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RESEARCH ON RECOGNITION of the GEOLOGIC FRAMEWORK of PORPHYRY COPPER DEPOSITS ERTS-I IMAGERY

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FINAL REPORT
September 1975

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Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

RESEARCH ON RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Summary Report and 10 Appendices

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PREFACE

This is the final report of ERTS-1 project entitled, "Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery," PR-510, Contract NASA-21769. It consists of a brief summary which states the positive results pertinent to porphyry copper exploration followed by 10 appendices which consist of the results on six test areas. Each of the 10 appendices may be treated as separate reports.

Appendix

I Haenggi, W. T., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site: Earth Satellite Corp. rept.

II Haenggi, W. T., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site: Earth Satellite Corp. rept.

III Lyon, R. J. P., and Haenggi, W. T., 1974, Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site: Earth Satellite Corp. rept.

IV Prindle, R. O., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Silverton, Colorado test site: Earth Satellite Corp. rept.

V Prindle, R. O., Haenggi, W. T., and Erskine, M. C., 1974, Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site: Earth Satellite Corp. rept.

VI Prindle, R. O., Lyon, R. J. P., Haenggi, W. T., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site: Earth Satellite Corp. rept.

VII Allan, J. W., Andrews, R. K., Ross, H. P., and Wilson, J. C., 1974, Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery, Ray Test Site, Arizona: Kennecott Exploration, Inc. rept.

VIII Bamford, R. W., 1974, Interpretation and evaluation of ERTS imagery from the Ok Tedi area, Central New Guinea: Kennecott Exploration, Inc. rept.

IX Bamford, R. W., 1974, Band reflectance ratio maps from ERTS-1 data over two copper prospects in New Guinea: Kennecott Exploration, Inc. rept.

X Barrett, L. F., 1974, Interpretation of one frame of U-2 infrared imagery in Gila County, Arizona: Kennecott Exploration, Inc. rept.

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Appendix IX -- Band Reflectance Ratio Maps from ERTS-1 Data Over Two Copper Prospects in New Guinea

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RESEARCH ON RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

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15. Supplementary Notes

16. Abstract The usefulness of bulk-processed ERTS-1 imagery in exploration for porphyry copper deposits in six test areas is described. The investigations found many new linear and circular features not previously shown on published maps. These features prompted novel tectonic classification and analysis. The general conclusion reached is that bulk-processed ERTS imagery by itself is not of great value to porphyry copper exploration programs. However, the imagery may be of value in: 1) evaluating exploration data base from a synoptic viewpoint, 2) extrapolating favorable mineral provinces, 3) detecting intrusions in structurally simple environments, 4) providing low-cost drainage maps in remote regions.

Direct detection of previously undiscovered prospects does not seem likely on bulk-processed imagery. The U-2 underflight infrared photography is, however, quite useful as a mapping aid in reconnaissance exploration. Future exploration-related interpretation of the ERTS-1 imagery should take place at a scale of 1:250,000 in order to facilitate comparison with exploration data compilations.

17. Key Words (Selected by Author(s))		18. Distribution Statement
Porphyry copper exploration		
Papua New Guinea	Arizona	
ERTS-1 Imagery	Colorado	
Queensland	Nevada	
Alaska		

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PREFACE

This is the final report of ERTS-1 project entitled, "Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery," PR-510, Contract NASA-21769. Only the positive results pertinent to porphyry copper exploration are summarized here, and the reader is directed to the underlying technical reports in the Appendix for more detail.

The objective of this investigation was to examine the general hypothesis:

> Mineral deposits of the copper/molybdenum porphyry type occur in a characteristic geologic setting which is recognizable in the surface data presented on space acquired imagery.

The general conclusion of this investigation is that the hypothesis stated above is not correct, but the synoptic viewpoint of the imagery is useful in:

1) extrapolation of favorable known mineral provinces,
2) detection of intrusions in structurally simple environments.

However, the imagery must be integrated in a multidisciplinary exploration program to achieve that usefulness.

RESEARCH ON RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

PR-510, CONTRACT NASA-21769

INTRODUCTION

In 1971, Kennecott proposed an experiment using ERTS-1 imagery and ground data to make tectonic and geologic maps of six regions of known porphyry copper/molybdenum mineralization. These six regions exhibit a wide range in climate, geography, topography, latitude, postmineral cover, and age of mineralization (Table 1). The experiment included a proposal to define how each of the above variables affected the interpretability of the ERTS imagery. In addition, a closely related technical objective was to establish a correlation between surface (ERTS) data and subsurface data (e.g., magnetics and gravity) in the porphyry environment.

Owing to economic constraints, a greatly reduced effort was proposed and approved in 1972. Imagery of the six test areas (Table 1) was examined by Earth Satellite Corporation, who produced maps based on their naive (not aided by published information) interpretation of the imagery. Their maps show linear features, circular features, drainage pattern, fold axes, intrusive centers, volcanic centers, tectonic map units, and, in some cases, lithologic units. The usefulness of the ERTS imagery in these six reports was assessed by comparing their naive interpretation to published and compiled ground truth data (1-6)*.

The imagery of the Ok Tedi and Ray test areas was also studied in detail by Kennecott's exploration and research staff. In the Ray Test Site (7), three things were examined:

1) The usefulness of the imagery to practicing exploration geologists,

2) The usefulness of the imagery in detecting mineral-related structures,

3) The relationship of structural interpretation of the imagery to structural interpretations of aeromagnetic maps.

The two reports on the Ok Tedi, PNG test area analyze the tectonic framework of the porphyry copper deposits (8) and the possible usefulness of band-reflectance ratio maps in porphyry copper prospecting in New Guinea (9). A report was also prepared on the usefulness of the U-2 imagery in porphyry copper prospecting in the Ray, Arizona test area (10).

*Numbers refer to underlying technical reports listed in Table 2 and attached as appendices I to X.

RESULTS

General

The investigators found many new linear and circular features not previously shown on published maps. These new features prompted novel tectonic classification and analysis especially in the Ray and Ely areas. Tectonic analyses of the Ok Tedi, Tanacross, and Silverton areas follow conventional interpretations.

Circular features are mapped in many cases and are interpreted as exposed or covered intrusive centers. Allan, et al, (7) disputes this in the Ray area and feels the circular features in most cases represent the weathering pattern of equidimensional mountain blocks. The small circular features reported in the Ok Tedi test area (6 and 8) are valid and useful correlations with Tertiary intrusion and volcanism in this remote part of New Guinea. Some of the circular features found in Ray, Ely, and Silverton test areas are certainly related to caldera collapse structures of Middle Tertiary age. They are younger than the events which produced the porphyry copper deposits in western North America.

Several major faults of regional dimensions, such as the Denali fault in Alaska and the Colorado Mineral Belt structures in Colorado are detected in the imagery. Many more faults and regional structures are found in the imagery than exist on present maps. However, the validity and importance of these linears remain unknown because of the prohibitive field expense of investigating the significance and validity of a particular linear.

Interpretation Methods

Most of the interpretation was performed on transparent overlays of black and white mosaics of Channel 7, 6, or 5 bulk-processed ERTS imagery at a scale of 1:1,000,000. Color composites of Channels 4, 5, and 7 at a scale of 1:500,000 were also used. The exploration geologists (7) were more at home with the color composite at a scale of 1:250,000. Channel 6 imagery was most useful in the Ray, Arizona and Papua - New Guinea test areas and Channel 5 was used on Ely. Seasonal changes were useful in the Silverton and Tanacross test areas. The I^2-S viewer was used to good advantage in the Mt. Perry, Queensland and Ok Tedi, PNG test areas and may warrant broader application.

The detail needed to solve the practical exploration problem is better illustrated on 1:250,000 imagery than on 1:1,000,000. A general conclusion is that the imagery is not useful by itself for mineral exploration. Other data must be combined with imagery in order to remove the time ambiguity present in all photointerpretation. Data from other sources generally become quite meaningless to mineral exploration when synthesized at scales smaller than 1:250,000. Therefore, it is important to enlarge the imagery to 1:250,000 so that it may be viewed at the same scale as the supporting data.

The enlargements of the bulk-processed imagery are quite coarse. Therefore, an improvement would be to use precision-processed imagery at a scale of 1:250,000 in future mineral-related studies.

U-2 underflight infrared photography was used as an aid in interpreting ERTS-1 imagery in the Ray test area (10) and was found to be a useful tool in reconnaissance exploration. A geologic interpretation from one image is compared to previous mapping and the appearance of formational rock units is described.

Value of ERTS Imagery to Porphyry Copper Exploration

The general conclusion reached here is that ERTS imagery by itself is not of great value to porphyry copper exploration programs. Equivalent funds could be used far more profitably to produce regional data bases, such as regional aeromagnetic maps with far more value to mineral exploration programs. However, when used in context of a multidisciplinary exploration program, the ERTS imagery can be of value in the following ways:

1) Synoptic view point.

2) Extrapolation of favorable known mineral provinces or known mineral related structures.

3) Detection of intrusions in structurally simple environments.

4) Drainage maps in remote, poorly mapped regions.

Exploration data compilation is a routine activity which precedes and accompanies most reconnaissance exploration programs. The kinds of data that are compiled are lithologic information, structural information, mining data, prospect data, geochemical data, aeromagnetic data and other geological, geophysical, and geochemical information. Most exploration groups routinely update these compilations as their knowledge increases about a given region. There is, however, a great disparity between the scale at which these data are collected and the scale at which they are compiled. Thus, a given compilation may contain scraps of information from quite unrelated sources, at many scales, and with a wide range of accuracy. The value of ERTS imagery to these compilations is that it may provide a coherent framework within which to evaluate and interpret seemingly unrelated scraps of data and to unify data compiled from many sources at much larger scales. In addition, the scale of the ERTS imagery forces the receptive mineral exploration geologist to review his data base and his exploration concepts from a different point of view. This review may produce the seeds of an idea which will ultimately lead to significant discovery, although the connection between that discovery, years hence, and the synoptic review of ERTS imagery, years before, will undoubtedly be lost.

The research on the Ok Tedi test area shows that a known favorable exploration environment can be extrapolated to uncharted regions by use of the ERTS imagery (6 and 8). The examination of the Silverton test area shows that the structures which form the Colorado Mineral Belt are recognizable in the imagery (4). Such structures are common in many mineral provinces and a mechanism to extrapolate such a structure into previously unrecognized areas would, of course, be valuable to mineral reconnaissance.

The work on the Ok Tedi test area shows that igneous intrusions, some of which are demonstratably mineral related, can be detected in this poorly mapped area if the region is structurally simple. In this case, a portion of the region is composed of flat-lying clastic and calcareous sediments which are gently folded and punctuated by igneous intrusions, some of which are mineral related.

All forms of mineral exploration depend on accurate location data, and if that is lacking, then accurate maps must be constructed either from photography, or radar imagery. In some parts of the world, maps are so poor that detailed knowledge of the drainage pattern is lacking. The ERTS imagery can remedy this need in some cases. In the case of New Guinea, many thousands of dollars were used to construct such a drainage map with radar imagery. This same job could have been accomplished with the ERTS imagery (6) had it been available.

In addition to the several things that ERTS imagery can do for the mineral exploration geologist, there are several things that it cannot do. Deposit detection seems very unlikely with the ERTS imagery. No characteristic signature was observed over many known prospects and undeveloped porphyry copper deposits on the bulk-processed imagery.

The imagery seems particularly useless to mineral exploration in areas of abundant postmineral cover such as the Basin and Range physiographic province of western North America. Here, more than 80% of the surface materials are composed of thick gravel, volcanics, lake deposits, or other rocks which are 20 to 100 million years younger than the porphyry copper deposits. These younger rocks cannot be easily separated from the older mineral deposit bearing rocks on the imagery. Further in the Basin and Range province, many authors and investigators feel that the structural framework which existed at the time of porphyry copper emplacement (55-65 m.y. bp) was grossly different and perhaps at right angles to the structural framework which existed during the formation of the current Basin and Range physiographic province. This structural overprint greatly obfuscates the underlying mineral-related structures. This problem affects structural and tectonic studies in general and is not specific to ERTS imagery.

TABLE 1. LOCATION OF TEST SITES

Site No.	Age of Location of Central Points	Age of Mineral-ization	Relief	Annual Temp. Range (°F)	Annual Rainfall (Inches)
1	Silverton, Colorado 38°00'N 107°30'W	30, 60 my.	High	-20° - +80°	40
2	Ray, Arizona 32°45'N, 111°30'W	60 my.	Moderate	+40° - +120°	9
3	Ely, Nevada 39°15' N 115°00'W	35, 120 my.	Low-Moderate	0° - +100°	14
4	Tanacross, Alaska 63°00'N 142°00'W	60 my.?	Moderate	-50° - +60°	10
5	Ok Tedi, Papua-New Guinea 06°00'S 141°15'E	5 my.	High	+60° - +85°	120-500
6	Mt. Perry, Queensland 24°30'S 151°30E	220 my.	Low	+50° - +70°	30-80

VEGETATION

1	Spruce-fir forest, sub-Alpine open woodland, Alpine meadow sagebrush, pine mountain forest and pine-juniper scrub.
2	Short grass Savanna, thinned pine and pine-juniper forest and creosote desert.
3	Sagebrush desert, thinned-pine and pine-juniper forest.
4	Mountain tundra, Piedmont spruce, high mountain spruce and sub-Alpine open woodland.
5	Tropical rain forest.
6	Savanna and temperate eucalyptus forest.

TABLE 2

TECHNICAL REPORTS ON ERTS-1 PROJECT -- NASA 21769

1) Haenggi, W. T., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site: Earth Satellite Corp. rept.

2) Haenggi, W. T., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site: Earth Satellite Corp. rept.

3) Lyon, R. J. P., and Haenggi, W. T., 1974, Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site: Earth Satellite Corp. rept.

4) Prindle, R. O., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Silverton, Colorado test site: Earth Satellite Corp. rept.

5) Prindle, R. O., Haenggi, W. T., and Erskine, M. C., 1974, Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site: Earth Satellite Corp. rept.

6) Prindle, R. O., Lyon, R. J. P., Haenggi, W. T., and Erskine, M. C., 1974, Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site: Earth Satellite Corp. rept.

7) Allan, J. W., Andrews, R. K., Ross, H. P., and Wilson, J. C., 1974, Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery, Ray Test Site, Arizona: Kennecott Exploration, Inc. rept.

8) Bamford, R. W., 1974, Interpretation and evaluation of ERTS imagery from the Ok Tedi area, Central New Guinea: Kennecott Exploration, Inc. rept.

9) Bamford, R. W., 1974, Band reflectance ratio maps from ERTS-1 data over two copper prospects in New Guinea: Kennecott Exploration, Inc. rept.

10) Barrett, L. F., 1974, Interpretation of one frame of U-2 infrared imagery in Gila County, Arizona: Kennecott Exploration, Inc. rept.

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site

W. T. Haenggi and M. C. Erskine, Jr.
Earth Satellite Corporation
2150 Shattuck Avenue
Berkeley, California 94704

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		6. Performing Organization Code
7. Author(s) W. T. Haenggi and M. C. Erskine, Jr.		8. Performing Organization Report No.
9. Performing Organization Name and Address Earth Satellite Corporation 2150 Shattuck Avenue Berkeley, California 94704		10. Work Unit No.
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15. Supplementary Notes

16. Abstract ERTS imagery has its greatest application in the study of regional tectonism. The synoptic view afforded by ERTS enables exploration geologists to have a "big picture" available for reference while working on local problems or studying regional tectonics. A porphyry copper model is discussed that is based upon Sillitoe's model, plate tectonic theories and tectonic units observed on ERTS. This model incorporates (1) collision between the Farallon and American Plates, and (2) development of a "shear subduction" zone along the present "Walker Lane" with generation of porphyry copper deposits as the Farallon plate was consumed.

On the ERTS mosaic it is evident that the Walker Lane can be extended into Arizona and extrapolated into the "Texas lineament zone" and both have a genetic relationship with the San Andreas fault.

Large (60km) and medium (30km) circular features observed on ERTS are associated with Laramide igneous intrusions. Smaller features (5 to 15km) do not have as obvious a relationship to Laramide intrusions. However, seven of thirty such features are associated with known porphyries.

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PREFACE

This report is one of six similar reports which describe research results accomplished by Earth Satellite Corporation under ERTS-1 project entitled, "Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery," PR 510 contract NAS5-21769. A list of these six reports follows:

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site: Earth Satellite Corp. rept.

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site: Earth Satellite Corp. rept.

Lyon, R.J.P, and Haenggi, W. T., 1974, Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site: Earth Satellite Corp. rept.

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Prindle, R. O., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site: Earth Satellite Corp. rept.

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INTRODUCTION

A mosaic of 19 ERTS black-and-white frames, covering approximately 400,000 square kilometers, at a scale of 1:1,000,000 was used to construct the ERTS Tectonic Map (Plate 1). Two color composite prints, made from bands 4, 5, and 7 at a scale of 1:500,000 were used for supplementary interpretation and for studies of alteration zones associated with porphyry copper deposits. Imagery used in the mosaic is from band 6, but several images from band 7 were used for local interpretation where print quality is superior to that of band 6 imagery. Table 1 lists ERTS imagery used in this study and Figure 1 shows the area.

The tectonic interpretation was done on transparent overlays to the ERTS mosaic. Geodetic control is from World Aeronautical Charts ONC G-19 and H-22 (1:1,000,000; Lambert Conformable Conic Projection). During our study, it became apparent that accurate location (less than 2 kilometer error) of geological features noted on ERTS imagery with respect to published maps can be troublesome. This is principally due to differences between map projections and the ERTS Universal Transverse Mercator (UTM) projection. Problems inherent in comparing data depicted on various maps with ERTS were underestimated during our investigation of the Ray test area. As a consequence, our overlays do not align perfectly. In our studies of the other test areas, except for Ok Tedi, we resolved this problem by constructing drainage maps, on transparent overlays, from the World Aeronautical Charts. ERTS interpretations were then performed on the overlays with constant adjustment of the ERTS drainage to the overlay. The resultant map is a transferral of ERTS data to a Lambert Conformable

Table 1. Imagery, Arizona

Mosaic

Date	I.D. No.	Center Coord.	Sun EL	Sun AZ
26 Sept. 72	1065-17204-6	N 34-38/W 108-18	47	141
01 Nov. 72	1101-17215-6	N 33-02/W 108-50	37	150
	1101-17221-6	N 31-36/W 109-16	38	149
	1101-17224-6	N 30-11/W 109-42	39	148
02 Nov. 72	1102-17265-6	N 35-51/W 109-27	35	152
	1102-17271-6	N 34-25/W 109-54	36	151
	1102-17274-6	N 32-59/W 110-19	37	150
	1102-17280-6	N 31-33/W 110-44	38	149
03 Nov. 72	1103-17323-6	N 35-52/W 110-51	34	152
	1103-17330-6	N 34-25/W 111-18	35	151
	1103-17332-6	N 33-00/W 111-44	36	150
	1103-17335-6	N 31-35/W 112-10	38	150
	1103-17341-6	N 30-09/W 112-35	39	149
04 Nov. 72	1104-17382-6	N 35-51/W 112-19	34	152
	1104-17393-6	N 31-33/W 113-37	37	150
20 Nov. 72	1120-17283-6	N 30-15/W 111-08	34	151
22 Nov. 72	1122-17385-6	N 34-31/W 112-43	30	153
	1122-17391-6	N 33-05/W 113-09	32	152
	1122-17394-6	N 31-39/W 113-35	33	152

Color Composites

Date	I.D. No.	Center Coord.	Sun EL	Sun AZ
02 Nov. 72	1102-17274-4, 5 & 7	N 32-59/W 110-19	37	150
03 Nov. 72	1103-17332-4, 5 & 7	N 33-60/W 111-44	36	150

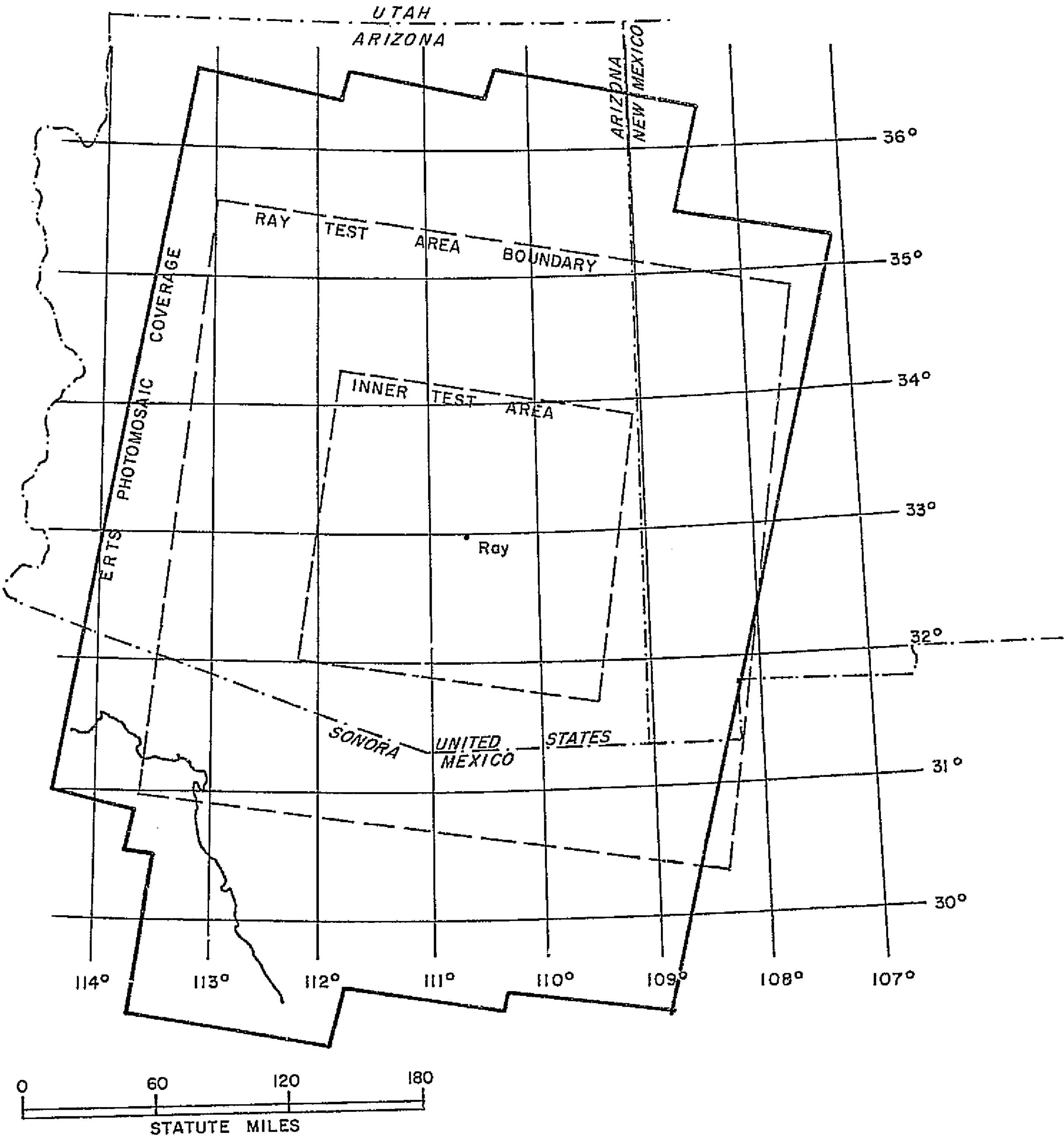

Figure 1. Ray Test Area

Conic Projection. However, it was not feasible to redo this procedure in the Arizona study, thus the ERTS tectonic map therefore is on a UTM Projection because the working base is the ERTS mosaic.

We feel that ERTS imagery in Arizona has its greatest application in the study of regional tectonism. The synoptic view afforded by ERTS and the UTM projection, which permits easy compilation of mosaics, permits a unique overview of regional relationships. This enables every exploration geologist to have the "big picture" available for reference while working on local problems or studying regional tectonics. In the past only a few very experienced men had access to this picture, which they acquired through years of work and reading. They carried the bulk of it in their minds where it could not be used effectively by less experienced geologists.

ERTS TECTONIC MAP

The ERTS Tectonic Map shows:

1. Major faults 2. Circular features 3. Tectonic units 4. Cinder cones and volcanoes	Taken from ERTS imagery
5. Laramide intrusions	From published maps
6. Porphyry copper deposits, copper, gold silver, lead, molybdenum and zinc occurrences	From ERTS imagery, where pits are visible, and published data

The principal geological output from studies of ERTS imagery is the recognition and/or delineation of linear features. Presently we feel that these lineations are generally associated with regional fault systems. However, extensive field checking is necessary to verify their nature. Lineations are recognized on ERTS imagery by conventional photogeologic techniques; examples are:

1. Alignment of drainages, scarps, and topographic highs and lows
2. Tonal contrasts across linear features
3. Bands of varying widths
4. Vegetation contrasts.

Many lineations can be drawn on ERTS imagery and, if all such features are noted, the resultant map is a "hodge-podge" of data that is difficult, if not impossible, to interpret. In construction of the ERTS Tectonic Map. the interpreter attempts to show only those lineations which he feels have a high probability of being faults that can be recognized by field geologic studies. Thus many linears caused by alignment of topographic highs and lows are not shown nor are lineations connected where the interpreter cannot recognize continuity even though many aligned lineations are certainly related genetically and spatially. In short, we have tried to filter the data by interpreter judgement to produce a useful map for regional tectonic studies. We have not attempted to depict every linear feature shown by ERTS imagery.

Determination of the tectonic significance of the observed lineations and their relationship to ground-observed structures requires construction of regional tectonic models, checking of the models with literature data and new field observations.

In Arizona we have developed a tectonic model which utilizes plate tectonic theories and the concept of tectonic units. Brewer, et al., in a report to NASA (1973, NAS5-21745, ID #297A) developed a model for the same region based on a regional crustal stress system. Their model utilizes the San Andreas Fault system as a primary, right-lateral strike-slip fault caused by a horizontal principal stress aligned N10°W and relates all tectonic unit boundaries to re-orientation of this stress caused by faulting. Their tectonic units do not necessarily coincide with those used here, but there is general agreement. These models are neither unique nor mutually exclusive.

Our studies of ERTS imagery show that numerous circular features of varying sizes are readily recognized. Some of these features appear to be the result of igneous activity and in some cases they are recognized where existing maps do not portray igneous relationships. Frequently they are subtly shown by the existing maps but are quite distinct on ERTS imagery, hence the emphasis of them in our interpretations.

As in the case of linear features, a model must be constructed to explain the significance of the circular features. We developed a volcanogenic model to explain these structures and their relationship to porphyry-copper mineralization. This model, developed during this study, is in basic accord with one recently presented by Sillitoe (1973).

Our basis for differentiation of tectonic units is based on "tectonic style" which can be related to the total character of a group of related mesoscopic (as observed on ERTS imagery) features. Principal criteria used in defining the tectonic units are:

1. Orientation of linear parallel and subparallel features
2. Density of structural, stratigraphic and geomorphic features
3. Relief
4. Relative abundance of rock types
5. Mode of deformation
6. Recognizable features which cannot be precisely defined in geometric terms.

Characteristics of the thirteen tectonic units shown on the ERTS tectonic map are:

Unit I: Elongated ranges and valleys trending N35°W to N40°W; low ratio of narrow range areas to broad valley areas (approximately 1:3); spacing between valley axes 15 to 20 kilometers; very few structures cross from one range to the next; predominant faulting trends N40°W to N45°W and N5°E; scattered lava flows, many ranges with foliation and/or fault/fractures trending N50°E to N60°E (within ranges); bounded on west by San Andreas Fault zone and Gulf of California; abrupt northern termination at Gila-Salt River Lineament.

Unit II: Low ratio of range area to valley area (1:3); ranges oriented N-S; valley axes spaced about 35 kilometers; extensive pediment development; relatively low relief; extensively faulted with NW, NE, N-S, and E-W trending faults; numerous small circular features that in some cases correlate to detrital aprons (5 to 13 kilometer diameters).

Unit III: Similar to Unit II but dominated by large circular feature (55 kilometer diameter); predominant major fault trends are N80°W ("clean-cut" trends), N10°W, and N50°W to N60°W.

Unit IV: Mountainous (5:1 ratio range to valley area); sharp, well-developed relief, ranges and valleys trend north; spacing between valley axes averages 45 kilometers except in extreme north where spacing is 15 to 20 kilometers; numerous major lineations crossing topographic trends at N50°W to N70°W and N40°E to N50°E; well-developed dendritic to rectilinear drainage, common evidence of volcanism (cones, lava flows); numerous intrusions (verified by Geological Map of Arizona, Wilson, E. D., et al., 1969); small to very small circular features in northwestern part of unit (2 to 10 kilometer diameters).

Unit V: Almost identical to Unit IV except ranges and valleys better defined and more faulting; predominant fault trend is N10°E and secondary fault trend is N70°E; scattered small circular structures (diameters to 10 kilometers) and one large, poorly-defined circular structure in northwest part of unit (60 kilometer diameter).

Unit VI: Irregular and unordered distribution of ranges and valleys (range to valley area ratio 1:3); predominant fault trends

N20°W to N75°W; some pediment development; large circular feature in north-central part of unit (60 kilometer diameter), scattered small circular features (to 13 kilometer diameter); boundaries with adjacent units poorly defined.

Unit VII: Very low ratio of range area to valley area (<1:10); predominant fault trend N70°E.

Unit VIII: Few ranges and valleys with 1:1 ratio between range and valley areas; some closed drainage basins (Wilcox Playa); sharp, rugged relief in mountains; ranges and valley trend N45°W, en-echelon arrangement of ranges; intensely faulted, numerous faults trend N10°W, N45°W, N60°E to N70°E, and N15°E; scattered small circular features (to 10 kilometers diameter), large circular feature (55 kilometer diameter) astride eastern boundary at junction of Units VIII, IX, X and XI.

Unit IX: Low ratio range to valley areas (1:4); some closed drainage basins, low relief, ranges and valleys trend N25°W, 30 kilometer spacing valley axes; principal faulting along ranges (N20°W to N30°W); several very small to small (3 to 10 kilometer diameters) and one medium-sized (20 kilometer diameter) circular features in northwest part of unit.

Unit X: Mountainous (southern part) to plateau (Colorado Plateau), much evidence of volcanism (cinder cones and lava flows); dominant fault trend N50°E, subordinant N70°W, N10°E and N20°W to N30°W fault trends; scattered small and medium-sized circular features between northwest boundary and major N45°E trending fault zone passing through Safford, Arizona.

Unit XI: Similar in most respects to Unit X and separated from it because suggested de-coupling on persistent N50°E trending fault zone along southeastern boundary; two large circular features (30 and 57 kilometer diameters).

Unit XII: Numerous cinder cones, one major volcano; some faulting along N50°E trending faults.

Unit XIII: Scattered cinder cones; probably basa.tic lava; rhombic shape of unit; occurs at intersection three tectonic units (V, VIII, and IX) and at eastern termination of major N80°W trending fault zone.

Comparison of ERTS Tectonic Map with Published Tectonic Maps and Aeromagnetic Data

Plate 2 is a compilation of structural data from the Tectonic Map of the United States (1962) and the Geologic Map of Arizona (1969). Comparison of the ERTS Tectonic Map (Plate 1) with this map shows:

1. Good general agreement of ERTS data with published data but poor detailed correlation of fault locations and trends.
2. Published data shows predominance of N and NW trending faults whereas ERTS show numerous NE trending faults as well as N and NW faults.
3. ERTS interpretation shows most faults to be relatively short (less than one kilometer) but does show alignment of faults for long distances whereas published data shows numerous long, continuous fault zones.
4. ERTS interpretation does not clearly define thrust fault zones, and in many cases does not recognize them as faults.
5. Published data does not recognize circular features as structures, although parts of them are mapped as faults.

Most of the faults shown on the published maps are boundary faults between basins and ranges. In the ERTS interpretation such faults are shown only where a lineation other than the alignment of parallel topographic highs (ranges) and lows (basins) is recognized. The interpreter is aware that these features are generally considered to be the result of "Basin and Range" tectonism, hence bounded by faults, but did not interpret faults along range fronts unless there are reasons other than the topographic break between ranges and valleys for their presence.

The predominance of N and NW trending faults over other directions of faulting on published maps is attributed to these directions being the predominant trends of ranges in the region. The large number of NE and E-W trending faults on the ERTS interpretation is powerful evidence that ERTS imagery is providing a means of rapid and accurate tectonic mapping that surpasses the detail of published data at the same scale. A program of literature and field checking should be designed to determine validity of this concept.

The determination from ERTS imagery that many "major throughgoing features,' when examined by other means, consist of relatively short (compared to the overall length of the feature) segments should be evaluated. The best place to recognize this phenomenon is along a N45°E trending lineation which follows the Gila River southward from Morenci, crosses the Pinajeno and Galiuro mountains and terminates southwest of the San Pedro River, at the edge of the Rincon Mountains (about 260 kilometers). At first glance this feature appears continuous on ERTS imagery, but detailed examination shows that it is composed of many segments 5 to 15 kilometers long. This lineation does not appear as a tectonic unit boundary in our interpretation yet may be a reflection of deep crustal (or mantle) structure. Another lineation trends N80°W from Tectonic Unit XIII across the area shown on Plate 1 to a volcanic area near the Gulf of California (380 kilometers). These are major tectonic features, which to our knowledge are recognized for the first time on ERTS imagery.

The significance of circular features is uncertain but there is a good correlation of these with Laramide intrusions. There is a general trimodal distribution of size of the feature--large ones 50 to 60 kilometer diameters, medium ones about 30 kilometer diameters, and numerous small ones 5 to 15 kilometer diameters. In general, the large circular features are incomplete (do not show up as full circles) and the medium and smaller ones tend to be complete.

