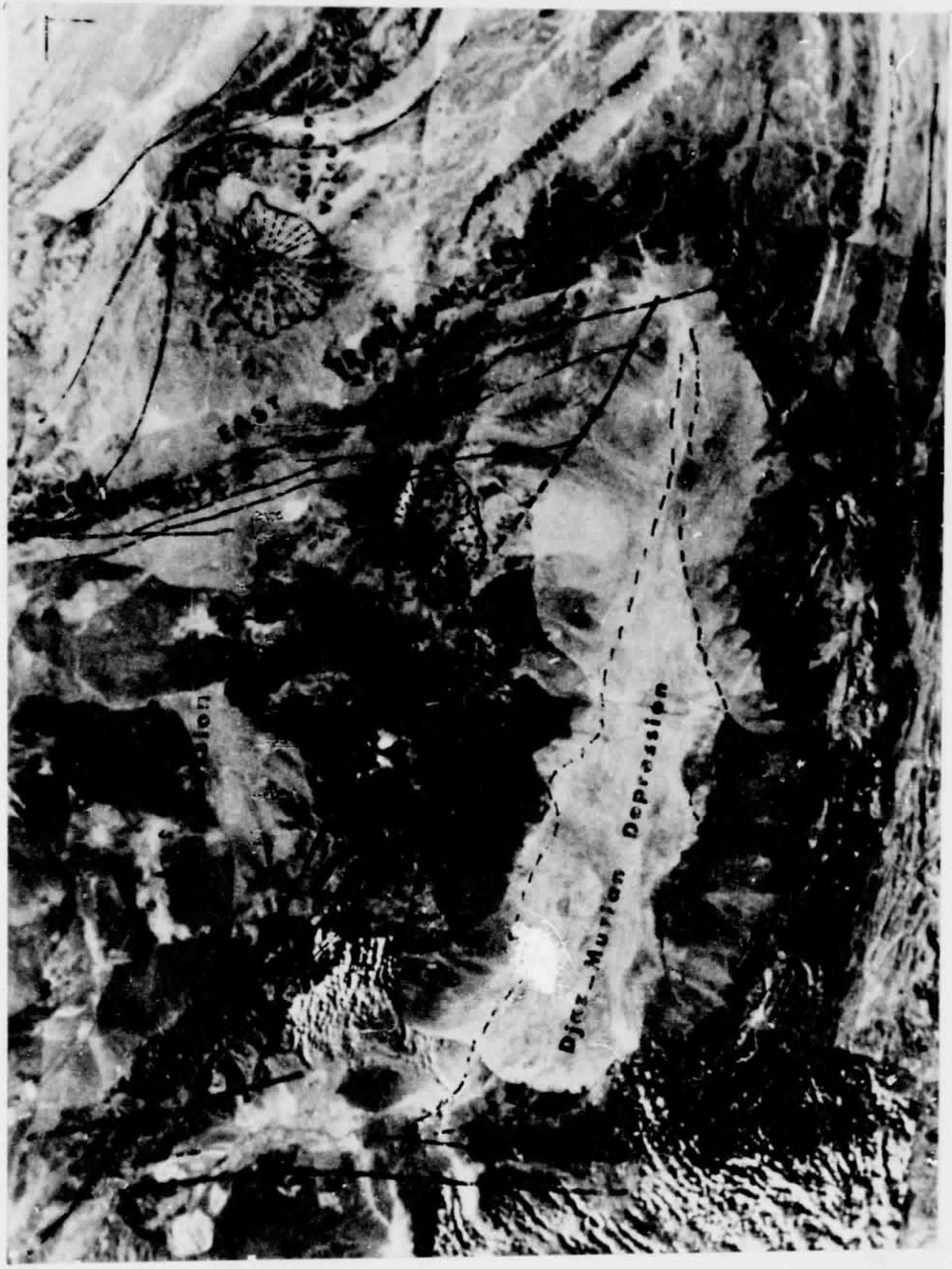


Figure 17 Bazman Volcanic Massif separating the Lut Djaz Murian Depressions.
Approx. scale 1:2,200,000

This would then require that the Djaz-Murian part of the Lut Block be seperated as another subunit (cf. Tabas Block), on the basis of the presence of this major fracture. However insufficient evidence as regards to the genesis and general tectonic history of this feature, coupled with the fact that the volcanic rocks of this belt are of different ages, makes this suggestion of a tentative nature only.

II. MAKRAN RANGES

The Makran Ranges in the south east of Iran, exhibit themselves as a series of generally east-west trending, gently folded anticlines of Upper Cretaceous flysch and Tertiary deposits, (Fig. 18) which gradually grade into the chaotic sequences of the "Coloured Melange" towards the junction of this province with the Lut Block (Fig. 19 and Fig. 12).

It should be noted that "the difference between the Createceous flysch and the Melange is not one of stratigraphic position but of intensity of deformation" (stocklin et. al. 1972). That is to say, there is a gradual transition from normal gently folded flysch to the structurally chaotic Melange, whose recognition also depends on the amount of ultrabasic material that is intermixed with the flysch. There exsists therefore, a relationship between the amount of ultrabasic rocks and the degree of tectonism, which reaches its peak at the junction of the Lut Block with the Makran Ranges. It is with this background, that the presence of "Coloured Melange" was chosen as one of the main parameters on which the basic division of tectonic provinces in this area was based.

The abundant lineaments recognized in this province are generally of an intermediate nature (100-350Kms), with northwest-southeast and eastwest directions, the former gradually merging in to the latter trend while approaching the Pakistan border (Fig. 10).

In terms of structural style the Makran Ranges superficially seem to be a continuation of the Zagros Fold Belt, but this similarity is considered to be coincidental, and the "Oman-Lut High" which seperates the flysch facies of the Makran from the thick marine sequences of the Zagros is thought to have played a vital role in the seperation of these two provinces.

Figure 18 The Makran Ranges.
Scale 1:1,000,000

Figure 19 Makran Ranges - Lut Block boundary

Approx. scale 1:1,660,000

III. EAST IRANIAN RANGES

The East Iranian Ranges, form an elongated reversed S-shaped mountain belt between the Lut Block to the west and the Iran-Afghanistan/Pakistan borders to the east. This province has a north-south extension of approximately 800 kilometers and a maximum width of above 200 kilometers in the extreme southeast. It is, on the whole, composed of tightly folded, occasionally metamorphosed clastic and calcareous flysch type sediments associated with diabasic and tuffaceous rocks (N.I.O.C Compilation Map). The whole sequence often grades into typical "Coloured Melange".

The limits of this province to the east and west with the Himland and Lut depressions respectively, are very abrupt and quite clear on the ERTS-1 images of this area (Fig. 20). They manifest themselves as two sets of north-south trending lineaments that branch off and gently swing in a northwest-southeast direction in the Zahedan area (Fig. 21), and finally merge into the eastwest trending Makran Province, to form the Baluchestan Flysch Belt.

To the north, the boundaries of this province with the Lut Block are less clear on the MSS, band 7, photomosaics, and are hence more difficult to define. While some of the lineaments continue their northward trend, others begin to swing around the Shahkuh granitic mass, becoming northwesterly orientated, and finally

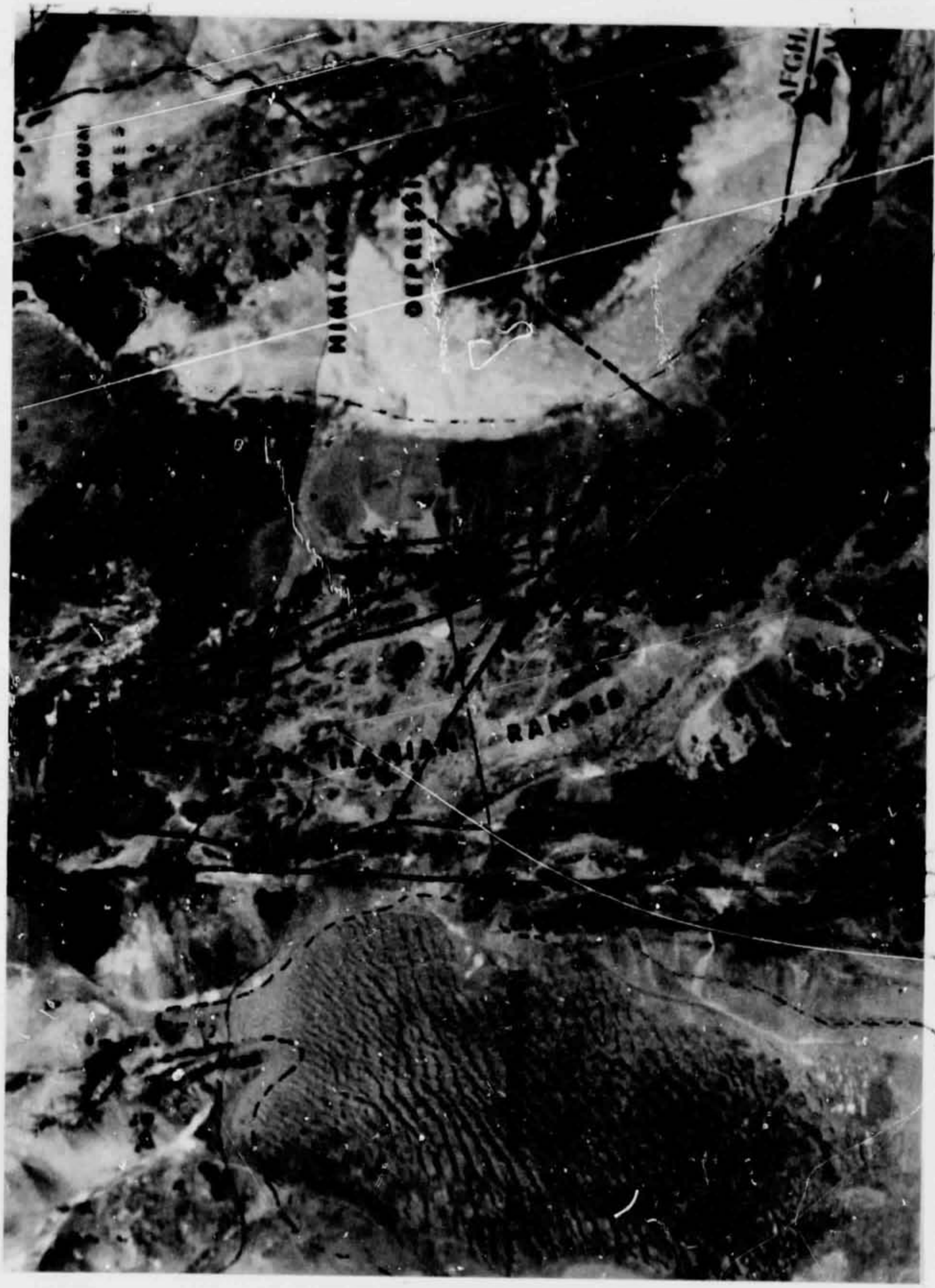


Figure 20 East Iranian Ranges.
Approx. scale 1:1,110,000

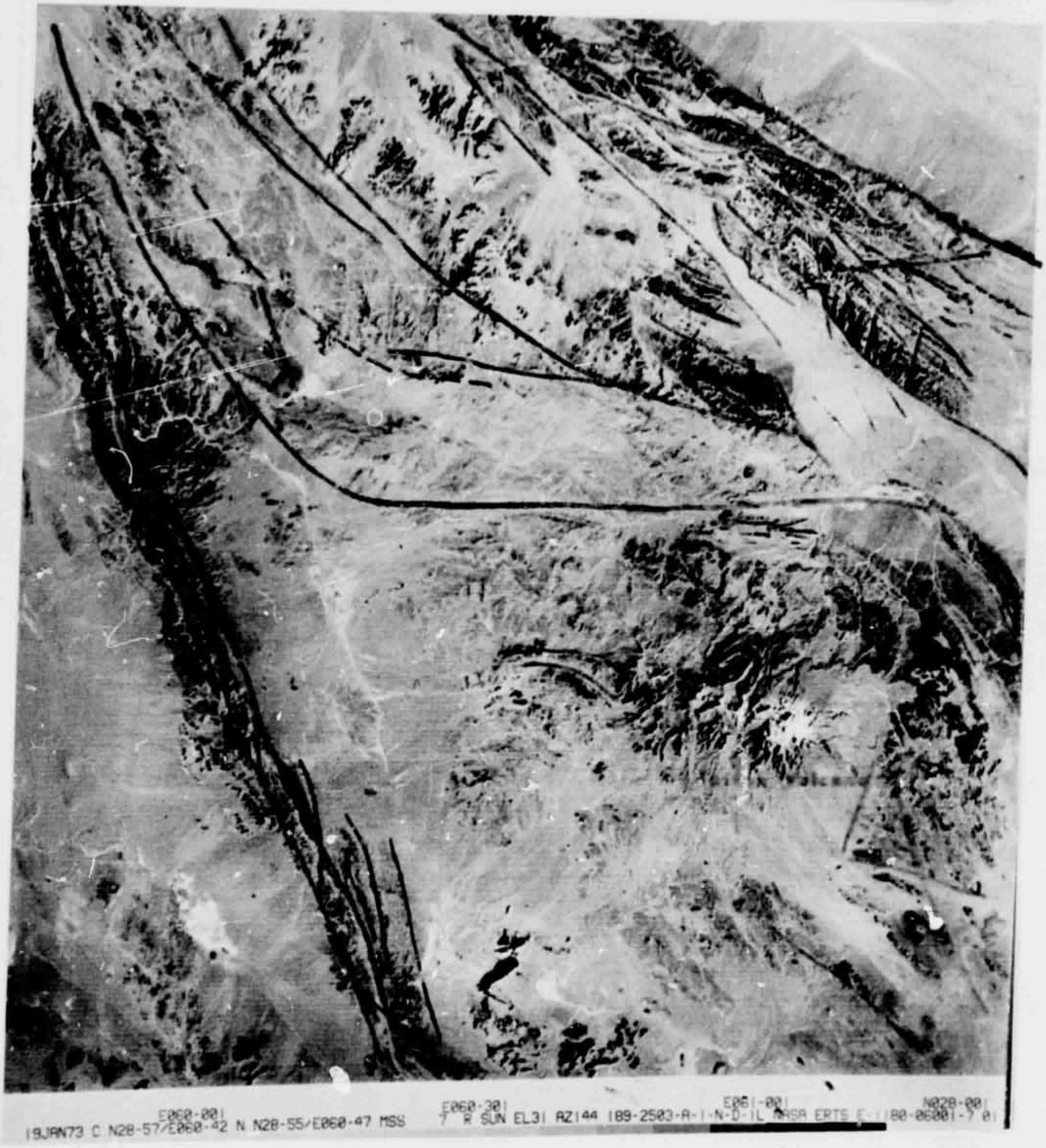


Figure 21 The boundary of the Middle and Lower East Iranian Ranges. Note the Taftan Volcano.
Scale 1:1,000,000

crossing into the Lut Block region with an east-west trend (Fig.10).

In this report, the East Iranian Ranges have been split up into three parts; Upper (III_a) Middle (III_b), and Lower (III_c); (see Fig. 10 , and overlay). The seperation of the Lower from the Middle Ranges has been based on the presence of an anomolous zone of granitic intrusions, (Zahedan Granite), with associated low grade contact metamorphism and "Coloured Melange" developments (Fig. 12). The lineaments of this region also show a clear deviation from their north-south trend to one that is generally northwest-southeast (Fig. 21).

The line dividing the Middle portion of this province from the Upper Ranges, is obscure and is basically chosen on geometric shape such as a change in the tectonic "grain" of the province from north-south in the Middle Ranges to the arcing northwest-southeast lineaments of the Birdjand area (Fig. 22).

It is interesting to note that, excluding the Rezaiyeh-Esfandagheh fault, only in the northwest of our study area do we find major or intermediate lineaments crossing into the stable Lut Block. It may be suggested that in general the northwestern part of the block is relatively less stable that the rest of the province, and has therefore allowed itself to be somehow involved in Tertiary tectonics of the Alpine Stage (albeit in a very minor way), the remainder of the block having stayed relatively undisturbed and "passive".

On the other hand, the "Coloured Melange" sequences of the upper East Iranian Ranges are reputed to be slightly older than those found in South East Iran, and can therefore be tentatively

Figure 22 The Upper East Iranian Ranges .
Scale 1:1,000,000

Figure 23 : Nimbus III , daytime image of Iran, orbit 858, taken on 17 June 1969

considered to be similar to those of Central Afghanistan (Personal communication; M. Takin). Consequently it becomes a possibility that the Upper East Iranian Ranges are in reality the northern part of another smaller reversed S-shaped feature (cf. East Iranian Ranges), the lower part of which dips below the recent deposits of the Himland Depression in a northwest-southeast direction, emerging again with a northeast-southwest orientation on the other side of the Depression, in the form of the Central Afghanistan Ophiolite Belt. The immediate consequence of the above is that the Upper East Iranian Range predate the formation of the Middle and Lower East Iranian Ranges, and might even be better classified outside this particular province.

It will be also noted that some of the lineaments in the lower part of the Upper East Iranian Ranges tend to continue in a northwest-southeast direction into Afghanistan, rather than joining the north-south trending lineaments of the Middle and Lower East Iranian Ranges.

A Nimbus III daytime imagery of Iran, clearly displays this smaller reversed S-shaped feature within the larger entrolithic megalineament, that runs through the Iran-Afghanistan-Pakistan Region (Fig. 23).

In conclusion, it would seem, that the Makran and the East Iranian Ranges (especially Middle and Lower portions) are much more closely related to the Baluchestan Ranges of Pakistan, and would therefore be better considered as part of a larger province, engulfing both southeast Iran and Western Pakistan.

PRELIMINARY TECTONIC MAP OF THE TABAS QUADRANGLE, EAST-CENTRAL IRAN

Background :

This section of the report deals with a test of ERTS imagery fo tectonic mapping of the Tabas Quadrangle in east-central Iran. This quadrangle was chosen as a test site because it has good geologic maps bordering it on two sides (see Figure 24): the geologic map of the Shirgesht Area (Ruttner, et al, 1968) to the northeast and the geologic maps of the Shotori Range (Stocklin, et al, 1965) and the Boshruyeh Quadrangle (Eftekar-nezhad, et al 1971) to the east. The Tabas Quadrangle is also, in part, included in a 1:5,000,000 scale tectonic map included in Stocklin (1968). In addition, we had access to excellent 1:500.000 scale false color ERTS images of this area.

In the ERTS imagery, the most readily available information is structural information. Thus, in this present experiment we will limit our objective to the production of a tectonic map (which emphasizes structural features) for the guidance of exploration for mineral resources and not attempt a geologic map which would require detailed lithologic information. This initial attempt involved interpretation at a scale of 1:500,000 for a map to be reproduced at 1:1,000,000 scale.

The scale limitation is such that we perhaps cannot expect to recognize directly intrusions the size of a typical porphyry copper deposit , but we might expect to see the structural intersections that may control their location. The petroleum exploration geologist should be able to use the map to guide his thinking as to the structural grain of the region. He will be able to directly recognize some of the larger anticlinal features. The map will also be useful for ground water exploration.

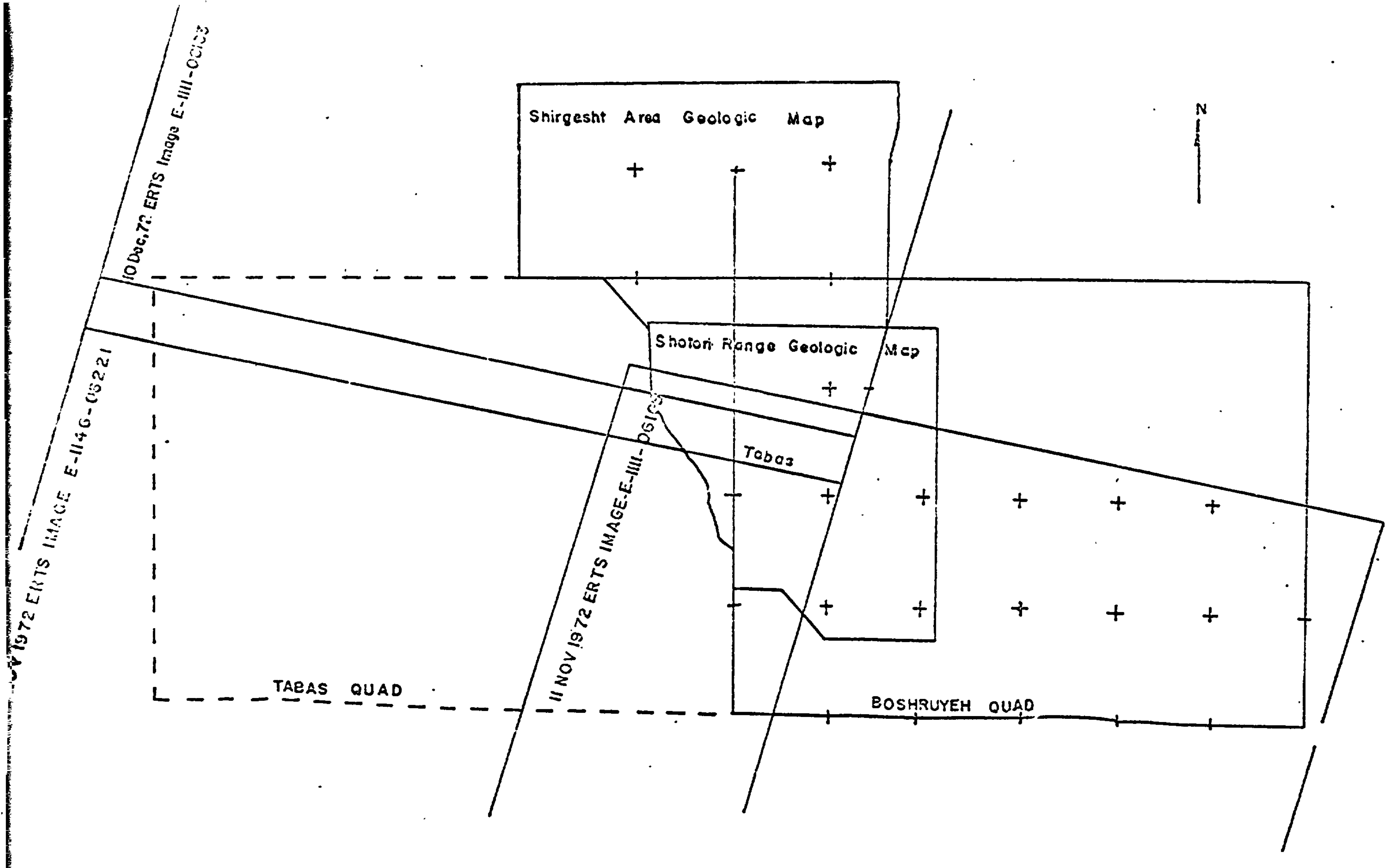


Figure 24 : Geologic mapping in Tabas Region , East-Central Iran . The limits of existing geologic maps adjacent to the Tabas quadrangle are outlined

To our knowledge, this is the first time ERTS imagery has been used on an operational basis for producing a tectonic map of an area. The results of this effort are so encouraging that we hope to map all of Iran eventually using the techniques we developed during this experiment.

Interpretation of the Tabas Quadrangle

The critical factor for tectonic interpretation is the boundaries between tectonic units must be based upon practical objective criteria that are observable in the imagery. Moreover, appearance of these boundaries may vary with the crustal level that is exposed and the thickness and character of any post-orogenic supracrustal cover.

Based on examination of the ERTS imagery (Frames 1148-06215 and 06221), and review of available literature, the Tabas Quadrangle consists of five major morphological units. This interpretation was performed on 1:500,000 scale color composites (band 4,5, and 7) of the ERTS imagery and photographically reduced to a scale of 1:1,000,000 (Figure 25). These units are:

1. The Shotori range in the northeast which was well mapped at a scale of 1:100,000 by Stocklin, et al, (1965). This range consists of a folded and strongly faulted block of Permian and Mesozoic sedimentary rocks bordered by a Paleogene volcanic sequence on the east. The range is a horst bounded on the east and west by grabens.
2. The sediments derived from the Shotori and Pirhajat ranges. These are also, in part, mapped by Stocklin, et al, (1965) and by Ruttner, et al, (1968). This is a graben in which the exposures are mainly gently folded Neogene continental red beds.

LEGEND FOR PRELIMINARY TECTONIC MAP OF THE TABAS QUADRANGEL

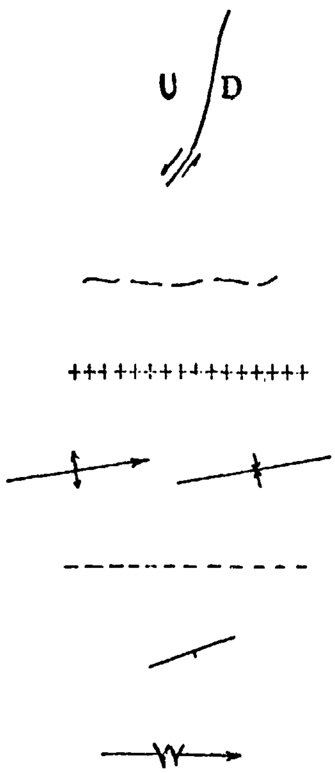
Symbol	Tectonic Unit	Description
S	Undeformed quaternary surficial deposits	
S_a		Alluvium
S_f		Alluvial fans
S_p		Pediment surface
S_e		Eolian deposits
S_s		Playa deposits (salt and clastics)
N	Gently folded and block faulted Neogene continental deposits	This is a gently deformed continental red bed sequence that represents the continuing upper Alpine deformation. Fold axis orientations are varied and related to adjacent block faulting.

Symbol	Tectonic Unit	Description
L	Long linear folds of well bedded Eocene marine sediments	The angular discordance between this unit and the next one is small and these sediments have participated in the same cycle of long linear folds with NS axes. This represents the culmination of the Middle Alpine stage deformation in this area.
M_u	Long linear folds of well bedded Cretaceous marine sediments	The folding is concordant with the above unit but the angular discordance in bedding suggests tilting and erosion (perhaps emergence) during Paleocene. Fold axes are NS.
M_m	Strongly faulted, well bedded Upper Jurassic evaporites and marine sediments	The abrupt difference in structural style indicates that the early Alpine stage in this part of Iran was responsible for intense brittle deformation (faulting) and jointing rather than the simple compressional folding of the later Alpine stages. However, long NS strike ridges are probably the result of the later Alpine stages of deformation. Fold axes are poorly defined, probably because of the development of axial faulting.

Symbol	Tectonic Unit	Description
M_L	Upper Triassic continental deposits which form the discordant cores of anticlinal features in the M_m sediments	The intensity of brittle deformation of initially poorly bedded continental sediments makes interpretation difficult in the small areas available for interpretation, but the outcrop location suggests that the Pirhajat Range is essentially anticlinal and that intense deformation occurred between the Upper Triassic and the Upper Jurassic. The anticlinal aspect of the range is a late Alpine stage feature.
P(?)	Older more highly metamorphosed rocks	These rocks do not have contacts in common with any of the deformed rocks listed above in this quadrangle, therefore, we will have to await the interpretation of adjacent quadrangles before commenting on their relative tectonic history.
I	One outcrop of massive unbedded rock occurs on the western edge of the quadrangle.	The geologic map of Iran (NIOC, 1959) indicates that the intrusion came into the P(?) above but further interpretation is needed on the quadrangle to the west.

Figure 25 : Tectonic map of Tabas Quadrangle

3. The Pirhajat ranges of which the northern parts, north of the Tabas Quadrangle, were well mapped by Ruttner, et al, (1968). This, on the basis of Ruttner's work and our interpretation, is essentially an anticlinal mountain range of folded and faulted Mesozoic marine sediments draped over a core of Paleozoic rocks. The Mesozoic rocks, which outcrop, are younger in the southeast and are progressively older to the northwest in the range, implying greater uplift by Quarternary block faulting in the northwest.



Faults

. Normal

. Transcurrent

Contacts of tectonic units

Traces of bedding

Fold axes

Intra unit contacts

Generalized strike and dip of bedding

Prevailing wind direction from June interpretat n

4. The eastern edge of the Great Kavir depression, including the western sediment of the Pirhajat range. The ERTS imagery interpretation suggests that this is a complex of grabens with isolated outcrops of gently folded continental red beds, rather similar to unit 2 above except for the enormous extent of this unit; the western boundary was not visible on our imagery.

5. Isolated small ranges of pre-Mesozoic metamorphic rocks in the southwestern portion of the quadrangle. These rocks are identified on the geologic map of Iran (NIOC, 1959) as metamorphic rocks of undetermined age. The ERTS correlation suggests that they are, at least similar to the Paleozoic core of the Pirhajat range.

The Tabas Quadrangle has been divided into eight Tectonic units on the basis of the interpretation of ERTS. The ERTS imagery appears to be excellent for this purpose. These units and their basis for identification are discussed below.

The youngest unit separated on the tectonic map is the essentially undeformed Quaternary surficial deposits. These deposits are unconsolidated and would only be expected to show deformation in exceptional circumstances such as the offsetting of salt rinds in the Great Kavir. West of the Pirhajat range large areas of dunes cover all outcrops and structures and completely mask the bedrock geology. The wind driving these dunes is controlled by local mountain locations and where interpretable, wind directions have been noted. Alluvial fans are noted as possible sources of stored ground water. This tectonic unit is important to exploration as it covers other units of interest and for the ground water stored in it.

The next older unit consists of a gently folded continental red bed unit which is symbolized on the map by an "N" because it is identified as Neogene by Stocklin et al (1965). The red beds are probably in part transitional into the overlying surficial deposits as the surficial deposits represent a continuation into the present of the Neogene depositional environment but in the Tabas Quadrangle interpretation the Neogene was indicated only where the bedding has a definite dip with respect to the present surface. The lower contact of the Neogene red bed sequence is a major angular unconformity in the Tabas Quadrangle as the next older unit is concentrically folded and strongly faulted Eocene marine sediments. The change in tectonic style between the two units is striking because the Eocene folding exhibits strongly parallel axial planes and extremely uniform spacing of fold axes in very well bedded marine sediments. The superjacent Neogene on the other hand is a poorly bedded, tectonically disrupted sequence with broad domal folds whose axes are more nearly related to local block faults. The two units are in fault contact everywhere observed in the Tabas Quadrangle. Thus, contact relations are somewhat obscured. In adjacent areas (Stocklin, et al, 1965) Paleogene volcanics and volcanic sediments separate the two units but the volcanics apparently do not occur in this quadrangle. According to Stocklin (1968), the Neogene deformation is late upper-Alpine stage deformation.

The Paleogene volcanism is important in porphyry copper exploration because in adjacent areas the igneous activity seems to be closely related in time and space to emplacement of the porphyry intrusions.

The next older unit outcropping in the Tabas Quadrangle, the Eocene marine sediments, have been described above. This unit outcrops in a very small area on the southern border of the quadrangle in the southeast part of the Pirhajat range. It is much more widespread in the quadrangle to the south. It rests with small angular discordance on a Cretaceous fold belt and for the purposes of this presentation could well have been represented as a subunit of the underlying Cretaceous because of the great similarity of tectonic style. The decision to depict this as a separate unit is based upon the need of porphyry copper exploration geologists to have all the details of tectonic events at about this period in the tectonic history.

The angular discordance between the Eocene (L) and the Cretaceous marine sediments (Mu) is small but well defined just south of the Tabas Quadrangle, but the tectonic style is very similar and fold trends and axes in one unit often continue into the next unit. The folds indicate post-Eocene pre-Miocene east-west compression followed by left lateral faulting along an essentially north-south system of faults, indicating a shift of the primary compression direction from west to northwest. These same faults were reactivated in the Neogene as normal faults in which appears to be a basin and range type crustal extension.

The next oldest tectonic unit is the middle Mesozoic (Mm) marine sedimentary, mainly limestone, sequence whose outcrop and tectonic style indicate that they had been deformed and welded into a compact unit before the Cretaceous deposition and deformation. Few signs of the east-west compression that produced the Cretaceous folding are apparent in the rocks because of the post-jurassic pre-Cretaceous Lower Alpine phase of deformation had already welded these rocks into a more or less uniform mass. This deformation does not appear to have been accompanied by igneous activity in the Tabas Quadrangle or in the adjacent well mapped areas. These rocks form a part of the basement for porphyry-copper exploration. Structural trends, fold axes, bedding traces and faults, are more varied than in the Cretaceous rocks, but the north trend is still dominant and bedding is not so well defined at ERTS scale. The contact between this unit and the Cretaceous above is faulted, but where interpretable, it is a strong angular unconformity.