Three (Sierrita Mountains, Mt. Turnbull, Santa Catalina Mountains) of the four large circular features (60 km) and the two medium ones (30 km), in the test area, are associated with Laramide intrusive igneous rocks while the other (Sierra Ancha) occurs in Precambrian sedimentary, volcanic and metamorphic rocks. We believe that the large and medium circular features are associated with Laramide igneous intrusions and suggest that the Sierra Ancha feature may be an area where the intrusions have not yet been exposed by erosion.

Young (Late Tertiary-Recent) volcanic fields and volcanoes are readily recognized on ERTS imagery. The ERTS Tectonic Map shows locations of cinder cones and volcanoes. Interpretation of cinder cones is not exact in that some features believed to be cones are probably erosional remnants of flow rocks, and all cinder cones are probably not recognized.

The other components of the ERTS Tectonic Map, Laramide intrusions, porphyry copper deposits and non-ferrous mineral localities are taken from published data. Open-pit copper mines are readily recognized on ERTS imagery, thus these mines were located directly on the imagery rather than by transposition from other data.

Interpretation of the Residual Aeromagnetic Map of Arizona (1970) for linear trends indicative of faulting is presented by Plate 3. Comparison of Plate 3 with the ERTS Tectonic Map shows general agreement in trends of faults and a good correlation between the number of faults interpreted from each source for given areas. However, there is a poor correlation between locations of faults presented by the two maps. One possible reason for this is that data for the magnetic map were collected at elevations of about 6,000 feet above terrain along North-South traverses spaced three miles apart. This causes anomalies due to sharp basement discontinuities, e.g., faults, to appear as broad features on the map (over three miles wide).

If tectonic units were derived from the magnetic data by evaluation of trend, continuity and density of faults, they would be in good agreement with those picked from ERTS imagery studies. This suggests that most of the surface phenomena used to denote tectonic units on ERTS imagery have similar origins to features which cause the magnetic lineations. Their origins must be at depths where temperatures are below the Curie point (less than 20 kilometers), hence within the crust. Several major lineations (as shown on ERTS) do not have magnetic signatures. Notable among these are the N45°E linear from Morenci to the Rincon Mountains and the N80°W linear from Tectonic Unit XIII across the area of Plate 1 which are mentioned previously. These latter features may have an origin within the mantle where temperatures are above the Curie point.

Study of the aeromagnetic map and porphyry copper locations shows that the porphyries are generally located on the flanks of magnetic lows, but there is no preferred orientation of magnetic faults or trends associated with the porphyries nor do they occur at intersections of features noted in the interpretation.

TECTONICS

Plate Tectonic Model

We have demonstrated that tectonic units can be readily delineated by the use of ERTS imagery where parameters that otherwise cannot be viewed in their entirety are mesoscopic. The units described have properties similar to Polygonal Crustal Blocks described by Cloos (1939).

Analysis of the tectonic units recognized in the test area seems promising for development of a coherent regional model which can be used to describe the environment of porphyry copper deposits. Sillitoe (1972) describes a plate tectonic model based on partial melting of oceanic crustal blocks in subduction zones at compressive junctions between lithospheric plates. His model appears reasonable for Andean and other copper provinces but is difficult to apply in Arizona because the nature of the subduction zone is not clearly evident. More recently, Livingston (1973) suggests that there is a systematic variation in age of porphyry copper mineralization from northwest (Mineral Park) to southeast (La Caridad) and that this is compatible with a "hot spot" origin as the North American plate rotated clockwise during the interval 72 to 52 m.y. before the present. Although intriguing, we feel that this hypothesis does not account for the origin of the deposits because the systematic age variation is a statistic (regression of distance from Mineral Park on age) and does not hold up when applied in detail to the deposits.

We suggest that the Arizona porphyries formed near a compressive junction of the Farallon and American plates but the relationship is complicated, with respect to Sillitoe's model, by transcurrent and/or transform faulting along the "Walker Lane." Our model is generalized and intended more as an example of the types of provocative hypotheses that can originate from ERTS imagery studies than as a definitive work on the region.

The "Walker Lane" structural system is generally interpreted as the structural depression, east of and sub-parallel to the Sierra Nevada in California and Nevada (with an extension into Oregon). When ERTS mosaics of Nevada and Arizona are combined, it is evident that the "Walker Lane" can be readily extended into Arizona. In Arizona, the "Walker Lane" becomes broader than in Nevada and California, extending from the southwestern margin of the Colorado Plateau to the projection of the San Andreas Fault along the Gulf of California. This area includes all the porphyry copper deposits in Arizona. Further extrapolation and a slight change in trend of the northern boundary of this zone extends part of it into the "Texas Lineament Zone." Thus, the ERTS interpretation suggests the hypothesis that, in Arizona, the "Walker Lane," San Andreas Fault System and "Texas Lineament Zone," have a genetic relationship. Application of plate tectonics theories to this observation suggests that the systems are related to interaction between two lithospheric plates. The model incorporates:

1. Collision between the Farallon and American plates during the Mesozoic Era, possibly as early as Early Jurassic (to account for the Bisbee deposit).

2. Development of a "shear-subduction" zone along the plate junction (present "Walker Lane") with attendant generation of porphyry copper deposits as the Farallon Plate was consumed along an irregular subduction zone.

In this model the plate junction is visualized as a combination shear and subduction zone. Shearing results from differential movement of the two plates along the junction, which causes a shear couple. Relative plate motion is not known with certainty; hence, the nature of transcurrent faulting along the "Walker Lane" (right or left lateral) is a matter of speculation. Simultaneously with shearing the Farallon Plate was consumed in a subduction zone. Figure 2 schematically shows the type of relationship we visualize.

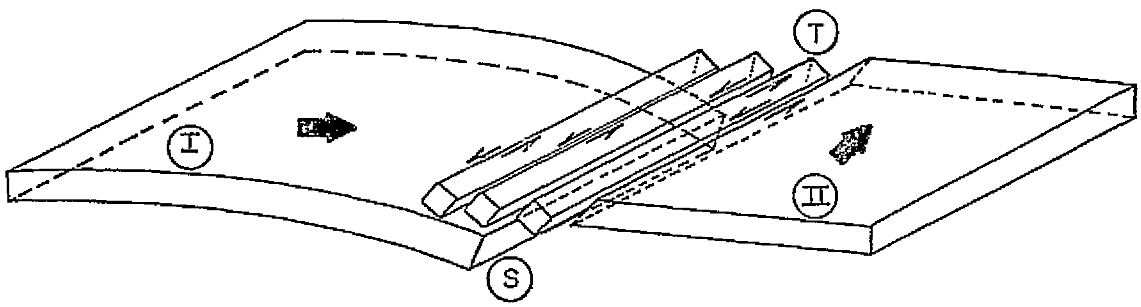

Figure 2. Schematic Illustration of Postulated Relationship for Creation of Shear and Subduction Zones along Junction between Colliding Plates. Large arrows indicate plate motion, T = transcurrent faulting (shearing) with relative displacement indicated by arrows, S = subduction zone where Plate I is consumed beneath Plate II.

If the basic tenets of this model are accepted, the NW trends reflected by the shapes of tectonic units of the "Walker Lane" (units I, II, III, IV, V, VI, VII, VIII, and IX) reflect shearing along the zone of plate junction.

Complexity of the shear zone can be related to lack of homogeneity in the plates, changes in frictional resistance with consequent "freezing" of existing shears and development of new ones as plate configuration due to subduction varied and to changes in plate motion directions. It is beyond the scope of this work to attempt to unravel these facets of the problem.

In conclusion, we feel that the basic model of Sillitoe (1972) seems applicable for the generation of porphyry copper deposits in Arizona once provision is made for the complex transcurrent faulting relationships, along the "Walker Lane," that we believe are the result of a complex collision between two plates.

Circular Feature Model

Large (60 kilometers) and medium (30 kilometers) circular or arculate features, with the possible exception of the Sierra Ancha structure, are associated with Laramide igneous intrusions (Plate 1). The smaller features (5 to 15 kilometers) do not have as obvious a relationship to Laramide intrusions, when studied at the scale of ERTS imagery, but seven of about thirty such features noted are associated with known porphyry copper deposits (Morenci, Safford, Globe-Maimi, Lakeshore, Chilito-Christmas, and two at San Manuel). Hence there appears to be a significant relationship of the small features as well as the large and medium ones to Laramide igneous intrusive activity.

A recent model of porphyry copper deposits relates them to comagmatic volcanic and intrusive igneous phenomena (Sillitoe, 1973). During our studies we derived a model for these features which is basically the same as Sillitoe's (Figure 3).

We relate the small circular features to surface manifestations (arching, caldera development, etc.) of the upper parts of the plutons associated with the system (-1 kilometer zone of Figure 3). The larger features are interpreted as expressions of batholitic sized plutons, presumably downward extensions of the system shown in Figure 3.

It would be convenient to relate size of circular feature to depth of erosion but, with the possible exception of some extremely small features (2 kilometers) in Mexico south of the test area (not shown by Plate 1), this does not seem to be a valid correlation. The circular features should occur in all gradations of size from small to large if depth of erosion were the control.

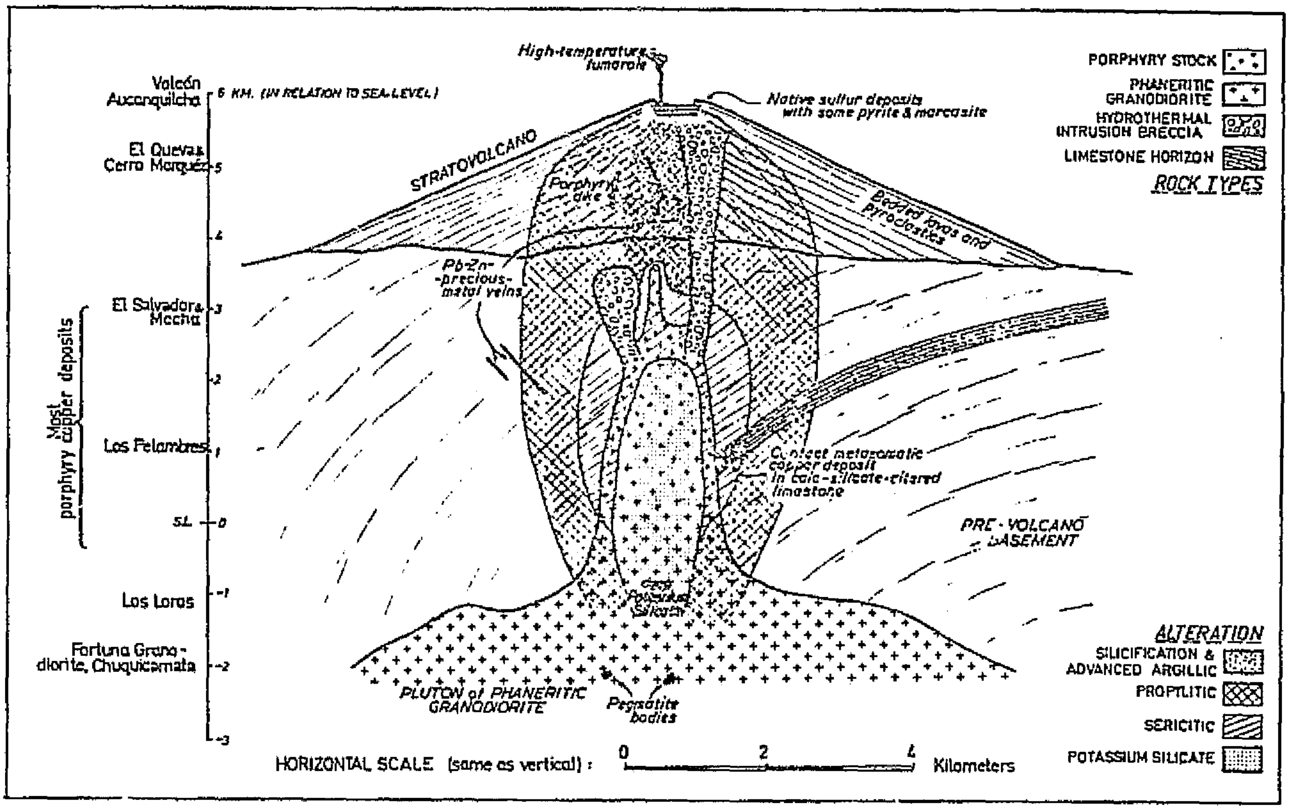

Figure 3. Idealized Cross Section of a Typical, Simple Porphyry Copper Deposit Showing its Position at the Boundary between Plutonic and Volcanic Environments. Vertical and horizontal dimensions are meant to be only approximate. (From Sillitoe, 1973.)

Because the features can be categorized by size with significant breaks between them, we feel that investigations relating to pluton shape, structural nature of the features (domes or basins), strength of country rock, contraction of magmas on cooling and relative ages of the features will be productive of viable models to explain their nature. These studies are beyond the scope of this study.

REFERENCES CITED

Brewer, W. A., M. C. Erskine, Jr., W. T. Haenggi, and R. O. Prindle, 1973, Mineral Exploration Potential of ERTS-1 Data (Draft), Earth Satellite Corporation, Final Report NASA Contract NAS5-21745, ID #297A.

Cloos, H., 1939, Hebung-Spaltung-Vulkanismus, Geologische Rundschau, V. 30, p. 401-527, 637-640.

Cohee, G. V. (Chairman), 1962, Tectonic Map of the United States (exclusive of Alaska and Hawaii) (Scale 1:1,000,000), U.S. Geological Survey and the American Association of Petroleum Geologists.

Livingston, D. E., 1973, The Age Variation of Porphyry Copper Deposits, Southern Basin and Range Province (Abs.), Paper Presented 1973 Annual Meeting, Geological Survey of America.

Sauck, W. A. and J. S. Sumner, 1970, Residual Aeromagnetic Map of Arizona, Department of Geological Sciences, University of Arizona, Tucson, Arizona.

Sillitoe, R. H., 1972, A Plate Tectonic Model for the Origin of Porphyry Copper Deposits, Economic Geology, Volume 67, p. 184-197.

________________, 1973, The Tops and Bottoms of Porphyry Copper Deposits, Economic Geology, Volume 68, p. 799-815.

U.S. Department of Commerce, 1965, Operational Navigational Charts (Scale 1:1,000,000) ONC, G-19 and H-22, National Ocean Survey, Washington, D.C.

Wilson, E. D., R. T. Moore and J. R. Cooper, 1969, Geologic Map of Arizona (Scale 1:500,000), Arizona Bureau of Mines and The U.S. Geological Survey.

Following
PLATES 1
Not filmed

APPENDIX II

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site

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December 1974
Final Report

Prepared for
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15. Supplementary Notes

16. Abstract

A tectonic map of the region centered on Ely, Nevada was made from a mosaic comprised of 20 ERTS images. Using plate tectonics and a model for porphyry copper emplacement developed for the Ray, Arizona test area, a new model was developed for the Basin and Range tectonism. The model incorporates a spreading center, within the American Plate, along the Snake River downwarp and its extension into Nevada.

Ten tectonic units were assigned to areas that have similar geological characteristics. Physiographically, these ten units differ principally in trends of ranges.

Two major fault trends are recognized: (1) N-S ± 10°; and (2) N45°E avg. (range N30°E to N60°E). Two secondary systems are also present: (1) E-W ± 10°; and (2) N20°W. The N-S system is the result of Basin and Range tectonism and common offsets of faults belonging to it along NE trending faults.

17. Key Words (Selected by Author(s))		18. Distribution Statement	
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7- ii

PREFACE

This report is one of six similar reports which describe research results accomplished by Earth Satellite Corporation under ERTS-1 project entitled, "Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery," PR 510 contract NAS5-21769. A list of these six reports follows:

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site: Earth Satellite Corp. rept.

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site: Earth Satellite Corp. rept.

Lyon, R.J.P, and Haenggi, W. T., 1974, Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site: Earth Satellite Corp. rept.

Prindle, R. O., and Erskine, M. C., Jr., 1974, Tectonic Interpretation of ERTS-1 imagery of the Silverton, Colorado test site: Earth Satellite Corp. rept.

Prindle, R. O., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site: Earth Satellite Corp. rept.

Prindle, R. O., Lyon, R.J.P., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site: Earth Satellite Corp. rept.

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INTRODUCTION

A mosaic of 20 ERTS black-and-white frames, covering approximately 420,000 square kilometers, at a scale of 1:1,000,000 was used to construct the ERTS Tectonic Map (Plate 1) and Lineation Interpretation (Plate 2). Four color composite prints, made from bands 4, 5, and 7 at a scale of 1:500,000 were used for supplementary interpretations. Imagery used in the mosaic is from band 5. Table 1 lists ERTS imagery used in this study and Figure 1 shows the area.

The tectonic interpretations were performed on transparent overlays to the ERTS mosaic. Geodetic control is from World Aeronautical Charts ONC F-16 and G-18 (1:1,000,000 Lambert Conformal Conic Projection). A stream drainage transparency was prepared from the Aeronautical Charts (streams not shown on Plates 1 and 2) and the interpretation was adjusted to it by shifting the drainage base to fit drainage on each ERTS frame before doing the work. The resultant maps are thus Lambert Conformable Conic Projections. For each ERTS frame, distortion between the ERTS and aeronautical chart projections is insignificant and location inaccuracies over the entire area should not exceed 2 millimeters (2 kilometers).

The method of investigation and use of ERTS imagery was similar to that used in the Ray, Arizona test area. As in Arizona, we conclude that the greatest application of ERTS imagery is in the study of regional tectonism.

Table 1. Imagery, Nevada

Date	I.D. No.	Center Coord.	Sun El.	Sun Az.
Mosaic				
16 Sept. 72	1055-18044-5	N 41-39/W 117-28	45	144
	1055-18050-S	N 40-14/W 117-59	46	142
	1055-18053-5	N 38-48/W 118-28	47	141
	1055-18055-5	N 37-22/W 118-56	48	139
15 Sept. 72	1054-17585-5	N 41-38/W 116-00	45	143
	1054-17592-5	N 40-14/W 116-30	46	142
	1054-17594-5	N 38-49/W 117-00	47	140
	1054-18001-5	N 37-23/W 117-28	48	139
14 Sept. 72	1053-17531-5	N 41-41/W 114-35	45	143
	1053-17533-5	N 40-16/W 115-05	46	142
	1053-17540-5	N 38-50/W 115-35	47	140
	1053-17542-5	N 37-24/W 116-03	48	138
13 Sept. 72	1052-17472-5	N 41-40/W 113-09	46	143
	1052-17475-5	N 40-14/W 113-40	47	141
	1052-17481-5	N 38-49/W 114-10	48	140
	1052-17484-5	N 37-23/W 114-38	48	138
12 Sept. 72	1051-17420-5	N 40-17/W 112-12	47	141
	1051-17423-5	N 38-51/W 112-41	48	139
	1051-17425-5	N 37-26/W 113-09	49	138
	1051-17432-5	N 36-01/W 113-36	50	136
Color Composites				
13 Sept. 72	1052-17475	N 40-14/W 113-40	47	141
	1052-17481	N 38-49/W 114-10	48	140
14 Sept. 72	1053-17533	N 40-16/W 115-05	46	142
	1053-17540	N 38-50/W 115-35	47	140

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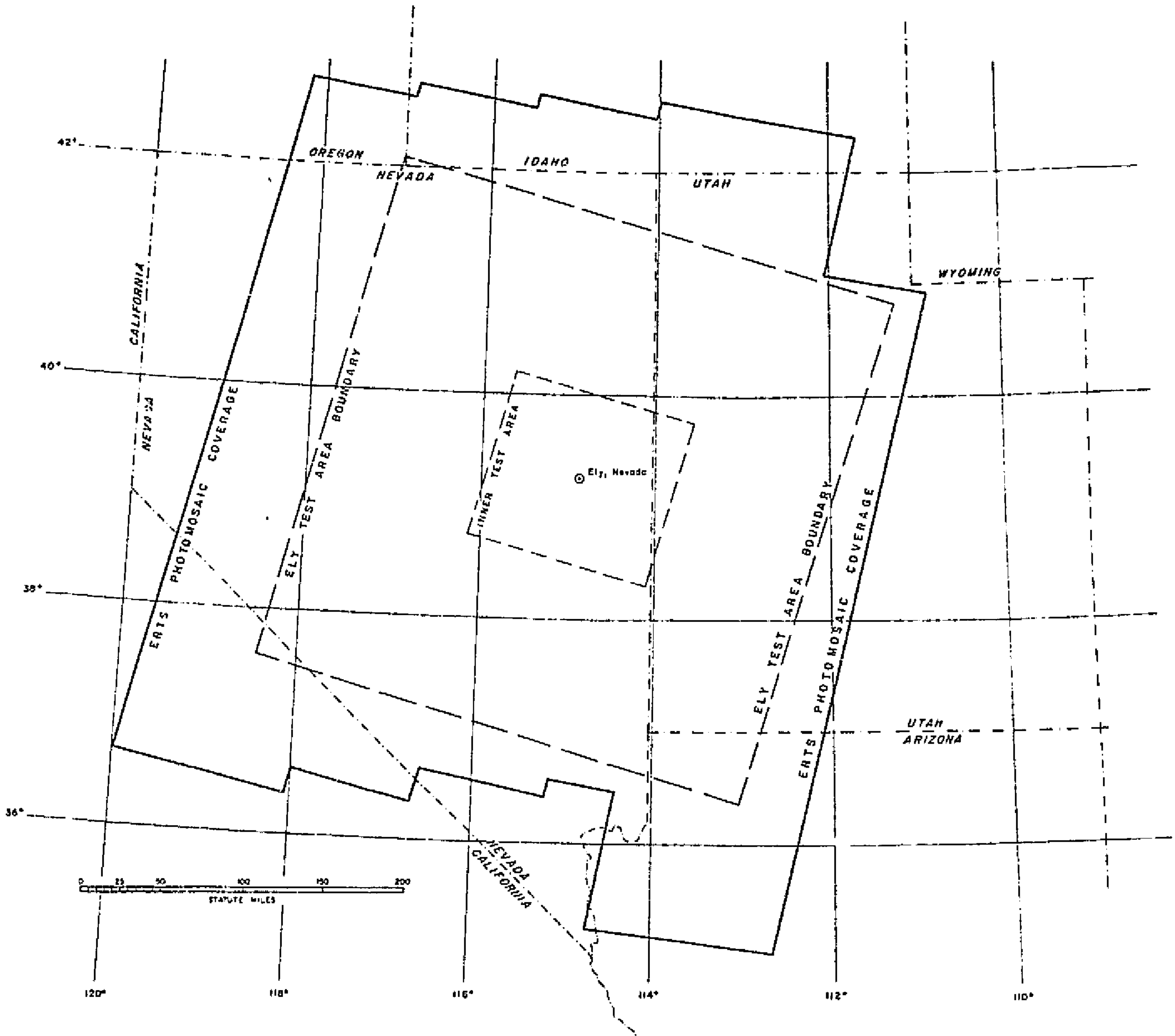

Figure 1. Ely, Nevada Test Area

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ERTS TECTONIC AND LINEATION INTERPRETATION MAPS

The ERTS Tectonic Map (Plate 1) shows:

1. Major faults (lineations)
2. Circular features
3. Tectonic units.

All features on the map are taken from ERTS imagery. The map shows only those lineations which the interpreter believes have a high probability of being faults that can be recognized by field geological studies. Many "Basin and Range" faults, those bounding the ranges, are not shown because they generally cannot be located on ERTS imagery by features other than topographic alignments. Using these alignments, readily defined from ERTS, and the typical Basin and Range models involving systems of horsts and grabens or tilted fault blocks, an interpreter can construct a tectonic map of the area that is similar to the Tectonic Map of the United States (1962). We have avoided this because placement of the faults would be based on a preconceived notion of the structural significance of topographic alignments rather than direct observation on ERTS imagery.

A further reason for deleting many of the "Basin and Range" faults is the nature of our study. We are attempting to define a geologic framework for emplacement of porphyry copper deposits. In Nevada, the known commercial porphyry deposits were formed during the Early Cretaceous Epoch (110 to 125 m.y. before the present), and Basin and Range structures characteristic of the area, developed within the past 17 m.y. (Stewart, 1971). Thus, genesis of the porphyry copper deposits cannot be related to

Basin and Range faulting, and elimination of the faults from a tectonic map devised for copper exploration seems desirable. Some caution must be used with this conclusion because the deposits can be affected by post-mineralization faulting, and knowledge of the nature of such faulting can be useful in exploration.

To evaluate the usefulness of ERTS imagery for detailed lineation studies, we have mapped the inner test area in detail (Plate 2). In contrast to the tectonic map, Plate 2 shows all lineations observable on ERTS imagery.

The mapped lineations were evaluated together with data from outside the inner test area to determine predominant fault trends and the presence or absence of regional fault systems. Two major fault systems are recognized; (1) N-S ± 10° and (2) N45°E avg. (range N30°E to N60°E). Two secondary systems are also present; (1) E-W ± 10°, and (2) N20°W.

The N-S system is certainly the result of Basin and Range tectonism and common offsets of faults belonging to it along NE trending faults (in a right-lateral sense) indicate that some faults of this latter group were formed or reactivated during Basin and Range deformation. Well developed repetition patterns of parallel fault trends, as observed in the Silverton and Ray test areas, are not present.

In addition to lineations, bedding and bed attitude, volcanic rocks are mapped on Plate 2. These features are mapped with the assistance of 2X magnification and stereo viewing in areas of side lap.

Circular features are common in the test area and are mapped on Plate 1. As in Arizona, there is a non-random distribution of size (diameter) of the features. The distribution is bimodal, consisting of medium-sized (25 to 30 kilometer diameters) and small (5 to 15 kilometer diameters) structures. These features do not appear on existing tectonic maps, with the exception of the medium-sized feature in Unit I at the edge of the map which is shown as a caldera on the Tectonic Map of North America (1969). When the ERTS tectonic map is compared with the Preliminary Geologic Map of Nevada (1965), the circular features are found in areas of outcropping Tertiary volcanic rocks and/or igneous intrusions. The porphyry copper deposits near Ely are associated with a medium-sized circular feature. As in Arizona, we propose a volcanogenic model to explain these structures.

Comparison of the Mineral Occurrence Map (Plate 3) with the ERTS Tectonic Map (Plate 1) shows that there is some relationship between circular features and non-ferrous mineral deposits but the correlation is not a good one. Nevertheless, we feel that the model presented for these features in our discussions of tectonics for the Ray test area is basically valid. Further literature and field studies are recommended to determine significance of the circular features in Nevada.

Tectonic units on Plate 1 are defined by "tectonic style." Principal criteria used for their definition are:

1. Orientation of linear parallel and subparallel features.
2. Density and configuration of structural, stratigraphic and geomorphic features.
3. Relative abundance of rock types.

Characteristics of the ten tectonic units shown on the ERTS Tectonic Map are:

Unit I: Range to valley area ratio 1:2; arcuate north trending ranges and valleys in west central part with radii of curvature about 50 kilometers (south of map area), predominant fault trend in ranges N60°E to N70°E; lava flows in western part; three medium (22 to 30 kilometer diameters) and two small (8 to 12 kilometer diameters off map) circular features in western part.

Unit II: Ranges and valleys aligned N45°W (ratio range to valley areas 1:2); extensive lava flows; extensive faulting in ranges with N5°W and N60°E to N65°E as predominant fault trends; one medium (20 kilometer diameter) circular feature (two small features off map to northwest); closed drainage areas.

Unit III: Orderly succession of ranges and valleys (range to valley area ratio 1:2), topographic trend of N15°E with 30 kilometer spacing between valley axes; ranges extensively faulted with predominant fault trends of N55°E and N80°E and some faults trending N10°W; numerous small and medium-sized circular features (most off map to west); numerous closed drainage basins.

Unit IV: Similar to Unit VII except ranges and valleys trend N25°E; and circular features absent.

Unit V: Similar to Units IV and VII but ranges and valleys trend N10°W; small circular feature (6 kilometer diameter) on boundary with Unit IV and medium-sized circular feature (20 kilometer diameter) on boundary with Unit VI.

Univ VI: Low ratio range to valley areas (1:5); no predominant orientation ranges and valleys; principal fault trends N-S and N60°E; extensive lava flows; numerous small-to-medium-sized circular features (10 kilometer to 25 kilometer diameters) including two "bullseye" features.

Unit VII: Low ratio range to valley areas (1:5); ranges trend north, extensive salt flats; predominant fault trends N-S, NE and NW; scattered medium circular features (20-25 kilometer diameters).

Unit VIII: Elongate ranges and valleys trending north (ratio range to valley area 1:2); spacing between valley axes about 30 kilometers; ranges extensively faulted, predominant fault trends N-S, N20°E, N50°E, N75°E and N35°W; numerous small (5 to 15 kilometer diameters), and medium (25 to 30 kilometer diameters) circular features.

Unit IX: One broad range (15 kilometers) trending N15°E (1:3 range to valley area ratio); predominant fault trends N40°E, N80°E, N85°W, N40°W; one small circular feature (9 kilometer diameter).

Unit X: Similar to Unit VIII but ranges and valleys trend N10°W; no circular features except for one astride boundary with Unit III.

TECTONICS

We have demonstrated that ERTS imagery is useful for dividing regions into tectonic units. Using these units, we have developed plate tectonic models for study of the geological environment during emplacement of porphyry copper deposits in Nevada and for subsequent Basin and Range tectonism.

The model for porphyry copper emplacement is an extension of the one developed for the Ray, Arizona test area. The model for Basin and Range tectonism is based on the interpretation of a spreading center, within the American Plate, along the Snake River Downwarp and its extension into Nevada. These models are developed to show the types of provocative hypotheses that can be developed with the aid of ERTS imagery and are not intended to be definitive works.

In our discussions we will refer to:

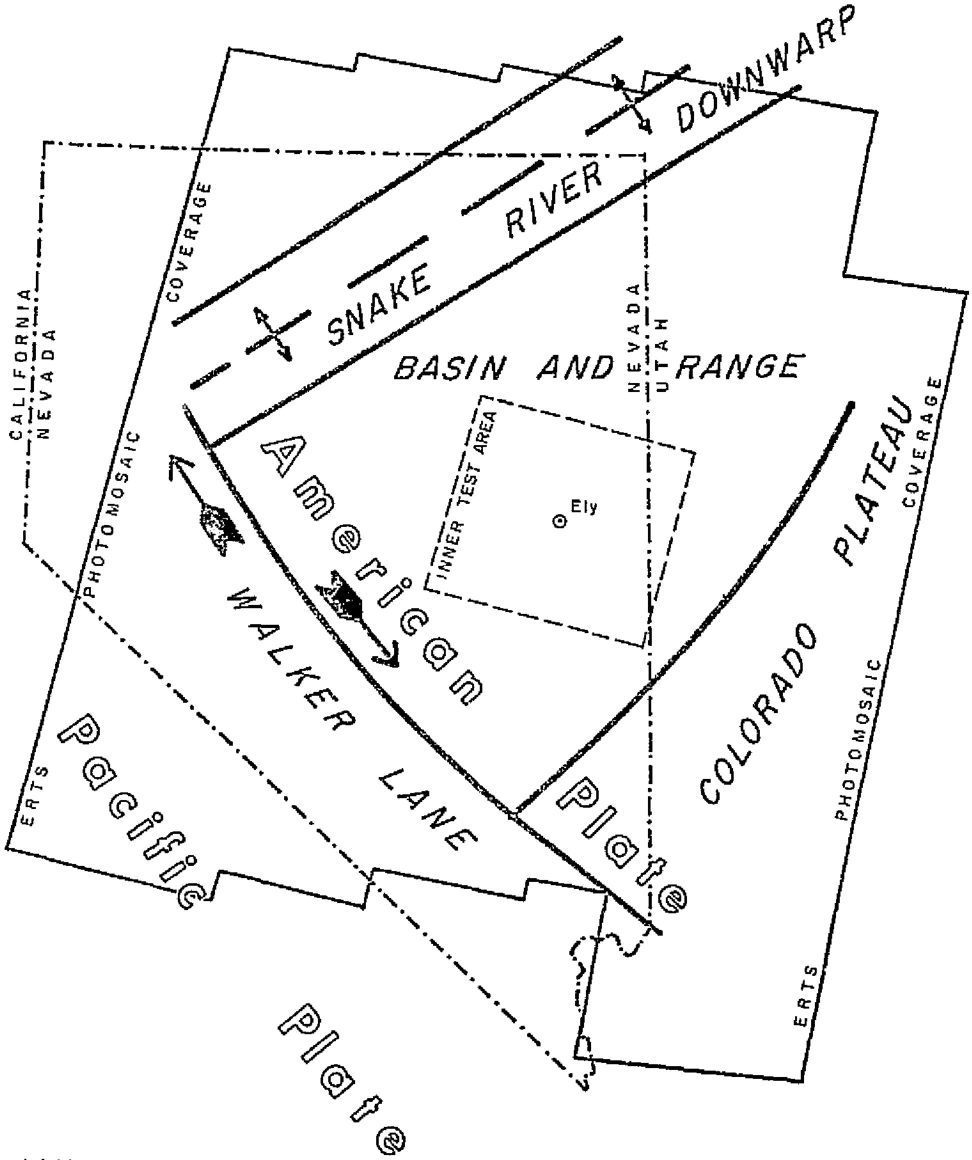
1. "Basin and Range" = Tectonic Units III, IV, V, VII, VIII, IX and X (Plate 1). These units have similar geological characteristics and differ principally in trends of ranges within them.

2. "Walker Lane" = Tectonic Units I and II plus others not shown on Plate 1.

3. Colorado Plateau = Tectonic Unit VI (more properly a transition unit from Basin and Range to Plateau) and several units to the east, not shown on Plate 1.

4. "Snake River Downwarp" = 100 kilometer wide unit trending N60°E and passing through the extreme northwest corner of Plate 1 (not shown).

These regional tectonic units are shown by Figure 2.



EXPLANATION

RELATIVE PLATE MOTION

SPREADING CENTER

Figure 2. Major Tectonic Elements--Basin and Range Province

Mesozoic-Early Cenozoic Model

The model developed for the Ray, Arizona test area calls for a complex compressional plate junction along the "Walker Lane" during the Laramide period when most of the Arizona porphyry copper deposits formed. The junction in Arizona may have existed as far back as Late Jurassic-Early Cretaceous if the Bisbee deposits are the result of the same process as the Laramide porphyries.

The plate junction, between the Farallon and American plates in Arizona, is considered as a combination shear and subduction zone. Sillitoe's (1972) model for emplacement of porphyry copper deposits into crustal material above subduction zones is used to explain genesis of the ore deposits.

To explain the location of the porphyry copper deposits of Nevada, we are extending our model northward from Arizona. A result of this is the conclusion that the system existed as long ago as Late Jurassic-Early Cretaceous because the Yerington and Ely porphyry copper deposits formed then.

The resultant model is in basic accord with the view that much of the Western United States is a broad transform fault zone (Atwater, 1970). The western boundary of the junction zone is probably related to the San Andreas fault and the eastern boundary is regarded as the eastern edge of the "Walker Lane."

The zone must have had its inception during Late Jurassic time, and consumption of the Farallon Plate along it was continuous until the spreading center between it and the Pacific Plate was overrun and consumed about 24 m.y. ago (Atwater, 1970).

Basin and Range Model

In Nevada, the geologic environment in which porphyry copper deposits formed in the Early Cretaceous Epoch has been severely altered by Basin and Range tectonism which began during the Late Tertiary (Miocene). This period of tectonism has been attributed to three basic causes (Stewart, 1971):

1. Removal of lateral support or sliding off regional highs to form structures similar to those found in landslides (Mackin, 1960a, 1960b, 1969; Moore, 1960).

2. Strike-slip deformation (Shawe, 1965; Slemmons, 1957).

3. Deep-seated extension (Thompson, 1959, 1966; Hamilton and Meyers, 1966; Cook, 1966; Roberts, 1968; Hamilton, 1969; Stewart, 1971; Thompson and Burke, 1973).

Our interpretation of ERTS imagery favors deep-seated extension related to a spreading center along the Snake River Downwarp and its extension southwestward to the "Walker Lane" as the cause of Basin and Range tectonism.

The postulated spreading does not create new material at the surface (at least not on the "Basin and Range" or southeast side of the "Snake River Downwarp") but results in addition of new material to an extension zone within the crust. The extension zone is described or postulated by several authors, notably Stewart (1971), and is below the limit of Basin and Range faulting, probably at least 14 kilometers beneath the present surface. Relative extension within the zone beneath pre-existing upper crustal material results in Basin and Range faulting.

Figure 2 shows the postulated relationships between the major tectonic elements used in our Basin and Range tectonic model. Briefly stated, the role of each is:

1. "Snake River Downwarp" - site of rifting of American Plate along a N60°E trend with mantle material upwelling to form a spreading center. The term as used here is extended considerably southwestward from the area most authors refer to as the Snake River Downwarp.

2. "Walker Lane" - zone of transform faulting

3. Colorado Plateau - stable area with thick crust (40 km)

4. "Basin and Range" - Nevada-Utah area of crustal extension with surface manifestation as series of horsts and grabens.

The interpretation is supported by heat flow data which show maxima along the postulated spreading center (Roy, et al., 1968; Sass,et al., 1971) and Thompson and Burke's calculated extension rate of 0.4 mm/yr. (past 15 m.y.) along a N55°W - S55°E direction in Dixie Valley, which is within the "Snake River Downwarp."

The latter data is in general agreement with the postulated N30°W-S30°E spreading direction of Figure 2. The Dixie Valley area may be somewhat atypical because it is at the junction of the postulated spreading center and transform fault ("Walker Lane"). Hence, arguments using data from it should be applied cautiously.

A vexing problem is that the proposed spreading direction is not parallel to generally accepted extension directions within the Great Basin. These are believed to be east-west, perpendicular to the general range (fault) trends (Gilluly, 1970). A possible explanation is that spreading rates varied systematically along the spreading center with maxima at its intersection with the transform fault and a general decrease toward the northeast. This differential spreading rate could cause the Nevada-Utah Basin and Range province to rotate counterclockwise, with a western boundary along the "Walker Lane" and rotation pole northeast of Yellowstone. In effect, this hypothesis rotates existing grabens from NE-SW trends to their present N-S alignments. If this hypothesis is correct, there should be a systematic change in alignment of grabens outward from the spreading center. Examination of the Tectonic Map of the United States (1962), a graben map presented by Stewart (1971, Figure 9) and the ERTS mosaic shows that grabens in the "Basin and Range" area do tend to change trend from east of north (N15°E to N25°E) to north in all directions outward from the intersection of the "Walker Lane" and the "Snake River Downwarp."

It is obvious that many factors must be resolved before the hypotheses presented here can become theories. We believe that the use of ERTS imagery in the investigation of these problems is essential to their eventual solution. Obvious areas for further investigation are:

1. Role of the Sierra Nevada.

2. Determine current status of extension in the Basin and Range--is there current fault activity there other than in the areas of recent faulting along the "Walker Lane" and junction area of the "Walker Lane" and "Snake River Downwarp?"

3. How do the Basin and Range areas north of the proposed spreading center fit into the model?

4. Are or were there subduction zones associated with the system and where are they located.

5. Relationship of post-Laramide mineralization; e.g. Bingham Canyon, to the proposed system.

6. Investigation of the relationship of the low velocity zone of the Great Basin with the postulated spreading.

7. Age relationships of intrusive and extrusive igneous rocks with the postulated activities.

8. Relationship of the Colorado Plateau to the model.

Investigation of these aspects of the problem is beyond the scope of this work. We believe that studies of ERTS mosaics of the Western United States using the concepts of Plate Tectonics is a logical continuation of our work and can lead to resolution of many of these questions and problems. The result of such a study can be development of a global tectonic model that can be utilized by Economic Geologists to design effective exploration programs.

REFERENCES CITED

Atwater, T., 1970, Implications of Plate Tectonics for the Cenozoic Tectonic Evolution of Western North America, Geological Society of America, Bulletin, Volume 81, p. 3513-3536.

Cohee, G. V. (Chairman), 1962, Tectonic Map of the United States (exclusive of Alaska and Hawaii)(Scale 1:2,500,000), U. S. Geological Survey and the American Association of Petroleum Geologists.

Gilluly, J., 1970, Crustal Deformation in the Western United States, in The Megatectonics of Continents and Oceans, Rutgers University Press, New Brunswick, New Jersey, p. 47-73.

Hamilton, W., 1969, Mesozoic California and the Underflow of the Pacific Mantle, Geological Society of American, Bulletin, Volume 80, p. 2409-2430.

Hamilton, W., and W. B. Myers, 1966, Mesozoic Tectonics of the Western United States, Review of Geophysics, Volume 5, p. 509-549.

Horton, R. C., H F. Bonham and W. D. Longwill, 1962, Copper Occurrences in Nevada by District, Nevada Bureau of Mines, Map 13, Mackay School of Mines, University of Nevada.

Horton, R. C., H. F. Bonham and W. D. Longwill, 1962, Lead Occurrences in Nevada by District, Nevada Bureau of Mines, Map 14, Mackay School of Mines, University of Nevada.

Horton, R. C., H. F. Bonham, and W. D. Longwill, 1962, Zinc Occurrences in Nevada by District, Nevada Bureau of Mines, Map 15, Mackay School of Mines, University of Nevada.

King, P. B. (Compiler), 1969, Tectonic Map of North America,(Scale 1:5,000,000) U. S. Geological Survey

Mackin, J. H., 1960a, Eruptive Tectonic Hypothesis for Origin of Basin and Range Structure (Abs.), Geological Society of America, Bulletin, Volume 71, p. 1921.

Mackin, J. H., 1960b, Structural Significance of Volcanic Rocks in Southwestern Utah, American Journal of Science, Volume 258, p. 81-131.

Mackin, J. H., 1969, Origin of Lunar Maria, Geological Society of America, Bulletin, Volume 80, p. 735-748.

Montgomery, K. M. and others, 1965, Preliminary Geologic Map of Nevada (Scale 1:1,000,000), U. S. Geological Survey.

Moore, J. G., 1960, Curvature of Normal Faults in the Basin and Range Province of the Western United States, in Geological Survey Research, 1960, U. S. Geological Survey Professional Paper 400-B, p.B409-B411.

Roberts, R. J., 1968, Tectonic Framework of the Great Basin, Missouri University, Research Journal, p. 101-119.

Roy, R. F., E. D. Decker, D. B. Blackwell, and F. Birch, 1968, Heat Flow in the United States, Journal of Geophysical Research, Volume 73, p. 5207-5221.

Sass, J. H., A. H. Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr., 1971, Heat Flow in the Western United States, Journal of Geophysical Research, Volume 76, p. 6376-6413.

Schilling, J.H., 1962, Molybdenum Occurrences in Nevada, Nevada Bureau of Mines, Map 8, Mackay School of Mines, University of Nevada.

Shawe, D. R., 1965, Strike-Slip Control of Basin-Range Structure Indicated by Historical Faults in Western Nevada, Geological Society of America, Bulletin, Volume 76, p. 1361-1378.

Sillitoe, R. H., 1972, A Plate Tectonic Model for the Origin of Porphyry Copper Deposits, Economic Geology, Volume 67, p. 184-197.

Slemmons, D. B., 1957, Geological Effects of the Dixie Valley-Fairview Peak, Nevada Earthquakes of December 16, 1954, in The Dixie Valley-Fairview Peak Earthquakes of December 16, 1954 (Don Tocher and others).

Stewart, J. H., 1971, Basin and Range Structure: A System of Horsts and Grabens Produced by Deep-Seated Extension, Geological Society of America, Bulletin, Volume 82, p. 1019-1044.

Thompson, G. A., 1959, Gravity Measurements Between Hazen and Austin, Nevada, A Study of Basin-Range Structure, Journal of Geophysical Research, Volume 64, p. 217-230.

Thompson, G. A., 1966, The Rift System of the Western United States, in The World Rift System, International Upper Mantle Commission Symposium, Ottawa, 1965, Canadian Geological Survey Paper 66-14, p. 280-290.

Thompson, G. A. and D. B. Burke, 1973, Rate and Direction of Spreading in Dixie Valley, Basin and Range Province, Nevada, Geological Society of America, Bulletin, Volume 84, p. 627-632.

U. S. Department of Commerce, 1965, Operational Navigational Charts (Scale 1:1,000,000) ONC, F-16 and G-18, National Ocean Survey, Washington, D. C.

Following Plates Not Signed

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site

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Final Report

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16. Abstract

Numerous circular features are observable on the ERTS images. Two sets of fracture patterns might be controlling the circular features. North of the study area the trend is N65°W to N70°W while in the south, although not as well developed, they are between N30°W and N55°W.

Grids were fitted to the circular features to determine fundamental spacings. The average diameter of the circular features was 11.5km. No relationship could be found between circular features and mineralized areas. However, of the four known porphyry copper prospects in the area, Mt. Cannindah, is on a circular feature.

A geologic map made from an ERTS frame compared favorably with a published reconnaissance map of the area. The ERTS map contains all significant structural data (fold and faults) shown on the published maps.

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PREFACE

This report is one of six similar reports which describe research results accomplished by Earth Satellite Corporation under ERTS-1 project entitled, "Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery," PR 510 contract NAS5-21769. A list of these six reports follows:

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site: Earth Satellite Corp. rept.

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site: Earth Satellite Corp. rept.

Lyon, R.J.P, and Haenggi, W. T., 1974, Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site: Earth Satellite Corp. rept.

Prindle, R. O., and Erskine, M. C., Jr., 1974, Tectonic Interpretation of ERTS-1 imagery of the Silverton, Colorado test site: Earth Satellite Corp. rept.

Prindle, R. O., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site: Earth Satellite Corp. rept.

Prindle, R. O., Lyon, R.J.P., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site: Earth Satellite Corp. rept.

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INTRODUCTION

The Mt. Perry test area is in Southeastern Queensland, Australia between latitudes 22°S and 27°30'S and longitudes 148°E and 155°E (Figure 1). Elevations within the area range from 0 along the coast to around 800 meters in the higher parts of the Great Dividing Range.

Figure 1 shows the location of ERTS imagery used in the study and Table 1 lists frames used. Our survey of the area was severely limited by extensive cloud cover which prohibits regional evaluations.

All studies were performed on individual frames at scales of 1:1,000,000 or 1:500,000 and results compiled to produce geological and lineation maps (Plates 1, 2, 3, and 4). Frame 1035-23221 is the only cloud-free frame in the area of maximum geological interest and our interpretations are practically confined to it.

Imagery from MSS band 7 provides the maximum geological detail in the area. Color composites of bands 4, 5, and 7 at a scale of 1:500,000 add detail for interpretation, but this seems more due to scale than color. We feel that enlargements of band 7 imagery to 1:500,000 would provide geological detail equal to the color composites.

Our study shows that useful geologic maps can be constructed from ERTS imagery in terrains like the test area, but ground control is necessary before stratigraphic interpretations can be made from them. We found that there is essentially no correlation between circular features and lineations, seen on ERTS imagery, and known mineral deposits.

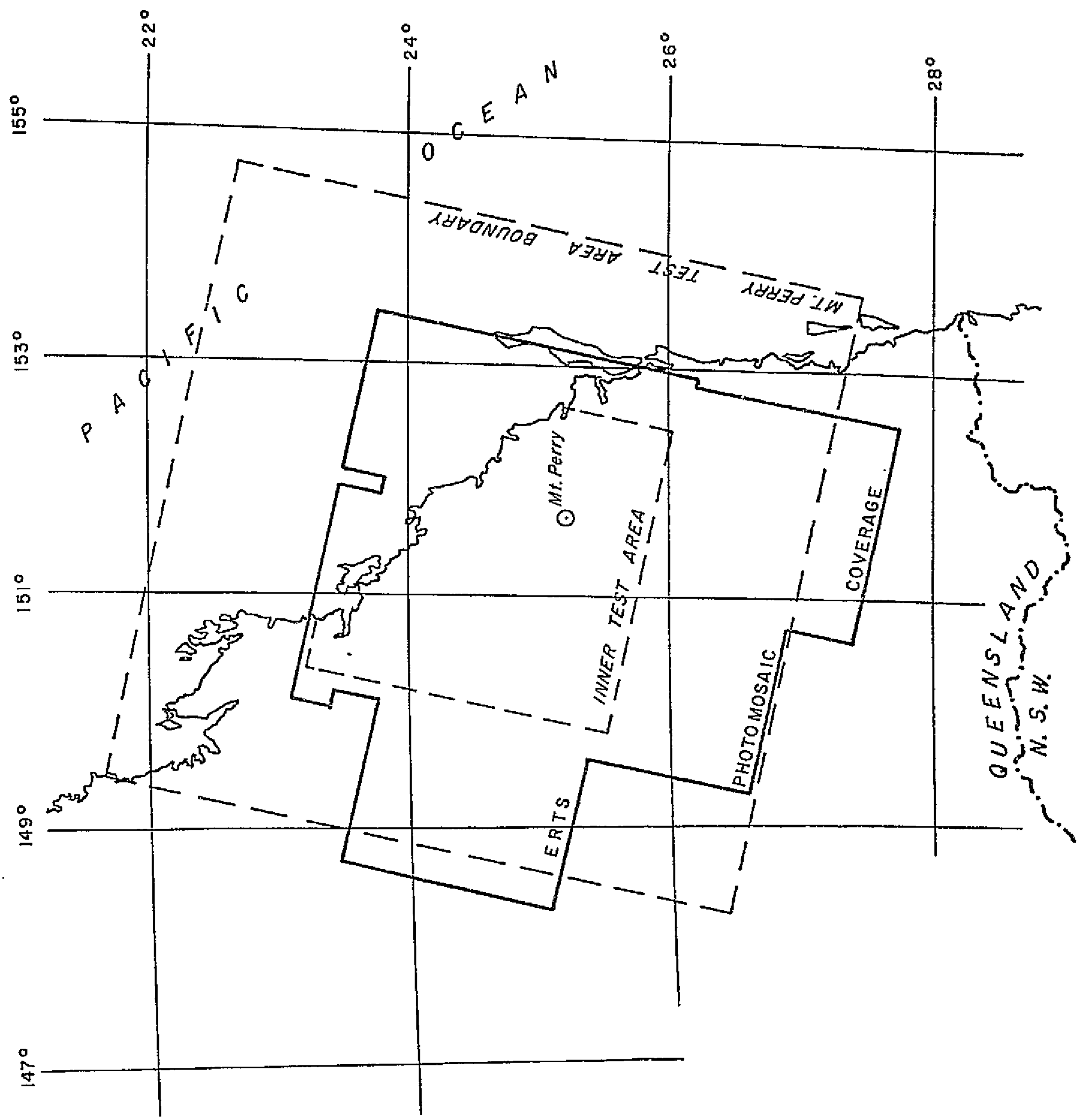

Figure 1. Mt. Perry, Queensland, Australia Test Area

Table 1. Mt. Perry ERTS Imagery

Date	I. D. No.	Center Coord.	Sun El.	Sun Az.	Cloud* Cover (%)
Black-and-white Channels 4, 5, 6, 7 (Scale 1:1,000.000)					
6 Nov. 72	1106-23173	S 26-02/E 151-48	56	80	85
28 Aug. 72	1036-23273	S 23-15/E 149-45	40	53	30
6 Nov. 72	1106-23175	S 27-27/E 151-25	55	78	15
27 Aug. 72	1035-23223	S 26-09/E 150-23	37	51	2
31 Dec. 72	1161-23222	S 23-17/E 151-10	54	97	80
6 Nov. 72	1106-23170	S 24-36/E 152-11	56	82	80
27 Aug. 72	1035-23221	S 24-42/E 150-53	38	52	0
3 Mar. 73	1233-23232	S 24-19/E 150-40	45	67	50
13 Mar. 73	1233-23234	S 25-46/E 150-17	44	66	25
Color Composites (Scale 1:1,000,000)					
6 Nov. 72	1106-23173-4-5-6-7				
13 Nov. 73	1233-23232-4-5-6-7				
Color Composites (Scale 1:500,000)					
31 Dec. 72	1161-23222-4-5-7				
27 Aug. 72	1035-23221-4-5-7				

*Percent of cloud cover estimated by EarthSat.

ERTS IMAGE LINEAR STUDY

Lineations are mapped at a scale of 1:1,000,000 on cloud-free imagery within the Mt. Perry test area (frames 1035-23221 and 1035-23223) and at a scale of 1:500,000 for frame 1035-23221 (color composite). Mapping was done on clear acetate overlays with linear patterns denoted by short india-ink lines. All directions, including characteristic curvilinear patterns, are shown on plates 1 (1:1,000,000) and 2 (1:500,000). The 1:500,000 interpretation was performed to determine if this scale and color composites give greater detail than 1:1,000,000 imagery.

Two 1:500,000 color composites were available for study, but frame 1161-23222 (31 December 1972) is extensively covered with "pop-corn" (cumulus) clouds which negates any but the most subjective analysis. Frame 1035-23221 (27 August 1972) is essentially cloud free and color quality is generally good. The print is made up from two tape runs and has a shift along an E-W line in the data just south of latitude 25°S. This was cut and manually shifted to make a match which is used for the study.

Tectonic Analysis 1:1,000,000 Scale

Circular features dominate the interpretation. These are generally 10 to 20 kilometers in diameter and are composed of concentric lineations that probably result from fracture patterns.

The area studied is divisible into two areas separated by a N52°W trending zone of major fractures (Plate 1). North of this zone, most non-circular lineations trend N65°W to N70°W, but sets trending between N-S and N55°W are also present. South of the "dividing zone" lineations are more random and not as well developed as in the northern area. In this area fracture trends between N30°W and N55°W appear best developed.

Grids have been fitted to the circular features in an effort to determine if fundamental spacings are present. North of the N52°W dividing zone, grid lines trend N85°W and N25°E (avg.) with the N85°W system most persistent. South of the dividing zone there is a change in the best-fit grid to N35°W and N40°E .

Spacings along the grids are variable with the following values representative:

North	N85°W	-	30 kilometers (range 8 to 40 km)
	N25°E	-	20 kilometers (range 5 to 35 km)
South	N35°W	-	no determination (range 10 to 45 km)
	N40°E	-	25 kilometers (range 10 to 30 km)

Selected direction mapping and/or Fourier analysis of the data might reveal that fundamental spacings are present but our data does not confirm or negate them.

Tectonic Analysis - 1:500,000 Scale (Frame 1035-23221)

The most obvious trends shown by Plate 2 are N40°W although individual linears can be curved into drawn out sigmoid shapes. There is also a suggestion that the image area can be subdivided, on the basis of direction changes, into 4 to 6 units.

Circular features are common and average diameter (outer circle) is 11.5 kilometers. Thirty-five of these features were identified in the area covered by frame #1035-23221 (Table 2) A separate overlay (Plate 3) was prepared showing only the circular features and several sets of grids connecting the features. One best fit has a major grid at N27°W with a spacing of 28.1 km (and a subsidiary spacing of 16.7 km) and N78°W. Another grid is approximately E-W and N15°E (Table 3).

Table 2. Circular Features--Frame #1035-23221

	Diameter of Outer Circle (Km)	Frequency
	3.5	1
	5.0	1
	6.5	1
	7.0	1
	7.5	4
	9.0	2
	10.0	5
	11.0	6
	11.5	2
	12.0	2
	12. 5	6
	15.0	1
	20.0	1
	21.0	1
	30.0	1
Average	11.5	35

Table 3. Grid Connecting Circular Features

	Normal to Grid	
	Prime Spacing	Secondary Spacing
N27°W SET	30.0 km	15.0 km
	25.0 km	17.5 km
	27.5 km	17.5 km
	30.0 km	16.7 avg (10.4)
	28.1 avg (17.6 mi)	
N78°W SET	15.0 km	22.5 km
	15.0 km	23.5 km
	16.5 km	23.0 avg (14.3 mi)
	17.5 km	
	12.5 km	
	16.0 km	
	16.0 km	
	15.7 avg (9.8 mi)	

	Orthogonal Spacings	
N27°W SET	28.1 km	16.7 km
N78°W SET	15.7 km	23.0 km

Mineralization

Encouraging correlations between circular features and mineralized areas are noted for some of our test areas (Ray, Ok Tedi, Ely). Metallogenic data from company files was compared with ERTS lineation studies to determine any relationships present in the Mt. Perry test area. Mineral occurrences and porphyry copper prospects are shown on Plate 3.

Comparison of the metallogenic data and ERTS lineation studies shows essentially no relationship between circular features and mineralized areas. However, of four known porphyry copper prospects in the area covered by Plate 3, one, Mt. Cannindah, is on a circular feature

ERTS GEOLOGIC MAP

Frame 1035-23221 (27 August, 1972) was geologically mapped and results are compared with published maps. The ERTS map base was a 1:1,000,000, black-and-white print in MSS band 7. Frequent reference was made to the 1:500,000 color composite (MSS bands 4, 5, and 7), to a 1:1,000,000 print of MSS band 5 and to various color composites produced from MSS bands 4, 5, 6, and 7 on an I^2S Addcol operated by the interpreter.

Plate 4 shows the resultant geologic map and a published structural sketch map of part of the area covered by the frame. Fifteen map units and an undifferentiated area are recognized on ERTS imagery. With the exception of recent alluvium (Unit 15) and some obvious intrusive igneous relationships (Units 5, 7, and 12) rock types cannot be differentiated on the ERTS imagery without assistance from ground data.

In spite of the constraints on ERTS interpretation caused by lack of lithologic data, a reasonable reconnaissance map was produced after several days' study. The accuracy of this map cannot be determined because the published data for the area is mostly from reconnaissance photo and ground data and cannot be considered as a reliable base for comparative evaluation. However, the ERTS map contains all significant structural data (folds and faults) shown by the published maps.

The geologic mapping part of this study does indicate that geologic maps can be prepared from ERTS imagery in non-forested orogenic belts and that these maps have sufficient data to permit regional geologic evaluations and assist explorationists in planning detailed surveys.

REFERENCES CITED

Geological Survey of Queensland, 1970, Mohto, Queensland, 1:250,000, Geological Series Explanatory Notes.

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RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Tectonic interpretation of ERTS-1 imagery of the Silverton, Colorado test site

R. O. Prindle and M. C. Erskine, Jr.
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15. Supplementary Notes

16. Abstract An ERTS mosaic utilizing 23 frames from different seasons of the year was used to make a tectonic map of approximately 210,000 square miles centered on the Silverton Mining District, Colorado. The Colorado Mineral Belt is displayed on this mosaic as a regional fault graben-caldera complex. It is postulated that this northeast trending tectonic feature is a remnant-spreading center, offset by transform faults. Substitution of different frames for the same location enabled access to more geologic detail because of differing cloud and snow cover, sun angles and azimuths, and seasonal effects on vegetation. The tectonic map shows major through-going lineations, folds, attitudes of bedding, circular features and tectonic units. Circular features in some cases can be identified as surface exposures of intrusive rocks, volcanic cones, or calderas. In other cases there are no surface outcrops of igneous rocks shown at these locations on the geologic map. Aeromagnetic highs correspond to ERTS circular features and represent near-surface intrusive rocks.

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Colorado mineral belt
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PREFACE

This report is one of six similar reports which describe research results accomplished by Earth Satellite Corporation under ERTS-1 project entitled, "Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery," PR 510 contract NAS5-21769. A list of these six reports follows:

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ray, Arizona test site: Earth Satellite Corp. rept.

Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ely, Nevada test site: Earth Satellite Corp. rept.

Lyon, R.J.P, and Haenggi, W. T., 1974, Geologic interpretation of ERTS-1 imagery of the Mt. Perry, Queensland test site: Earth Satellite Corp. rept.

Prindle, R. O., and Erskine, M. C., Jr., 1974, Tectonic Interpretation of ERTS-1 imagery of the Silverton, Colorado test site: Earth Satellite Corp. rept.

Prindle, R. O., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site: Earth Satellite Corp. rept.

Prindle, R. O., Lyon, R.J.P., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site: Earth Satellite Corp. rept.

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INTRODUCTION

The Leadville, Colorado test site, originally chosen for this study, was moved southwest to Silverton, Colorado because of extensive cloud and snow cover in the original area. The Silverton area is shown on Figure 1 along with the ERTS mosaic coverage used for the investigation. The ERTS coverage of approximately 210,000 square miles was extended well beyond the boundaries of the inner test area so that regional geological features could be recognized and interpreted for their structural influence on the Silverton area.

A mosaic of 23 ERTS frames was used to make a tectonic map. Table 1 lists the ERTS frames used in the making of the tectonic map. Substitution of different frames covering the same location enabled access to more geologic detail because of differing cloud and snow cover, sun angles and azimuths, and seasonal effects on vegetation. The ERTS imagery used was black-and-white prints at a scale of 1:1,000,000. Most imagery was channel 7, and occasionally channels 6 and 5 were used where quality of the prints was variable. An effort was made to maintain uniform grey levels throughout the mosaic.

The tectonic interpretation was performed on a transparency overlay to the ERTS mosaic. A stream drainage transparency based on the World Aeronautical Chart Series, Scale 1:1,000,000, Lambert Conformal Conic Projection, was used for geodetic control. The drainage map was shifted from each ERTS frame as the interpretation progressed over the mosaic. The distortion between the Universal Transverse Mercator (UTM) of the

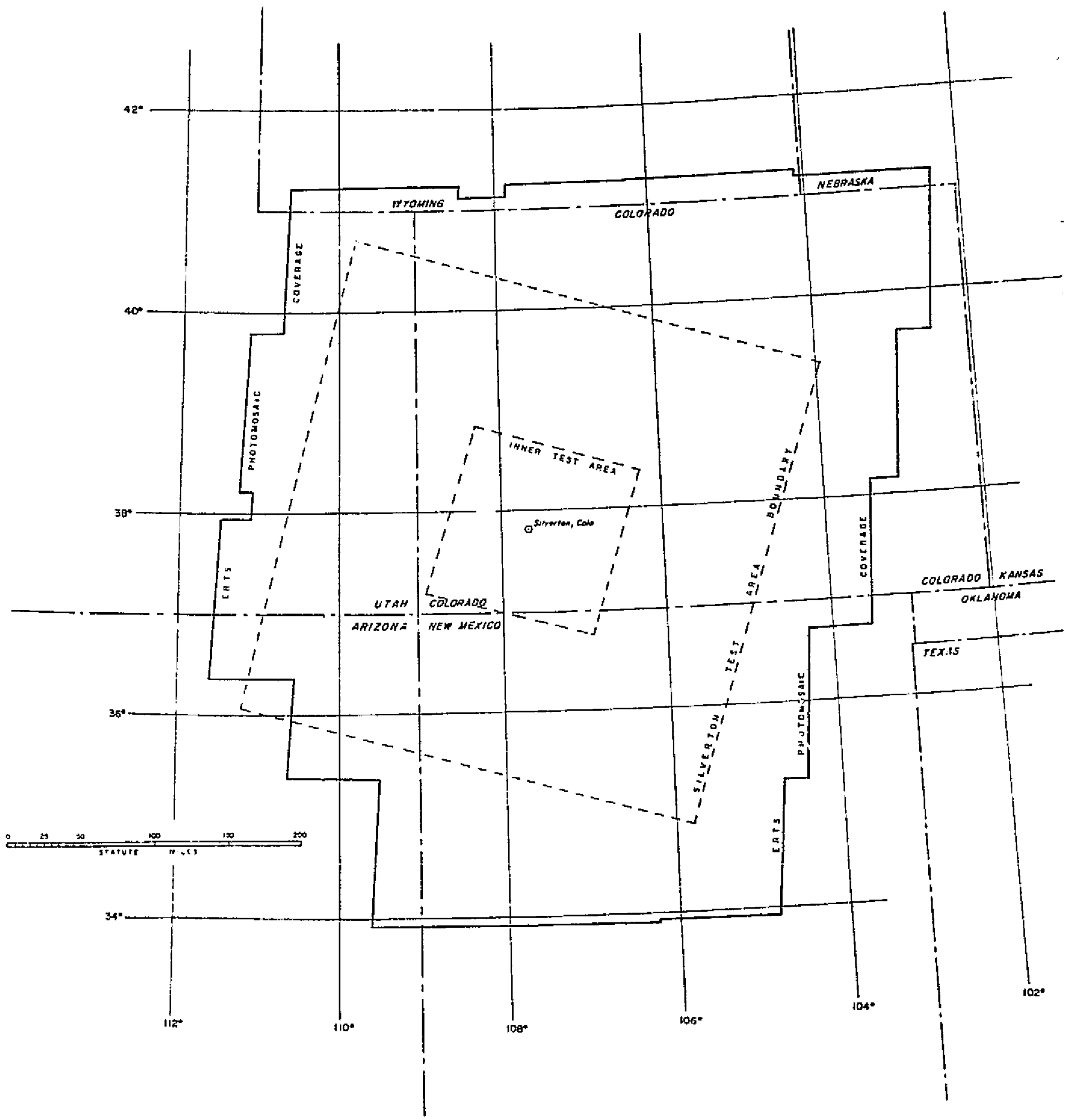

Figure 1. Silverton, Colorado Test Site Location and ERTS Imagery Coverage

Table 1. Silverton, Colorado ERTS Imagery

Date	I.D. Number & Channel	Center Coordinates	Sun Angle & Azimuth
Aug. 1, 1972	1009-17073-5	N 40-24/W 103-32	Sun El 56 Az 124
Aug. 1, 1972	1009-17075-6	N 38-59/W 104-02	Sun El 57 Az 122
Aug. 1, 1972	1009-17082-7	N 37-33/W 104-30	Sun El 57 Az 119
Aug. 2, 1972	1010-17143-5	N 36-02/W 106-26	Sun El 58 Az 117
Aug. 23, 1972	1013-17311-6	N 38-36/W 000-00	Sun El 53 Az 130
Aug. 23, 1972	1013-17313-6	N 37-11/W 000-00	Sun El 53 Az 128
Sept. 8, 1972	1047-17200-5, 7	N 37-30/W 107-26	Sun El 49 Az 136
Sept. 26, 1972	1065-17195-7	N 36-05/W 107-51	Sun El 45 Az 142
Sept. 26, 1972	1065-17202-7	N 36-05/W 107-51	Sun El 45 Az 142
Sept. 27, 1972	1066-17245-7	N 40-20/W 107-49	Sun El 42 Az 146
Sept. 27, 1972	1066-17251-6, 7	N 38-54/W 108-19	Sun El 43 Az 145
Sept. 27, 1972	1066-17254-6, 7	N 37-28/W 108-47	Sun El 44 Az 143
Sept. 27, 1972	1066-17260-6	N 36-03/W 109-15	Sun El 45 Az 142
Jan. 28, 1973	1189-17084-6, 7	N 38-58/W 104-05	Sun El 26 Az 147
Jan. 28, 1973	1189-17091-6, 7	N 37-32/W 104-34	Sun El 27 Az 147
Jan. 28, 1973	1189-17093-5	N 36-06/W 105-01	Sun El 28 Az 146
Jan. 29, 1973	1190-17143-7	N 39-00/W 105-29	Sun El 26 Az 147
Jan. 29, 1973	1190-17145-7	N 37-35/W 105-57	Sun El 27 Az 146
Jan. 30, 1973	1191-17202-6, 7	N 38-56/W 106-58	Sun El 26 Az 147
Jan. 30, 1973	1191-17204-6, 7	N 37-30/W 107-27	Sun El 27 Az 146
Jan. 31, 1973	1192-17254-6	N 40-22/W 107-56	Sun El 26 Az 148
Feb. 1, 1973	1193-17312-7	N 40-24/W 109-23	Sun El 26 Az 147
Feb. 17, 1973	1209-17201-7	N 40-22/W 106-34	Sun El 30 Az 145
Feb. 17, 1973	1209-17203-7	N 38-56/W 107-03	Sun El 31 Az 144
Feb. 18, 1973	1210-17262-7	N 38-54/W 108-31	Sun El 32 Az 144
Feb. 18, 1973	1210-17264-7	N 37-29/W 108-59	Sun El 33 Az 143
Apr. 10, 1973	1261-17103-7	N 34-41/W 105-45	Sun El 52 Az 129
Apr. 11, 1973	1262-17161-7	N 34-41/W 107-10	Sun El 53 Az 128
May 17, 1973	1298-17142-7	N 40-27/W 105-14	Sun El 59 Az 126
May 17, 1973	1298-17153-7	N 36-11/W 106-40	Sun El 61 Az 118
May 18, 1973	1299-17200-7	N 40-27/W 106-44	Sun El 59 Az 125
May 18, 1973	1299-17203-7	N 39-01/W 107-12	Sun El 60 Az 123
May 18, 1973	1299-17205-7	N 37-35/W 107-40	Sun El 60 Az 120
May 18, 1973	1299-17212-7	N 36-09/W 108-08	Sun El 61 Az 117
May 18, 1973	1299-17214-7	N 34-44/W 108-36	Sun El 61 Az 115
May 20, 1973	1301-17313-5	N 40-27/W 109-37	Sun El 60 Az 125
May 20, 1973	1301-17315-7	N 39-01/W 110-06	Sun El 60 Az 122
June 3, 1973	1315-17091-7	N 37-32/W 104-52	Sun El 62 Az 115
June 6, 1973	1318-17265-7	N 36-10/W 109-33	Sun El 62 Az 112
July 11, 1973	1353-17192-7	N 40-17/W 106-45	Sun El 60 Az 119
July 10, 1973	1352-17134-7, 5	N 40-21/W 105-17	Sun El 60 Az 118

ERTS imagery and the conic projection of the aeronautical chart over one frame in this latitude is insignificant, and it is felt location inaccuracies over the entire area do not exceed 2 mm (2 kilometers).