The oldest tectonic unit present on the Tabas Quadrangle is mapped as undated "metamorphics" (P?) on the Geologic Map of Iran (NIOC, 1959) and as "Ancient Cores" (Ml) by stocklin (1968). It includes, in this area, the low grade metamorphic equivalent of the Paleozoic sedimentary rocks of the Shirgesht area to the north (Ruttner, et al, 1968). In the Tabas Quadrangle these rocks form the cores of antiformal features and occur as isolated mountain ranges in the southwestern part of the quadrangle. In both areas they show major structural discordance with the younger rocks but none of the areas are large enough at the interpretation scale to allow interpretation of their internal structure and tectonic style. The older rocks form a northeast trending string of structural highs along the east edge of the Dasht-i-Kavir making the westernmost ranges of the Pirhajat ranges anticlinal. This string of highs is at a 30^{0} angle with the younger grain and probably represents the grain of earlier Alpine phase deformation. These rocks are also basement for porphyry copper deposits.

The results of our attempt to produce a tectonic map of the Tabas Quadrangle are portrayed in Figure   This figure consists of a legend and a delineated image and demonstrates the level of tectonic detail it is possible to extract from ERTS imagery at a scale of 1:1,000,000.

Projects In Hand And Planned For Future

The following are some of the projects that have either been recently initiated, or are planned to commence in the near future:

1 Tectonic Analysis of the Zagros Fold Belt Using Satellite Imagery

This area is considered ideal for this type of excercise, because, whereas in areas of thinner sediment cover of basement and volcanic rocks, ERTS observed features mainly tend to coincide with know surface trends, in the Zagros Fold Belt, due to their concealment by the extensive sediment pile, major and fundementally important deep-seated crustal trends, lend themselves to detection only through a technique using a synoptic mode of viewing such as ERTS-1 imagery.

2 Several projects are in hand in an attempt to determine the feasability of geological mapping based as much as possible or non subjective parameters.

Test site areas in these projects include the Zagros Fold Belt, Central and Northwest Iran, and extensive "ground check" programs in these areas have been planned for this purpose.

3 A program of geomorphological or landform mapping of Iran at 1:250,000 or 1:500,000 is at present in the initial stages of commencement. The evidence so far indicates that the synoptic and repetitive properties of ERTS imagery will no doubt provide new perspectives into the geomorphology of Iran that could not have been attained by other means. One problem that exsists however, is the lack of a standard and generally accepted classification system applicable to small scale landform mapping.

SUMMARY AND CONCLUSIONS

A detailed systematic evaluation of the potential of ERTS-1 imagery for geological applications in Iran was undertaken. This consisted of analysing several test sites in detail to ascertain what types of geological information could be obtained, and the level of detail that could be extracted from the imagery.

From this general evaluation, the following conclusions were made :

With some major exceptions, the geological application of ERTS-1 imagery tend to be more observational than explanatory.

Of all spectral Bands, Band 7, and occasionally Band 5 are the most useful.

The principal "output" of geological studies using ERTS-1 imagery is in defining structural features at the earth's surface. These include folds (as strikingly noted in the Zagros fold belt), and abundant circular and linear features It would seem that the synoptic and illumination properties of ERTS imagery are the main factors, responsible for the detection of these hitherto unrecorded features. It is concluded therefore that the greatest value of this imagery lies in its potential to produce regional structural maps.

Regarding geological mapping from ERTS imagery, while conceeding its value in correcting exsisting maps in the form of recording omitted or mislocated rock units, it would seem that geological mapping per se, is not as yet a feasable proposition.

Following the conclusions attained in the preliminary evaluation of ERTS imagery it was decided to carry out a regional structural and tectonic analysis of Eastern Iran, in the form of a study of structural lineaments and associated trends. As a result several major "Tectonic Provinces" based on the recognition of differing structural styles, were recognized. In addition several new theories, regarding the tectonics of this region have been put forward, the most importand being:-

- The possibility of the Upper East Iranian Ranges belonging to a genetically different phase of formation, from that which formed the Middle and Lower Ranges.

- The theory of the Rezaiyeh - Esfandagheh lineament continuing across the Lut Block and joining the east-west lineaments of the Baluchestan Province.

The verification of the above suggestions, as well as the answer to the many unsolved problems that still remain regarding this region, will have to await further "ground truth" studies.

In this context, a program of detailed geological mapping entitled "Geological Mapping and Mineral Exploration of Eastern Iran", covering an area of 330,000 square Kilometers is planned to be carried out by the Geological Survey of Iran. This program of detailed mapping will be locally augmented by airborne geophysical surveys of selected areas, thus completing the "Multistage Sampling" of this region.

Satellite analysis of geological phenomena will undoubtedly benefit from the basic "ground truth" as well as geophysical data that will be available at the end of this survey, and it is hoped that with increasing experience in analysing ERTS-1 imagery, and the wealth of multistage geological information that will soon be at hand, important steps maybe taken in fully understanding the geology, and in particular, the tectonic evolution of Eastern Iran.

With regards to the trial intermediate level tectonic mapping of the Tabas Quadrangle, it can be concluded that the ERTS image interpretation provides a uniquely valuable basis for prepration of tectonic maps for the whole country. A tectonic unit defined in terms of characteristics interpretable from ERTS imagery proves to be an invaluable correlation tool for analysis of large areas. It must be emphasised that Iran is particularly well suited to this type of interpretation based on ERTS (or other space acquired imagery) because of generally clear atmospheric conditions and the absence of masking vegetation. This approach may not be as effective in other regions of the world that do not have these characteristics.

SECTION III

Applications to Hydrology and Water Resources Management in Iran

This report has been prepared by :

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INTRODUCTION

Iran is located between geographic coordinates 26^{o}-38^{o}N, and 46^{o}-62^{o}E. The central portion of the country is covered by a plateau, surrounded by very high and snow covered mountains. Temperatures vary from well below 0^{o}c to over 50^{o}c, and freezing conditions in some areas may occur simultaneously with enormous evapotranspiration losses in other areas. The average annual amount of precipitation for Iran does not usually exceed 28 centimeters, and in terms of distribution, is highly variable across the country. For example, it is quite common to have over 130 centimeters of precipitation in the mountainous areas of the northwest or in the Caspian Sea region, while in some desert areas no rain may fall for several years.

More quantitatively, it has been estimated that basins 1,2 and 7a, (Figure-1) which cover only 25% of the country receive half of the total annual precipitation, while, the other half is distributed over the remaining 75% of the country.

Due to the scarcity and non-uniform distribution of precipitation, the study and management of water resources are of prime importance to Iran. Therefore, new sources of obtaining supplementry information such as satellite acquired data are extremely important.

In this report an attempt has been made to satisfy the

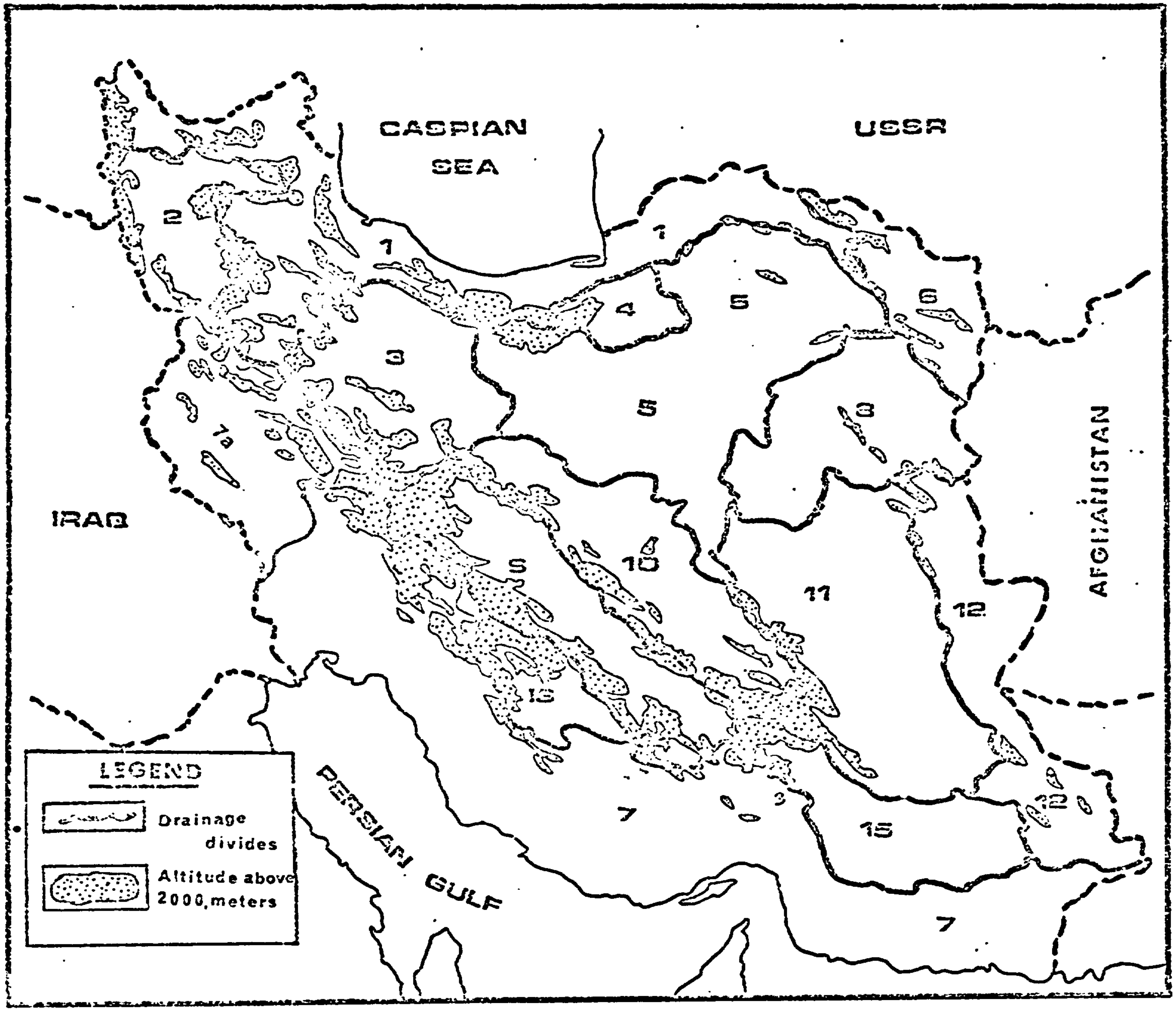


FIG-1 DRAINAGE BASIN OF IRAN

main objectives which had been originally proposed for the use of satellite imagery in water resources management. These objectives can be summarized as follows :

1- Demonstration of the ability of ERTS-1 imagery to add significantly to the present available data.

2- To use the satellite data together with "ground-truth" information to expand on the knowledge of the hydrological processes in Iran.

3- To employ the repetitive nature of ERTS-1 imagery in developing seasonal inputs to water management operation.

The following results are part of the attempt to meet the above objectives in the use of satellite imagery in water resources management.

RESULTS

In the present investigations, the ERTS-1 images were used to collect supplementary water resources data in Iran. The significant results may be summerized as follows:

A. Updating, and Correcting the Existing Hydrological Map

The only national hydrological map available at present is the Main River Basins and Rain Gauge and Runoff Stations Maps of Iran, prepared by the Ministry of Water & Power, in 1971. On comparing the above mentioned map with ERTS-1, imagery a number of hitherto unrecorded hydrological features such as lakes, resorvoirs and playas, as well as major discrepancies in drainage patterns, were noted which are discribed below.

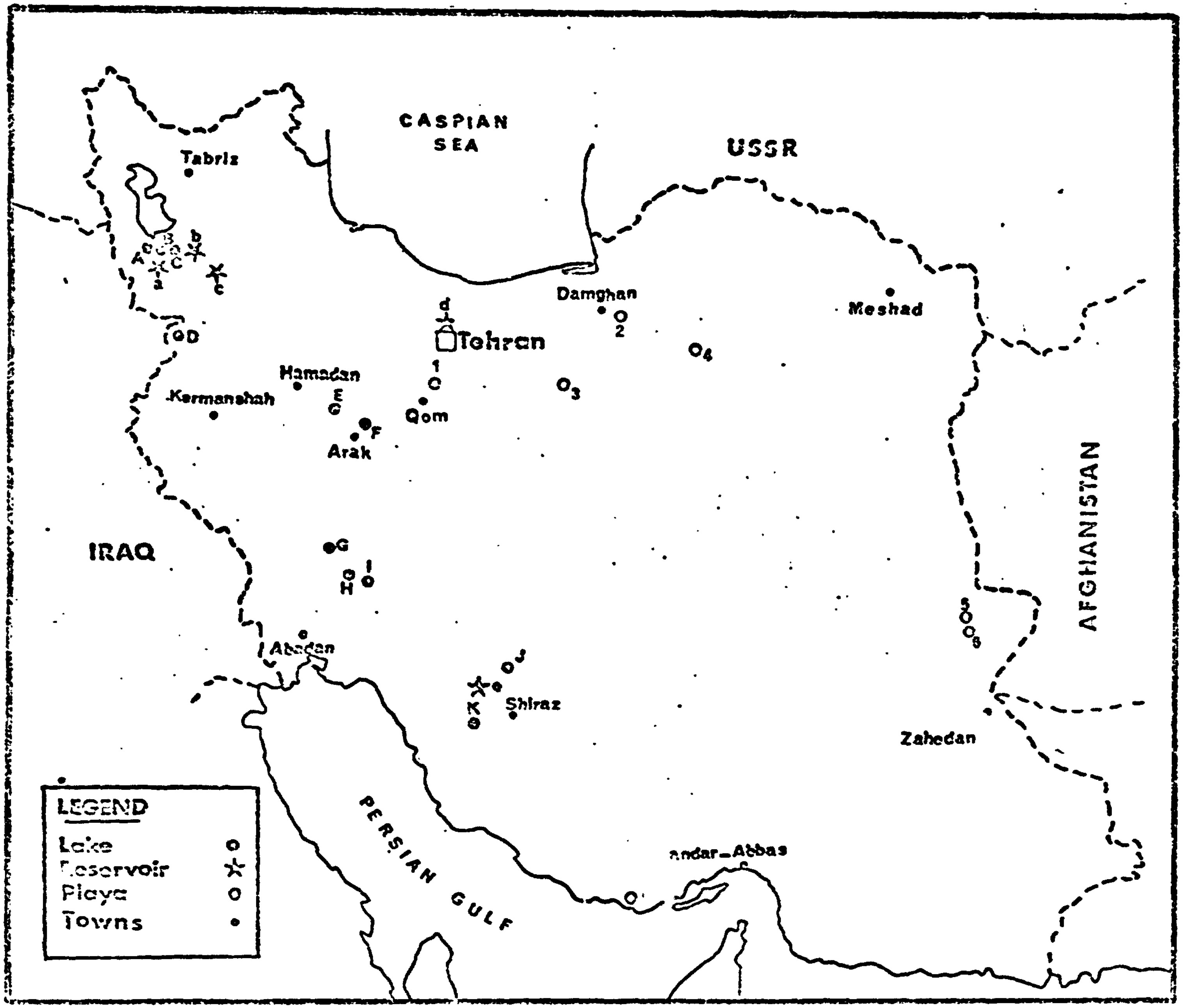
I- Lakes and Reservoirs

1. The following lakes and reservoirs were identified on the ERTS-1 imagery which do not appear on the existing Hydrological Maps (Figure-2).

(i) Lakes

A- Shor Gol : West Azarbayejan Province, South of Lake Rezaeheh

B- Dargah : West Azarbayejan Province, South of Lake Rezaeheh



A. Shor Gol
B. Dargah
C. Kopi
D. Marivan
E. Cheran
F. Mishan
G. Keynow
H. Shatt-I-Mangar
I. Ab-Bandun
J. Kaftar
K. Arjan

a. Shapour Aval
b. Nowroz Loo
c. Kurush Kabir
d. Farahnaz
e. Darius Kabir
f. Kowreh

1 Hoze Sultan
2 Damghan
3 Dasht-e-Kavir
4 Great Kavir
5 Chah Now
6 Chah Darashti
7 Mehregan

Fig. 2 Newly observed Hydrological Features with the use of ERTS-1 Imagery

C- Kopi : West Azarbayejan Province, South of Lake Rezaeheh; the above mentioned lakes are located on a east-west linear trend, and are possibly fault controlled.

D- Marivan Kurdestan Province, north west of Kermanshah, near the Iran-Iraq border.

E- Cheran : Hamadan Province, north of Malayer.

F- Mighan : Central Province, north east of Arak.

G-* Keynow : Khuzestan Province, a small lake loca- ted on crestal area of Kuh-e-Keynow, probably fed by snow melt of the sur- rounding area.

H- Shatt-i- Mangar : Khuzestan Province, north of Izeh.

I-* Ab-Bandun : Khuzestan Province, south east of Izeh. The above two lakes (H,I) appear to be "deflation hollows," formed by ground

---

* Confirmed by field checking

water discharges, possibly from near-by exposed Assmari, Limestone.

J-* Kafter : Fars Province, north of Zargan. This lake is formed by ground water discharges from a Karst limestone into a shallow depression.

K- Arjan : Fars Province, north of Lake Parishan, in the Kazerron area.

(ii) Reservoir

a- Shapour Aval : West Azarbayejan Province, on Mahabad River south of Lake Rezaeyeh.

b- Nowroz-Loo : West Azarbayejan Province, an associated reservoir to a diversionary dam on Zarineh rud River, south east of Lake Rezaeyeh.

e- Darius Kabir : Fars Province, on Kor River.

f-* Kowreh : Fars Province, a reservoir formed as a result of the construction of a small dam at a gully mouth, near Lar.

The absence of some of the previously mentioned lakes

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* Confirmed by field checking

and reservoirs on the existing Hydrological Maps of Iran might be explained as follows:

1. The map was published in late 1971, and at that time construction of some of the dams were not yet completed.

2. The relatively high precipitation during 1971-1972 may have had an anomalous effect on the normally dry topographic depressions.

Using color additive technique to study the ERTS imagery, it was noticed that some lakes exhibited tonal differences. This phenomena presumably is due to one or some combination of such factors, as depth of water, chemical composition of the water, suspended sediments, and the presence of organic material, i.e. algal growth. The cause of the tonal variations is probably different for different lakes and needs to be investigated on the ground.

II Playas

One of the most readily detectable hydrological features on the ERTS, imagery is the Playa. This phenomena is due to a great tonal differences caused by the evaporitic content of this feature, which appears as white patches on the ERTS-1 imagery. In some instances the delineation of the boundaries between playas and adjacent geomorphic features is by far easier using ERTS-1 imagery than by using ground observation. Therefore, the use of satellite imagery has increased the detectability of these features.

Some of the major Playas in Iran that had not been previously recorded on the existing hydrological maps and are visible on the ERTS-1 imagery are listed as follows :

1-	Hoze Sultan:	North or Qom
2-	Damghan:	South of Damghan
3-	Dasht-e-Kavir:	East of Qom
4-	Great Kavir:	Southeast of Damghan
5-	Chah Now:	West of Lake Hamun
6-	Ghah Darashti:	West of Lake Hamun
7-	Mehregan:	North of Bandar-e-Lengeh

III Drainage Pattern

Within the different ERTS-1, MSS, bands, bands 6 and 7 are considered more suitable for drainage studies. In terms of drainage resoulution, the norm is usually taken as 40 meters, whereas in some of the images studied, gullies with estimated width of no more than 15 meters could be detected.

Upon comparing the drainage patterns shown on existing hydrological maps with those visible on (MSS, band 7) ERTS-1 imagery, numerous discrepancies were noted.

To illustrate this point, two examples have been chosen and are presented in the form of two plots of the same area, showing the ERTS-1 interpretation against that which is shown on the existing maps (Figure-3).

B. Dynamic changes of the Darya-e-Namak (Salt Lake)

The lower part of the Qom Watershed, which is located in a corridor between the southwest flank of the Alborz Range and the northeast flank of the Zagros Range is termed "Darya-e-Namak". The latter which is located to the south of Tehran, is actually a playa covered by salt crust, underlain by wet, gray, clayey silt. This playa, in its northwestern border

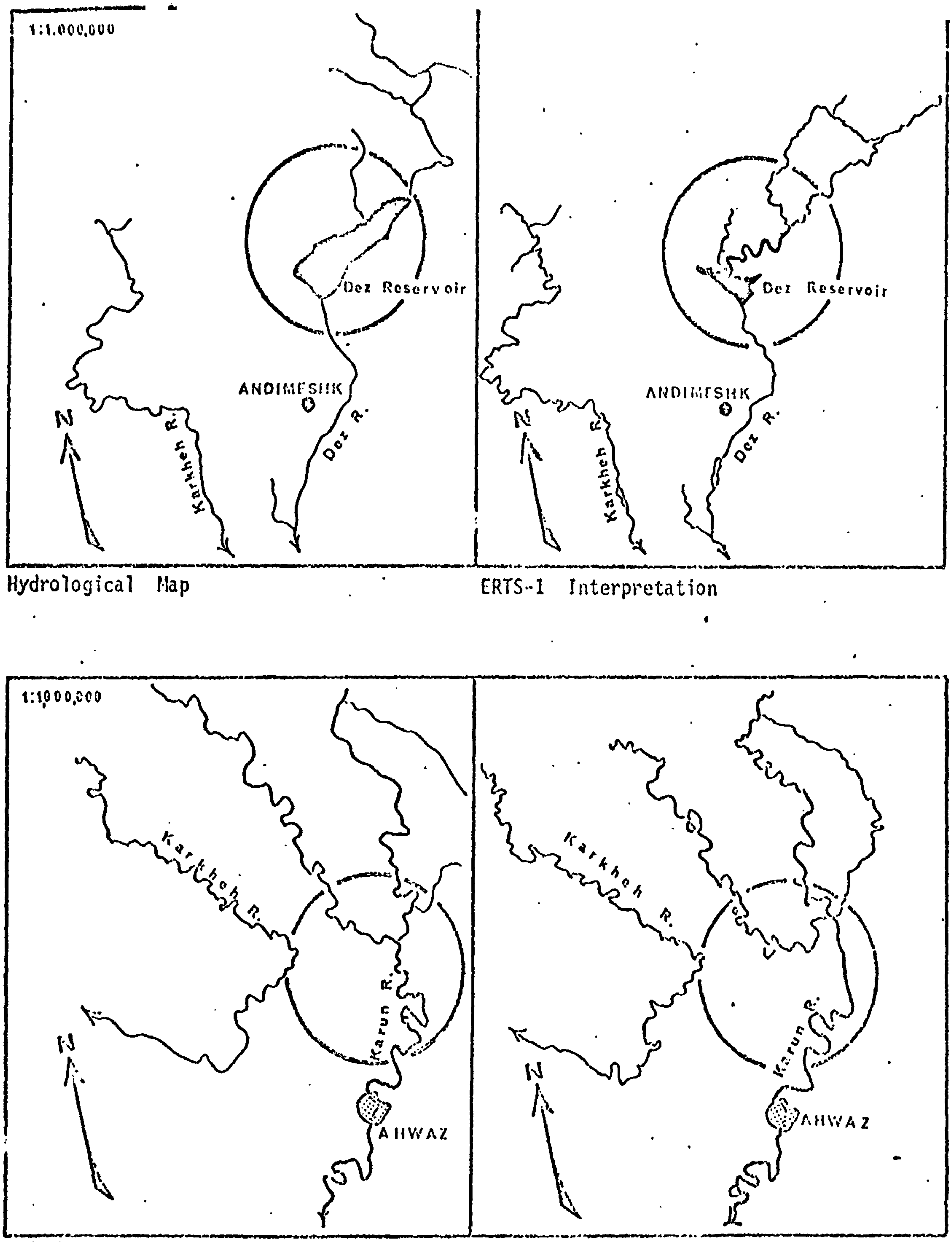

Fig.3 Examples of correcting and updating of existing Hydrological data by using ERTS-1 imagery

receives water discharged from a network of braided stream channels. These streams with a northwest to southeast direction are the terminals of the Karaj River, Rud-i-Shur, and Qom Rud. Due to the extreme aridity and the high rate of evaporation, the Darya-e-Namak is usually dry during most of the year. However, the repetitive satellite imagery coverage of the lake during the year 1972-1973 indicates that a body of water has been accumulating in its western part. Observation of the water fluctuation of this lake indicates that the areal extent of the water body has augmented during the wet season i.e. from December 3, 1972, to May 14, 1973 (Fig-4). With an average depth of 2 meters the volume of water accumulated from the end of the dry season till the end of the wet season was estimated (Table 1).

Table 1. Water fluctuation in the western part of the Darya-e-Namak

Date of ERTS-1 Imagery	Time Interval (in Days)	Surface Water Area	Estimated Volume of water (m3)
September 22, 1972	First Image	Dry	None
December 3, 1972	73	70	140,000,000
December 21, 1972	18	245	490,000,000
January 8, 1973	18	333	,660,000,000
May 14, 1973	126	296	592,000,000

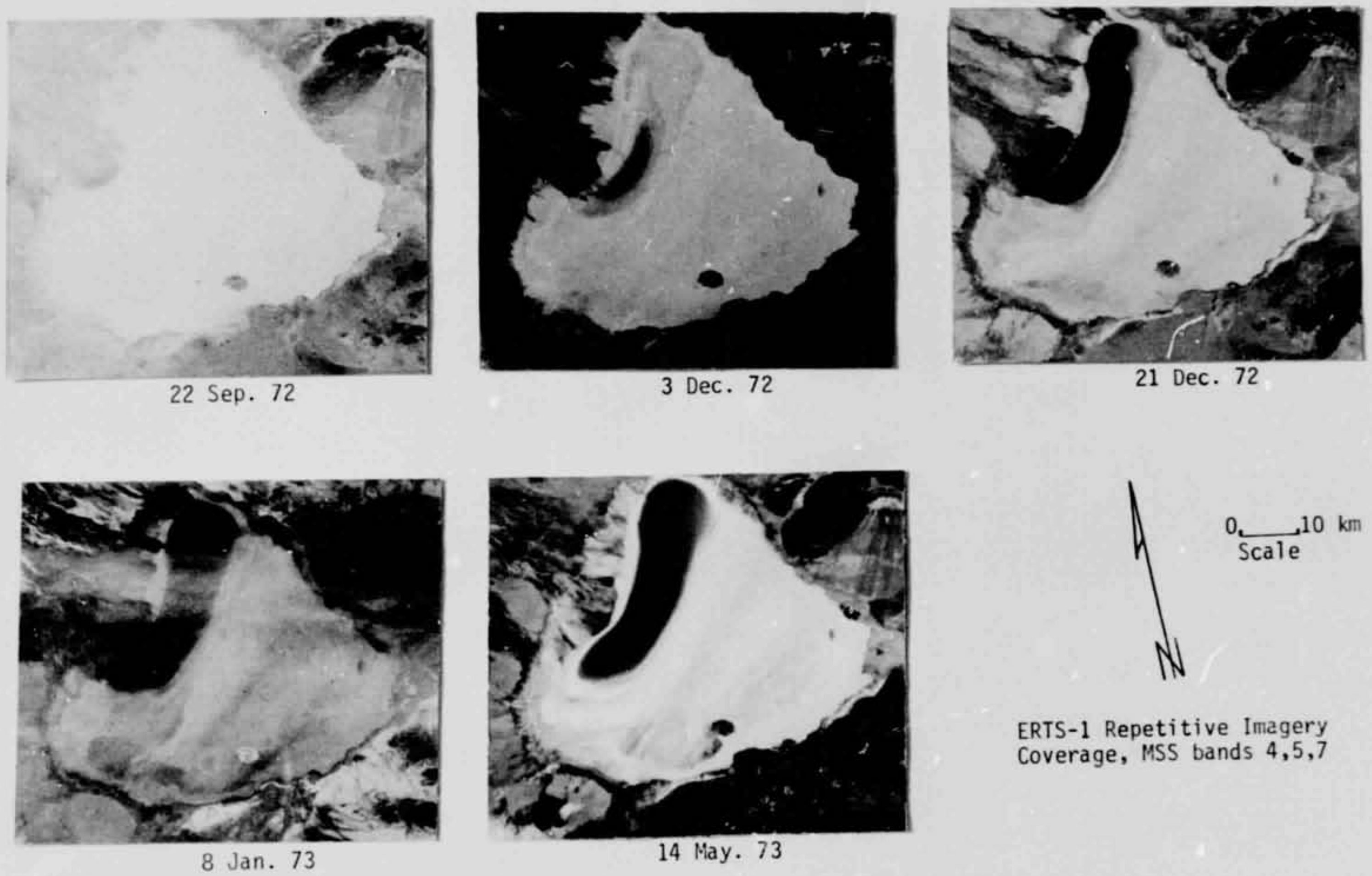

Figure 4 - Surface water fluctuation in the western part of the Darya-e-Namak

The results of the preliminary investigation described here not only demonstrate the monitoring capability of ERTS-1 repetitive imagery coverage as a reliable means of studying dynamic changes, but also indicate its vital significance in the economic management of water resources in a country like Iran, where the average annual precipitation is about 280mm.

Summary and Conclusions

The work submitted here is the result of investigations carried out in the field of hydrology with the aid of ERTS-1 imagery. The significant results obtained can be summerized as follows :

1- Discovery of a number of lakes, reservoirs and playas in different parts of the country which do not appear on the existing hydrological maps (Fig-2).

2- Demonstration of the ability of ERTS-1 imagery to provide an accurate assessment of the national water drainage net work.

3- Monitoring the fluctuation of surface water in Darya-e-Namak (Salt Lake) and an estimation of the volume of water which accumulates annually in this lake. (Fig-3, table-1).

In conclusion, satellite imagery has proved itself to be a very valuable tool in the study of water resources and it is firmly believed that by complementing data obtained from the interpretation of satellite imagery, with field observations, a substantial as well as an extremely useful volume of data will become available for water resources management and planning for the entire country.

Future Planning

The following projects are planned to be carried out in the field of hydrology with the aid of satellite imagery.

1- Preparing of new hydrological maps of Iran at scale of 1:1,000,000, 1:500,000, 1:250,000 and evaluation of individual drainage basins in detail.

2- To Map areas of possible ground water potential, such as alluvial deposits as well as regions of intense rock fracturing which may be relevant in ground water studies.

3- Monitoring the surface water fluctuations in various lakes and reservoirs.

4- To carry out snow surveys in order to determine a relationship between snow coverage of a region and its corresponding runoff.

5- To map flood plain areas, especially around the Karun and Karkheh Rivers in Khuzestan Province.

6- To carry out sedimentation and water pollution studies along rivers and in land locked water bodies.

SECTION IV

Applications to Iranian Marine Resources

This report has been prepared by :

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A. Elikaie	Drawing Technician

INTRODUCTION

Iran is bordered by the Persian Gulf to the south, and partly by the Caspian Sea to the north, with an estimated total coastline of about 2000 kilometers.

The Fishing industry related to the above two water bodies is an important supplier of protein for the nation as well as having great potential in terms of national economics. However, due to the lack of adequate information such as oceanography and marine biological data, the fishing production to date, has remained remarkably low. It would seem therefore, that the study of satellite imagery combined with marine surveys will provide valuable information pertinent to the Fishing industry in Iran.

In the present investigation, interpretive efforts of ERTS-1 data have been concentrated on analysis of sedimentation and wetland area delineation in the southern coastal zone. This study, is considered to be of paramount importance in the identification of high potential fishing zones and associated nurseries along the Persian Gulf area. Owing to the short period of study and the absence of ground truth data, the results reported here are therefore of a preliminary nature.

RESULTS

The present investigation is an attempt to use the ERTS-1 data for the determination and identification of gross hydrographic features along the Persian Gulf. The result obtained can be summerized as follows:

I. Identification and Areal Determination of Coastal Wetlands

One of the most readily detectable hydrographic features on the ERTS-1 imagery is coastal wetland. The ease of identification of these features is concluded to be due to the high moisture content, causing a reduction in the reflectivity of these areas, resulting in a darker appearance on all MSS bands.

In this study a series of MSS band-7 imagery was studied, and as a result, three major wetland areas were identified along the Persian Gulf. These are found to cover an area of 430,000 hectars at head of the Gulf, 15,000 hectars near Bushehr, and finally a total of 5500 hectars in northwest of Geshm Island and coastal Bandar-e-Abbas.