A NE trending intrusive axis (three parallel faults) shown on Plate 1 is mapped with greater detail on January 30, 1973 ERTS coverage (1191-17204-6 and 1191-17202-6) than on imagery from September 27, 1973 and May 18, 1973. This greater detail is possible because the low, oblique sun angle (27°) of the winter imagery (as opposed to 44° in the fall and 60° in the spring) casts shadows that aid in detecting subtle topographic changes associated with faults. Light snow cover on the January imagery also enhanced the fault systems by increasing the contrast between shadowed and unshadowed areas. Grouped around the three parallel faults are numerous circular features that are interpreted to be either calderas or near-surface intrusions.

Another example of the advantage of repetitive coverage in the detection and mapping of faults can be seen by comparing an ERTS frame from 18 May 1973 (1299-17200-5-6-7) with a frame from 11 July 1973 (1353-17192-5-6-7). A N-S fault trending along the west side of North Basin can be easily traced on the latter. The 18 May coverage has the same spectral response for all types of vegetation, with some snow coverage at the higher elevations, but the fault cannot be recognized at all. The range of grey levels on the 11 July imagery is sharp along the fault trace and is attributed to the lower moisture content of the soils at this time of the year which, in turn, has changed the spectral response of differing vegetation types. Species of vegetation that inhabit higher elevations appear darker, and the combination of vegetation, subtle relief and absence of snow cover permits recognition of the fault trace. It should be noted that the sun angles and azimuths were very similar for the two frames (18 May, 59° and 125°; 11 July, 60° and 119°) and are not the reason for the fault detection on the 11 July imagery.

ERTS TECTONIC MAP

The ERTS Tectonic Map (Plate No. 1) shows the following features:

(1) Major through-going lineations

(2) Folds, attitudes of bedding

(3) Circular features

(4) Tectonic units.

In an effort to locate areas of possible mineralization, we interpreted circular features based on a number of different criteria; i.e., circular features, circular topography highs and lows, tonal contrast, and circular stream drainage patterns. In some cases these circular features are grouped together in interlocking circles, their diameters varying from a few large ones of 40 miles to numerous small ones with diameters of 3 to 10 miles. In some cases they can be identified as surface exposures of intrusive rocks, volcanic cones, or calderas. In other cases there are no surface outcrops of igneous rocks shown at their locations on the Geologic Map of Colorado. In the latter case, the features are interpreted as near-surface intrusions, or intrusions that are not shown on the geologic map because they cannot be represented at a scale of 1:500,000.

If these features turn out to be near-surface intrusions not previously mapped, they would then constitute an exploration target and warrant a closer examination by ground investigations and geophysical surveys. Most of these circular features occur along the Colorado Mineral Belt, San Juan Volcanic Plateau, and to the north in the Front Range Uplift.

The criteria used in defining the tectonic units are based partly on those shown in the Tectonic Map of the United States (1962) for this locality. It should be noted that these units are more conventional than those devised from the ERTS studies of Arizona and Nevada.

Boundaries have been assigned to tectonic units based on changes in the following observable features:

(1) Regional direction of lineations, folds, and attitudes of beds,

(2) Differing texture and tonal patterns,

(3) Relief that is a function of recent structural movement,

(4) Relative abundance of major rock types,

(5) Density of structural, stratigraphic and geomorphic features.

The location of these boundaries can be assigned with a high degree of confidence in the areas where abrupt changes occur between the above features. In other areas the transition between tectonic units is gradual, and in these areas the boundary locations represent broader zones and have been dashed accordingly.

The Colorado Mineral Belt can be identified on ERTS imagery as three general trends consisting of parallel faults. The southernmost trend that is shown in Plate 1 is a N70°E trend (three parallel faults) that can be traced from the southwest of Silverton mining district to just north of Bonanza (approximately 130 miles). The next subunit is a N-S fault system that extends north (approximately 60 miles) from Bonanza to the Breckenridge mining district, not shown on Plate 1, where two predominant fault systems intersect; one being slightly curvilinear and trending E-W ± 10° while the other trends N45°E.

COMPARISON OF ERTS TECTONIC MAP WITH PUBLISHED TECTONIC, AEROMAGNETIC, GRAVITY, INTRUSION, AND MINERAL MAPS

Comparison between the ERTS tectonic map and Plate 2, "Published Tectonic Map of Silverton, Colorado ERTS Test Site," shows that:

(1) There are many more faults on the ERTS map than there are on the published map.

(2) The two maps do not show good agreement on the location of faults.

(3) Only three circular features appear on the published map (compared to more than 40 mapped on ERTS) but these three agree with those locations mapped from ERTS.

(4) The configuration of the structural contours on the published map is in excellent agreement with the tectonic unit boundaries assigned on the ERTS. A large, circular feature (approximately 32 miles in diameter) mapped on ERTS in the San Juan Basin agrees with a predominant nosing of the structural contour lines for the same location and is interpreted to be a reflection of basement relief.

(5) Locations of dikes are more accurately drawn from the ERTS.

(6) Most rock types are not easily identified from ERTS, and for this reason were not mapped on the tectonic map.

The three parallel faults associated with the Colorado Mineral Belt, although not as apparent, can be interpreted as linears on the regional

Aeromagnetic Map of Colorado by I. Zietz and R. Kirby, Jr. (1972) and the Aeromagnetic Map of The Central Colorado Plateau, Utah, Colorado and Arizona, USGS Open File Report (1970). We believe the magnetic trends (Plate 3) are due to faults in the Precambrian basement that have been rejuvenated in Laramide and Tertiary times. These faults, especially the one aligned with late Tertiary intrusions (Silverton and Animas areas), have acted as fissures for magma to reach the surface from the base of the crust.

Some of the magnetic highs on Plate 3 correspond to the circular features on the ERTS tectonic map (Plate 1) and therefore probably represent near-surface intrusive rocks. Similar results were reported by Case and Joesting (1972) in their analysis of regional aeromagnetic and gravity anomalies from the central Colorado Plateau that correlate polygonal fracture patterns with laccolithic intrusions emplaced near intersections of basement fracture zones.

A possible theory for the two NE trends shown on ERTS imagery and verified by aeromagnetic data is that they represent a remnant spreading center that never fully developed, with the N-S trend being a transform fault. Plate 4, "Laramide and Late Tertiary Intrusions, Mineral Occurrences, Negative Gravity Contours on Drainage Base Map," shows that most of the mineralization is along these NE trends and not along the N-S (transform) trend.

Tweto (1963) stated that "The mineral belt follows an ancient zone of weakness defined by northeast-trending shear zones of Precambrian age in a belt 10-35 miles wide. Individual shear zones or clusters of zones are spaced from a mile or less to many miles apart. In most parts of the belt, a major northeast-trending shear zone is flanked by lesser shear zones in an echelon arrangement.

C 12

"During Paleozoic and Mesozoic time, minor differential movements occurred repeatedly in the regional zone of shearing, as recorded by thinning, wedgeouts, and changes in facies of several sedimentary formations along the zone.

"With the onset of the Laramide orogeny, magma invaded the regional zone of shearing and imparted to it the conspicuous features that characterize the mineral belt--intrusive igneous bodies and ore deposits. Fault movement occurred along the zone at this stage also but was on a smaller scale than it had been previously."

We believe that the satellite imagery with its synoptic view does an excellent job of highlighting this NE trend and associated shear zones, as has been noted on our ERTS tectonic map (Plate 1).

Plate 4, mentioned earlier, displays the following published information of the same area as Plate 1:

(1) Laramide and late Tertiary intrusions,

(2) Mineral occurrences,

(3) Negative Bouguer Gravity Contours, and

(4) Drainage map.

This plate was used in the interpretation by placing the transparency master over the ERTS tectonic map and directly comparing lineations and circular features to the known intrusives and mineral locations. A number of the intrusions line up with fault zones mapped from the ERTS, whereas, circular features often occurred around intrusions. The mineral occurrences were often located near circular features, and a number of nearby features warrant further analysis as possible mineral targets. The gravity-270 milligal contour line taken from the "Bouguer Gravity Anomaly Map of the United States," 1964, outlines the Colorado Mineral Belt and its associated mines. This negative anomaly outline, attributed to density contrasts resulting from differing rock types close to the surface, follows the higher topographic features in the Rockies. This suggests that the mountains are composed of lighter material and, according to Airy's Hypothesis, that under mountains the base of the crust would penetrate further into a heavier substratum making the "roots" of the mountains account for a deficiency of mass below the mountains.

The detailed "Lineation Interpretation of ERTS Imagery for Geologic Structure" for the inner test area shown in Plate 5 was analyzed for parallel fault strike trends. Plate 6, "Photo Index," shows the key ERTS frame centers and gives the identification numbers that were used in the detailed lineation interpretations. The isolated fault segments were connected into regional systems on a separate map (not shown) to develop four separate systems of E-W (±10°), N-S (±10°), N45°E and N45°W.

The repetition in the E-W system is well developed and shows 8, 16, and 25 mile spacings between trends. The N-S is poorly developed and the N45°E is clustered around the center of the Colorado Mineral Belt. The N45°W system is hard to recognize except when viewed on the 21 frame mosaic.

Comparison of ERTS imagery to a strip of photos of Skylab color photography taken on June 5, 1973 (scale 1:500,000) of an area along the northern boundary of the San Juan Basin located north and east of Durango, Colorado, shows that many of the lineations observed in the ERTS could not be detected on the Skylab photography. The main reasons offered for this are the low look (sun) angle of the ERTS, small-scale imagery that enables regional faults that are obscured locally due to alluvium to be recognized, and the light snow cover that adds contrast to the black-and-white ERTS prints.

CONCLUSIONS AND RECOMMENDATIONS

In summary, it is felt that the ERTS Colorado study has produced the following significant concepts:

(1) ERTS imagery displays for the first time a synoptic view of the Colorado Mineral Belt as a regional fault graben-caldera complex.

(2) This NE trending tectonic feature (item 1) might be a remnant spreading center that is cut by a transform fault.

(3) Regional mosaics of ERTS imagery are useful for making maps to guide exploration when combined with published data.

(4) Some of the circular features observed on ERTS imagery might prove to be potential targets of mineralization, and these areas should be analyzed further.

(5) Lineation studies of ERTS imagery can be an inexpensive exploration tool for gaining information on Precambrian basement faulting that has been rejuvenated in Laramide and Tertiary times. These studies would be useful in areas that do not have aeromagnetic coverage in that the fault trends associated with mineralization could then be used to design aeromagnetic flight lines to be at right angles to these trends, thus enhancing the amplitude of the anomalies over the faults. The interpretation of lineations from both ERTS and aeromagnetic maps is useful in that it gives the explorationist a more complete picture of structures associated with ore deposits.

It is recommended that an interpretation of those frames shown in Plate 6 (black-and-white) and summertime imagery (color composites) at a scale of 1:250,000 would add more detail at those locations that look like promising targets of possible mineralization.

REFERENCES CITED

Cohee, G. V. (chairman), 1962, Tectonic Map of the United States (exclusive of Alaska and Hawaii) (scale 1:1,000,000), USGS and the American Association of Geologists.

Dane, C. H. and Bachman, G. O., 1965, Geological Map of New Mexico (scale 1:500,000), USGS, Washington, D. C.

Eckel, E. B., Williams, J. S., and Galbraith, F. W., 1949, Geology and Ore Deposits of the La Plata District, Colorado, USGS, Prof. Paper 219.

Larsen, E. S., Jr. and Cross, W., 1956, Geology and Petrology of the San Juan Region Southwestern Colorado, USGS, Prof. Paper 258.

Lovering, T. S. and Goddard, E. N., 1950, Geology and Ore Deposits of the Front Range Colorado, USGS, Prof. Paper 223.

Mendenhall, W. C., 1967, Geological Map of Colorado (scale 1:500,000), USGS, Washington, D. C.

Tooker, E. W., 1963, Altered Wallrocks in the Central Part of the Front Range Mineral Belt, Gilpin and Clear Creek Counties Colorado, USGS, Prof. Paper 439.

Tweto, O. and Sims, P. K., 1963, Precambrian Ancestry of the Colorado Mineral Belt, Geological Society of America Bulletin, V. 74, pp. 991-1014.

Varnes, D. J., 1962, Analysis of Plastic Deformation According to Von Mise's Theory with Application to the South Silverton Area, San Juan County, Colorado, Geological Survey, Prof. Paper 378A.

____________, 1963, Geology and Ore Deposits of the South Silverton Mining Area, San Juan County, Colorado, USGS, U. S. Government Printing Office, Washington, D. C., Prof. Paper 378A.

Woolard, C. P. and Joesting, H. R., 1964, Bouguer Gravity Map of the United States, Am. Geophy. Union and USGS, scale 1:2,500,000.

Zietz, I. and Kirby, R., Jr., 1972, Aeromagnetic Map of Colorado, Geophysical Investigations Map GP-880, USGS, Washington, D. C.

______________, 1970, Aeromagnetic Map of the Central Colorado Plateau, Utah, Colorado, and Arizona, USGS, Open File Report, Denver, Colorado.

Following PLATES Not Filmed

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Linear map and geologic interpretation of ERTS-1 imagery in the Tanacross, Alaska test site

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15. Supplementary Notes

16. Abstract An ERTS mosaic was used for making a tectonic map of the Tanacross, Alaska Area. The area was divided into two tectonic units: (1) the Denali Fault located in the southern half of the test area, and (2) the Yukon-Tanana Upland located to the north. Major characteristics of the Denali Fault unit are: abundant N30°W (±) lineations parallel and, in part, constituting the Denali Fault system which controls topography and a geosynclinal downwarp that is consistent with this trend. The characteristics of the Yukon-Tanana Upland unit are numerous circular features, arcuate lineations, and mountainous terrain. Although the apex of the Alaska Orocline lies 200 miles to the west, N30°W trending fold belts and strike/slip faults, observed on the ERTS mosaic, bend more E-W in direction the further west they are traced. The spectral reflectance signature and hue changes of the high vegetation cover (30%) and complex community patterns were used to map different lithological units on ERTS color composite transparencies that showed good agreement with published geologic maps. Mineral occurrences show good correlation to mapped ERTS lineations and circular features and aeromagnetic anomalies.

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PREFACE

This report is one of six similar reports which describe research results accomplished by Earth Satellite Corporation under ERTS-1 project entitled, "Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery," PR 510 contract NAS5-21769. A list of these six reports follows:

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Prindle, R. O., Lyon, R.J.P., Haenggi, W. T., and Erskine, M. C., Jr., 1974, Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site: Earth Satellite Corp. rept.

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INTRODUCTION

The Tanacross test area is in eastern Alaska between latitudes 62°N and 64°15N and longitudes 139°15'E and 144°E (Figure 1). Elevations within the area range from 610 meters, in the Northway Basin, to 2592 meters in the Nutzotin Mountains in the southern portion of the area.

Figure 1 shows the location of ERTS imagery and Table 1 lists the frames used in the study. A mosaic of 12 black-and-white ERTS prints of channels 6 and 7 at a scale of 1:1,000,000 was used for the investigation. Six frames were used in the inner test area to give adequate cloud-free coverage (Table 1). Plate 1, "Photo Index and Mineral Prospect Locations," shows centers and identification numbers of frames used in the inner test area along with copper and molybdenum occurrences. We find low sun-angle (20°-25°) imagery best for mapping lineations and high sun-angle (38°-40°) color composite imagery (bands 4, 5 and 7) best for mapping geological contacts and distinguishing rock types. The high northern latitude and early hour (approximately 10:20 a.m.) at which the satellite crossed the test area, resulted in dark (still shaded) valleys and northern slopes of mountain ranges that hinders interpretations.

A large side overlap (approximately 70 percent) of adjacent flight paths occurring in the far northern latitudes is helpful for choosing cloud-free portions of frames for complete mosaic coverage of the test area.

The ERTS Lineation and Geological Interpretation (Plate 2) was performed on a transparent overlay to the ERTS mosaic. A stream drainage transparency based on the World Aeronautical Chart Series, C-9, D-11 and D-12 (Scale 1:1,000,000 - Lambert Conformal Conic Projection) provided geodetic control.

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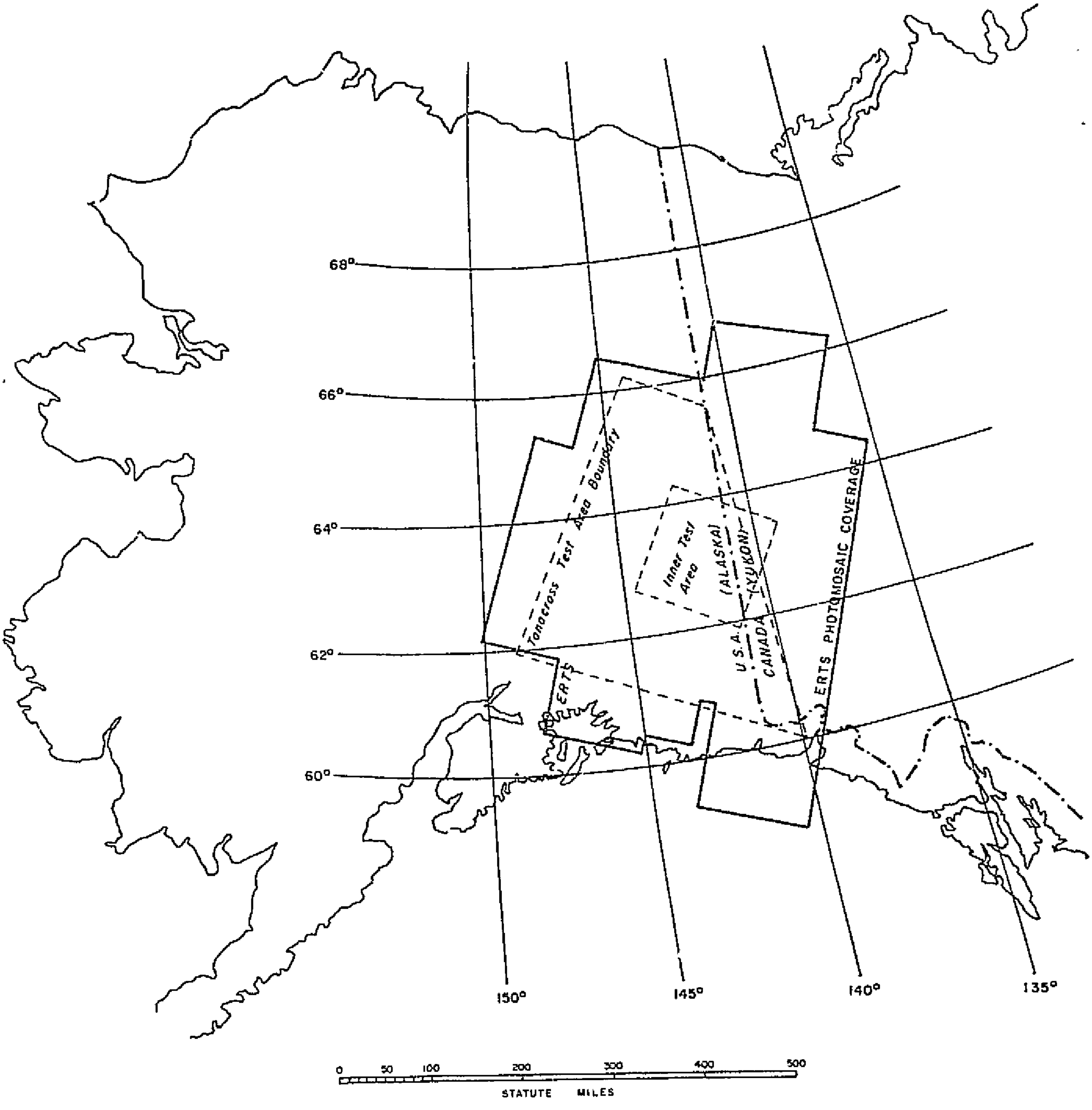

Figure 1. Tanacross, Alaska Test Area

Table 1. Tanacross, Alaska ERTS Imagery

Date	I. D. No.	Center Coord.	Sun El.	Sun Az.	Cloud+ Cover (%)
8-18-72	1026-20205	6548N 13902W	36.2	162.4	0
8-18-72	1026-20211	6427N 14025W	37.3	160.5	"
8-18-72	1026-20214*	6306N 14150W	38.4	158.7	"
8-18-72	1026-20220*	6144N 14249W	39.4	157.0	"
8-21-72	1029-20381	6532N 14338W	35.4	162.4	"
8-21-72	1029-20383	6411N 14459W	36.5	160.6	"
9-03-72	1042-20100*	6403N 13756W	32.3	162.3	"
9-04-72	1043-20161	6241N 14033W	33.0	160.9	"
9-04-72	1043-20163	6119N 14142W	34.2	159.3	"
9-05-72	1044-20212***	6403N 14043W	31.5	162.6	10
9-05-72	1044-20215***	6242N 14157W	32.7	161.0	"
9-24-72	1063-20271***	6404N 14206W	24.5	165.5	"
9-24-72	1063-20273**-***	6242N 14319W	25.7	164.1	"
9-24-72	1063-20280**	6120N 14427W	26.8	162.8	"
9-25-72	1064-20331	6241N 14446W	25.3	164.3	"
9-25-72	1064-20334	6119N 14555W	26.5	162.9	"
9-27-72	1066-20444	6246N 14734W	24.5	164.6	"
10-09-72	1078-20103*-***	6249N 13856W	20.0	166.2	"
10-09-72	1078-20105*-***	6126N 14005W	21.2	165.0	"

* 1:1,000,000 color composites from Channels 4, 5, & 7

** 1:1,000,000 color composites from Channels 4, 5, 6, & 7

*** 1:1,000,000 black-and-white frames used for inner-test area mosaic

\+ Percent cloud cover in portion of frame included in mosaic of inner test area (estimated by EarthSat).

Two color composites of channels 4, 5, 6 and 7 were made on an I^2S Addcol in an effort to enhance vegetation and geological features. Filter combinations and brightness control of the Addcol accentuate vegetation and terrain differences so that bedding attitudes and contacts can be more easily mapped than on individual frames from channels 6 and 7. Tan-to-reddish-brown hues are superior to commercially produced color composites that do not utilize channel 6 and are a uniform red color. There is an advantage in having the interpreter make color composites because color combiners enable him to control the hue intensity, colors, and combinations of channels to enhance geological features.

GEOLOGICAL MAPPING

Plate 3 combines four published geologic maps that were used as references in geological mapping on black-and-white ERTS imagery, and color composites of the test area. Color composites are better than imagery from individual channels for identifying different lithological units. A 1:1,000,000 transparent color composite frame (channels 4, 5, and 7; 18 August 1972, I.D. No. 1026-20214), furnished by NASA, covering 90 percent of the test area has excellent color saturation and a wide variety of hues. This frame has no snow cover, but has approximately 20 percent cloud cover. Fortunately most of the clouds are of the "popcorn" variety and do not greatly hinder interpretation. Color composites from October and September imagery are too dark or too obscured by snow for good interpretation work.

On ERTS color transparencies, many hues are observed that indicate reflectance properties of the earth's surface in the 0.5 to 1.1 μm interval. When vegetation cover exceeds 20 to 30 percent, spectral signature and hues on color transparencies are directly related to vegetation. Discrimination between vegetation species is best between 0.5 and 0.7 μm, whereas the near-infrared range (0.7 to 1.1 μm) is useful for determining vegetation or soil/bedrock locations. Therefore, depending upon the vegetation cover, it can be either an aid or hindrance to geological mapping.

In Alaska where vegetative cover is high and community patterns complex, the interpreter must take into consideration the contribution vegetation makes in mapping lithological units. Because aspect (steepness of slope and position with relation to the sun) and elevation are factors that affect distribution of plant communities, it can be misleading to map geological contacts based on changes in hue on ERTS color composites. In the test area, the following vegetation-environmental relationships were used for explaining differing colors and intensities while mapping contacts:

1. Vivid red--deciduous trees (usually aspens or poplars); generally on south-facing slopes which have more sun exposure and little or no permafrost.

2. Light black or steel grey--high elevations that are bare Alpine rocklands; rocky, shallow soils.

3. Dark red--dominantly white spruce; also black spruce and small amounts of aspen; these are usually on mountain slopes with moderate-to well-drained soils.

4. Pinkish-brown--black spruce, tamaracks and small amounts of white spruce and deciduous trees, often located in low, cold depressions.

5. Browns--low growing plants (shrubs and herbs); boggy sites.

6. Dark black areas--burn areas.

7. Light orange--willows and tall Arctic shrubs; often at higher elevations.

Geological contacts mapped on color composites show agreement with those shown on published maps (Plate 3). When the previously-mentioned vegetation and geomorphological effects are considered, the following generalities concerning rock types mapped on ERTS and their corresponding descriptions given by geological maps can be made:

1. Precambrian metamorphic rocks, e.g., schist, gneiss and some volcanic rocks appear chocolate brown or grey. The terrain appears to have well-rounded hills and curved stream patterns.

2. Paleozoic limestone sequence appears bright red.

3. Cretaceous volcanic rocks (andesite, diabase and basalt) appear very bright red.

4. Quaternary pyroclastic volcanic rocks are also very bright red and usually form topographic ridges.

5. Mesozoic banded shale and argillite, sandstone, and conglomerate appear light black and steel grey. This color might be due partly to higher elevations in the Mentasta and Nutzotin mountains.

Glaciation throughout the test area hinders ERTS geological mapping, especially in areas of lower elevation where deglaciation features mask underlying geology.

Hughes, et al., (1968) report that during both the Reid and McConnell glacial advances (late Wisconsin) ice lobes, about 30 miles from the St. Elias Mountains, expanded into the Wellesbey Basin and valleys in the southeast corner of the test area. A transparency reduction (1:250,000 to 1:1,000,000) of "Glacial Map of Yukon Territory" from Hughes, et al., paper, overlaid on a 9-1/2" x 9-1/2" ERTS color transparency (1026-20214) of the same area was useful for mapping glaciated areas. Areas of non-glaciation have more potential for finding porphyry copper deposits because (1) surface mineralization can be more easily detected, and (2) residual soils favorable for supergene enrichment have not been removed by glacial action.

TECTONICS

The test area can be divided into two tectonic units: (1) the Denali Fault located in the southern half of the test area, and (2) the Yukon-Tanana Upland located in the northern part of the test area (Plate 2). Major characteristics of the Denali Fault unit are: abundant N80°W (±10°) lineations parallel and in part constituting the Denali Fault system which control topography and a geosynclinal downwarp that is consistent with this trend in the southeast corner of the area but departing to a northward trend to the west. The characteristics of the Yukon-Tanana Upland unit are numerous circular features (shown on Plate 4), arcuate lineations and mountainous terrain.

The apex of the Alaska Orocline (Carey 1955 and Grantz 1973) lies 200 miles to the west. The N80°W trending fold belts and strike-slip faults, when observed on the ERTS mosaic, bend more E-W in direction the further west they are traced; while in the eastern edge of the mosaic the structural trends are N40°W.

Churkin (1973) reports the Cordilleran geosyncline began a new pattern of high tectonic activity in the Jurassic which lasted throughout most of the Mesozoic and locally continued into the Cenozoic. The general pattern of Mesozoic, and to a lesser degree Tertiary, basins and uplifts tends to be arcuate and follows the Paleozoic trends, reflecting a strong influence of Precambrian and Paleozoic basement on the developing tectonic features. The test area is transversed by the Denali fault; to the north is another strike-slip fault zone called the Tintina Trench (Figure 2). This area has been subjected to two dynamic forces: (1) oroclinal bending and/or strike-slip movement, and (2) uplift and batholith emplacement (Mesozoic).

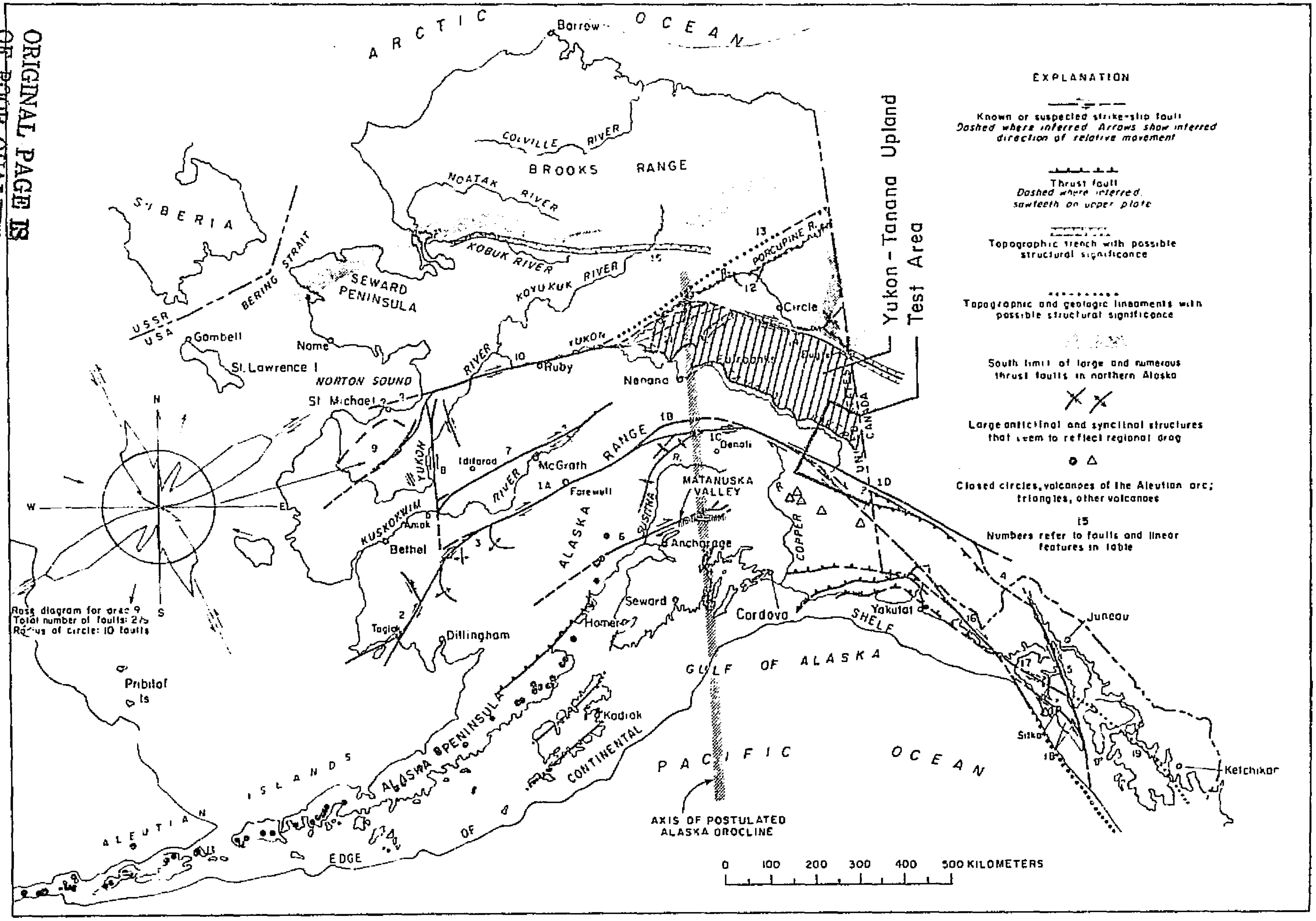

Figure 2. Map of Alaska Showing Known and Suspected Large Strike-Slip Faults and Selected Linear Features. (Modified from Grantz, 1973).

Key to Faults and Linear Features Shown on Figure 2

Denali Fault System

(1A) to (1D) Denali fault

(1A) Farewell segment

(1B) Hines Creek strand

(1C) McKinley strand

(1D) Shakwak Valley segment

(2) Togiak-Tikchik fault

(3) Holitna fault

(4) Chilkat River fault zone

(5) Chatham Strait fault

Faults and lineaments in southwestern and central Alaska

(6) Castle Mountain fault system

(7) Iditarod-Nixon Fork fault

(8) Aniak-Thompson Creek fault

(9) Conjugate strike-slip faults in the Yukon delta region

(10) Kaltag fault

(11) Stevens Creek fault zone

(12) Porcupine lineament

(13) Yukon Flats discontinuity and fault

(14) Tintina fault zone and Tintina trench

(15) Kobuk trench

Faults and lineaments in southeastern Alaska

(16) Fairweather fault

(17) Peril Strait fault

(18) Chichagof-Sitka fault

(19) Clarence Strait lineament

North of the target area, the Tintina fault (trough) can be easily traced on ERTS imagery by the narrow valley that parallels the Yukon River and effectively separates the unmetamorphosed Precambrian-through-Mesozoic stratigraphy on its north side from strongly metamorphosed sedimentary and volcanic rocks on its south side. South of the Tintina Fault Zone, tectonic style is dominated by intrusions into metamorphic rocks (circular features as seen on ERTS imagery).

St. Amand (1957, Lathram (1964), Grantz (1973) and others have suggested that 80-240 km of right-lateral strike-slip displacement has occurred along the Denali Fault system (over 2150 km long; Grantz, 1973). Their evidence for this is from displacement of Paleozoic and Tertiary rocks along the fault. We have not measured this displacement on ERTS imagery because we cannot accurately identify corresponding rock types on opposite sides of the fault.

We postulate that maximum tectonic activity in the test area is due to: (1) strike-slip faulting, (2) northward bending of the Alaska Orocline, and (3) batholith emplacement accompanied by rejuvenation of Precambrian and Paleozoic fracture systems and structural trends which acted as plumbing systems for copper and molybdenum-bearing hydrothermal solutions.

COMPARISON BETWEEN ERTS AND AEROMAGNETIC DATA

A number of magnetic anomalies shown by Plate 5 correspond to topographic features noted on the ERTS mosaic. The positive magnetic anomaly indicated on Plate 5 as '1' corresponds to a circular feature mapped independently on ERTS imagery (Plate 3) and interpreted as a near-surface intrusion. Plate 3, Compilation of Published Geologic Maps, shows a number of circular intrusions in the test area that correlate to magnetic highs, which are not recognizable on the ERTS imagery. Features 2 and 3, indicated on Plate 5, correlate to topographic ridges that are interpreted to be composed of volcanic rocks. Feature 2 can also be interpreted as a fault zone with post-fault mineralization. Plate 2, ERTS Lineation and Geological Interpretation, shows a lineation zone along this fault.

Dashed contact lines are placed around anomalies that are interpreted to be due to contrasting rock types. Many of these anomalies correspond to topographic features and geological formations with similar boundaries, that are recognized on ERTS imagery.

About half the magnetic lineations do not agree with lineations shown on Plate 2. Re-examination of ERTS imagery shows that some of these features are edges of topographic features, or straight segments of streams, which implies that they are faults. Those that do not correspond to features observable on the imagery are explained as (1) deep-seated faults in the basement which may not be reflected in the surface rocks, (2) location discrepancies caused by excessive flight line separations and altitudes, and (3) lineation is not correctly interpreted.

Table 2. Copper, Molybdenum Locations that Coincide with Mapped ERTS Features

Mineral Occurrence Location No.	Element	ERTS Circular Feature	ERTS Lineation	Aeromagnetic Anomaly	Aeromagnetic Lineation	ERTS Geological Contact
1	Mo		x	Ⓐ		
2	Cu		x			
3	Cu	x		x		x
4	Cu		Intersection of 4 lineations	x		
5	Mo	x	x	x		
6	Cu		x	x	x	
7	Cu	x	x			
8	Cu	x	x	x		
9	Cu	x	x	x		
10	Mo		x	x	x	
11	Cu		x		x	
12	Cu	x	x	x	x	
13	Cu	x	x	x		
14	Mo		x			
15	Cu	Clouds obscure terrain				
16	Mo		x	Ⓐ		
17	Mo	x	x	Ⓐ		

Ⓐ No aeromagnetic coverage of these locations

CORRELATION OF MINERAL OCCURRENCES AND FEATURE NOTES ON ERTS IMAGERY

Mineral occurrences taken from Cobb (1960, Plate 1) show good correlation to mapped ERTS features (Plates 2 and 4) and excellent correlation to aeromagnetic anomalies (Plate 5).

Table 2 was constructed by superimposing transparency copies of plates 1, 2, 4 and 5 and tabulating the occurrences of features interpreted on ERTS imagery with the mineral locations. Re-examination of ERTS imagery at some mineral locations showed that subtle circular or half-circular features and small lineations had been overlooked. The diameters of these circular features range from 3 to 6 km and show good agreement with similar features associated with porphyry copper mines in Arizona and Nevada.

Correlation between ERTS-mapped lineations and positive aeromagnetic anomalies is excellent. Four of the five parameters noted occur at Location 12 and six locations (3, 5, 6, 8, 9 and 13) have three parameters present. Geological contacts have the poorest correlation factor, which may be due to the inability to distinguish them on ERTS imagery.

We believe that a similar correlation of ERTS and aeromagnetic features will be useful as an exploration guide for new copper and molybdenum deposits.

REFERENCES CITED

Cairnes, D. D., Boyd, W. H., 1917, Geologic Map of Southwestern Yukon, Map 154A, Scale 1:506,880, Canada, Dept. of Mines Geological Survey.

Carey, S. W., 1955, The Orocline Concept in Geotectonics - Part 1: Papers and Proceedings of the Royal Society of Tasmania, V. 89, p. 255-288.

Churkin, Jr., M., 1973, Paleozoic and Precambrian Rocks of Alaska and Their Role in Its Structural Evolution, USGS Prof. Paper 740.

Cobb, E. H., 1960, Molybdenum, Tin and Tungsten Occurrences in Alaska, USGS Minerals Investigations Resource Map MR-9.

Cobb, E. H., 1960, Molybdenum, Tin and Tungsten Occurrences in Alaska, USGS Minerals Investigations Resource Map MR-10.

Cookfield, W. E., 1920, Geologic Map of Sixtymile and Ladue Rivers, Yukon Territory, Canada Dept. of Mines, Geological Survey Publication No. 1812, Scale 1:250,000.

Dutro, J. T., Payne, T. G., 1957, Geologic Map of Alaska, Scale 1:2,500,000, USGS.

Geological Survey of Canada, 1952, Map 1012A, Northwest Shakwak Valley, Yukon Territory, (Geologic Map); Scale, 1:253,440, Geological Survey of Canada.

Grantz, A., 1973, Open File Report, Strike Slip Faults in Alaska, USGS, Menlo Park, California.

Hughes, O. L., Campbell, R. B., Muller, J. E., and Wheeler, J. O., 1969, Glacial Limits and Flow Patterns, Yukon Territory, South of 65 Degrees North Latitude, Report and Map 6-1968, Paper 68-34, Geological Survey of Canada, The Queen's Printer, Ottawa, Canada.

Matson, N. A., 1969, Metallic Mineral Resources Map of the Nabesna Quadrangle, Alaska, USGS Open File.

Moffit, F. H., 1954, Geology of the Eastern Part of the Alaska Range and Adjacent Area, USGS Bulletin 989D.

U. S. Geological Survey, 1971, Aeromagnetic Contour Map Tanacross Quadrangle, Alaska, Scale 1:250,000, Drawing No. AKO-302, Kennecott Exploration Inc., Salt Lake City, Utah. Compiled from 24, 1:63,360 Sheets of USGS Aeromagnetic Maps.

U.S. Geological Survey, 1971, Aeromagnetic Survey Nabesna Quadrangle, Alaska, Scale 1:250,000, Drawing No. AKO-301, Kennecott Exploration, Inc., Salt Lake City, Utah, compiled from 23, 1:63,360 sheets of USGS Aeromagnetic Maps.

Following

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Tectonic interpretation of ERTS-1 imagery of the Ok Tedi, Papua New Guinea test site

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16. Abstract

Nine ERTS frames of NW Papua were used to make a tectonic map. Unfortunately two ERTS frames covering the inner test area had cloud cover in the mountainous regions obscuring many geological features, including the Ok Tedi porphyry copper deposit. ERTS imagery of tropical jungle areas, i.e., Papua, proved useful for reconnaissance tectonic mapping and will prove useful for similar areas if two criteria are met: (1) low cloud coverage, and (2) relief sufficient for stream drainage and geomorphological mapping. Using SLAR imagery, two known porphyry copper deposits, Mt. Fubilan and Frieda River, can be identified as small (2-6 km diameters) circular features on ERTS. Similar circular features in the area of Frieda River deposit can be identified. Four tectonic units based on differences in relief, landforms, drainage, density and pattern are interpreted on the ERTS imagery. The boundary between two of these is interpreted to be the site of the Indian-Australian Plate and the Pacific Plate, (a continent-island arc collision).

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PREFACE

This report is one of six similar reports which describe research results accomplished by Earth Satellite Corporation under ERTS-1 project entitled, "Recognition of the geologic framework of porphyry copper deposits on ERTS-1 imagery," PR 510 contract NAS5-21769. A list of these six reports follows:

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The Ok Tedi (Mt. Fubilan) porphyry copper deposit is in northwest Papua on the Island of New Guinea. The exact location is 141°8'14" East longitude, and 5°12'27" South latitude, on the southern slopes of the Victor Emanuel Mountain range near the headwaters of the Fly River, about 15 kilometers east of the West Irian-Papual Border (Figure 1). Relief at the deposit is 1800 meters and elevation ranges from sea level to 4000 meters within the test area. Annual rainfall at Ok Tedi is around 400 inches, and the entire region is covered by dense tropical rain forest. Temperatures range from about 59° to 90° Fahrenheit.

Figure 1 shows ERTS mosaic coverage used for the investigation. The ERTS coverage of approximately 280,000 square kilometers extends beyond the boundaries of the inner test area so that regional geological features can be recognized and interpreted for their structural influence on the Ok Tedi test site.

A mosaic of 9 ERTS frames was used to make a tectonic map. Table 1 lists ERTS frames used in making the tectonic map, and Plate 1 "Photo Index" shows key ERTS frame centers and identification numbers. The mosaic is composed of black-and-white prints of channels 6 and 7 at a scale of 1:1,000,000 (channel 6 is best for geological interpretation). Two color composite prints from bands 4, 5, and 7 at a scale of 1:500,000, and two color composites from bands 4, 5, 6, and 7 at a scale of 1:100,000, were used for supplementary interpretations.

The tectonic interpretation was performed on a transparency overlay to the ERTS mosaic. A stream drainage transparency based on ERTS imagery

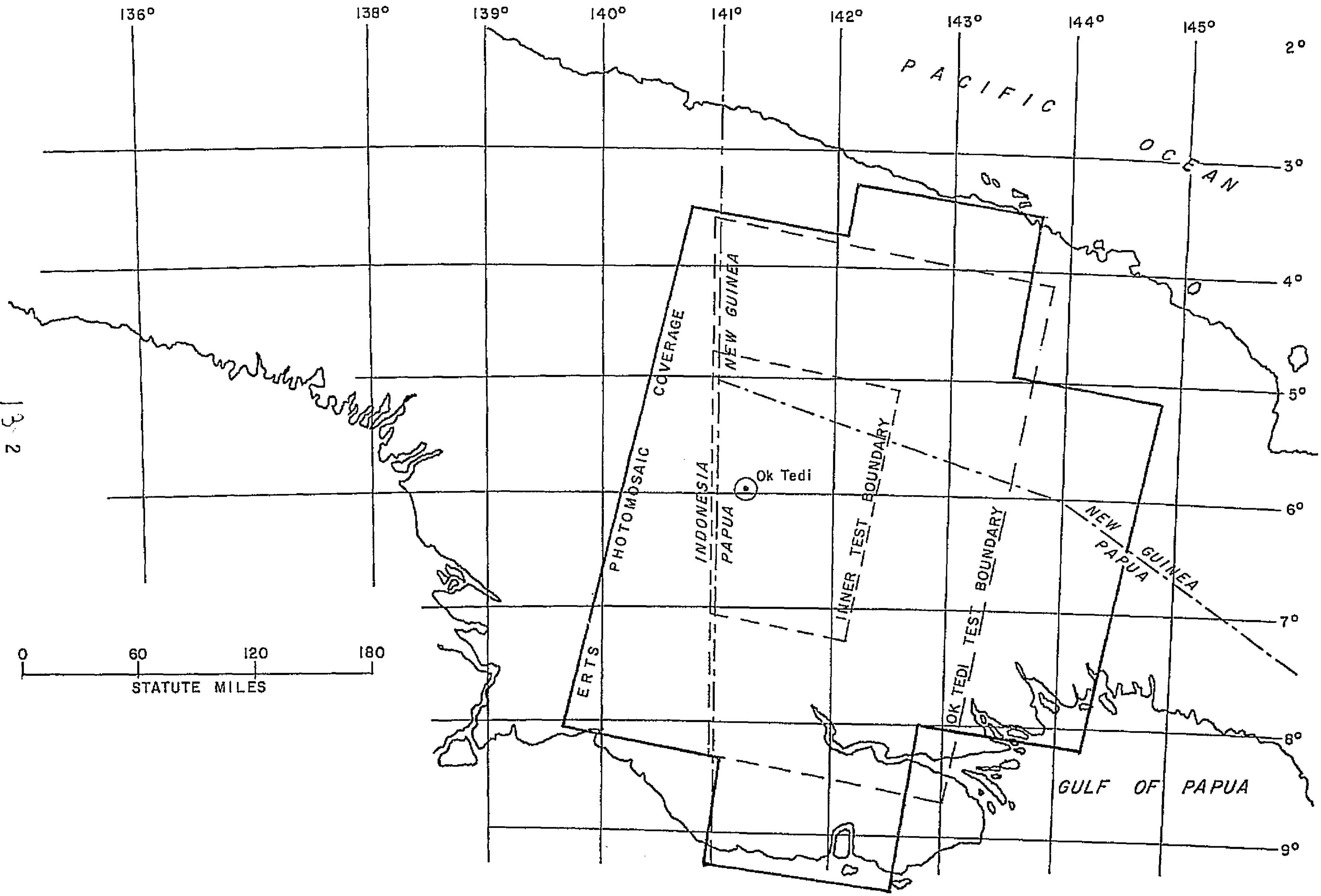


Figure 1. Ok Te Papua Test Area

Table 1. Ok Tedi ERTS Imagery

Date	I. D. No.	Center Coord.	Sun El.	Sun Az.	Cloud* Cover (%)
Mosaic (Black-and-white - Scale 1:1,000,000)					
18 Aug. 72	1026-00023-6,7	S 05-50/E 143-60	49	62	15
	1026-00030-6,7	S 07-16/E 143-40	48	60	15
19 Aug. 72	1027-00075-6,7	S 04-11/E 142-52	50	64	50
	1027-00081-6,7	S 05-39/E 142-32	49	62	25
	1027-00084-6,7	S 07-06/E 142-12	48	61	25
	1027-00090-6,7	S 08-32/E 141-52	47	60	35
20 Aug. 72	1028-00134-6,7	S 04-24/E 141-28	50	64	40
	1028-00140-6,7	S 05-50/E 141-08	49	62	15
	1028-00143-6,7	S 07-17/E 140-48	48	61	60
Color Composites (Scale 1:500,000)					
20 Aug. 72	1028-00134-4,5,7	S 04-24/E 141-28	50	64	40
	1028-00140-4,5,7	S 05-50/E 141-08	49	62	15
Color Composites (Scale 1:1,000,000)					
20 Aug. 72	1028-00140-4,5,6,7				
19 Aug. 72	1027-00081-4,5,6,7				

*Percent of Cloud Cover estimated by EarthSat combined with major stream locations taken from the World Aeronautical Chart Series, M-13 (Scale 1:1,000,000, Lambert Conformal Conic Projection) provided geodetic control. Unfortunately the two ERTS frames that cover the inner test area have cloud cover in the mountain regions that obscures many geological features, including the Ok Tedi deposit. These frames have approximately 50% scattered cloud cover in the mountain areas, but are the best imagery available. The densely forested plain in the southern part of the area has no detectable topography or ERTS imagery that can be used as a guide for geomorphic and structural mapping. Because low sun angles do not occur in equatorial regions, subtle relief features and their shadows are not useful aids to geological interpretation. The imagery for the major part of the test site has a 49° sun angle (August 20, 1972) which is low for this latitude. The plain to the north of the mountains has low relief but geological features can be mapped in cloud-free areas.

Two color composites using channels 4, 5, 6, and 7 were made on an I^2S Addcol in an effort to enhance vegetation and geological features. Filter combinations and brightness control accentuate vegetation changes so that bedding attitudes and volcanic features can be more easily mapped than on individual frames from channels 6 and 7. Tan-to-reddish-brown hues are superior to commercially produced color composites that do not utilize channel 6 and are a uniform red color. There is an advantage in having the interpreter make color composites because the color combiners enable him to control the hue intensity, colors, and combination of channels to enhance geological features. However, larger scale (1:500,000) prints made from 9" x 9" negatives permit greater detail in mapping.

The spectral response of dense lush vegetation, on channel 6, has a uniform grey level (narrow range) on the black-and-white prints compared to other geographical locations that are not jungle covered. The color composites were, in general, solid magenta, again reflecting dense vegetation. The Gebergte and Victor Emanuel Mountain ranges show darker hues of red, indicating different species of trees and probably greater precipitation than occurs on the plains. Immediately north of these mountain ranges, in a high central plateau, there are a number of pinkish colored areas. These are interpreted as areas where the forest has been cleared for agricultural purposes. One of these areas occurs at latitude 5°7'S and longitude 142°25'E near the town of Kiaram.

Extensive cloud cover and heavy vegetation hinder tectonic mapping, as anticipated. However, we believe that important geological information pertaining to mineral exploration can be gained by mapping regional tectonic features on ERTS imagery in remote jungle covered areas where very little published data exists.

ERTS TECTONIC MAP

The ERTS Tectonic Map (Plate 2) shows:

1. Tectonic units
2. Folds, attitudes of bedding
3. Circular features
4. Major faults.

Plate 2 shows four tectonic units that strongly influence regional topography. Units I and IV are flat plains, whereas Units II and III have high relief and are the south and north slopes of a northwest-southeast trending mountain range that runs the length of New Guinea.

As with the previously discussed test sites, the differentiation of these units is based on differences in relief, landforms, and drainage density and pattern as interpreted from ERTS imagery.

The boundary between Tectonic Units II and III is probably a convergent plate junction between the Indian-Australian Plate and the Pacific Plate, and is probably the site of a continent-island arc collision in Middle Tertiary time (Hamilton, 1970; Dewey and Bird, 1970). Tectonic Units I and II formed part of an epicontinental extension of the Australian Continental Platform on the northward-moving Indian-Australian Plate, while the tectonic unit to the north (III) is possibly part of an island arc on the west-northwest moving Pacific Plate. The dominant west-northwest trend of fold axes, bedding attitudes and faults, and the south-southeast movement of thrust plates along the boundary between Tectonic Units II and III is caused by compressional shear stresses created by collision of the plates.

The southern portion of Tectonic Unit II has a thick section of sedimentary rocks with broad folds and has undergone relatively little regional metamorphism. The attitudes of the sedimentary beds can be easily identified, and the signature of them is similar to areas where medium-to-fine grained clastic rocks exist.

Tectonic Unit III has a number of parallel, east-trending valleys with streams and smaller tributaries forming a trellis pattern. The valleys are interpreted as fault controlled and are longer than the N and NW faults of Unit II.

Tectonic Unit IV is a plain, characterized by circular features and low ratio of range to valley area (1:4). The Sepik River follows a large circular bend (approximately 60 miles in diameter) as it flows to the north around gently rolling mountains that contain a number of circular features.

We believe that this large bend in the river may reflect a buried igneous complex.

COMPARISON OF ERTS TECTONIC AND DRAINAGE MAPS WITH SLAR AND PUBLISHED TECTONIC AND GRAVITY MAPS

The Geological Map of Western Papua and Generalized Regional Sections Across the Folded Belts of Papua produced by the Australasian Petroleum Company Pty. (1961) are lacking in detail and do not fully cover the test area. They should be updated by an interpretation from ERTS imagery. A portion of the latter map (Figure 2) classifies the Ok Tedi outer test area into four tectonic units: (1) shelf area, (2) gently folded belt, (3) strongly folded belt, and (4) imbricated zone with the boundaries being most likely arbitrary based upon global tectonics and regional geology. These tectonic units correspond to the ERTS classification of four tectonic units, except that the boundary between the shelf area and gently folded belt is much farther south than the northern boundary of ERTS Unit I, which is placed at the contact between the plain and the base of the mountains. The gently folded belt includes most of the area that we map as Unit II, and the strongly folded belt and imbricated zone are in general agreement with our Units III and IV.

The following observations are noted in a direct comparison of Plate 2, ERTS Tectonic Map, and the Australian Bureau of Mineral Resources (B.M.R.) map, "The Geology of Papua New Guinea," Figure 3, page 10, which was received after Plate 2 had been finished. Table 2 lists the legend for Figure 3.

1. A portion of the boundary between Tectonic Units III and IV (Plate 2) is located on the Frieda fault (Figure 3).
2. The Lagip fault zone (Figure 3) can be identified on Plate 2 as a series of short fault segments on either side of the fault trace shown in Figure 3.

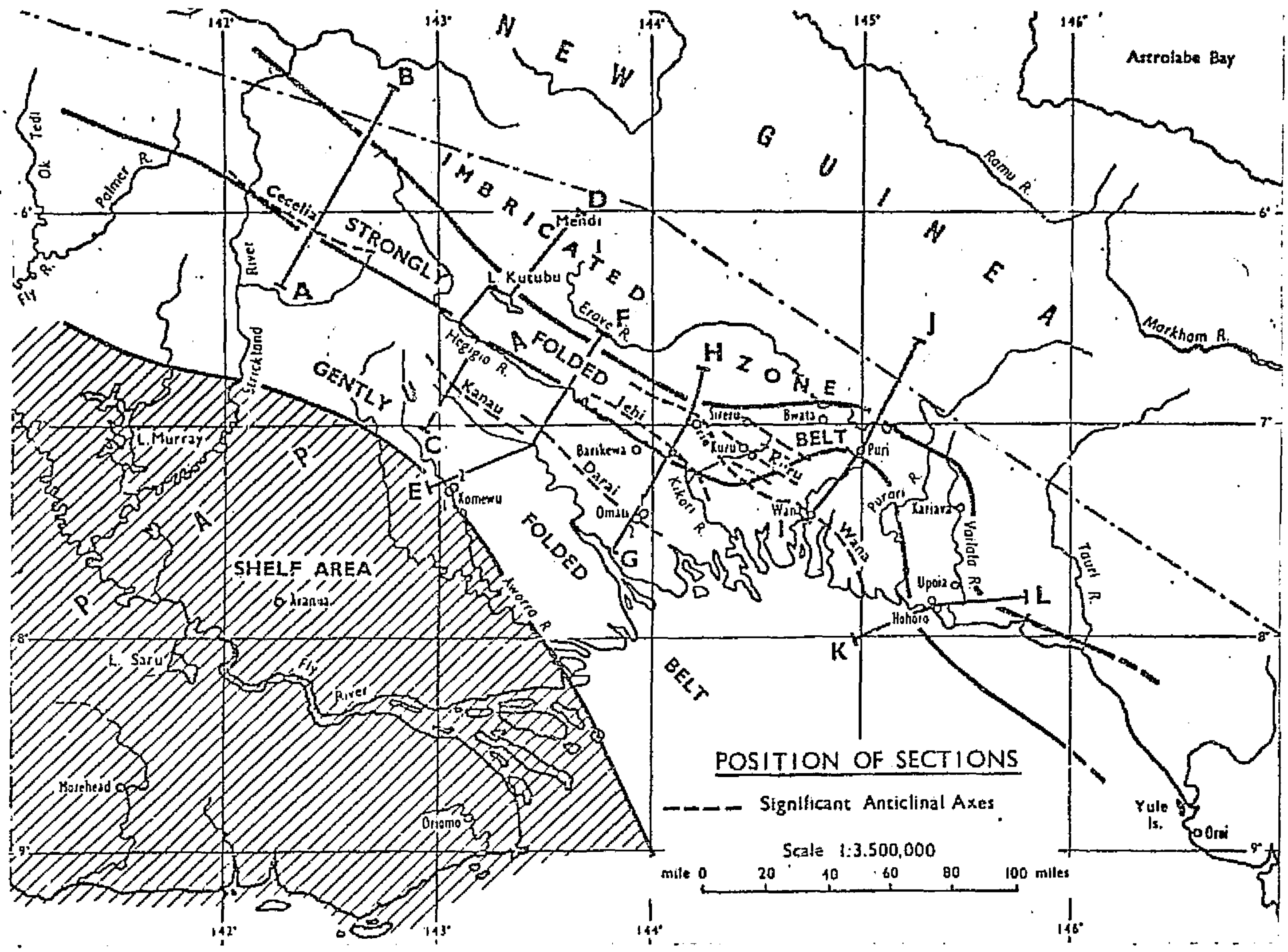


Figure 2. Tectonic Map of Western Papua. From Geological Results of Petroleum Exploration in Western Papua 1937-1961, plate 2, Generalized Regional Sections Across the Folded Belts of Papua.

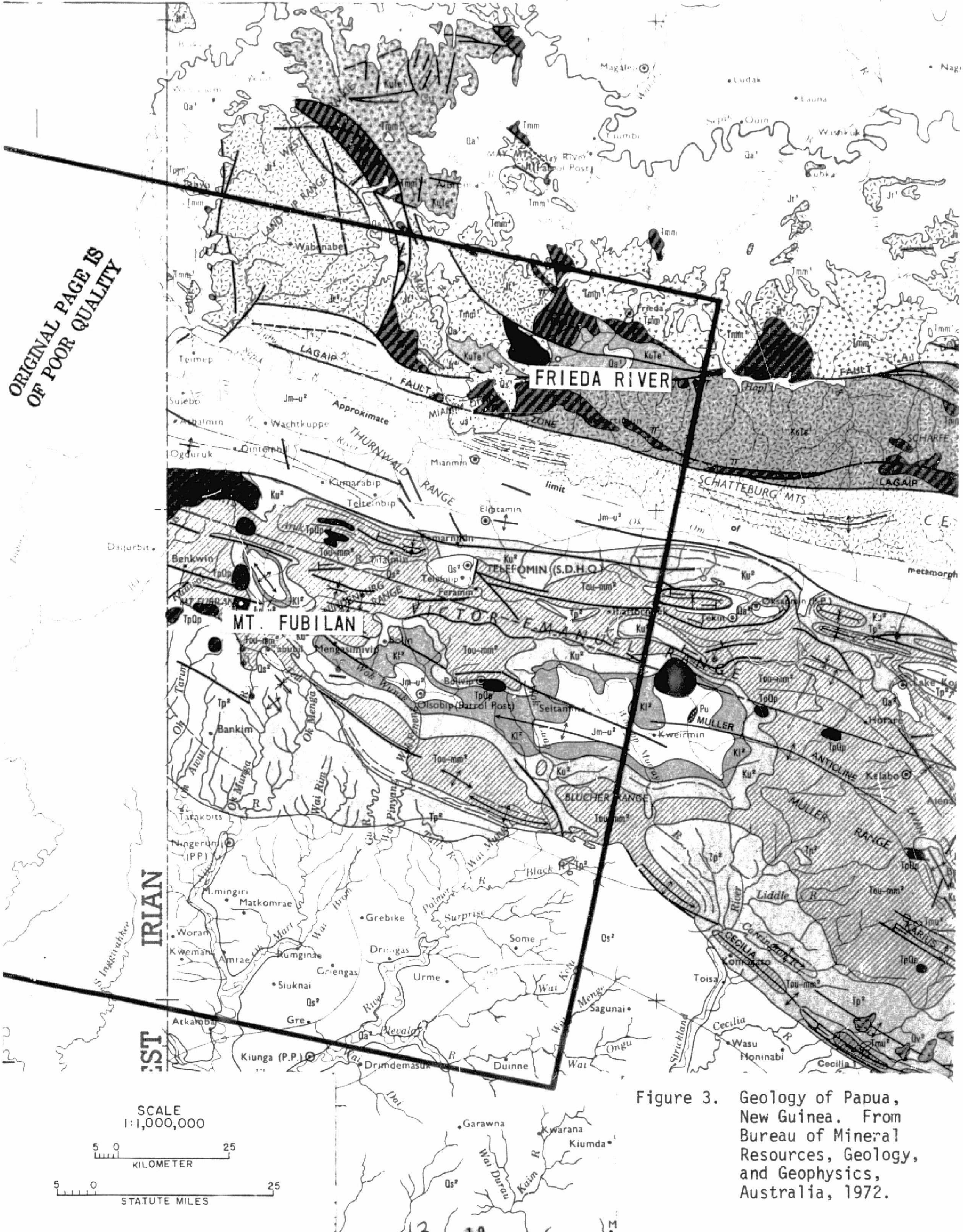
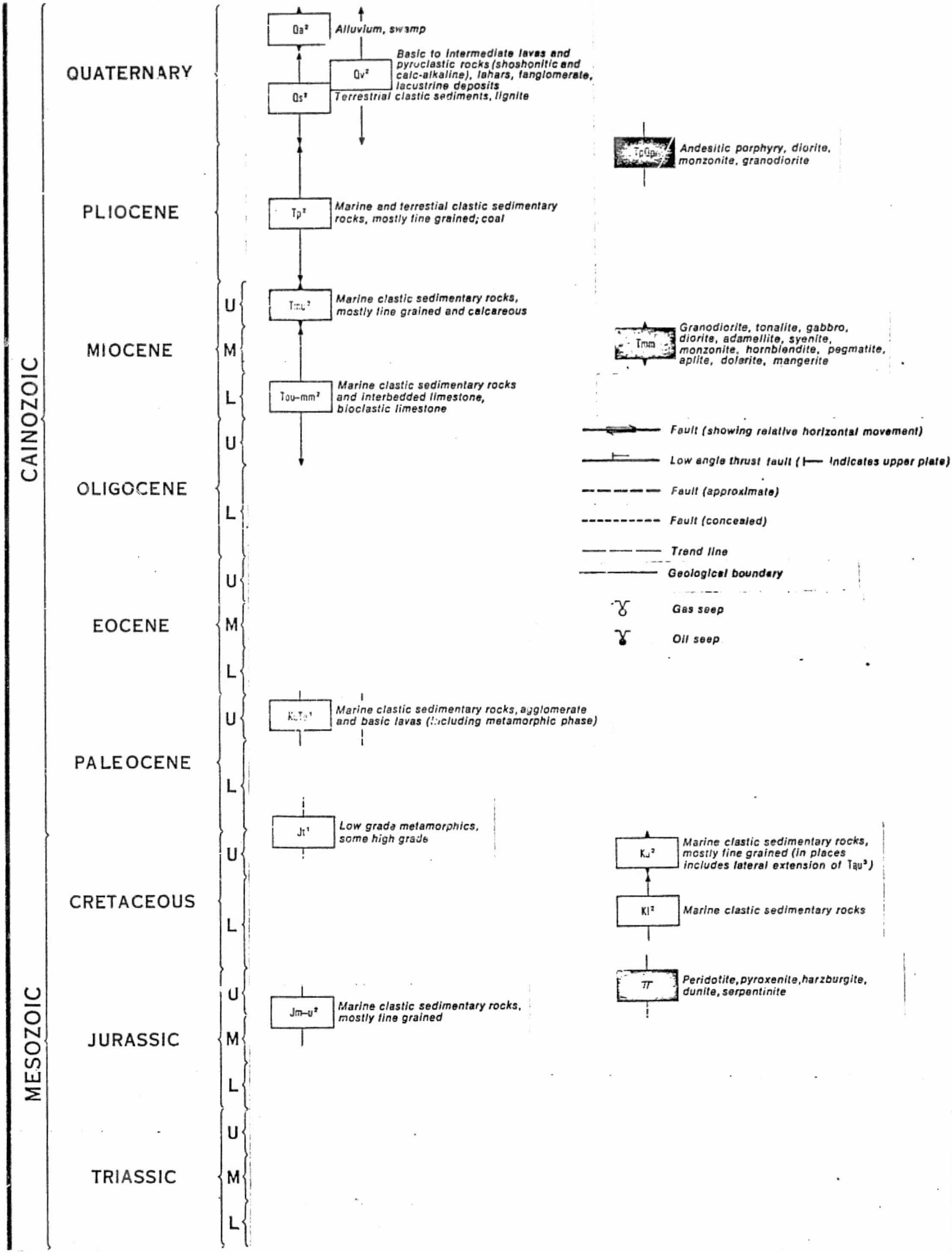


Figure 3. Geology of Papua, New Guinea. From Bureau of Mineral Resources, Geology, and Geophysics, Australia, 1972.

Table 2. Legend (For Figure 3)

Reference



3. The synclinal axis, associated bedding, and faultings shown in Figure 3 at ① have been mapped on Plate 2.

4. More bedding and faults are mapped on Plate 2 than Figure 3. Some of the bedding in plate 2 corresponds to geological contacts on Figure 3.

5. The anticlinal feature at ② is mapped on Plate 2.

The ERTS interpretation in general agrees with that of the B.M.R. map.

Plate 3, "SLAR Interpretation," is from imagery produced on a Side-Looking Airborne Radar (SLAR) survey performed for Kennecott Exploration by Earth Satellite Corporation. The survey was flown to collect imagery for stream drainage in the Ok Tedi porphyry copper prospect area. This region has extensive cloud cover throughout the year, making the acquisition of conventional photography extremely difficult.

Plate 4, "Location Map of SLAR Features as Recognized on ERTS Imagery," shows many of the same drainage, bedding, and ridgeline features (total of 45 separate features) that are mapped on Plate 3. Unfortunately, clouds in the vicinity of the Ok Tedi deposit obstruct the known igneous intrusions that could possibly be identified directly or interpreted by circular drainage patterns or topographical features on ERTS imagery.

Although the ERTS imagery used to construct Plate 4 has a much smaller scale (1:1,000,000) than the SLAR (1:216,000) and lower ground resolution (75 meters vs 5 meters), a total of 45 different features are identified. This indicates that, with supplementary data and ground truth, ERTS imagery is useful for reconnaissance mapping in heavily vegetated areas.