Figures-1,2 and 3 show the extent of the areas involved; they were prepare by outlining the coastal wetland areas using band-7 imagery and overlaying the resultant wetland delination on the respective MSS band 4. This was done mainly to show the turbidity of the immediate off shore areas and their relation to adjacent wetlands.

Figure-1 Coastal wetlands and adjacent turbid areas, at the Head of the Persian Gulf. (Scale 1:1000,000)

Figure-2 Coastal wetlands and adjacent turbid areas, in Coastal Bushehr. (Scale 1:1000,000)

Figure-3 Coastal wetlands and adjacent turbid areas of northwest Geshm Island and southwest Bandar-e-Abbas. (scale 1:1000,000)

II. Seasonal Variation of Suspended Load at Head of the Persian Gulf

The present study is an examination of ERTS-1 repetitive imagery to demonstrate the distribution of the suspended load and its variations at head of the Persian Gulf.

Of all the different ERTS-1 images, bands, 4 and 5 are usually considered more applicable for detection of suspended load. In this report however MSS, band 4 imagery was disregarded because of the observed hazyness in this band and difficulties involved in differentiating between the littoral bank areas and suspended load. Other problems involved in using band 4, also include the lack of differentiation between the various density loads within the study area.

In this study, the test site area is a deltaic region fed by the Arvand, Bahmanshir, Jarrahi and Hendijan Rivers. (Figure-4). These rivers discharge large quantities of silts and clayes into the Gulf, resulting in the steady growth of the delta seaward.

To observe the seasonal variations of this load two MSS band 5, images taken during different seasons (early September and late December) were analyzed. As a result, several zones were differentiated on the basis of their density variation of suspended load. Figures 5 and 6 show the density variation patterns in the above mentioned dates from which the following significant observations were made:-

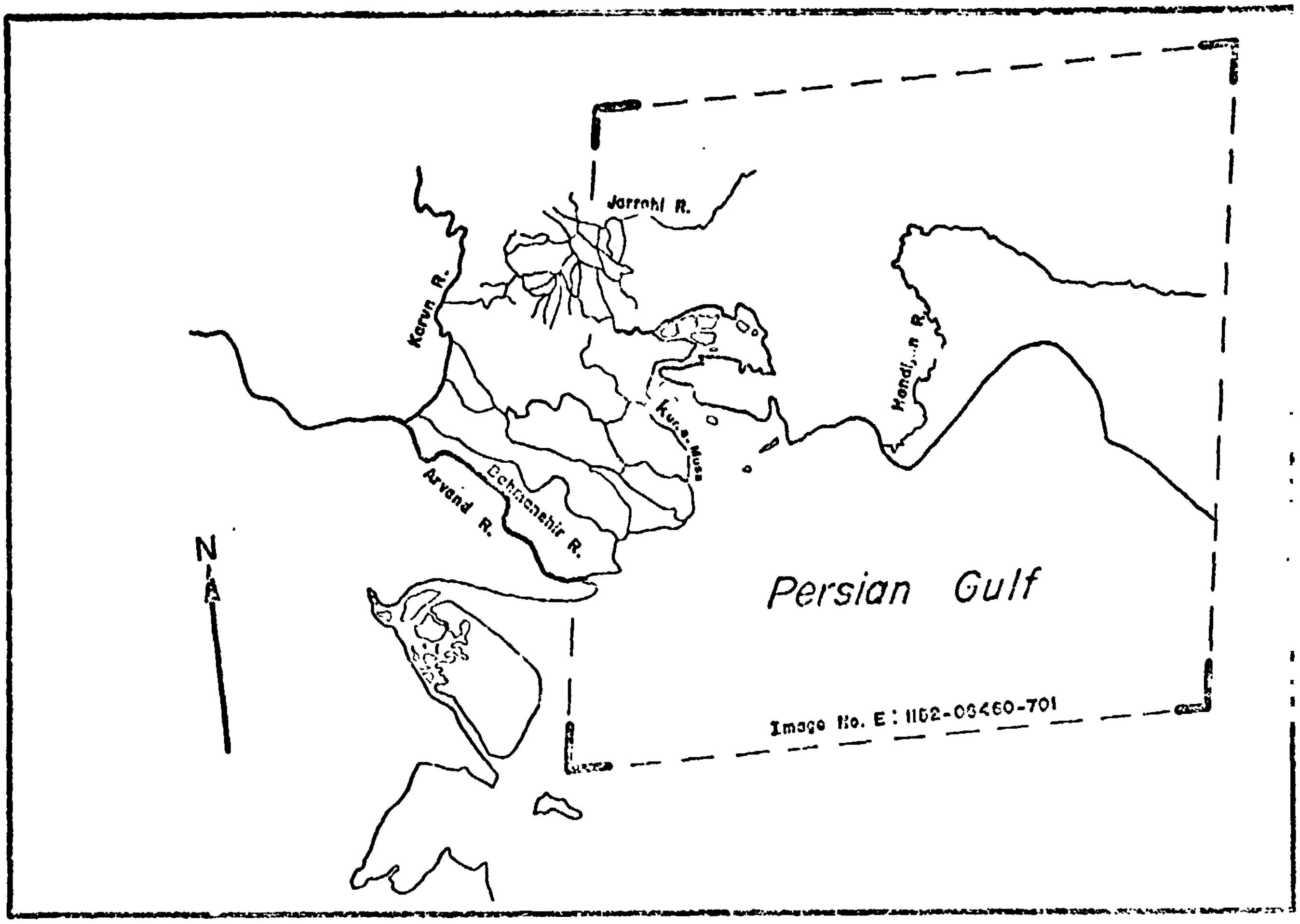


Figure-4 General study area also showing area covered by ERTS-1 image: 115-06460-701

1. In both images, three zones of high, medium, and low density of the suspended load are identified.

2. These zones in general, are notably shifted to the northeast from their main point of supply. This phenomenon is particularly noted in the medium and low density zones on the late December frame. On the early September frame however, the medium density zone, exhibits an anomalous tongue to the south.

The general northeast ward deviation of density patterns is believed to be the result of a near shore coastal current, travelling parallel to the coastline. This is especially pronounced at the mouth of the Hebdijan

High density Boundary

Medium density Boundary

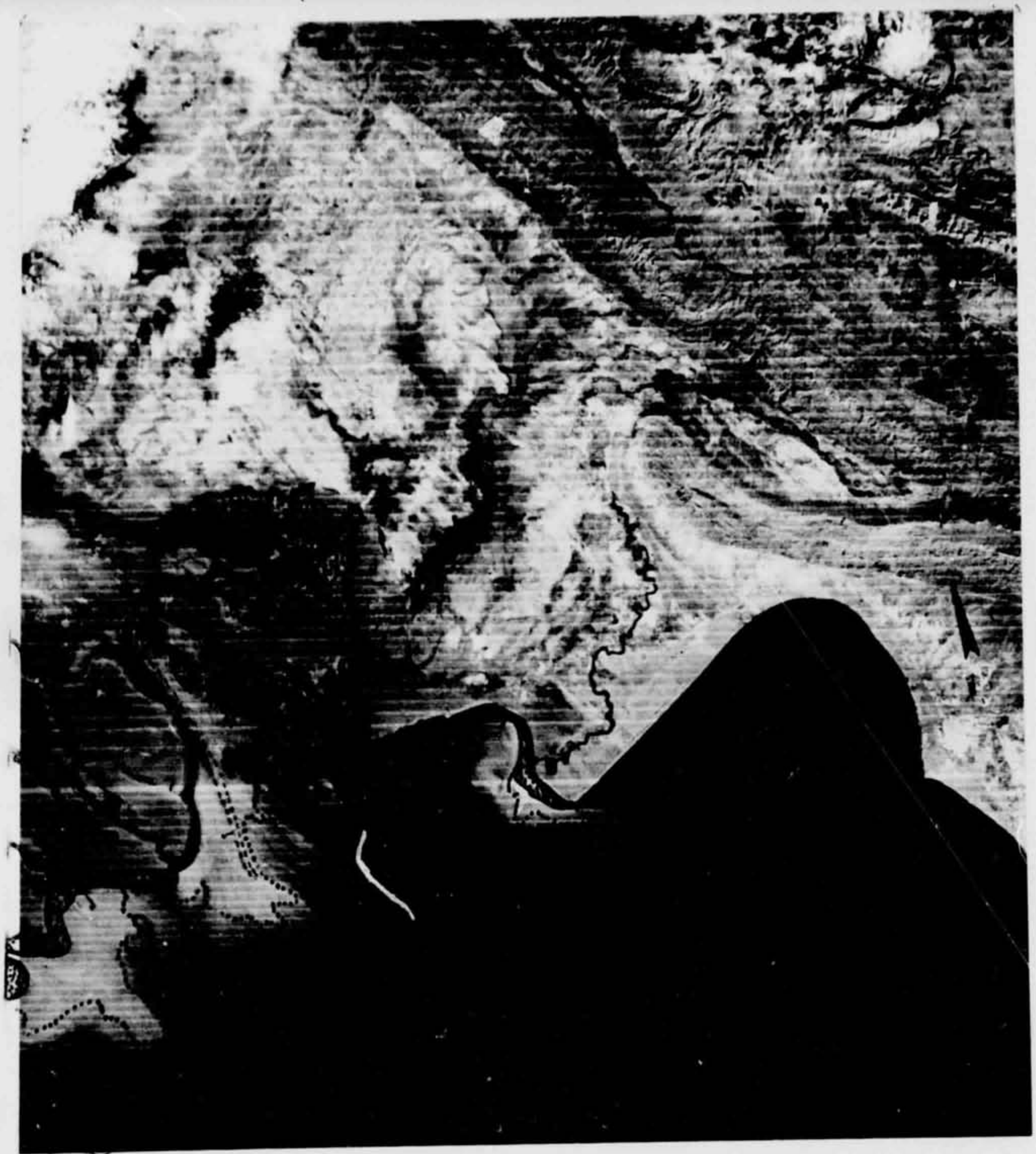
Low density Boundary

Areas always above sea level

Intertidal zone

Coastal current

Figure-5 Density variations of suspended load in the Test Site area, on 5 September 1972



High density Boundary — Areas always above sea level

Medium density Boundary — Intertidal zone

Low density Boundary — Coastal current

Figure-6 Density variations of suspended load in the Test Site area , on 22, December , 1972

River in the late December frame (Figure-6), where the medium and low density extensions are seen to deviate completely in an easterly direction, whereas the Hendijan River, flows into the Gulf with an opposing southwesterly course.

The above mentioned sourtherly tongue of the medium density zone in the September image, may be attributed to a density current, resulting from tidal backwash in the Kur-e-Musa Inlet. The absence of a similar anomaly in the late December frame is possibly due to higher velocity of the previously mentioned coastal current during that season, which drives the load north-eastwards.

3. In the late December frame, there is an increase in the seaward extension of the high density zone, as compared to that of the early September image, while the low density zone in the latter fram exhibits a reverse phenomenon.

The changes of the seaward extensions of the high and low density zones in the above mentioned dates are due to several factors, such as variations in river discharges, quantity and quality of suspended load, tidal action, surface and subsurface costal currents. In the December frame, (Figure-6), the increase in precipitation, causing an increase in the run off and respective sediment load, results in a seaward extension of the high density zone, whereas stronger coastal currents, and more turbulent conditions in general, do not permit the smaller sized particles (of the low density zone) to extend far into the Gulf. On the other hand, the reverse conditions apply in the September image.

In addition to the above single band analysis, colour additive techniques were also utilized for better definition of load density distribution. Of all the color combinations used, the best results were found to be obtained with the following band/filter/intensity combinations.

Band	Filter	Intensity
6	red	maximum
5	blue	maximum
4	green	moderate

Using the above configuration, the high, medium and low density zones manifest themselves clearly in red, blue, and green respectively.

Future Planning

The following projects are planned to be carried out in the fields of Oceanography and Marine resources with the use of satellite aquired data :-

1. Preparing Hydrographic Maps of Iran, along the persian Gulf and the Caspian Sea, at various scales.

2. Studies on the feasibility of delineating high potential fishing areas in the Persian Gulf and the Caspian Sea.

3. Extending the present investigations of the seasonal variatiors of suspended load to the remaining off-shore areas of the Persian Gulf and the Caspian Sea.

SUMMARY AND CONCLUSIONS

The overall synoptic view coupled with the repetitive nature of ERTS-1 imagery has offered us a unique opportunity to study the hydrographic features along the Persian Gulf coast line. The significant results obtained can be summerized as follows :

1- Identification and areal determination of three major wetland areas along the Persian Gulf coast line, (totalling 450,500 hectars).

2- Monitoring and analyzing the seasonal variations of suspended load at the head of the Persian Gulf.

With the relevance of the above studies to the fishing industry, in so far as wetlands are considered excellent nurseries and turbidity action may be considered as one of the most important factors in locating fish concentrations, it can be concluded that repetitive ERTS-1 imagery in conjunction with other relevant data, such as temprature and salinity variations, or biological considerations of an area, can be extremely useful in the task of allocating higher potential fishing priorities in different seasons.

SECTION V

Application to Agriculture, Forest and Rangeland Management

This report has been prepared by :

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A. Mansuri , Drawing Technician

ERTS-1 APPLICATIONS TO AGRICULTURE, FOREST, AND RANGELAND MANAGEMENT

Introduction

The agriculture, forest, and range resources of Iran are presently the subjects of large scale, intensive development programs. Several studies have been undertaken in agriculture in recent years, particularly in the Caspian Sea area, to determine the best strategy for allocating land use between agricultural crops and pasture grasses. The determination of an optimum balance of land use between crops and pasture is particularly pressing now because of the urgent need to increase animal protein production throughout Iran. One important way of achieving increased animal production is by pasturing more animals, from time to time, that normally feed on natural range lands so that these lands can at least partially recover from years of overgrazing.

A range survey of Iran, which uses ERTS-1 data in a multistage sample design, has been undertaken to determine the current status of the range resources and to locate areas of the highest productive potential. The use of ERTS-1 imagery to help monitor the status and distribution of range grasses could prove to be of tremendous benefit in a cattle expansion program. This survey is described in more detail later in this report.

The Ministry of Agriculture is engaged also in studies to improve food production through irrigation, fertilization, and genetic improvement of planting stock. In order to monitor the current crop production, the Ministry periodically gathers statistics concerning the amount of distribution of yields.

These are tremendously difficult tasks. Currently, the Ministry depends heavily on questionnaires and reports sent in by farmers. Because of the inaccessibility of many villages, the gathering of the information is very difficult. Furthermore, many farmers do not respond, and different interpretations of the questions are not uncommon. Also, different agricultural practices prevail in various parts of the country. Altogether, these conditions make it difficult to obtain consistent data over the entire country in any one period of time. The introduction of ERTS technology, therefore, could greatly facilitate the planning and execution of crop surveys in relatively short periods of time. Because of the divergence in land form and climate varying, strategies are being examined. In the Caspian Sea area, the farm lands are more or less contiguous with some inermingling of high quality grazing land. This situation calls for one class of possible sample designs. On the other hand, the remainder of Iran has a much dryer climate. Hence, the agricultural areas are relatively small and widely scattered. The latter situation calls for a different sampling approach than the former for optimum results. In both instances, however, ERTS-1 imagery provides an excellent medium for locating all the crop areas in the population and setting up the sampling frame for crop census activity.

In the current ERTS-1 investigation in Agriculture, four major objectives are being sought. These are:

1. The development of methods to inventory farming and grazing lands.
2. The identification of new lands suitable for farming.
3. A classification map showing land use, and
4. The development of techniques to discriminate between agriculture and range areas and to measure change.

Forest resources of Iran are restricted mainly to the north slopes of the Elburz Mountains which ring the agriculture region south of the Caspian Sea. While restricted in area, the forests do contain significant amounts of beech, maple, oak and pine in addition to several minor species. There are also some oak forests in the western part of the country, but these do not have the productive capacity of the Caspian Sea forests because of the much more arid climate.

The main problems in forestry that can be addressed by means of ERTS-1 technology deal with obtaining an adequate inventory of the forest resources and in monitoring changes that are taking place as a result of logging, burning or grazing. Historically, the forests have been heavily used for timber, firewood, charcoal and grazing. However, much of this usage has been sporadic in nature depending on the needs of local residents. Therefore, there is no consistent record of the status of the present forest resources even though they are now protected from indiscriminate use. Since some of the prime forest areas are now being brought under more intensive management and utilization, (i.e. the Neka Zalem Rud Project) the need for more current information concerning the quantity, quality and location of forest resources will steadily increase. The introduction of ERTS technology into Iran's forest inventory and management program would help accelerate the achievement of these goals.