Plate 5, "ERTS Drainage Map," (scale 1:500,000) shows detailed stream drainage, ridgelines, SLAR coverage, and structural control derived from the drainage. This interpretation was performed on color composites composed of channels 4, 5, and 7. Reddish and pinkish hues caused by dense vegetation lack good contrast, and we believe that a 1:500,000 enlargement of channel 6 would give a wider range of contrast and be more suitable for drainage mapping in such areas. The lineation interpretation shows a strong NW trend through the Ok Tedi region. We feel that these lineations reflect a NW-trending fold or structural belt, approximately 100 kilometers wide, in which Tertiary and older sedimentary rocks, mostly limestone and clastic rocks, have been intruded by hypabyssal stocks of Plio-Pleistocene age that R. W. Bamford (1972) refers to in a discussion of the regional and structural setting of Mt. Fublian. The SLAR mosaic composed of east-looking image strips with low illumination angle accentuates this NW trend and is the model for the ERTS lineation mapping and extension beyond the SLAR coverage.

It is interesting to note that a volcanic belt parallels this hypabyssal trend to the east and extends across the four tectonic units. It can be traced from Bosavi Peak (latitude 6°38', longitude 142°50') through the Muller Range (latitude 6°20', longitude 142°30'), through two unidentified or unnamed peaks in the Thurnwald Range (latitude 4°50', longitude 141°50') that appear to be of volcanic origin, to numerous circular features in Tectonic Unit IV.

A Bouguer Gravity Map of the Ambunti Quadrangle (1:250,000) shows a positive anomaly near the Sepik River (latitude 4°15', longitude 142°35') that may be indicative of a near-surface intrusion. Dense cloud cover at this location on the ERTS imagery does not allow us to see if there are any circular features that could be correlated with the gravity anomaly. This location is 200 kilometers east of the large circular bend in the Sepik River discussed under the ERTS Tectonic Map Section.

CONCLUSIONS AND RECOMMENDATIONS

ERTS imagery of tropical jungle locations is useful for reconnaissance geological mapping if two criteria are met: (1) low cloud coverage, and (2) relief sufficient for stream drainage and geomorphological mapping.

Three known porphyry copper prospects (Mt. Fubilan, Tifalmin and Frieda River) are in the test area (Plate 1). Two of these deposits, Mt. Fubilan and Frieda River, are associated with small (2 to 6 kilometer diameters) circular features that can be detected on ERTS or SLAR imagery.

The SLAR survey of the Mt. Fubilan area shows twelve small circular features (Plate 3). Eight of these features are recognized as igneous intrusions and the others, including Mt. Fubilan, are probably associated with igneous intrusions. Unfortunately, ERTS imagery has extensive cloud cover in the Mt. Fubilan area which precludes recognition of these features. We believe that cloud-free ERTS imagery of the area would show these features and permit interpretation of the area as favorable for mineral occurrences.

Four small (4 to 5 kilometer diameters) circular features are recognized on ERTS imagery in the area of the Frieda River deposit (Plate 2). This area was recognized to be favorable for porphyry copper occurrences by the interpreter before he was aware of the existence of the prospect.

We conclude that studies of ERTS imagery along the junction between the India-Australia and Pacific plates will permit delineation of favorable areas for prospecting and that small circular features are a key factor for recognizing these areas.

We recommend that cloud-free coverage of the plate junction be acquired from ERTS-B. The imagery should be presented at scales of 1:500,000 and 1:250,000 for detailed stream drainage and circular features mapping. Color composite enlargements, utilizing varied bands and filters, e.g., bands 5 and 7, should be analyzed to determine if vegetation anomalies like the one at Ok Tedi (Bamford, 1972) are present in other areas. If the visual analysis is encouraging, computer-graphic presentations of magnetic tape pixel data ratioing of channels, e.g., bands 5 and 7, should be evaluated for recognition of anomalies that are not visually apparent.

REFERENCES CITED

Australasian Petroleum Company Proprietary, 1961, Geological Survey of Australia, Journal 8, Part 1, Geological Results of Petroleum Exploration, Western Papua, 1937-1961.

Australian Bureau of Mineral Resources, Geology & Geophysics, 1969, Ambrunti Territory of New Guinea, Bouguer Anomalies, scale 1:500,000.

Australian Bureau of Mineral Resources, Geology & Geophysics, 1969, Wabag, Papua, Bouguer Anomalies, scale 1:500,000.

Australian Bureau of Mineral Resources, Geology & Geophysics, 1972, Geology of Papua New Guinea (map scale 1:1,000,000), Canberra, A.C.T., Australia.

Bamford, W. R., 1972, The Mount Fubilan (Ok Tedi) Porphyry Copper Deposit, Territory of Papua and New Guinea, Economic Geology, Vol. 67, pp. 1019-1033.

Dewey, J. F. and J. M. Bird, 1970, Mountain Belts and the New Global Tectonics, Journal Geophysical Research, Vol. 75, pp. 2625-2647.

Hamilton, W., 1970, Tectonic Map of Indonesia--A Progress Report, U. S. Geological Survey Open-file Report.

Page, R. W., and McDougall, I., 1972, Ages of Mineralization of Gold and Porphyry Copper Deposits in the New Guinea Highlands, Economic Geology, Vol. 67, pp. 1034-1048.

U. S. Department of Commerce, 1967, Operational Navigational Charts (scale 1:1,000,000), ONC, M-13, National Ocean Survey, Washington, D. C.

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RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Ray Test Site, Arizona

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Final Report

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16. Abstract

Eight interpretations of bulk processed imagery from the Ray, Arizona test area are compared with an extensive compilation of faults and other documented linear features and with an interpretation of aeromagnetic data. The ERTS imagery interpretations add little new geologic knowledge of the test area and poorly reflect well-known mineral-related structures and intrusions. The imagery interpretations do not correlate well with interpretation of the regional magnetic data. It is concluded that the imagery is not useful in directly detecting mineral deposits in this test site. In contrast, the U-2 underflight infrared photography is a valuable aid in the reconnaissance geologic mapping phase of mineral exploration in this environment.

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PREFACE

This report discusses work accomplished by Kennecott Exploration, Inc. under its ERTS-1 project entitled, "Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery" PR 510 Contract NASA-21769. Research on the Ray test site, one of six test sites investigated under this contract, examines the usefulness of imagery to mineral exploration geologists, and analyzes eight interpretations with a set of 45 key structural features in the Ray test area. A detailed structural map of the test area compiled from published geologic information, extensive interpretation of AMS high altitude black and white photography, and extensive field checking is presented as a base with which to compare interpretations of satellite imagery in this or other ERTS reports on Arizona. This report also compares the interpretation of linears on the imagery with linears interpreted from aeromagnetic data.

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[1] Present of former employees of Bear Creek Mining Company, Tucson, Arizona; domestic exploration subsidiary of Kennecott Copper Corporation.

[2] Earth Satellite Corporation, Berkeley, California.

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SUMMARY AND CONCLUSIONS

Bulk-processed ERTS imagery covering the Ray Test Site, Arizona (Fig. 1) was studied by several investigators and a residual aeromagnetic contour map interpreted to determine whether geological or geophysical features, particularly those related to porphyry copper deposits, are recognizable on the imagery. Exploration and research geologists with varying degrees of familiarity with the area and with the use of photo interpretive techniques, produced eight interpretations of the inner Test Site. The features recognized in these interpretations are tabulated and compared to known key geologic features. The stronger aeromagnetic linear features were interpreted from the residual magnetic map and compared to interpreted geologic features.

Results of interpretive geologic mapping based on ERTS imagery add little to geologic knowledge of the Ray Test Site. The expectation that previously undetected, large scale structures with subtle surface expression could be identified on the imagery has not been realized. The dimensions of most individual structural features which collectively form a structural setting or picture generally are too small to be consistently recognizable at the scale of ERTS imagery. However, these features generally are readily identifiable on conventional, high altitude aerial photography which is available over the entire region, or on underflight U2 imagery.

Based on this study, it is concluded that the interpretation of bulk-processed satellite imagery is not useful in directly detecting mineral deposits. It may aid in the extrapolation of large linear features, some of which may be useful in predicting target areas for more detailed prospecting.

Inability to distinguish age or relationship of lineaments to mineral deposits in the imagery strongly limits the usefulness of satellite imagery in ore deposit recognition or even target-area generation.

INTRODUCTION

Bulk-processed ERTS imagery covering the Ray Test Site, Arizona (Fig. 1) was studied by several investigators and a residual aeromagnetic contour map interpreted to determine whether geologic and geophysical features, particularly those related to porphyry copper deposits, are recognizable on the imagery. The Ray Test Site covers about 14,000 square miles in southeastern Arizona and within its boundaries are 11 major porphyry copper deposits. The terrain within and adjacent to the test site is geologically one of the most studied and carefully mapped on earth. The porphyry copper deposits in Arizona are closely related to quartz monzonite intrusions which were emplaced at a high level in the earth's crust during the Laramide age 55 to 65 million years ago and subsequently have been covered by several ages of postmineral rocks. Many investigators feel that the location of Laramide intrusions in general and specifically the porphyry-copper bearing intrusions have been in part controlled by major crustal structures and to a lesser degree by stratigraphy. The satellite imagery would be useful in mineral exploration in this area if it could detect the porphyry copper phenomena directly or if it could recognize unique porphyry-related geologic characteristics in the immediate area (100 square miles) surrounding porphyry copper centers. Therefore, it is desirable to recognize through analysis of the imagery:

- Laramide intrusions as opposed to intrusions of other ages.
- Dike swarms which may be lateral indicators of buried Laramide intrusions.
- Alteration zones related to mining districts.
- Deep crustal structures controlling mineral-related intrusions.
- Favorable pre-Laramide host rocks.

Early in the investigation, it was observed that little hope existed for recognizing alteration zones or intrusions related to the porphyry copper districts through unaided visual examination of bulk-processed imagery. Therefore, this study concentrated on the structural framework of the Ray test area and the ability of the imagery to elicit knowledge about that structure.

The structure of the Ray test area has been studied by numerous investigators using many different methods. Figure 2 is a compilation of all mapped and verified structures in the test site. The map was compiled from published and private geologic map collections augmented with extensive photointerpretation during the last five years of AMS high altitude photography (scale 1:62,500). The photointerpretation and the compilation were extensively field checked over a period of two years. Where the age of the structures can be documented, displacement has occurred principally in Precambrian, early Tertiary and late Tertiary time. Many faults have displacements during more than one age. The age determination cannot be made without inspection on the ground, thus neither the AMS photography nor the satellite imagery can determine the all-important age of structures identified through photointerpretation. This is a major shortcoming of photointerpretation in general.

The infrared color photography collected from the U-2 underflight was interpreted as an intermediate step in correlating ground data to satellite imagery data. An example of that interpretation is shown in a separate report (Barrett, 1974). Although the infrared photography did not markedly aid the interpretation of the satellite imagery, it did prove to be very useful in its own right. The users assessment of this photography is that it is vastly superior to AMS black and white photography in several respects:

- Lithologic discrimination
- Clarity
- Synoptic viewpoint

This infrared photography will be a definite aid in reconnaissance-scale geologic work associated with mineral exploration.

GEOLOGIC INTERPRETATION OF IMAGERY

Methods

In order to evaluate the reliability of geologic interpretations from ERTS imagery, a ground truth map of key structures and intrusions in and around the Ray Test Site was prepared (Fig. 3). The map presents 65 named features derived from published maps or literature (see references) and Kennecott's structural studies of the Southwest U. S. (Fig.).

Review of the several types and scales of available ERTS imagery indicated the enlarged color composite prints offered the greatest potential for recognition of geologic features related to, or indicative of, porphyry copper mineralization. These features include: 1) major fracture zones, 2) Laramide intrusive bodies, including dike swarms, and 3) possible "direct" indicators such as exposed capping and vein systems. Seven of the interpretations in this report are from a color composite print of image 1102-17274 enlarged to approximately 1:215,500. All mapped features were observed with unaided vision on the enlarged image print and subsequently transferred by tracing to transparent mylar bases. These interpretations are included in this report at a reduced scale of 1:1,000,000 (Figs.5-12). An eighth interpretation of this area (Fig. 4) was derived from a mosaic of bands 6 and 7 imagery and from two color composite prints (Haenggi and Erskine, 1974).

Independent interpretations of the same image were made by geologists with a wide range of geologic and photointerpretation experience, inclinations, and degree of familiarity with the Ray Test Site. Results of the several interpretations, were scored against the 65 key geological features and the results were tabulated (Table 1), hopefully reaching some degree of objectivity in this evaluation of the usefulness of ERTS imagery.

The image used for the interpretations does not exactly coincide with the designated inner detailed Ray Test Site, but covers very nearly the same size area slightly offset to the east. This image selection permitted the inclusion of the important Morenci district near the eastern edge and the exclusion of several hundred square miles of desert bolson along the western edge.

Results of Interpretations

The tabulated results of ERTS imagery over the Ray Test Site are given in Tables 1 and 2. The tables indicate the number of geologic features of a certain type noted by each investigator in a "naive" interpretation; the features are grouped as older and younger faults, volcanic features, large crystalline intrusions, veins and dike swarms, and tilted or warped bedding structures. In evaluating the tables as they deal with fault recognition, no attempt was generally made to distinguish between different types and ages of faults. In most interpretations, the lines are referred to as "linear features," probably faults or fractures, and where they generally coincided with a known key fault, the interpreter was accorded recognition of the fault.

Discussion

Faults. The faults used for control (Fig. 3) are classed as older or younger in age. The older faults bear close, but not perfect, structural relationship to porphyry copper ore-forming events, whereas the younger faults generally displace the ore deposits or bear no structural relationship to them at all. As stated before, the important older versus younger distinction cannot be made through imagery interpretation. Faults which were noted as linear features by each investigator are tabulated in Table 2.

Older faults and fracture zones of regional proportion that are strongly expressed topographically generally are discernible on ERTS imagery. Several faults chosen as key structures whose traces are accentuated by deeply incised rectilinear canyons or bold, persistent scarps were noted by practically all of the investigators. Examples of these are the Kennedy, Mogul, Stockton Pass, Happy Valley, and Galiuro faults. Others which were consistently noted are generally well exposed, major faults with walls of strongly contrasting rock types like the Goodwin Canyon and Romero Wash faults.

About half of the older faults chosen as key structures were generally not detected by the investigators. Surprisingly, a few of these like the Price, Miami, San Francisco, Pontotoc, and Apache faults show strong, recurrent late Tertiary-Quaternary movement and presumably would be conspicuous on all types of photography and imagery. Several older fault zones whose traces are generally transverse to topographic trends also went undetected. Examples of these include the Ray, Seven Mile Mts., Coronado, and Champion fault zones. One gravel covered fault, the Antelope Tank, whose existence has been established by indirect structural relationships and geophysics is not visible on ERTS imagery.

Key faults which are part of the Tertiary Basin-and-Range structural framework were noted by less than one-third of the investigators. Presumably, the main reason for this is the nature of the faults themselves; their normally sinuous strikes and relatively flat dips result in curving and irregular surface traces which are not generally apparent on the imagery. Two Basin-and-Range faults, the Natanes Rim and Polecat, were mapped by more than three-quarters of the investigators; both of these faults are expressed by bold scarps more than 500 feet in height and several miles in length.

Few, if any, of the faults indicated on the several interpretations bear close resemblance in detail to their counterparts as they are mapped on the ground or on conventional air photos. Three examples are shown in Fig. 12; these may be compared to their appearance on the interpretations which are credited in Table 2 with their recognition.

Intrusions. Intrusions, including the large, crystalline stocks of post-Cretaceous age, major dike swarms, and middle Tertiary and younger intrusive volcanic features, went almost unrecognized on ERTS imagery. About half noted the Teresa-Goodwin Canyon stocks but none of the interpretations approached the correct outline of the stocks. A few investigators suspected an intrusion in the vicinity of the Texas Canyon stock but here also, the configuration and location of the stock is in error. All are credited with recognition of the intrusions in the tabulation, however.

One of the aspects most difficult to explain concerning the ERTS interpretations is the essentially complete lack of recognition of major dike swarms. Most of the 12 key dike swarms which range in age from Precambrain to middle Tertiary are several miles in length and are composed of dozens of individual dikes which range up to 100 feet and more in width.

Middle Tertiary and younger volcanic intrusive features were rarely noted by the investigators. Five noted the approximate location of the Peridot vent but probably were alerted to its existence by the conspicuous lava flow extending northeasterly from the vent. Some of the investigators mapped as an intrusive, the elliptical apron of dark detritus being derived from the Picacho dikes which intrude stratified volcanic formations.

Circular Features. Circular features abound on ERTS imagery and the number which can be mapped is limited only by the inclination of the observer. Most of these features appear to be drainage patterns or alluvial fans radiating from an approximately equidimensional outcrop blocks surrounded by gravel.

Calderas which by their nature are difficult to define and map, even on the ground, are scarce in the Ray Test Site. Only one, at Government Mountain, has been reliably documented. An accurate linear feature near the caldera's north rim was noted in Figure 4 as one of some 22 similar features mapped within the test area.

Other Features. Known areas of exposed stockwork sulfide mineralization were carefully studied on the imagery. No such capping areas could be recognized. Of several vein systems within the test site, two of the most strongly developed, Mineral Mountain and Globe, are included among the key features on Figure 3. Neither of these vein systems or any others were recognized by any investigator.

Large monoclines and synclines, of which four are included as key structures, were not consistently recognized; four investigators recognized one of three monoclines and two investigators noted the one syncline. The recognized features, the Mescal monocline and Deer Creek syncline, are each more than 10 miles long and 4 miles wide.

AEROMAGNETIC LINEARS

Background and Interpretation

The purpose of this part of the research is to test the hypothesis that the linears seen on the satellite imagery are related more to deep crustal geologic boundaries than to the surface geology.

Aeromagnetic linear features are interpreted from a residual map prepared from the Aeromagnetic Map of Arizona (Sauck, et al, 1969) for comparison to mapped geology and geology interpreted from ERTS imagery in the Ray Test Site area. The contour map (Fig. 13) was constructed from north-trending aeromagnetic profiles 3 miles apart flown at a constant barometric elevation of 9,000 feet MSL.

Magnetic anomalies shown in Figure 13 are fairly coherent, low-frequency features, indicating that interference from topography is low.

The lines shown on Figure 13 mark the interpreted boundaries of causative magnetic bodies. Specifically the lines isolate a magnetic anomaly of significant coherence and amplitude or define the edges of the source causing the magnetic anomaly. Therefore, these linears reflect actual contacts between rock types of different magnetizations, i.e., a geologic transition of some kind. In order to reduce subjectivity to a minimum, magnetic linears have not been traced across areas where no direct evidence for a magnetization contrast exists. The actual locations of the magnetic source contacts which give rise to the magnetic linears may be in error by a mile or more in places owing to interpretational uncertainty and a flight line spacing of 3 miles.

Stippled patterns on Figure 14 are interpreted as regional geologic boundaries which are distinct from the solid-line linears that are continuous over a long distance, e.g., the edge of a magnetic high of regional dimensions, represented by a continuous, low-frequency gradient.

Discussion

Many of the magnetic linears identified have no ready explanation in the surface geology or the satellite imagery, at least on this regional scale. However, certain correlations between magnetic linears and geology are immediately apparent, and are worthy of brief comment. The following numbered features may be identified on Figure 14 by corresponding location numbers:

Mogul Fault. A strong northwest-trending zone of linears (Location 1) follows the Mogul fault in the southwest-central part of the map, and extends the trace of this major fault zone northwest and southeast of its mapped exposure near the town of Oracle. The Mogul fault zone can be traced over a distance of at least 70 miles using the magnetic data, but only 9 miles using published geologic maps.

Most of the imagery interpretations record the Mogul fault and a few also identify linear segments on the northwest magnetic projection of the trace. However, none of the investigators observed a major geologic boundary in the vicinity of this major magnetic feature.

Nantanes-Santa Teresa Trend. A north-south structural zone (Location 2) characterized by a series of aligned magnetic highs, trends southward off the Natanes Plateau through the Santa Teresa Mountains before disappearing as a discrete magnetic feature near the south end of the Galiuro Mountains. Magnetic gradients to the east and west define the edges of this 15-mile-wide feature.

The Santa Teresa stock is a large, north-south elongated intrusion of Laramide age that relates closely to the west border of this magnetic feature. If the magnetic linear represents a fundamental structure (a zone of weakness) in the Precambrian basement, then the Santa Teresa stock may have been emplaced along that structure. In the Aravaipa mining district to the west, mineralized north-south fractures of mid-Tertiary(?) age indicate that faulting associated with this structure may have been active in more recent geologic time.

This broad magnetic feature is not represented on any of the ERTS interpretations.

Globe-Miami Zone. The strong east-west set of linears (Location 3) that pass immediately north of the Globe-Miami area define the south edge of a regional magnetic high. At its west end, this feature correlates closely with the Precambrian schist/granite contact. The magnetic signature of this feature is apparently displaced along the north-south Nantanes-Santa Teresa structural zone described above.

Although this magnetic feature passes through an important porphyry copper mining district, it is not reflected in the imagery interpretations.

Summary

Seventeen percent of the key linear elements shown on Figure 3 correlate with linear elements shown on the aeromagnetic interpretation map, Figure 14. An average of 14% of the magnetic linears correlate with linears on the six, more complete, satellite imagery interpretations. More careful interpretation of a more detailed aeromagnetic map could, no doubt, produce a more accurate magnetic linear map than Figure 14. Further, ERTS interpretations based on higher grade imagery and scenes from different seasons could probably produce a higher quality interpretation. However, separation of observation from extrapolation would be extremely important on the next generation of maps. An improved combination imagery-aeromagnetic linear map would be helpful in:

- Unravelling the tectonic framework of Arizona, or
- Prediction of the offset of mineral belts, or
- Eliciting understanding of suspected deep crustal control on mineral belts, or
- Prediction of potential geothermal centers.

However, in each of these potential uses, lineament maps derived from ERTS and magnetic data would have to be used in conjunction with a more expensive data base compiled from ground data such as:

1) Minerogenetic maps which graphically display the distribution and type of mineral deposits generated during geologic history.

2) Lithologic maps showing the age and type of sedimentary and igneous rocks found at the surface as well as in drill holes beneath the abundant postmineral rocks in Arizona.

References Cited

Haenggi, W. T., and Erskine, M. C., 1974, An interpretation of ERTS-1 imagery in the Ray, Arizona test area: in Recognition of geologic framework of porphyry copper deposits on ERTS-1 imagery, Contract NASA-21769.

Barrett, L. F., 1974, Interpretation of one frame of U-2 imagery in Gila County, Arizona, as part of Recognition of geologic framework of porphyry copper deposits on ERTS-1 imagery, Contract NASA-21769.

Sauck, W. A., and Sumner, J. S., 1971, Residual aeromagnetic map of Arizona: Tucson, University of Arizona Press. Scale 1:500,000.

SELECTED PUBLISHED REFERENCES

Allan, J. W., and Swan, M. M., 1973, Southwest structural study: K. C. C. Private Reports.

Broomfield, C. S., and Shride, A. F., 1956, Mineral resources of the San Carlos Indian Reservation, Arizona: U. S. Geol. Survey Bull. 1027-N.

Broomfield, C. S., et al., 1972, Geological and geophysical investigations of an Apollo 9 photo anomaly near Point of Pines, Arizona: U. S. Geol. Survey Open File Report.

Brown, W. H., 1939, Tucson Mountains, an Arizona Basin-and-Range type: Geol. Soc. America Bull. 5, v. 50.

Cooper, J. R., 1959, Reconnaissance geologic map of Southeastern Cochise County, Arizona: U. S. Geol. Survey Map MF-213.

________, 1960, Reconnaissance map of the Willcox, Fisher Hills, Cochise, and Dos Cabezas Quadrangles, Cochise and Graham Counties, Arizona: U. S. Geol. Survey Map MF-231.

Cooper, J. R. and Silver, L. T., 1964, Geology and ore deposits of the Dragoon Quadrangle, Cochise County, Arizona: U. S. Geol. Survey Prof. Paper 416.

Cornwell, H. R., Banks, N. G., and Phillips, C. H., 1971, Geologic map of the Sonora Quadrangle, Pinal and Gila Counties, Arizona: U. S. Geol. Survey Map GQ-1021.

Creasey, S. C., 1965, Geology of the San Manuel area, Pinal County, Arizona: U. S. Geol. Survey Prof. Paper 471.

________, 1967, General geology of the Mammoth Quadrangle, Pinal County, Arizona: U. S. Geol. Survey Bull. 1218.

________, 1967, Geologic map of the Benson Quadrangle, Cochise and Pima Counties, Arizona: U. S. Geol. Survey Map I-470.

Creasey, S. C., Jackson, E. D. and Gulbrandsen, R. A., 1961, Reconnaissance geologic map of parts of the San Pedro and Aravaipa Valleys, South-Central Arizona: U. S. Geol. Survey Map MF-238.

Creasey, S. C., et al., Map showing potential for copper deposits in the E. 3/4 of the Nogales 2° Quadrangle, Tucson area, Arizona: U. S. Geol. Survey Map I-844-G.

Darton, N. H., 1925, A resume of Arizona geology: Ariz. Bur. Mines Bull. 119.

Drewes, H., 1971, Geologic map of the Sahuarita Quadrangle, southeast of Tucson, Pima County, Arizona: U. S. Geol. Survey Map I-613.

________, 1972, Preliminary geologic map of the Happy Valley Quadrangle, Cochise County, Arizona: U. S. Geol. Survey Open File.

Drewes, H., and Cooper, J. R., 1973, Reconnaissance geologic map of the west side of the Sierrita Mountains, Palo Alto Ranch Quadrangle, Pima County, Arizona: U. S. Geol. Survey Map MF-538.

Durning, W. P., 1972, Geology and mineralization of Little Hill Mines area, Northern Santa Catalina Mountains, Pinal County, Arizona: M.S. Thesis Univ. of Ariz.

Erickson, R. C., 1968 Geology and geochronology of the Dos Cabezas Mountains, Cochise County, Arizona: Ariz. Geol. Soc. Guidebook III.

Finnell, T. L., 1966, Geologic map of the Chediski Peak Quadrangle, Navajo County, Arizona: U. S. Geol. Survey Map GQ-544.

________, 1966, Geologic map of the Cibeque Quadrangle, Navajo County, Arizona: U. S. Geol. Survey Map GQ-545.

________, 1971, Preliminary geologic map of the Empire Mountains Quadrangle, Pima County, Arizona: U. S. Geol. Survey Open File.

Gastil, G., 1968, Older Precambrian rocks of the Diamond Butte Quadrangle, Gila County, Arizona: Geol. Soc. America Bull. 12, v. 69.

Gilluly, J., 1956, General geology of Central Cochise County, Arizona: U. S. Geol. Survey Prof. Paper 281.

Krieger, M. H., 1968, Geologic map of the Brandenburg Mountain Quadrangle, Pinal County, Arizona: U. S. Geol. Survey Map GQ-668.

________, 1968, Geologic map of the Holy Joe Peak Quadrangle, Pinal County, Arizona: U. S. Geol. Survey Map GQ-669.

________, 1968, Geologic map of the Lookout Mountain Quadrangle, Pinal County, Arizona: U. S. Geol. Survey Map GQ-670.

________, 1968, Geologic map of the Saddle Mountain Quadrangle, Pinal County, Arizona: U. S. Geol. Survey Map GQ-671.

________, 1972, Preliminary geologic map of the Black Mountain Quadrangle, Arizona: U. S. Geol. Survey Open File.

________, 1972, Preliminary geologic map of the Crozier Peak Quadrangle, Arizona: U. S. Geol. Survey Open File.

Krieger, M. H., 1972, Preliminary geologic map of the Putnam Wash Quadrangle, Arizona: U. S. Geol. Survey Open File.

________, 1972, Preliminary geologic map of the Winkelman Quadrangle, Arizona: U. S. Geol. Survey Open File.

Langton, Jackson M., 1972, Ore genesis in the Morenci-Metcalf district: AIME Preprint.

Lindgren, W., 1905, Description of the Clifton Quadrangle: U. S. Geol. Survey Geologic Atlas Folio 129.

Marlowe, J. I., 1960, Diatremes and a ring intrusion on the San Carlos Indian Reservation: Ariz. Geol. Soc. Digest, v. III.

McKay, E. J., 1972, Geologic map of the Show Low Quadrangle, Navajo County, Arizona: U. S. Geol. Survey Map GQ-973.

Morrison, R. B., 1965, Geologic map of the Duncan and Canador Peak Quadrangles, Arizona and New Mexico: U. S. Geol. Survey Map I-442.

Nelson, E. W., 1966, The geology of Picketpost Mountain, Pinal County, Arizona: M.S. Thesis, Univ. of Ariz.

Peterson, D. W., 1960, Geology of the Haunted Canyon Quadrangle, Arizona: U. S. Geol. Survey Map GQ-128.

________, 1968, Zoned ash-flow sheet in the region around Superior, Arizona: Ariz. Geol. Soc. Guidebook III.

________, 1969, Geologic map of the Superior Quadrangle, Pinal County, Arizona: U. S. Geol. Survey Map GQ-818.

Peterson, N. P., 1954, Geology of the Globe Quadrangle, Arizona: U. S. Geol. Survey Map GQ-41.

________, 1962, Geology and ore deposits of the Globe-Miami District, Arizona: U. S. Geol. Survey Prof. Paper 342.

________, 1963, Geology of the Pinal Ranch Quadrangle, Arizona: U. S. Geol. Survey Bull. 1141-H.

Ransome, F. L., 1904, Description of the Globe Quadrangle: U. S. Geol. Survey Geologic Atlas, Folio 111.

________, 1923, Description of the Ray Quadrangle: U. S. Geol. Survey Geologic Atlas, Folio 217.

Ratte, J. C. et al., 1969, Mineral resources of the Blue Range primitive area, Greenlee County, Arizona and Catron County, New Mexico: U. S. Geol. Survey Bull. 1261-E.

Richard, K., and Courtright, J. H., 1954, Structure and mineralization at Silver Bell, Arizona: AIME Trans. v. 199.

Ross, C. P., 1925, Geology and ore deposits of the Aravaipa and Stanley Mining Districts, Graham County, Arizona: U. S. Geol. Survey Bull. 763.

________, 1925, Ore deposits of the Saddle Mountain and Banner Mining Districts, Arizona: U. S. Geol. Survey Bull. 771.

Sabins, F. F., Jr., 1957, Geology of the Cochise Head and western part of the Vanar Quadrangles, Arizona: Geol. Scc. America Bull. 10, v. 68.

Schmidt, E. A., 1967, Geology of the Mineral Mountain Quadrangle, Pinal County, Arizona: M.S. Thesis, Univ. of Ariz.

Schmidt, E. A., 1971, A structural investigation of the Northern Tortilla Mountains, Pinal County, Arizona: Ph.D. Thesis, Univ. of Ariz.

Sheridan, M. F., 1968, Volcanic geology along the western part of the Apache Trail, Arizona: Ariz. Geol. Soc. Guidebook III.

Simons, S. F., 1964, Geology of the Klondyke Quadrangle, Graham and Pinal Counties, Arizona: U. S. Geol. Survey Prof. Paper 461.

Swan, M. M., The Stockton Pass fault zone, Graham County, Arizona: M.S. Thesis (in preparation), Univ. of Ariz.

Wallace, R. M., 1954, Structures at the northern end of the Santa Catalina Mountains, Arizona: Ph.D. Thesis, Univ. of Ariz.

Willden, R., 1964, Geology of the Christmas Quadrangle, Gila and Pinal Counties, Arizona: U. S. Geol. Survey Bull. 1161-E.

Wilson, E. D., 1952, General geology between Ray and Superior, Arizona: Ariz. Geol. Soc. Guidebook I.

DOCUMENTED KEY GEOLOGIC FEATURES / INVESTIGATORS	Degree of familiarity with Test Area. Rated from 0 (none) to 10 (complete)	FAULTS TOTAL 32: Older faults with little or unknown amounts of post-Tertiary movement. Total 12	FAULTS TOTAL 32: Older faults with strong post-Tertiary movement. Total 13	FAULTS TOTAL 32: Younger faults of Basin and Range origin. Total 7	INTRUSIONS TOTAL 26: Volcanic plugs, vents, ring dikes, etc. Total 8	INTRUSIONS TOTAL 26: Large crystalline intrusives. Total 6	INTRUSIONS TOTAL 26: Dike swarms Total 12	MISCELLANEOUS TOTAL 7: Caldera Total 1	MISCELLANEOUS TOTAL 7: Vein systems Total 2	MISCELLANEOUS TOTAL 7: Monoclines Total 3	MISCELLANEOUS TOTAL 7: Syncline Total 1	SUMMARY: Mineral related features. Total 45 (older faults, large crystalline intrusives dike swarms and vein systems)	SUMMARY: Other features listed in this table. Total 20
Haenggi-Erskine	1	4	6		1			1				10	2
M. Martineau	2	4	5	2	1	2				1		11	4
G. Hughes	2	6	6	1	1	1				1	1	13	4
G. Lister	2	5	7	2		1				1		13	3
J. Lyons	2	5	6	1		1						12	1
G. McKelvey	3	5	6	2	3	1					1	12	6
D. Bulmer	7	5	5	3								10	3
J. Allan-M. Swan	9	7	9	4	2		1			1		17	7
Percent of features mapped (average)		33%	49%	27%	13%	12%	1%	12%	0	17%	25%	27%	19%

TABLE 1. Summary of Results. Number of Key Geologic Features Mapped in Each of Eight Independent Interpretations of ERTS Imagery

Kennecott Exploration Services

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15-14

TABLE 2. KEY GEOLOGIC FEATURES MAPPED IN EACH OF EIGHT INDEPENDENT INTERPRETATIONS OF ERTS IMAGERY

X Feature mapped fairly accurately
? Feature mapped in part or inaccurately

Numbers refer to selected references listed in report.