The mair orestry objectives of the present ERTS-1 study are to:

1. Explore the feasibility of classifying forest types on the imagery for use in inventory and management programs,
2. Plan the location and development of access roads and fire breaks on a broad scale, and
3. Determine the feasibility of monitoring changes in forests that occur as a result of planned harvesting and sporadic cutting by local residents.

Results to Date

The progress achieved toward satisfying the objectives specified above in agriculture, range and forestry, during the first year of this effort has been:

1. Training in the handling and use of ERTS data
2. Familiarization with the interpretation equipments available
3. The exact identification of test areas, their deli- neation on ERTS imagery, and the gathering of ground truth information.
4. The implementation of a range resources inventory using ERTS-1 data in the first stage of a multistage sampling design.

Training and Familiarization

A course in remote sensing techniques and the application of ERTS imagery to resource surveys and management problems was conducted by Earth Satellite Corporation (EarthSat) and attended by ten key scientists and administrators from the Plan Organization and other resource ministries of Iran. During this program, ERTS images of Iran were studied in conjunction with the study of images of similar areas in the Southwestern United States. Farm, range, and forest areas were studied to determine the appearance of different agriculture and forest areas were studied to determine the appearance of different agriculture and forest types on ERTS images. Image enhancement devices, such as the I^2S Digicol were employed to determine the improvement that can be gained in identifying these kinds of resources compared to the black and white material.

Field trips were undertaken throughout California and Arizona for the purpose of comparing the appearance of the different kinds of vegetation on the ground with their signatures on the ERTS data. During these trips, different kinds of crop and forest types were visited and compared with the imagery. In addition, several visits were made to range areas in the American Southwest.

Establishment of Test Areas in Iran

After the study team returned to Iran, ground visits were made to several areas that resulted in the establishment of four test sites; two in agriculture, one in forestry, and one in range.

A. Agricultural Test Sites

The Shah Mazraeh Development Area

One site chosen to study the signatures of key agricultural crops on ERTS images over time is the Shah Mazraeh Development area near Gorgan, in the Caspian Sea area. This agricultural development area was established about ten years ago to study farming methods and crop rotation plans in this prime agricultural region of Iran. The main crop types currently being grown here are cotton, wheat, barley (irrigated and dry land), and pasture grasses with smaller amounts of corn, sunflowers, and orchard crops.

During the field visit to this area in April 1973, an identification was made of the crop that was grown on each field in 1972 as well as the crop being grown in 1973. These identifications were indicated on large scale maps which show clearly the locations of the field boundaries. Then an overlay was prepared at a scale of 1/250,000 to match an enlargement of ERTS frame number 1294-06324, 13 May 1973 (Figure 1). While this scene is partially obscured by clouds, there is enough of the area visible to allow an investigation into various multispectral techniques for discriminating among the crop types. Figure 2A, shows a barley field in the center of the test site. This field has visible color values very similar to nearby pasture grasses (Figure 2B). To distinguish between these two kinds of

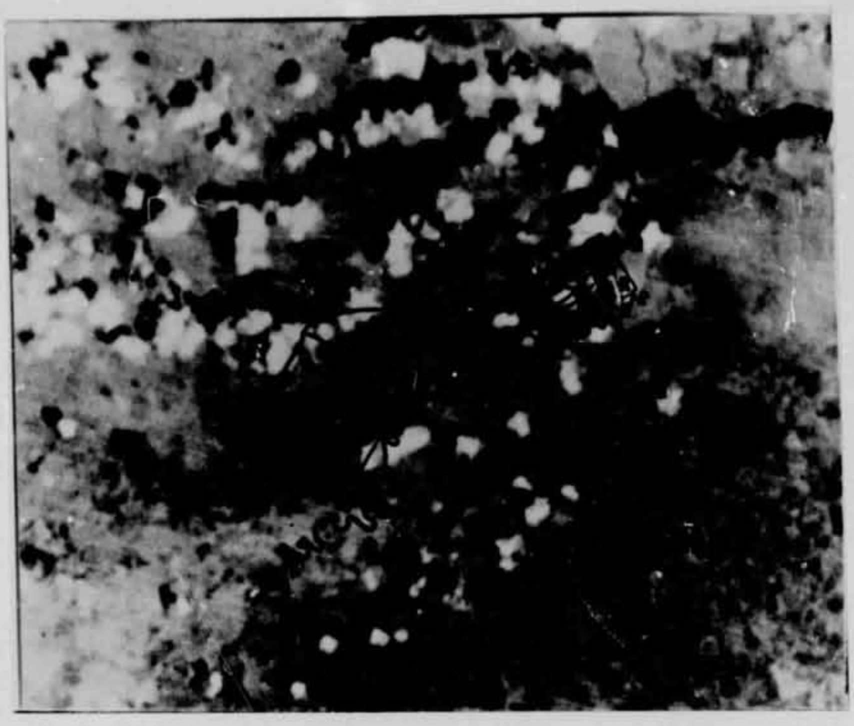


Figure - 1 : THE SHAH MAZRAEH DEVELOPMENT AREA TEST SITE

Crops grown in each field during the 1972 and 1973 season may be found by matching the letter on the image to the corresponding letter below

FIELD	1972	1973
A	PASTURE	PASTURE
B	WHEAT	PASTURE
C	(NO DATA)	BARLEY
D	COTTON	WHEAT
E	COTTON	COTTON
F	BARLEY (IRRIGATED)	BARLEY (IRRIGATED)
G	WHEAT	COTTON
H	(NO DATA)	WHEAT
I	BARLEY	WATER MELONS
J	COTTON	BARLEY (DRYLAND)
K	BARLEY (DRYLAND)	BARLEY (DRYLAND)
L	COTTON	BARLEY (DRYLAND)
M	BARLEY	COTTON
N	PASTURE	COTTON
O	(NO DATA)	SUNFLOWER
P	(NO DATA)	CORN
Q	(NO DATA)	ORCHARD
R	PASTURE	PASTURE

FIGURE - 2

A - shows the barley field designated as (J) in Figure - 1.

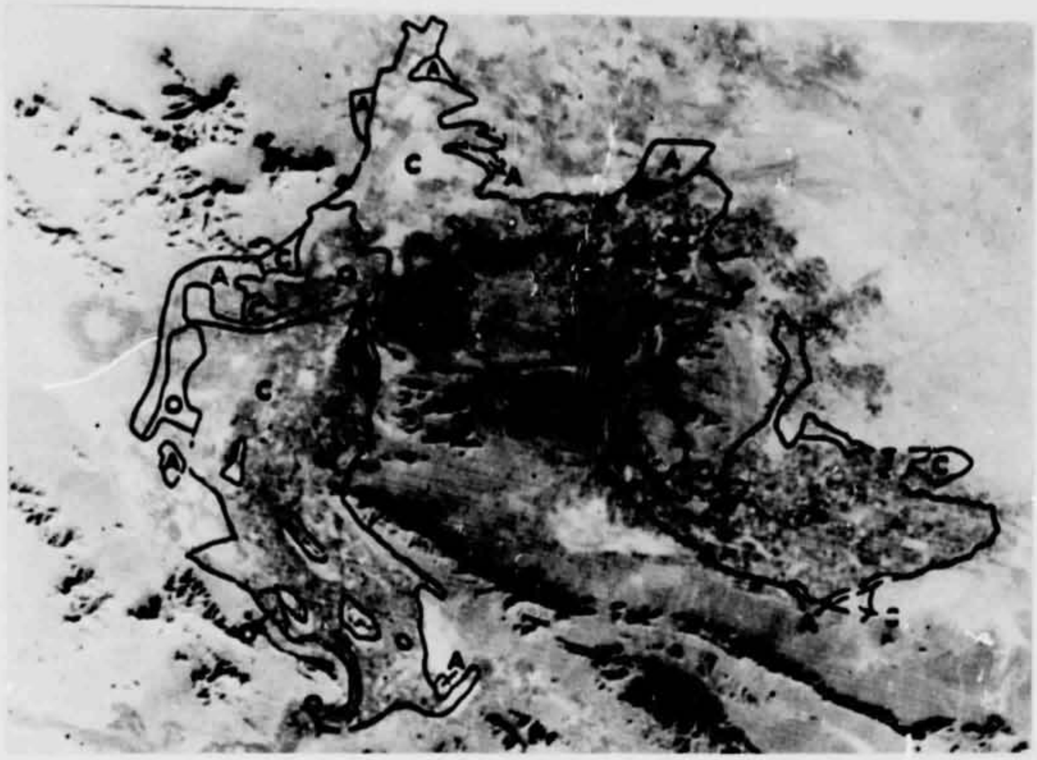
B - is a range area just north of the field designated as K in the same figure.

vegetation will probably require some form of pattern recognition technique in addition to point-by-point multispectral analysis. Discrimination between these two classes of vegetation is extremely important in order to plan and monitor the balance of land use between agriculture and grazing in this area. Maintenance of this balance is crucial to the success of the range improvement program and therefore to the entire animal protein production program.

The Isfahan Study Area

The second agricultural test site selected is the crop region immediately surrounding the City of Isfahan (Figure - 3), about 400 kilometers south of Tehran. This region, being surrounded by desert, is much drier than the Caspian Sea region to the north. Crops grown there are similar to the Caspian region. Therefore, it will provide a contrasting set of similar crop species that can be used to determine spectral differences on the ERTS images that result from climatic variations. A 1/10,000 scale map was obtained for this area showing the general distribution of crops. Then an overlay was prepared at a scale of 1/500,000 to match ERTS frame Number 1133-06393, 3 December 1972 (Figure - 3). As can be seen from the illustration, the mapping of the agricultural zone at this point in time can be greatly improved by means of the ERTS-1 image.

As of this date, field checking has not been sufficient in this area to identify actual crops field by field. However, 1/20,000 scale aerial photographs are available for the area which can be used to annotate actual crops during the next field visit. The ground photo of Figure - 4 are typical of the kind of agriculture and range that surrounds the Isfahan area. it can be seen



C-Cultivated
O-Orchard
A-Arid

Figure - 3 : ISFAHAN AGRICULTURAL TEST AREA

FIGURE - 4

A shows a typical grain field in the vicinity of Isfahan while B shows a typical desert range in the same area.

that, in contrast to the Gorgan area, there should be no great problem here in distinguishing between agriculture and range resources from ERTS imagery. Also, there should be no great difficulty in identifying agricultural areas by size and location because of their extreme contrast with the surrounding desert.

On the other hand, discrimination among crop types will be more difficult due to the generally smaller size of individual field compared to the northern areas around the Caspian Sea. Only a detailed spot-by-spot multispectral analysis combined with cluster analysis by means of the ERTS digital tapes will determine the possibilities for discriminating among crop types in this area. The Isfahan study area and the area around it is much like the cropping pattern in the entire southern portion of Iran. Therefore, reliable techniques for locating and identifying these small scattered agricultural oases are vital to the implementation of ERTS data into the crop survey and monitoring program of the Ministry of Agriculture.

The Golestan Park Rangeland Study Area

The April 1973 trips also resulted in the selection of the Golestan Park area as a rangelands test site (Figure- 5). This area lies about 75 kilometers east of the southern shore of the Caspian Sea. Here, both protected and unprotected range lands are present in large contiguous areas. The area also encompasses a significant range of elevational differences as well as grass and browse types. It is an ideal area to study the varying signatures of range vegetation on the ERTS imagery.

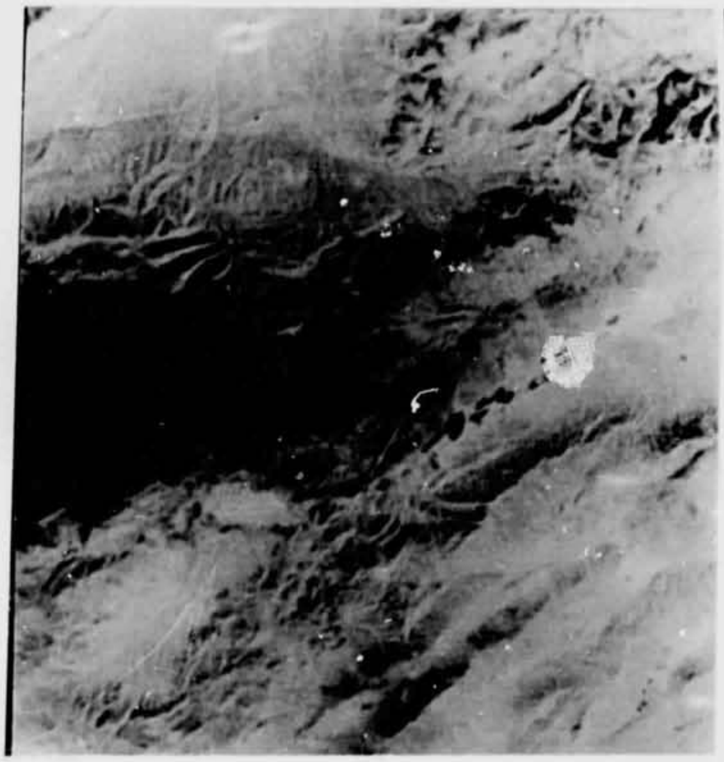


FIGURE - 5

ERTS frame 1059-06260-7, 20 September 1972 showing the Golestan Park range study area. (A) indicates the approximate location of Figure - 6A showing the higher elevation range area. (B) indicates the lower elevation sage area of Figure - 6B.

FIGURE - 6

(A) is an example of the higher elevation, good quality rangeland in the Golestan Park. (B) is an example of the lower altitude, poorer quality sage area.

Large scale maps of the area have been obtained which show the annotated boundaries of Golestan Park. At the time of writing, it has not been possible to annotate the exact boundaries of the study area on ERTS frame Number 1059-06260, 20 September 1972 (Figure - 5). This will be done in the near future. A color composite of ERTS frame Number 1221-06270, 1 March 1973 has been obtained which shows some of the study area. Unfortunately, the best rangelands, which are located at high altitudes, were covered with snow. Also, many of the remaining areas are partially obscured by clouds and cannot be intensively studied using ERTS digital tapes.

Figure - 6 shows two kinds of rangeland characteristics of the Golestan area. The photo on the left (A) shows a portion o the higher elevation range area of superior quality that has been under protection from grazing for several year. The right photo (B) shows a typical sage-type browse area that has also been under protection. The approximate location of the ground photos are indicated on Figure - 5 . One of the low altitude photographic strips used in the multistage range inventory, described later in this report, traversed across the higher elevation range area shown in Figure - 6A . Therefore, this is an ideal area for more intensive study later in the investigation. The development of techniques to stratify effectively the rangelands of Iran into significant productivity groups will be most important to the animal protein improvement program of the Ministry of Agriculture.

The Neka Zalem Rud Forestry Study Area

The site chosen as the forestry test site is the Neka Zalem Rud Project (Figure - 7). This project area encompasses approximately 80,000 hectares of which 60,000 hectares are in commercial

FIGURE - 7

ERTS Frame 1294-06330, 13 May 1973 showing the southeastern corner of the Caspian Sea and the Neka forest study area. The study area is the bright red area just to the left of the photo center.

forest. The Neka project is a long term, experimental forest management and utilization program. It includes the installation of an integrated timber processing facility consisting of a sawmill and particle board plant as well as various remanufacturing equipment for producing finished products.

The forest management program of the Neka project calls for partitioning the forest into five twenty-year management section. Harvesting and reforestation activities are to take place in each area so as to obtain a sustained yield of forest products over a one-hundred year period. Within each twenty-year section, forest stands have been identified on aerial photographs and mapped by type classification. Timber cruises have been completed in the first twenty-year management area so that the species composition and timber volumes are known for each forest type mapped. Copies of these maps and the accompanying data are now being obtained so that the locations of these known stands can be accurately projected into the ERTS images for study.

The study area is shown as the bright red area near the center of Figure - 7 ERTS Frame Number 1294-06339, 13 May 1973.

Figure - 8A shows a typical stand of young beech within the Neka forest project.

Figure - 8B shows a typical grain field that borders the Neka project.