FAULTS

	Kennedy (39)	Iron Mtn (1)	Ray (1)	Capitan (45) (1)	Blackjack (1)	Sevenmile Mts (1)	Coronado (34) (1)	Mogul (16) (57)	Goodwin Canyon (55)	Stockton Pass (56)	Antelope Tank (7)	Champion (14) (1)	Price (1)	Miami (42) (1)	San Francisco (33) (1)	Red Rooster (58)	Guild Wash (1)	Pirate (57) (1)	Pantatac (1)	Happy Valley (16)	Galiuro (1)	Zapata Mtn (26)	Apache Pass (19)	Romero Wash (1)	Emigrant Pass (1)	Concentrator (41)	Copper Butte-Hackberry (53)	Natanes Rim (1)	Sardine (1)	Sombrero Butte (1)	San Manuel (9)	Polecat (1)
HAENGGI-ERSKINE	X	X		?	?			X								X		X		X	X	?		X	X							
M. MARTINEAU	X				?			?	?	X								?		X	X	X		X	X			X				X
G. HUGHES	X	?		X	?			X	X	X							X	X		X	X			X	X							X
G. LISTER	X			X	?		?	X	?	?						X	X	X		X	X	?		X	X			X				X
G. MC KELVEY	X				X			X	X	X							X			X	X	?	?	X	X			X				X
J. LYONS	X	?			X			X	X	X								X		X	X	?	?	X	X			X				?
D. BULMER		X			?			X	X	X							X	X		X	X		?		?			X	X			X
J. ALLAN-M. SWAN	X	X		X	X			X	X	X				?		X	X	X	X	X	X	?	?	X	X	X	?	X	X			X

INTRUSIVES

	VOLCANIC									DIKE SWARMS											LARGE INTRUSIVES						MISC.						
	Hells Peak plug (59)	Picketpost Mtn plug (38)	Mt Triplet plug (1)	Black Rock plug (1)	Peridot vent (1)	Corral Mtn vent (1)	Mt. Triplet ring dike (35)	Picacho dike (1)	Four Mile dike (55) (1)	Kelvin (53)	Ripsey (53)	Beargrass (1)	Box O (1)	Sycamore Canyon (1)	Red Hill (1)	Grand Reef (55)	Klondyke Pass (1)	Fort Grant (56)	Willow Springs (56)	Reed Basin (58) (1)	Granite Basin (58) (1)	Gillespie (56)	Schultze (43)	Amole (4)	Texas Canyon (7)	Santa Teresa-Goodwin Canyon (55)	Mineral Mtn vein system (52)	Globe District vein system (42)	Government Mtn caldera (40)	Deer Creek syncline (58)	Mescal monocline (14) (1)	Hayes monocline (1)	Apache Ridge monocline (1)
HAENGGI-ERSKINE					?																								?				
M. MARTINEAU					X																X				?	?					X		
G. HUGHES					X																					?				X	X		
G. LISTER																										?					?		
G. MC KELVEY			X		X		X																		?	?			?	X			
J. LYONS																									?	?							
D. BULMER																																	
J. ALLAN-M. SWAN					X		X										X														X		

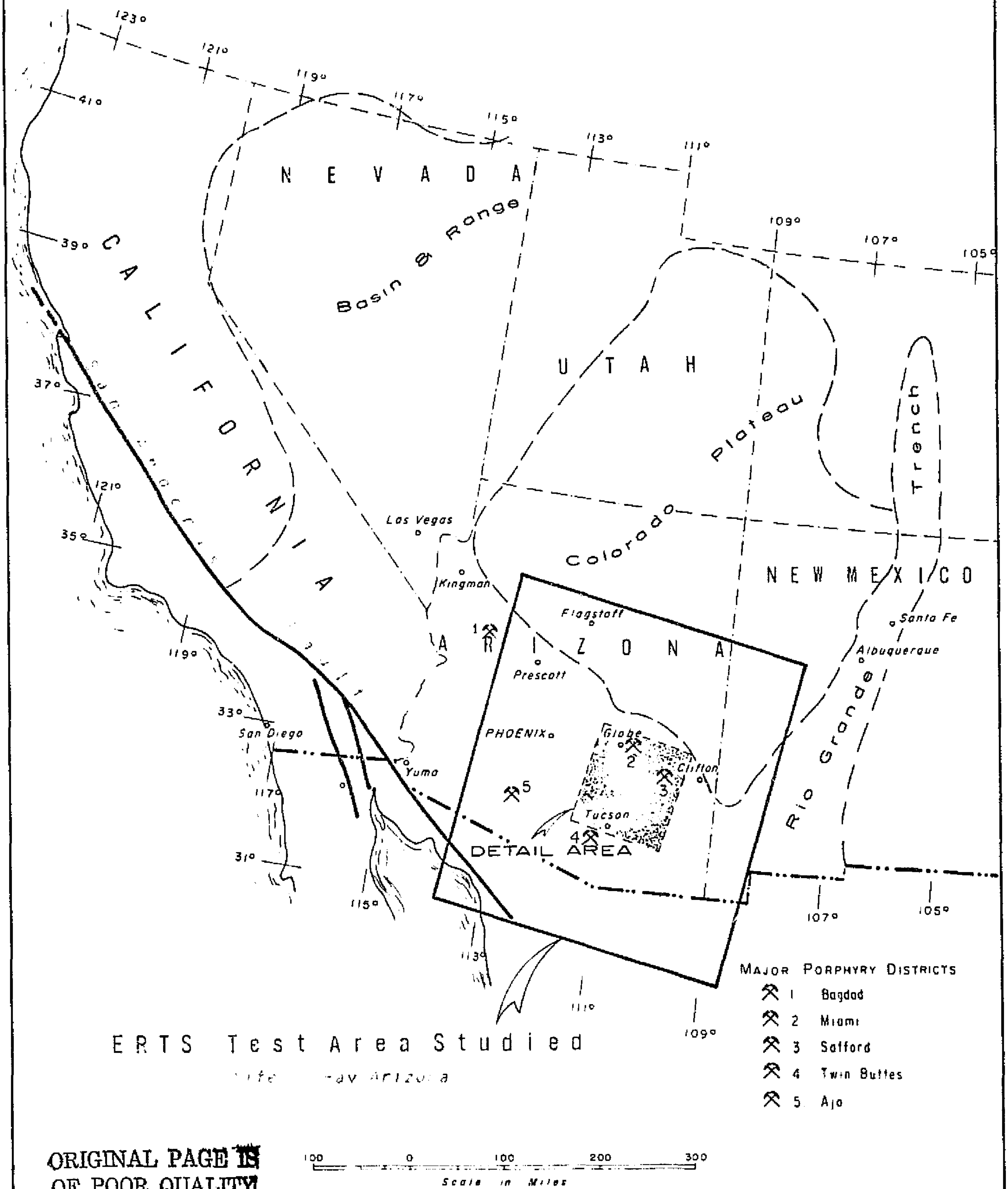


Figure 1. LOCATION MAP

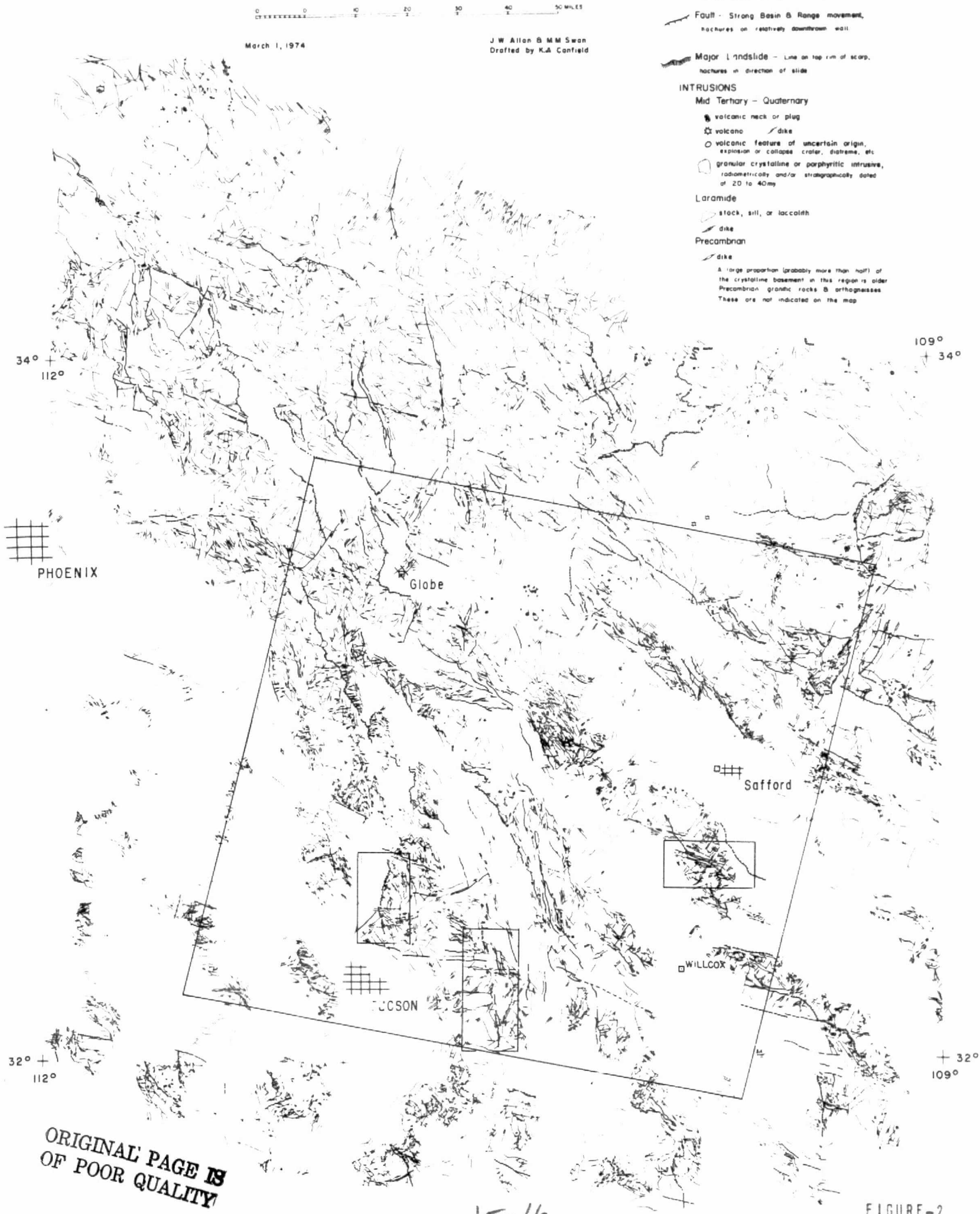
KENNECOTT EXPLORATION INC

SOUTHWEST STRUCTURAL STUDY

STRUCTURE AND INTRUSIONS IN A PORTION OF SOUTHEASTERN ARIZONA

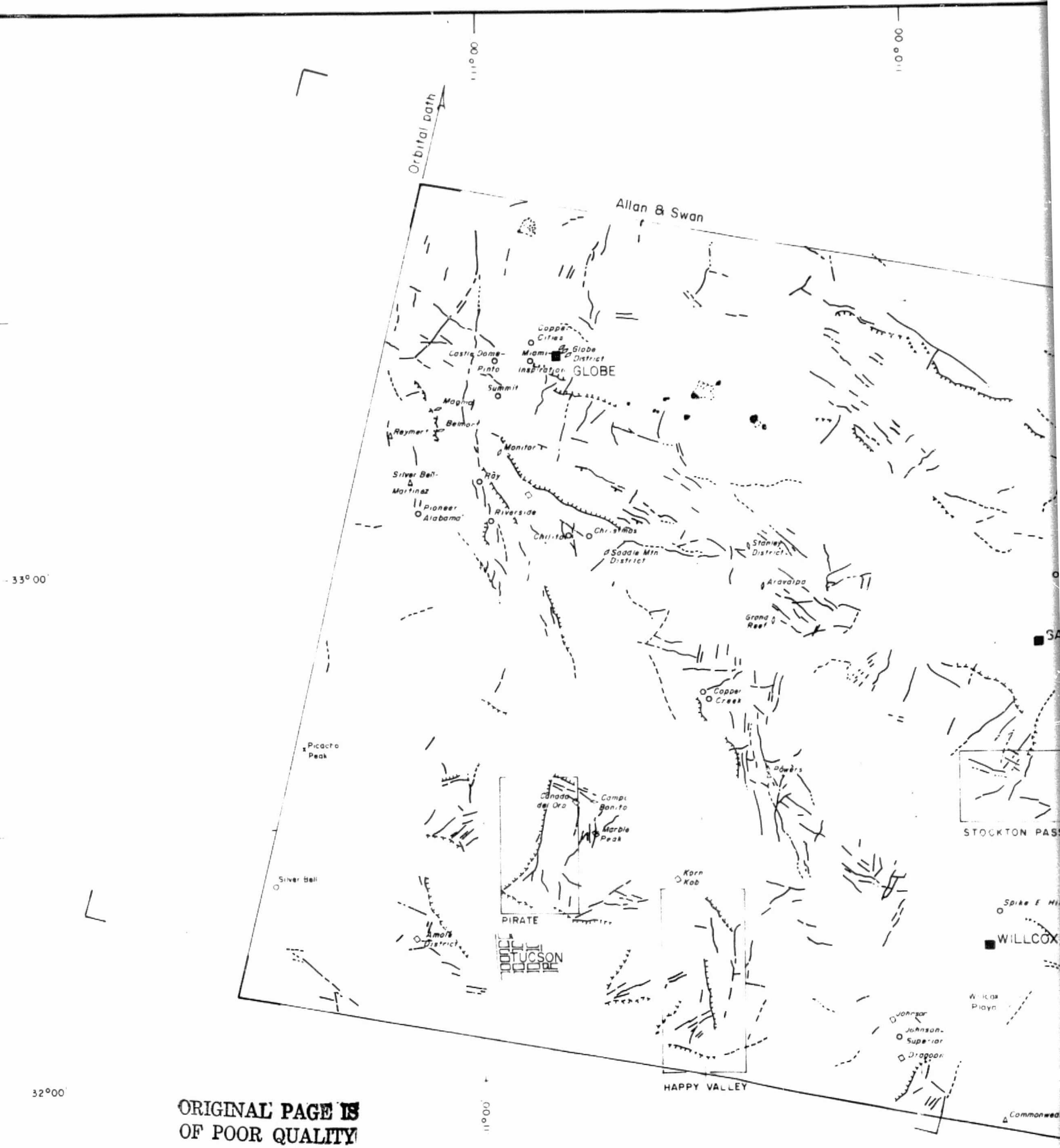
March 1, 1974

J W Allan & M M Swan
Drafted by K.A Canfield



15-16

FIGURE-2



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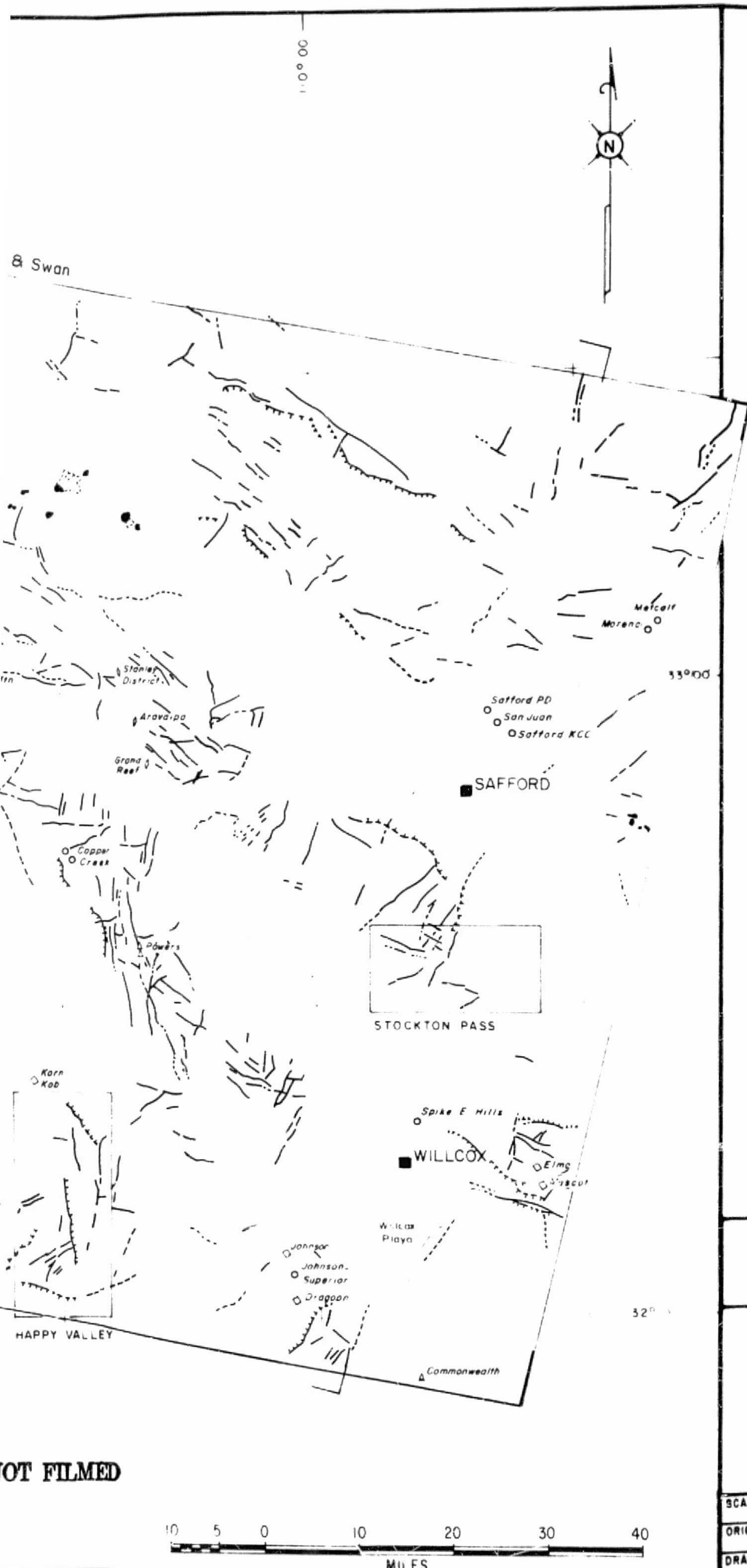
MILES



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EXPLANATION

- Linear feature probably fault or fracture
- Basin and range fault hachures on rel downthrown wall
- Volcanic plugs necks etc. and assoc. lava flow
- Dike swarm
- Strike and dip of layered rocks

FOLDOUT FRAME 2

MINERAL DEPOSITS

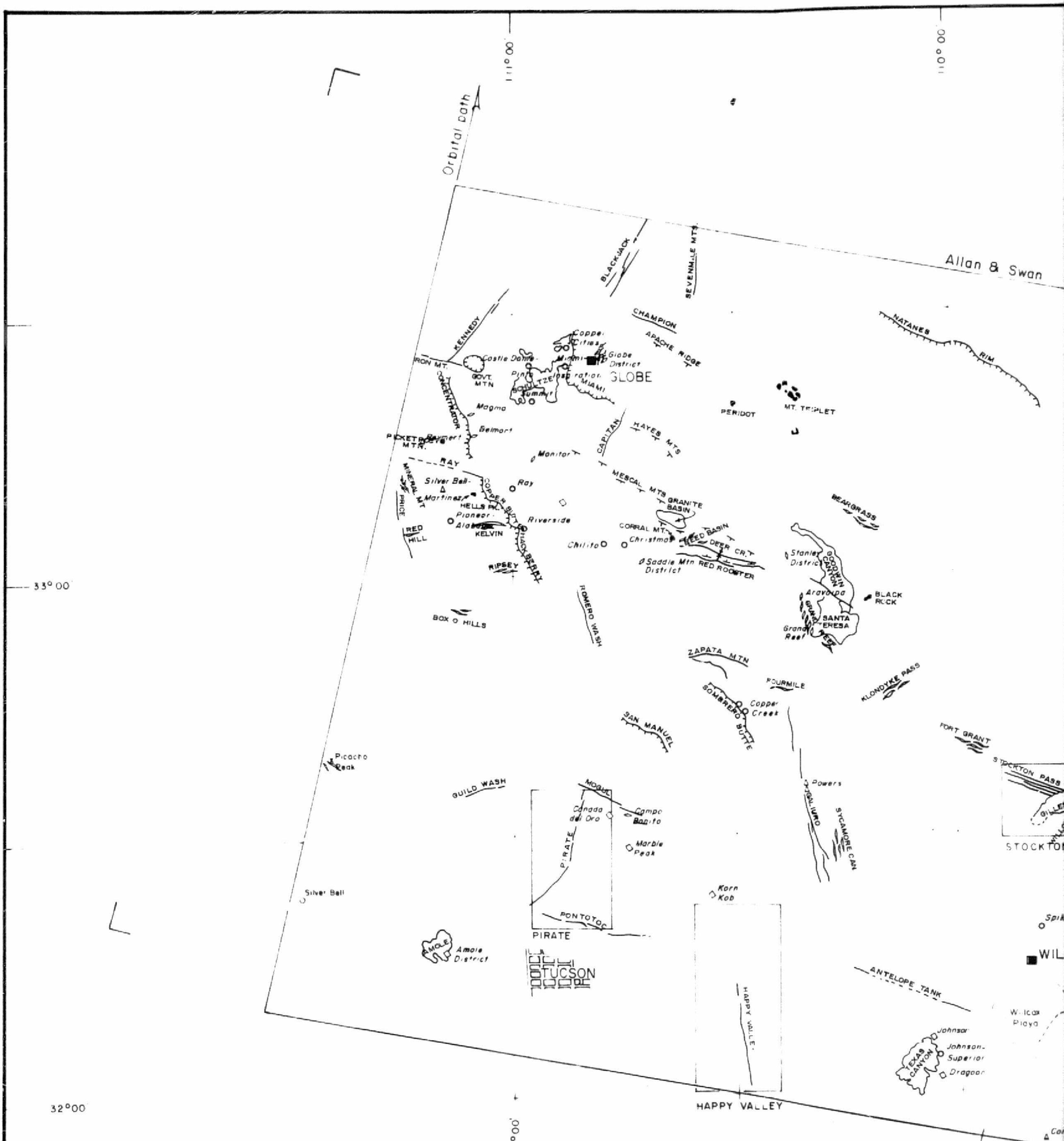
- ○ Stockwork sulfide (includes porphyry coppers)
- ◇ Contact pyrometasomatic
- Veins
- △ Tertiary epithermal veins

Kennecott Exploration, Inc.
Exploration Services Department

GEOLOGIC FEATURES
INTERPRETED FROM
ERTS COLOR COMPOSITE IMAGERY
by
J. ALLAN and M. SWAN
RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3-28-74	No FIGURE-5
ORIGINATOR J.A and M.S		
DRAFTING jdm		REVISED 7-24-75

16A



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15-17

EXPLANATION

- Fault
- Fault - basin and range type
- Dips of bedded rocks
- Synclinal axis
- Vein system
- Volcanic intrusive - plug, vent, dike, etc.
- Caldera
- Dike swarm
- Large post-Cretaceous intrusion

FOLDOUT FRAME 2

MINERAL DEPOSITS

- ○ Stockwork sulfide (includes porphyry coppers)
- ◇ Contact pyrometasomatic
- Veins
- △ Tertiary epithermal veins

Kennecott Exploration, Inc.
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KEY GEOLOGIC FEATURES

RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3 28 74	No FIGURE-3
ORIGINATOR J. W. A. and M. M. S.		
DRAFTING jdm		REVISED 7-24-75

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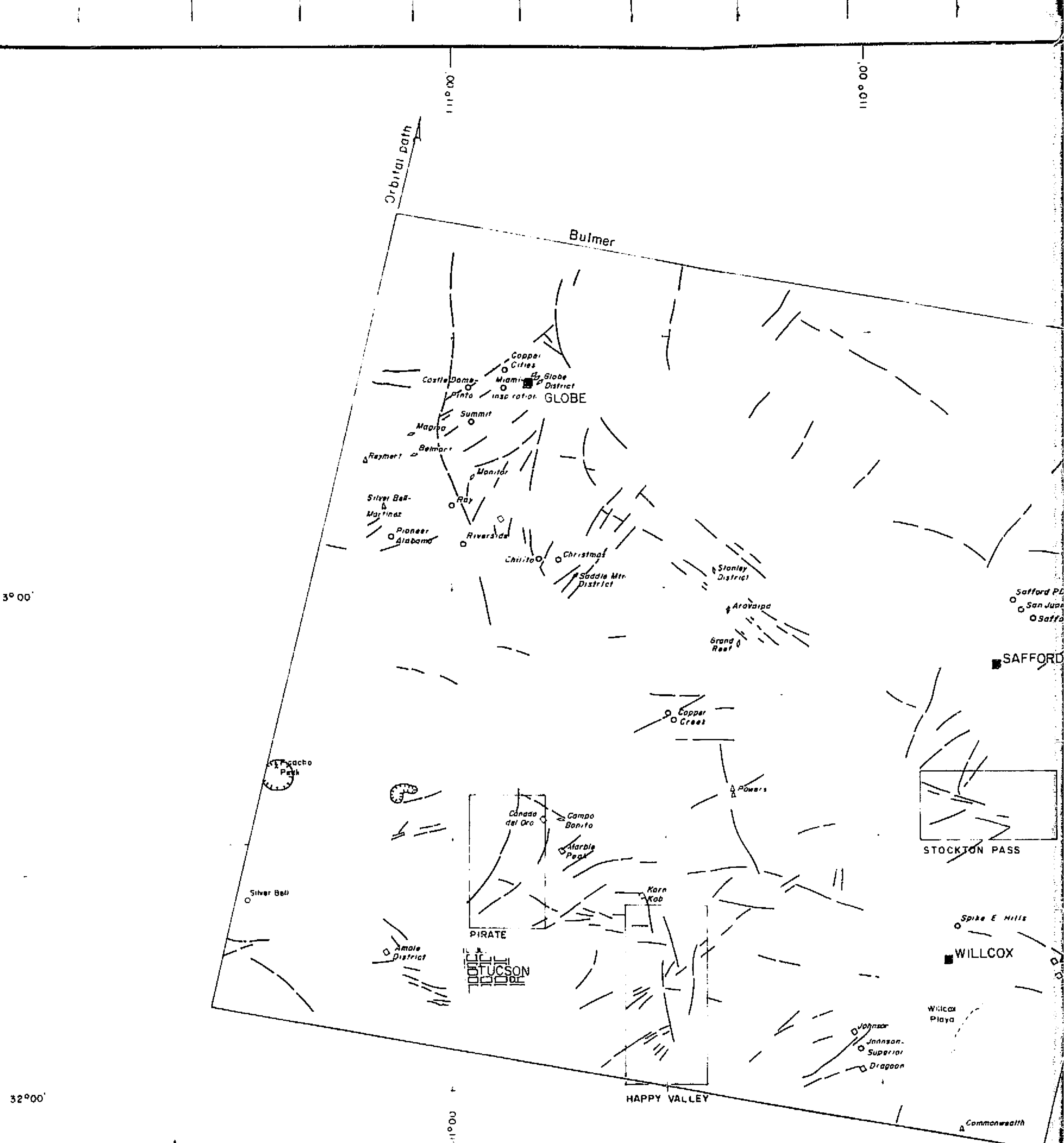

OLDOUT FRAME

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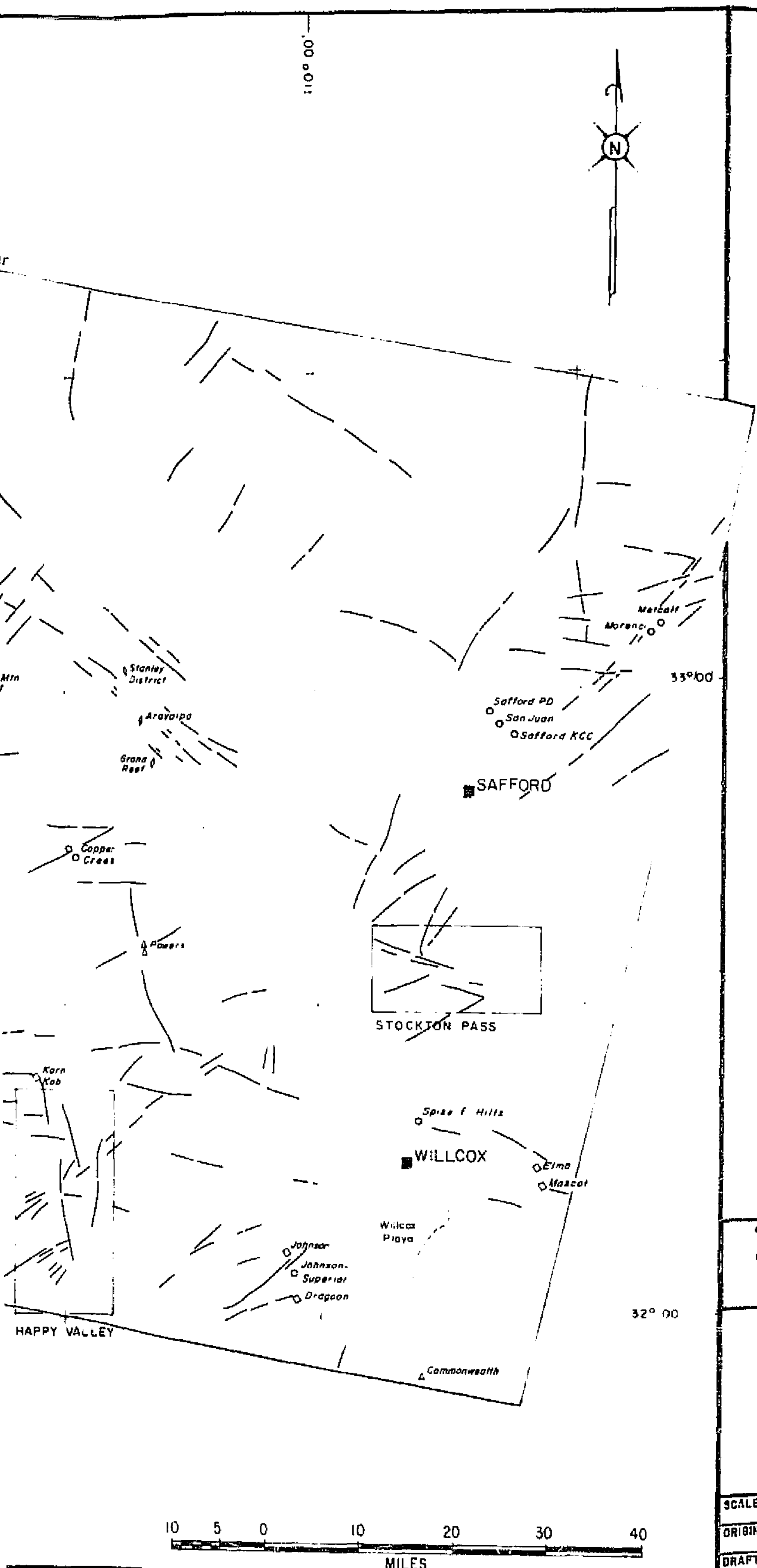

EXPLANATION

Fractures and other linear features

Volcanic field

FOLDOUT FRAME 2

MINERAL DEPOSITS

- Stockwork sulfide (includes porphyry coppers)
- Contact pyrometasomatic
- Veins
- Tertiary epithermal veins

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GEOLOGIC FEATURES
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RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3-28-74	No FIGURE-6
ORIGINATOR D. B		
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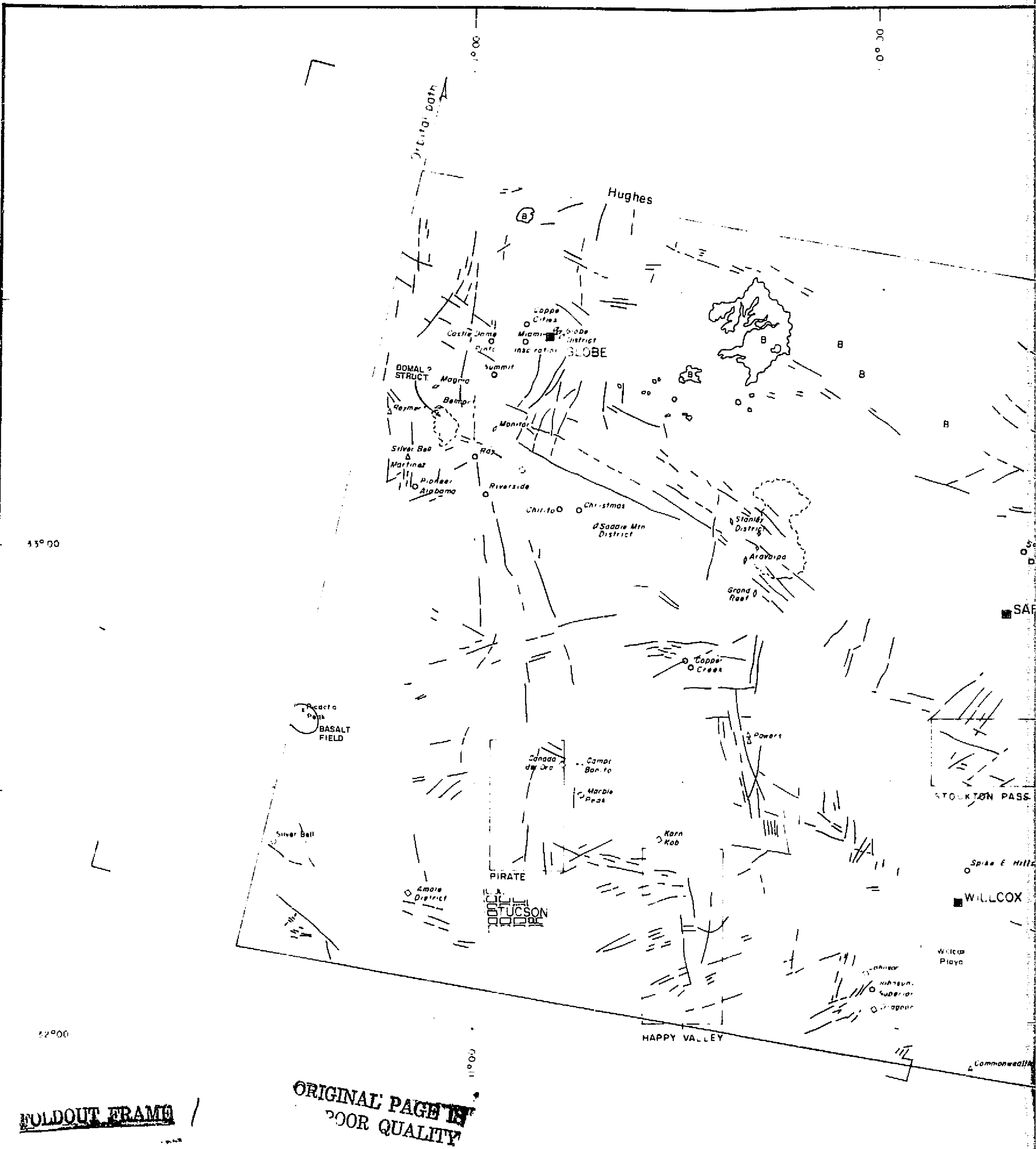