The intermingling of forest, agriculture and range lands is fairly typical of much of the Elburz mountain area. Therefore, the discrimination among them on ERTS imagery is important to the survey and monitoring of these kinds of vegetation

FIGURE - 8

(A) is a typical young growth beech stand in the Neka forest project area. (B) shows a typical grain field intermingled with the forest and range land in this area.

resources. While it is obvious that there are color differences discernible in different portions of Figure - 7, their exact meaning is as yet unknown. A study of the crop calendar of agriculture, and the annual phenologic variations of the major forest and range types will probably be required to discriminate consistently among these three major vegetation groups in this area.

Plans for the Next Reporting Period

During the field trips to the above areas, with ERTS images in hand, it was possible to identify at least the broad differences between agricultural, range and forest areas that are intermingled throughout the region. It was also apparent that finer differentiations on ERTS imagery are possible among agriculture and forest types and that rangeland areas can be categorized as to forage density.

Next, the principal tasks are to quantify the observations in such a way as to permit meaningful experiments to be conducted in multispectral analysis over time. The objectives of t' .se experiments would be to:

1. Determine the extent to which major agriculture, range and forest types can be consistently distinguished by means of ERTS-1 data,
2. Determine the extent to which differentiations between species types within each of the three main categories can be made,
3. Determine how well the productive capacity of rangelands can be quantified from ERTS data,
4. Determine the relative efficiency of using ERTS data as an integral part of sampling designs for surveying and monitoring agricultural, range and forest resources. and

5. Determine how accurately timber volumes can be determined from an analysis of ERTS data.

The most likely form of experimentation will be by means of discriminant analysis of the form $Y = X B + e$ in which

Y is the vector of discrete variables relating to classes of vegetation,

X is the matrix of independent variables which describes the vegetation as it appears on the ERTS imagery (i.e. tone, density, color, pattern, etc.),

B is the matrix of coefficients that relate X to y, and

e is the random error term that is not accounted for by X.

In the short term, manual interpretation techniques will be used to generate the X matrix, while in the long term, the computer compatible digital tapes will be used for this purpose. After determining the coefficients of the training models in the agriculture, forest, and range areas, each test field, forest type, and range condition will be classified by means of the appropriate model. Finally, classification matrices will be prepared showing the performance of the various models. On completion of these experiments, it will be possible to determine the extent to which the ERTS data can be used in a practical way to achieve the objectives set forth above.

The Iranian Range Resources Survey

As mentioned earlier, the Ministry of Agriculture in Iran is engaged in a program to improve animal protein productivity. As part of this program a range resources survey has been initiated to determine the extent and present condition of the rangelands in Iran and to identify specific areas on which forage improvement programs might be profitably undertaken.

In this range survey, ERTS imagery is being used as a medium for stratifying the population into geobotanical units based on elevation, aspects, and geographical location. Meteorological satellite data are also being employed to plot rainfall and soil moisture patterns, in an effort to interject vegetation growth potential into the range quality evaluation as depicted on ERTS imagery.

The sampling design for the range survey is a stratified threestage model with variable weights at each stage of the model. The weights are derived from an analysis of each of three scales of imagery. The first stage (primary sample units) of the design consists of ERTS frames. Ten frames are to be selected over the entire country; four in the north around the Caspian Sea and Mashhad areas, and six in the southern part of Iran.

The second stage sample units consist of approximately twelve 1/60,000 scale aerial photographs within each ERTS frame included in the primary sample. On these photos, a more detailed delineation is being made of the lands that are devoted to grazing. As with the data extracted from ERTS imagery, the information extracted from the 1/60,000 scale photo will be used as weights for expanding the data from the third stage to the entire aerial photo.

The third stage of the design consists of sample strips of large scale (1/3,200) 70mm color IR photographs flown across the areas of the 1/60,000 scale aerial photos. Each sample strip is nearly 10 kilometers in length. On these photos, detailed analyses of the range vegetation complexes and densities are being made. Then, a small number of these area is visited on the ground where the actual determinations of browse species and tons of forage per hectare are made. These measurements are expanded back through the sampling model to obtain estimates of forage yield for the country.

At this writing, all the data collection has been completed for the four ERTS frames in the northern part of Iran throughout the Elburz Mountains from Tabriz to Mashhad. The three scales of imagery are now being analyzed through which the ground data will be expanded. The final interpretations of the ERTS imagery over the entire area will be done on the color mosaic that is now being prepared for Iran. The data collection for the southern part of Iran will be conducted in early spring of 1974.

SECTION VI

ERTS-1 Applications in Soil Sciences

This report has been prepared by :

I. Sadighian, M.S. Senior Pedologist

"ERTS-1 APPLICATIONS IN SOIL SCIENCES"

INTRODUCTION:

An area of approximately 30,000 sq. Kilometers, the Dasht-e-Qazvin region, was chosen for a pilot project, in which an attempt was made to assess the value of ERTS imagery in large scale soil mapping.

Geographically, Dasht-e-Qazvin is bounded to the East, North, and West by the Alborz Mountain range, while to the south the Central Iranian ranges form the boundary of this unit. (Fig-1)

This semi-arid intermountain basin is characterized by an average rainfall of 225mm per annum, and a temperature range of-3^{o}C in the winter to 39^{o}C in summer. In terms of water supply, this area, being part of the Greater Tehran Watershed, is fed by the southern Alborz drainage network as well as extensive sub-surface sources, in the form of deep wells.

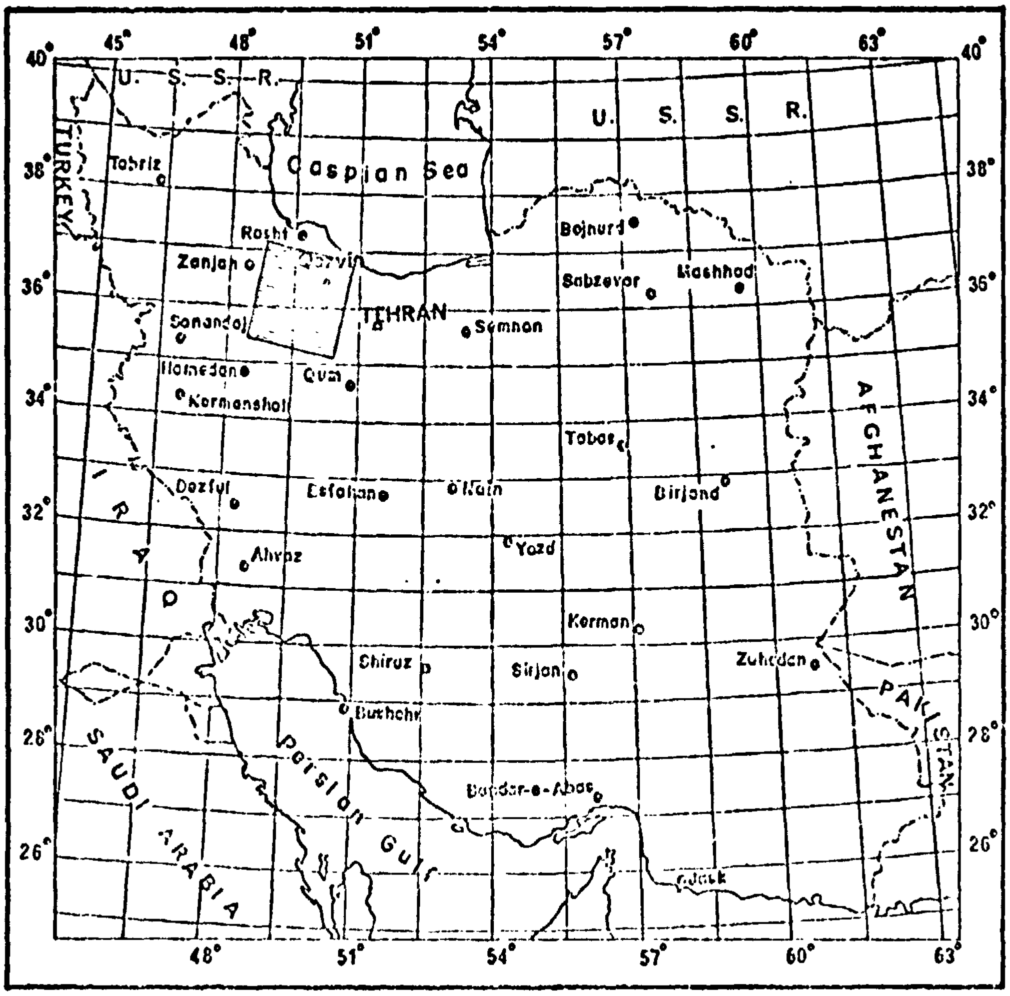


Fig-1 . Qazvin Test Site Location

AREA OF STUDY:

The area chosen for the present preliminary study is part of the Dasht-e-Qazvin intermountain basin, which is one of the most fertile basins in Iran, and is presently being intensely cultivated.

The main reasons for the choice of the above mentioned area for initiating pedological studies using ERTS imagery are as follows :

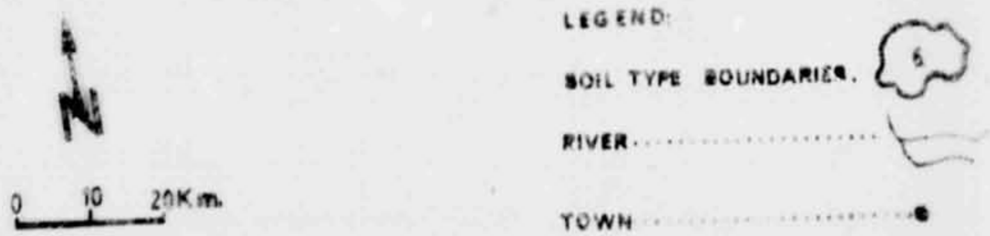
1. Excellent ERTS-1 coverage of the area, especially the image take on 3 June 1973 on which the present study is based.

2. Geographically, as well as in terms of climate, this area can be considered very representative of the various areas under cultivation in Iran, and is therefore a good region for trials in soil mapping using ERTS-1 images.

3. This is one of the only regions in Iran, where adequately accurate "ground truth" is available. in the form of soil maps at 1:20,000, and almost all other data that may be considered relevant in such a study.

4. The proximity of the area of study to Tehran, facilitates any "ground truth" checking that may be required.

Figure - 2 ERTS-1 interpreted soil map of the Qazvin Test Site .



METHODOLOGY :

The main mode of analysis carried out for this survey has been as follows :

I. The reconnaissance level delineation of Soil Type of this area using 1/500,000,MSS, band 5 imagery, based on change of tone, colour and texture.

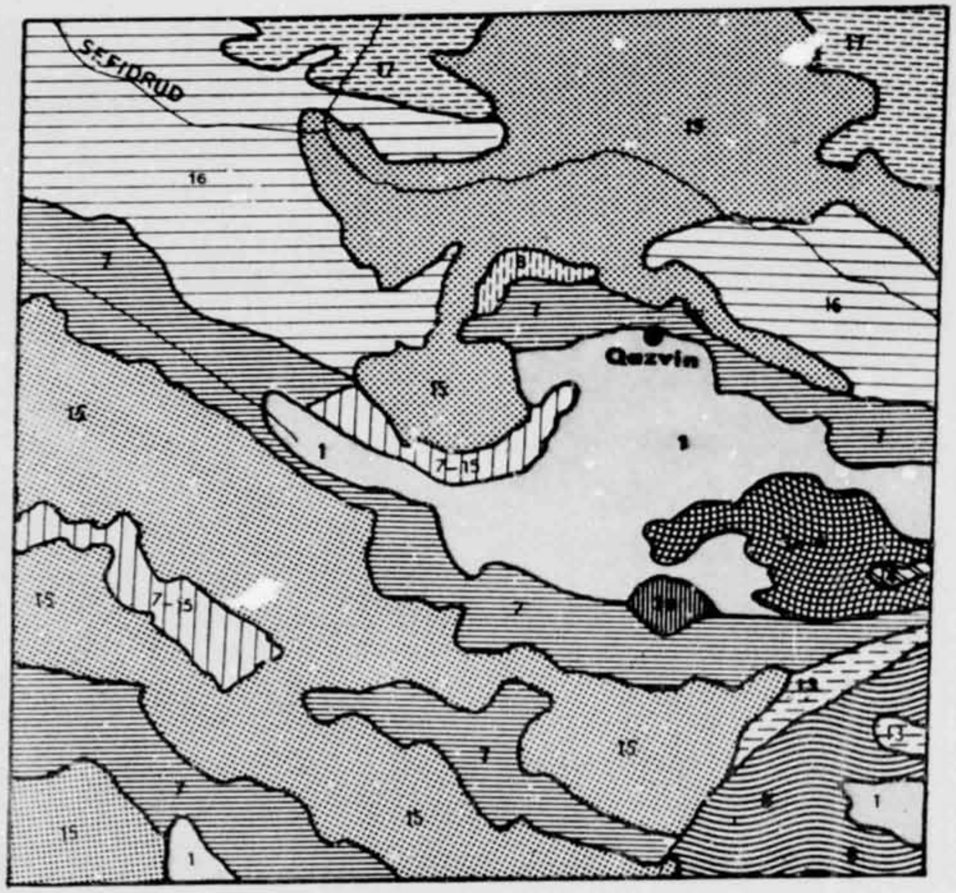
II. The use of false colour composite imagery (bands 4,5 and 7), for a more detailed identification of the soil boundaries plotted above.

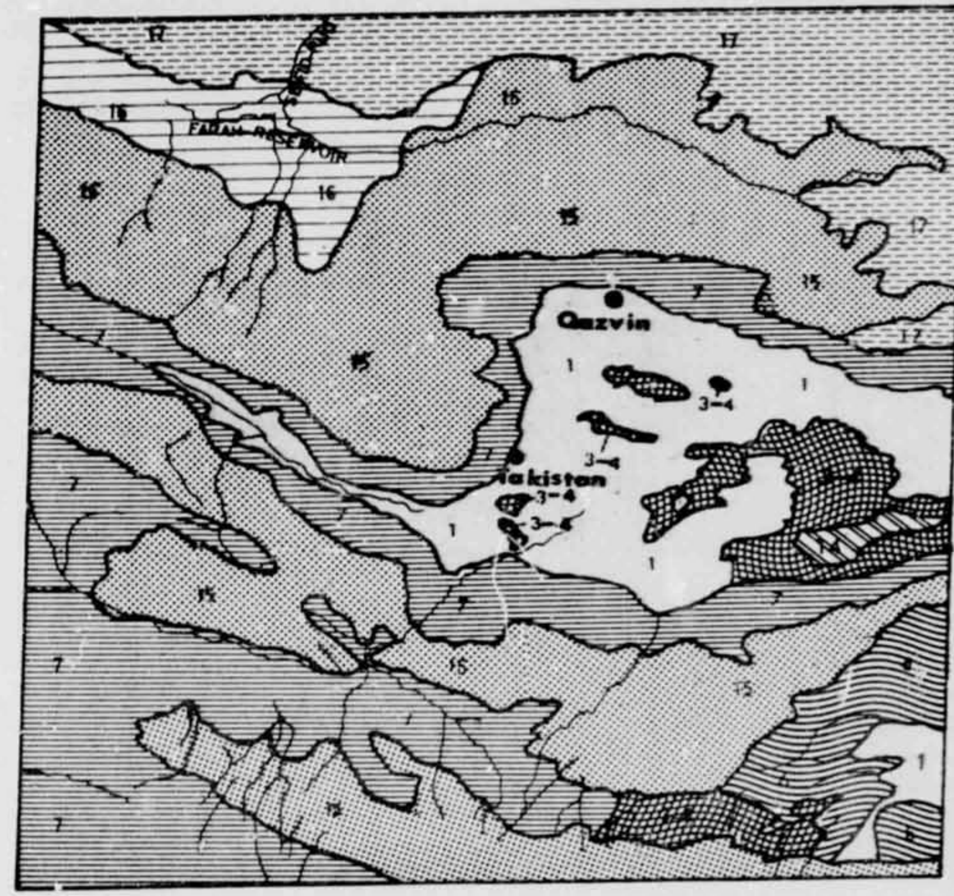
III. The use of colour additive viewer techniques for the final detailed discrimination of soil types, as well as vegetative cover and associated drainage patterns.

RESULTS :

Using ERTS-1, MSS band 5, imagery, several soil associations based on tonal and textural contrasts were recognized. These are shown on Fig. 2 and also diagramatically in Fig-3.

Fig3 , shows the presently available soil map of this area prepared by the Soil Institute of Iran, as compared to the map obtained using ERTS-1 imagery.





Soil Association Map Of Qazvin Region

(Soil Institute Of Iran)

ERTS-1 Interpretation Map

Scale Approximately 1:1500 000

Figure-3 Comparison of ERTS-1 interpreted map with that produced by the Soil Institute of Iran.

LEGEND

SOIL-ASSOCIATION

1	Fine Textured Alluvial Soils.
2a	Coarse Textured Alluvial and Colluvial Soils and Regosols.
[illegible]	Salt Marsh Soils.
6	Sierozem Soils.
7	Brown Soils.
8	Chestnut Soils.
7-15	Brown Soils - Lithosols.
13	Calcareous Lithosols - Desert and Sierozem Soils.
14	Calcareous Lithosols (from Saliferous and gypsiferous marls) - Desert and Sierozem Soils (including salt plugs).
15	Calcareous Lithosols - Brown Soils and Chestnut Soils.
16	Lithosols (from igneous rocks) - Brown soils and sierozem Soils.
17	Lithosols - Brown forest Soils and Rendzinas.

The striking resemblance between Figures 3a and 3b, clearly illustrates the value and utility of ERTS-1 imagery in soil studies.

As can be seen on Figure 3, in general, most of the soil types present, were differentiable using changes in contrast and texture on the ERTS-1 1:500,000 imagery.

There were however some difficulties encountered in the separation of Brown Soils (7) and Brown Soils - Lithosols (7-15). This problem, though expected due to the very small differences in the composition of the soil types, is hoped to be overcome by using 1:250,000 Band 5 imagery in conjunction with false colour enhancements of the area. It should be emphasised that any soil boundaries manifesting themselves with poor tonal contrasts have not been drawn on figure 2b, in order to give the ERTS-produced map the maximum credibility possible.

A particular advantage of the ERTS-1 imagery as compared to conventional soil maps is its repetitive nature, making possible the detection of seasonal soil types which may not have been included in the conventional soil map. An example of this phenomenon is the identification of patches of Salt Marsh Soils (3-4) south of the town of Qazvin, which are not recorded on the Soil Institute map. Notwithstanding, the soil map of this area is otherwise considered adequately viable for general soil type identifications, hence detailed "ground truth" studies were not undertaken for the present study . Nevertheless, even in this case it can be seen that some of the boundaries in fig 2b could be corrected or made more up to date using the ERTS-1 imagery.

For Iran the great value of this type of excercies is not primarily correcting existing maps, although this is obviously an asset, but to carry out a similar excercise in more remote and "unknown" areas. This in conjunction with a small associated "ground truth" program, will enable one to prepare a general soil map of a very large area, which would be, both very time consuming, as well as extremely costly, if conventional methods were use.

In this context, although our studies have not reached a stage where we might be in a position to carry out a comparative cost analysis between ERTS-1 interpretation cost as compared with aircraft data, we would readily agree with Dr. Colwell of Berkelly california, who has reported a reduction in analysis and interpretation costs of up to 20 times, using ERTS data. It is our opinion that in a country like Iran, where c. unication problems coupled with extreme weather condi .s tend to increase survey costs enormously, the figure proposed by Dr. Colwell in at best a minimum.

Another major advantage of the ERTS-1 imagery is its potential for digital use. This means that by using well chosen "trained" samples for computer analysis, a quick and reasonably accurate means for obtaining soil maps over large areas is at our disposal.

SECTION VII

Experiments in Urban Land-Use analysis using ERTS-1 Digital Tapes

This report has been prepared by :

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EXPERIMENTS IN URBAN LAND-USE ANALYSIS USING ERTS-1 DIGITAL TAPES

Introduction

In April, 1973, having performed a considerable amount of analysis using the 70 mm and 9"x9" NASA film products, the Government of Iran began to investigate the potential of the computer compatible digital tapes. The motivation for this investigation was two-fold: first, conversations with other active investigators had suggested that the dynamic range of radiometric intensity present on the digital tapes exceeded that of any of the image format film products; and second, a number of applications relevant to Iranian needs call for the rapid assessment of area and for the differentiation of types of ground cover. Reports from workers using digital methods (Sheffield, 1972) had shown that area estimation and ground cover analysis could be performed using computer processing of the ERTS-1 tapes to good effect.

Investigations to date have been confined to the analysis of tapes of an area surrounding Tehran (See Figure-1).

Digital Processing

Following a digital expansion of the computer stored image of the Tehran image shown in Figure-1 and output to a film recording device, it was possible using bands 5 and 7 of the MSS Imagery to see clear evidence of road networks in and around Tehran. Using this image, taken on 5 October, 1972, the Plan Organization set out to apply a sequence of Digital Image Processing techniques, with the specific objective of sharpening the road nets visible in the image,

FIGURE - 1

Tehran frame from ERTS-1 digital tapes, Band 5 (using a gray level slicing and area computation). Each of these applications should benefit from an appropriate use of the computer-compatible tapes provided by ERTS-1 .

Plans for Continuing Work Using Digital Tapes

The work of the Plan Organization using the ERTS-1 digital tapes is still at an early stage. In the next reporting period, it is proposed to evaluate images of the same area in bands 4 and 6, to determine their potential for land-use analysis similar to that now being conducted using bands 5 and 7.

It is also proposed to perform experiments in the area of multispectral analysis using classification programs that have been developed for crop classification in the United States. The Plan Organization is currently investigating the availability of the LAESYS programs, developed by purdue University, for use on the 370/145 computer located at the Plan Organization in Tehran.
Additional analytical programs and output recording devices are also under consideration.

Conclusions

Although the experiments to date using the digital tapes have been very limited, it seems clear already that they represent an information source of considerable promise. The first results obtained suggest that their radiometric range and ground resolution are superior to that of the film products. It therefore seems logical to perform a considerable amount of digital analysis on the ERTS-1 tapes, before moving to image production. The Plan Organization of Iran looks forward to a continuing series of experiments utilizing ERTS-1 digital tapes, in applications to agriculture and forestry (using multispectral analysis), to hydrology and turbidity analysis (using intensity adjustments and area computation), geological analysis and urban land-use analysis (using enhancement techniques) and to snow cover mapping and of providing a first analysis of land use within the urban area of Tehran. The choice of bands 5 and 7 reflected experience derived in work using the 70 mm and nine-inch film products, which suggested these bands should show most clearly the road networks.

The sequence of digital operations performed on the tapes was as follows:

1. Reformat ERTS tapes of Northern Iran to separate spectral bands.
2. Gray scale adjust band 5 (red) to linearly stretch the gray level values from 5 to 95 into the range 0 to 255.
3. Output the adjusted picture to a Litton Image Recorder. A 1536x1536 window was initially displayed. This was used to determine the location of a 512x512 window showing the city of Tehran and environs.
4. The unadjusted original image was windowed to separate out the appropriate 512x512 region and this region was subjected to the Laplacian operation. This operation computes at each point an isotropic derivative and consequently designates the location of edges in the scene.
5. This Laplacian image was gray scale adjusted to give gray levels in the range 0 to 255.
6. The adjusted Laplacian and the original image were added together.
7. The adjusted Laplacian was added to the result of step (6)
8. The result of step (7) was gray scale adjusted to fill the range 0 to 255.
9. The result of step (8) was output to the Litton Recorder.
10. The segment of the image produced in step (9) that exhibits the city of Tehran itself was photographically enlarged and printed on high contrast paper.

FIGURE - 2

City of Tehran from ERTS-1 digital tapes, Band 5

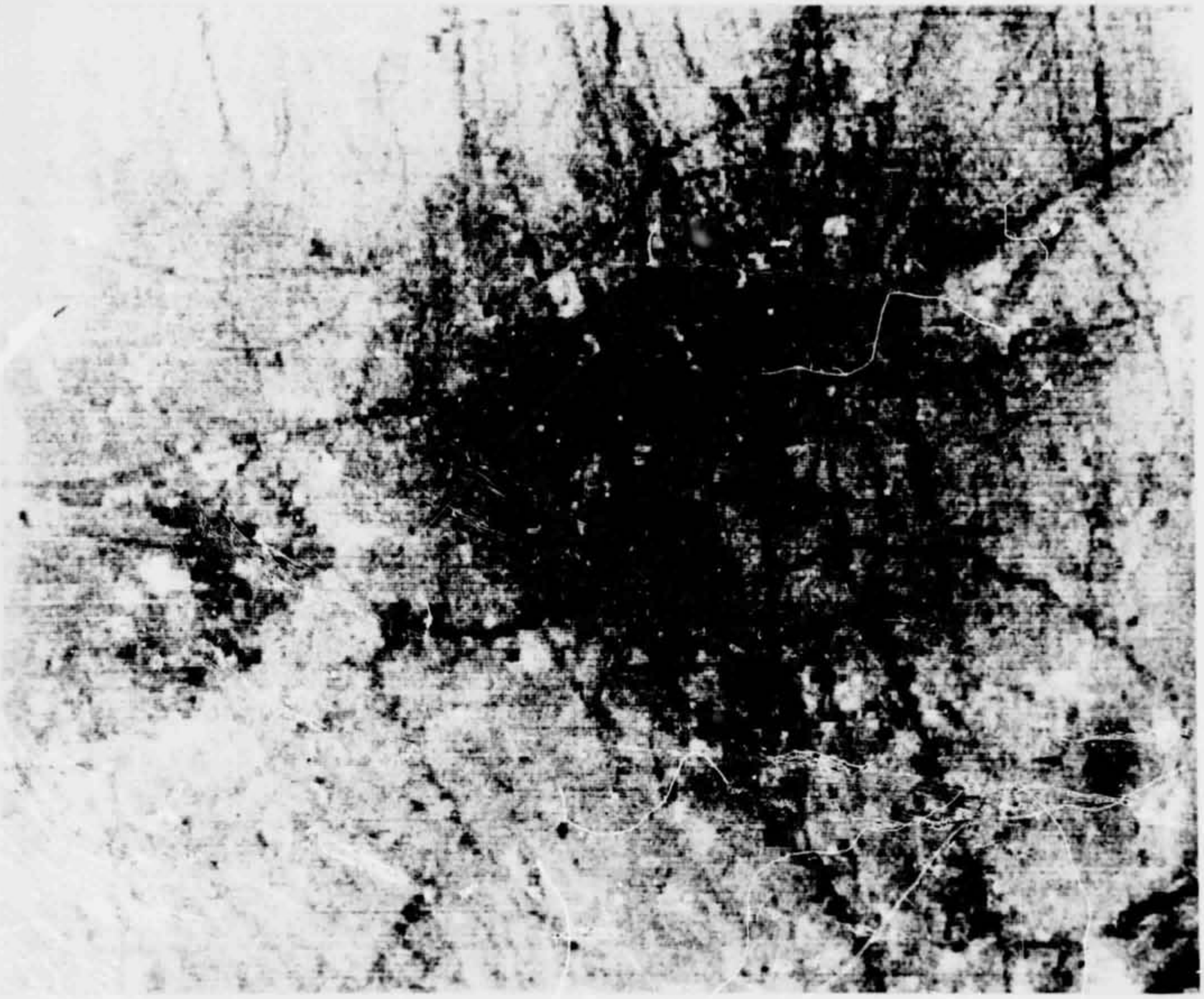

FIGURE - 3

City of Tehran from ERTS-1 digital
tapes, Band 7 (Scale approximately 1:100,000)

The addition of the Laplacian to the original image is an edge enhancement operation that sacrifices radiometric fidelity for sharpness or crispness of lines and edges. Similar operations were performed on Band 7 (second IR band). The final product, created as the end product of the above sequence, is displayed in Figures 2 and 3.

The images of Figures - 2 and 3 were compared with a standard commercial highway and urban feature map of Tehran. A Bausch and Lomb zoom transfer scope was used to overlay the map and the image. The device permits rotation, translation and differential scale change of the two, so that a very accurate overlay was possible.

It is apparent that the ERTS-1 image revealed urban developments that had occurred since the production of the map (dated 1970, but probably containing a good deal of information that had not been updated since 1968). In particular, major new building developments were readily identified.

The city can be partitioned into several land-use categories simply by delineating between basic tone and texture groups on the image. For example, the central business district of Tehran is imaged as a region of scattered black picture elements on a dark gray background. It is noticeable that the road network is less discernible in the central part of the city than it is in the older sections, and that at the scale displayed here single major buildings produce definite recognizable effects on the image tone.

It is clear that even with a ground resolution of only 70 meters, ERTS-1 offers a tool under good cloud-free conditions by which urban developments in major cities can be easily and cheaply identified, at least to a first level of accuracy.

SECTION VIII

The Cartographic Aspects of ERTS-1 Imagery

This report has been prepared by :

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Interpretation Laboratory

CARTOGRAPHIC ASPECTS OF ERTS-1 IMAGERY

At this point it is worth discussing some of the "cartographic" characteristics of the ERTS-1 imagery, and in particular the mosaic. Photogrammetrically this is an uncontrolled mosaic, but it is much more accurate for its scale than any controlled aerial photography mosaic in x-y errors, primarily due to the absence of x-y errors, caused by tilts in the camera and to excellent dimensional stability of the film and digital data.

Errors of a single frame 1:1,000,000 are not increased by reproduction, as first generation and fourth generation positives have essentially identical geometrical errors (based on monocomparator work by Colvocoresses of the U. S. Geological Survey).

The largest error is in scale, although this is relatively removed if all 70 mm images are enlarged at the same time with the same enlarger settings. However, the achievement of exactly 1:1,000,000 scale is very difficult because of the problem of precisely identifying geodetic control points. We can probably achieve two parts in 10,000 (0.2 mm across) scale accuracy. Thus, the scale from mosaic sheet to mosaic sheet may vary from 1:1,000,200 to 1.999,800.

Using least squares solutions of a best fit to ground control, it appears that a standard error of ±300 meters is usually acheived for bulk MSS imagery. There is a variation of the error from ±225 meters to ±400 meters in imagery of different dates with early (July 1972) imagery being geometrically less accurate. This means that at 1:1,000,000 routine accuracy of ±0.3 mm per frame can be achieved.

Enough for a single frame, but how accurate is a sheet of twenty frames? Little has been done (from a written literature search) on errors of mosaics because standard photo mosaics have high errors due to the inaccuracies inherent in the original geometry of the entire system. It appears that standard error propagation in a mosaic of ERTS images would be a random walk system along a line from point to point. If so, the error is about ±0.45 mm for lines across 4 to 6 frames. This is consistent with the mosaics we have observed. However, it probably reaches a plateau at 7-10 images after which the rate of error accumulation decreases because of the correlating effects of the frames on either side, which inhibit error propagation above certain visible limits. Thus the error over many frames would approach an asymptote of perhaps ±0.7 mm.

This means that a 1,000,000 scale ERTS photomap may meet National Map Accuracy Standards. In future work efforts will be made to identify established geopoints (geodetic ground control points) on the imagery in order to determine or confirm the geometric fidelity of such uncontrolled mosaics and investigate the feasibility and value of compiling ERTS mosaics with control. Iran has a geodetic network (triangulation and radio trilateration) and is currently establishing a series of positions utilizing the Doppler geoceiver and active navigation satellites.

SECTION IX

Conclusion

CONCLUSION

This report is a compilation of the results obtained from investigations using ERTS-1 imagery in the fields of geology, water resources, agriculture, soil sciences, and cartography, at the Remote Sensing and Data Collection Division of the Plan and Budget Organization. These results have been found to be extremely fruitful and encouraging, and have indicated that spacecraft imagery analysis can play a major role in the effective development and utilization of natural resources in Iran.

A number of studies are continuing in all the above mentioned disciplines. A list of programs planned for the future, or presently at hand, is included at the end of each section.

In order to optimize the effectiveness of future investigations, extensive training programs in the field of remote sensing with particular emphasis on ERTS data interpretation have been planned. It is hoped that by the end of 1975, a large cadre of specialists will be available to carry out numerous investigations on a national scale.

Finally, in view of the extremely promissing results obtained thus far from the analysis of ERTS data, the Imperial Government of Iran, through its Plan and Budget Organization has reached the decision to establish a regional ground station, with full complementary recording and processing facilities. It is envisaged that the station will be operational by early 1976, and thus serve both national and regional needs.

SECTION X

Bibliography

SECTION X

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