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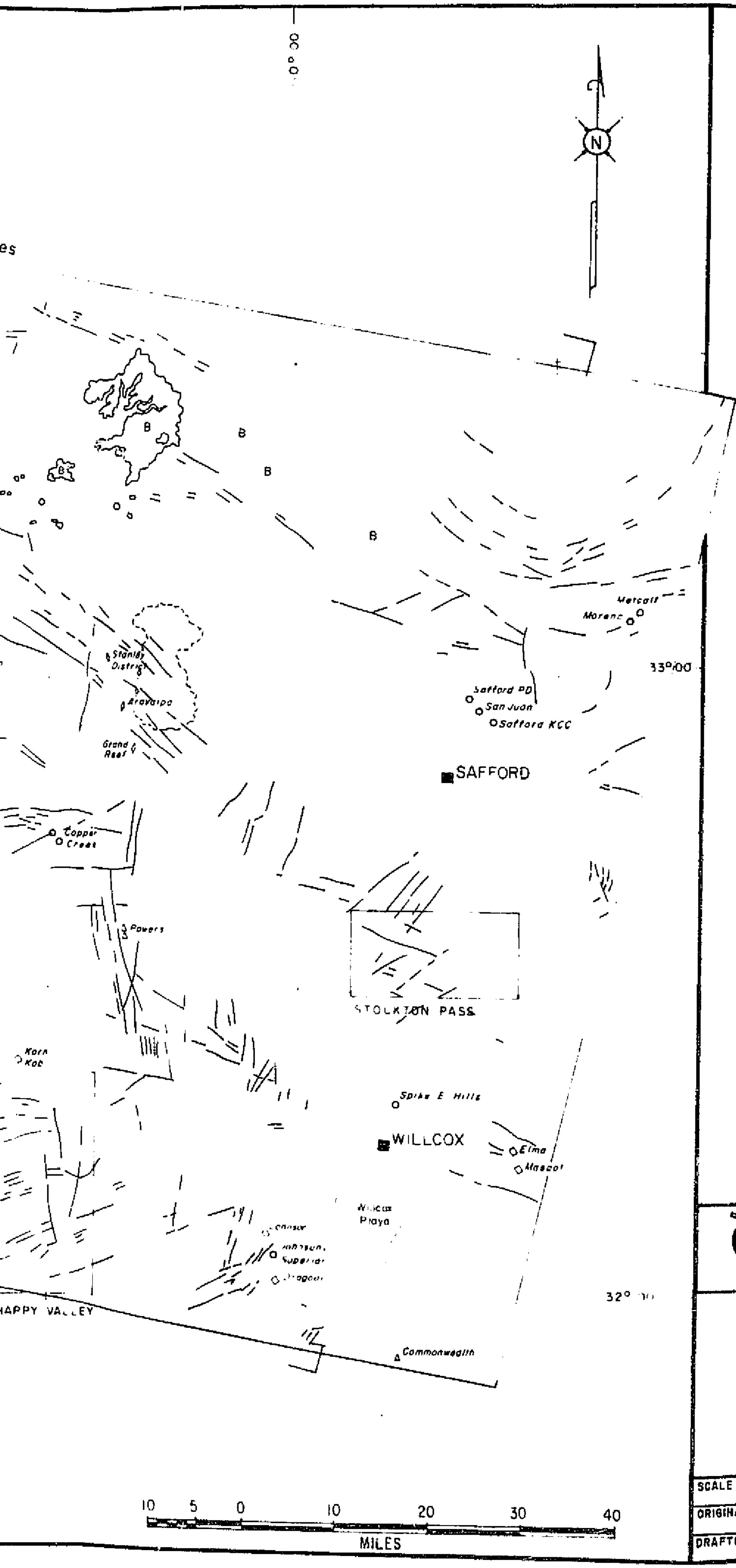

EXPLANATION

- Linear feature, probably fracture zone
- Igneous stock
- Volcanic neck
- B Basalt

FOLDOUT FRAME 2

MINERAL DEPOSITS

- Stockwork sulfide (includes porphyry coppers)
- Contact pyrometasomatic
- Veins
- Tertiary epithermal veins

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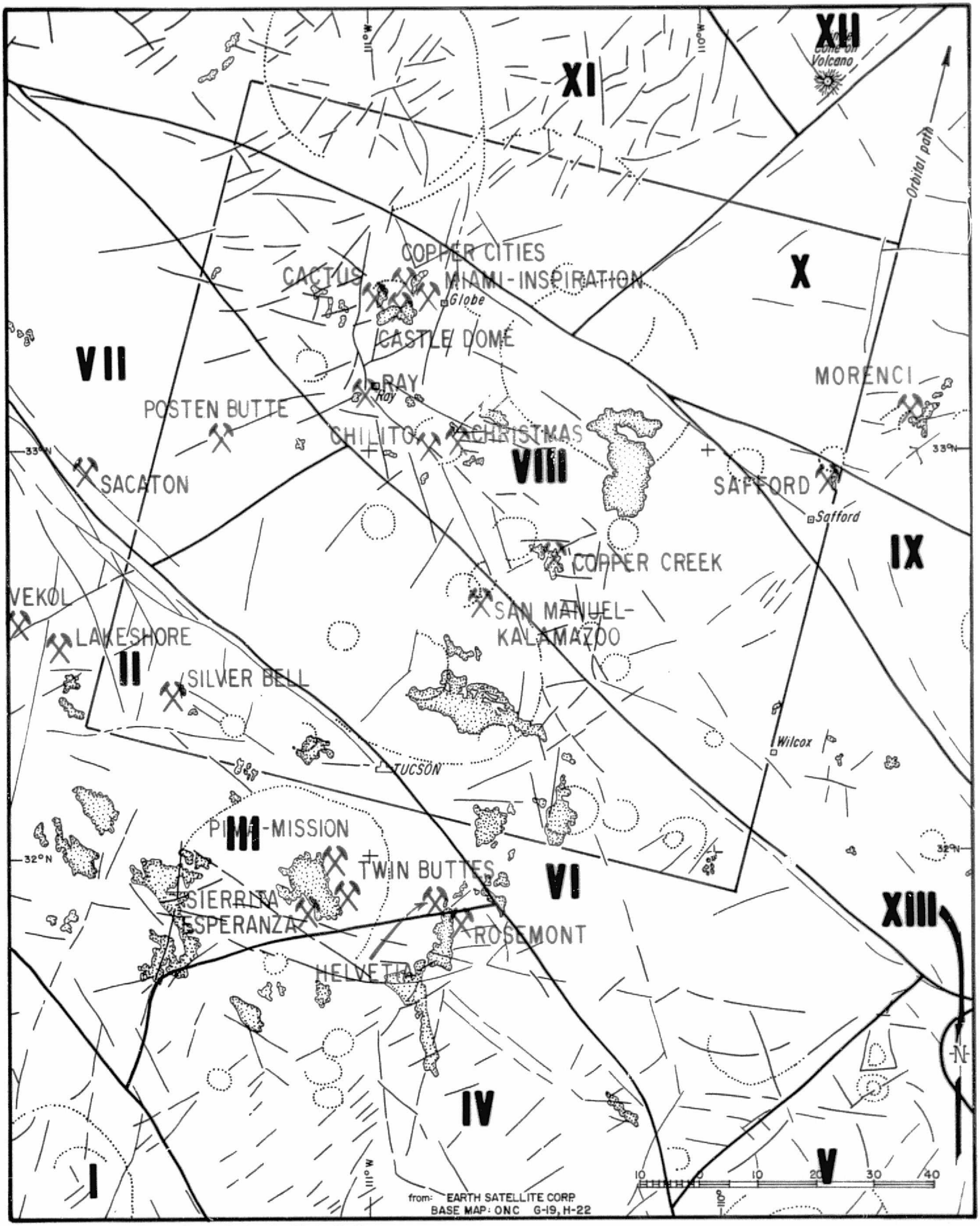
Exploration Services Department

GEOLOGIC FEATURES
INTERPRETED FROM
ERTS COLOR COMPOSITE IMAGERY
by
G. HUGHES
RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3 28.74	No FIGURE-7
ORIGINATOR G.H		
DRAFTING jdm		REVISED 7-24 75



EXPLANATION

LARAMIDE INTRUSION (after Forrester, 1962)

MAJOR FAULT

CIRCULAR FEATURE BOUNDARY

IX TECTONIC UNIT NUMBER

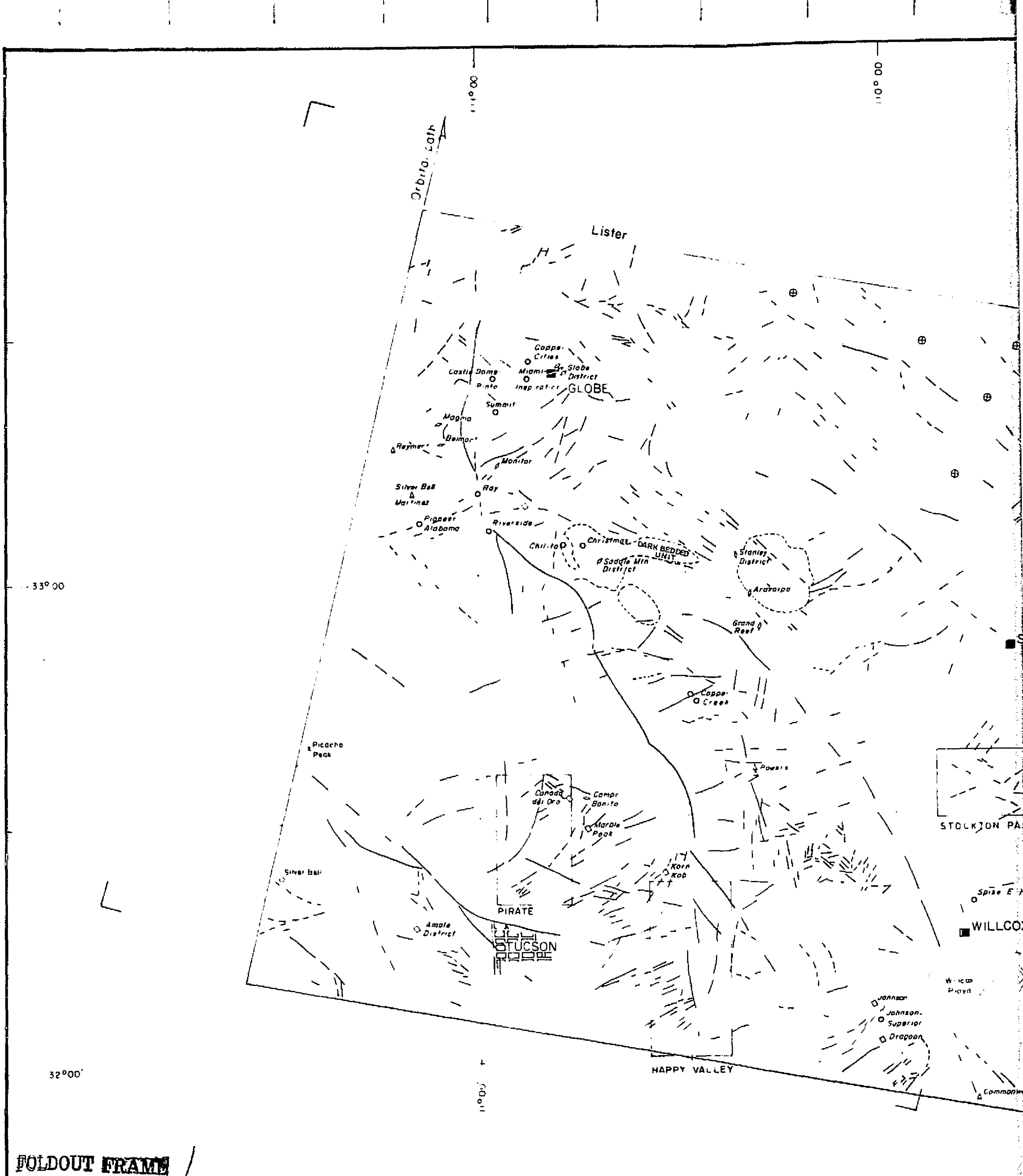
PORPHYRY COPPER DEPOSIT

KENNECOTT EXPLORATION SERVICES

ERTS TECTONIC MAP
RAY, ARIZONA AREA
showing
TECTONIC UNIT BOUNDARYS
AND
POROPHYRY COPPER DEPOSITS

115-15A-18-B

FIGURE-4



FOLDOUT FRAME /

Base Image Frame 1102-17274
Covering most of RAY TEST AREA, ARIZONA

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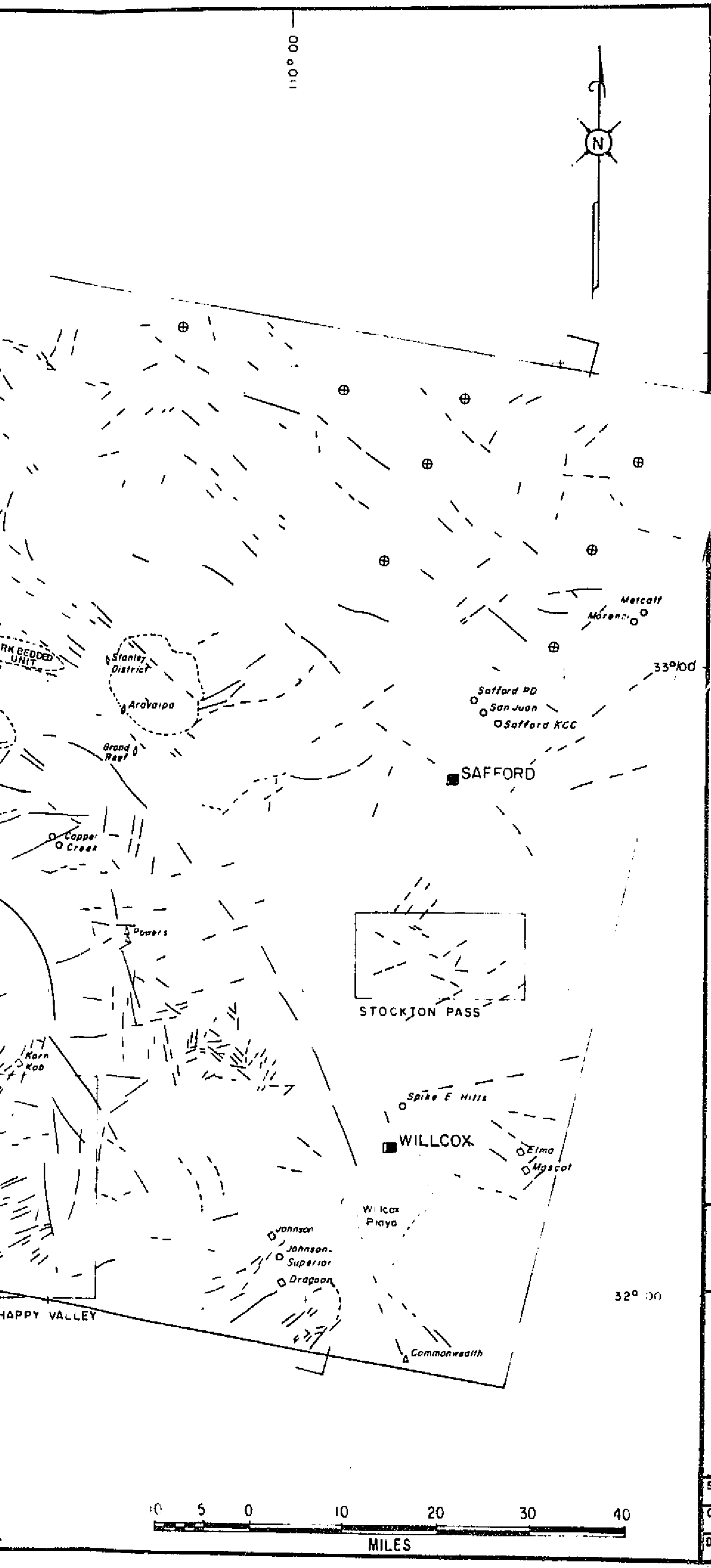


EXPLANATION

- Strike and dip of layered rock
- Horizontal bedding
- Photo linear
- Dike swarm
- Possible stock

FOLDOUT FRAME 2

MINERAL DEPOSITS

- Stockwork sulfide (includes porphyry coppers)
- Contact pyrometasomatic
- Veins
- Tertiary epithermal veins

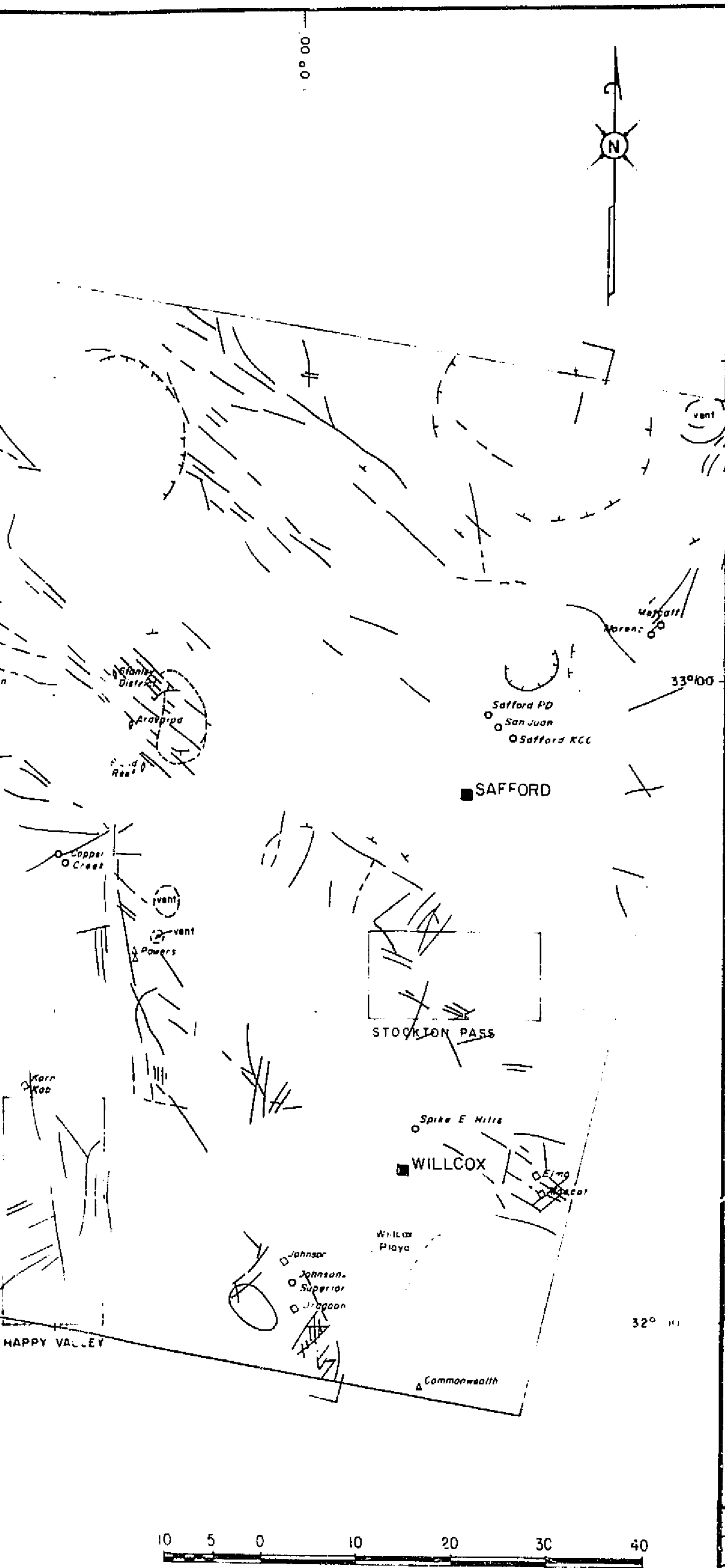
Kennecott Exploration, Inc.
Exploration Services Department

GEOLOGIC FEATURES INTERPRETED FROM ERTS COLOR COMPOSITE IMAGERY
by
G. LISTER
RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3 28 74	No FIGURE-8
ORIGINATOR G. L		
DRAFTING jdm		REVISED 7-24 75

FOLDOUT FRAME

Base Image Frame 1102-17274
Covering most of RAY TEST AREA, ARIZONA



EXPLANATION

- Intrusive
- Collapse structure

FOLDOUT FRAME 2

MINERAL DEPOSITS

- Stockwork sulfide (includes porphyry coppers)
- Contact pyrometasomatic
- Veins
- Tertiary epithermal veins

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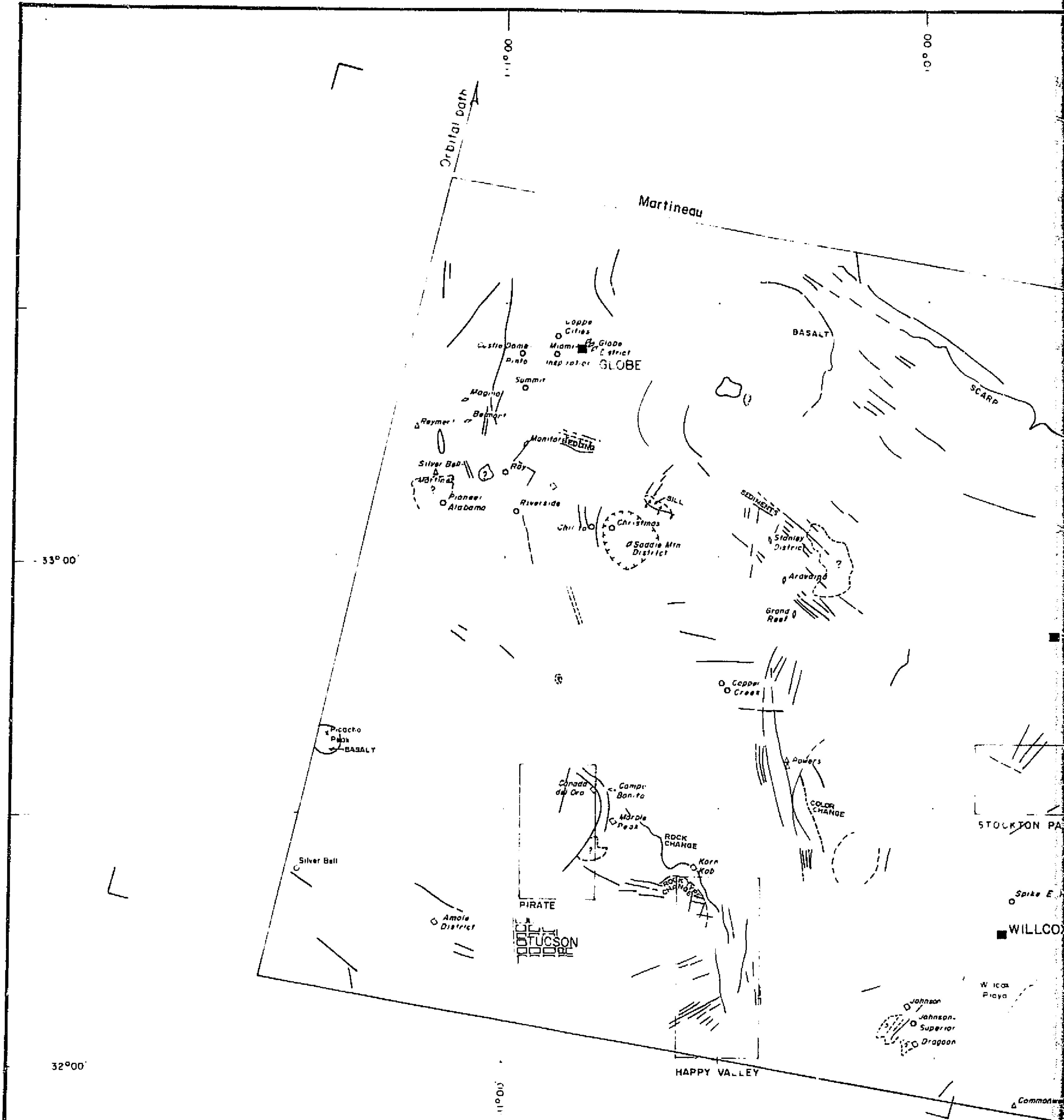
Exploration Services Department

GEOLOGIC FEATURES
INTERPRETED FROM
ERTS COLOR COMPOSITE IMAGERY
by
J. LYONS
RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3-28-74	No FIGURE-9
ORIGINATOR J.L		
DRAFTING jdm		REVISED 7-24-75



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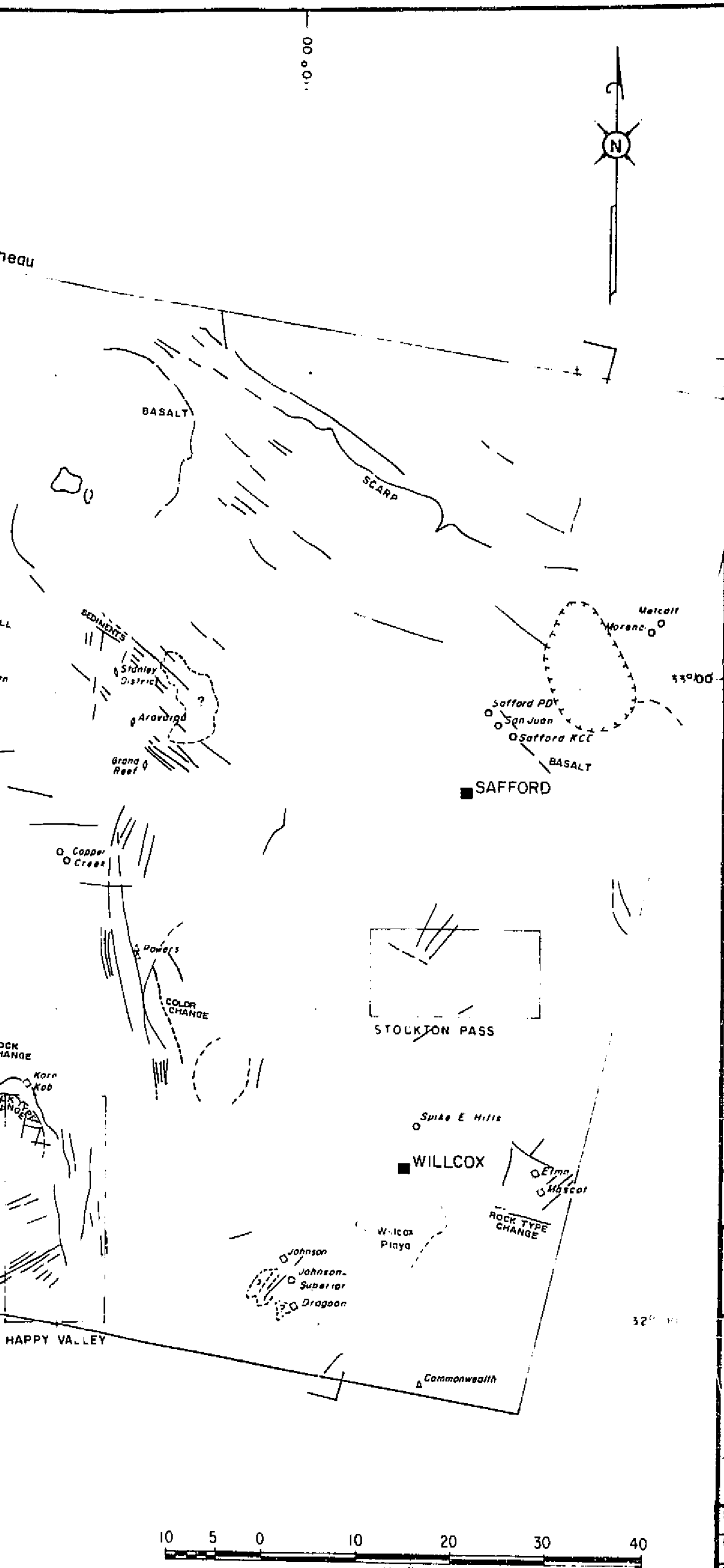
ORIGINAL PAGE IS
OF POOR QUALITY

Base Image Frame 1102-17274
Covering most of RAY TEST AREA, ARIZONA

10 5 0 10 20
MILES



EXPLANATION

- Linear feature probably fault
- Caldera boundary

FOLDOUT FRAME 5

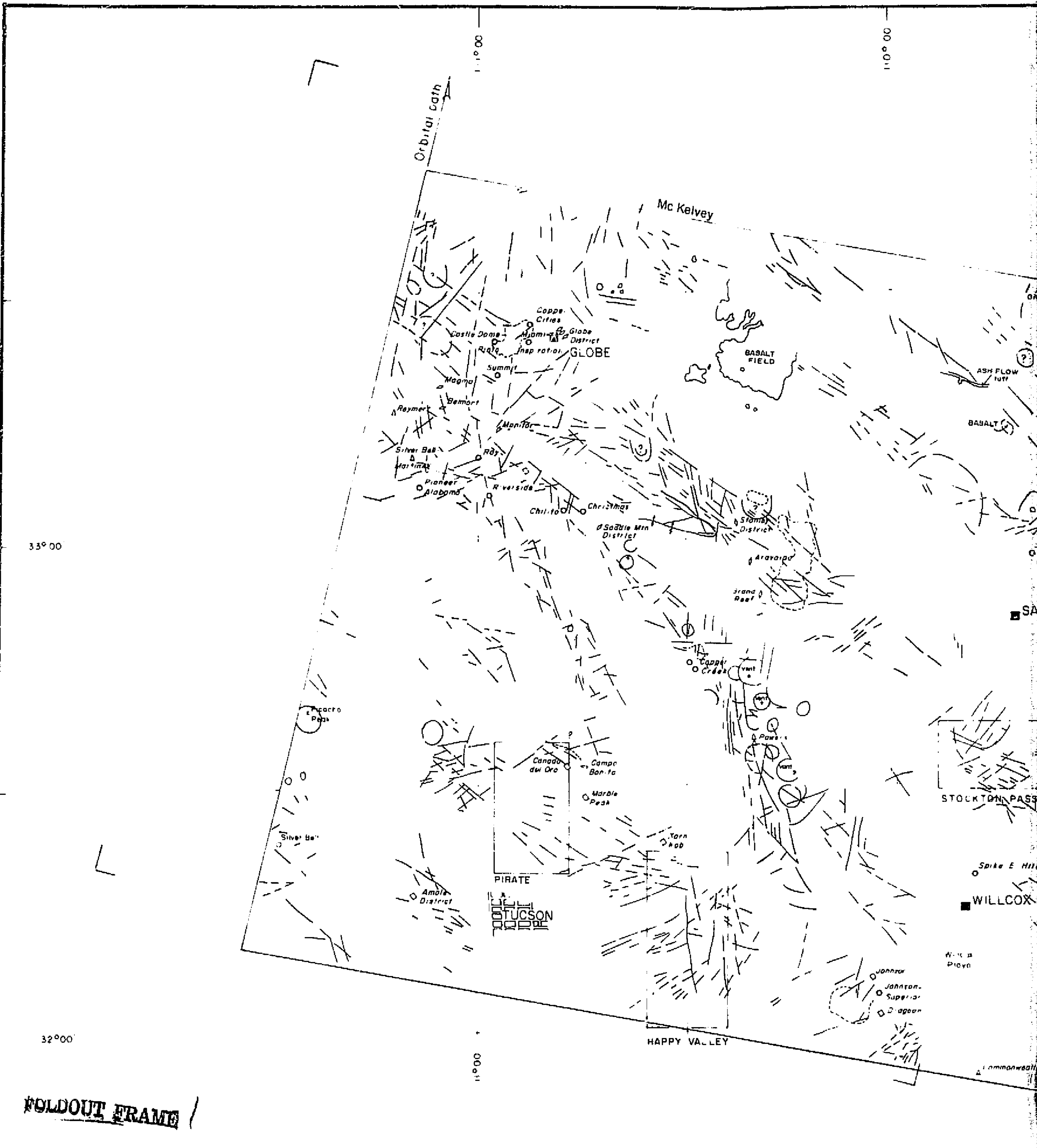
MINERAL DEPOSITS

- ○ Stockwork sulfide (includes porphyry coppers)
- ◇ Contact pyrometasomatic
- Veins
- △ Tertiary epithermal veins

Kennecott Exploration, Inc.
Exploration Services Department

GEOLOGIC FEATURES
INTERPRETED FROM
ERTS COLOR COMPOSITE IMAGERY
by
M. MARTINEAU
RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3 28 74	No FIGURE-10
ORIGINATOR M.M		
DRAFTING jdm		REVISED 7-24 75



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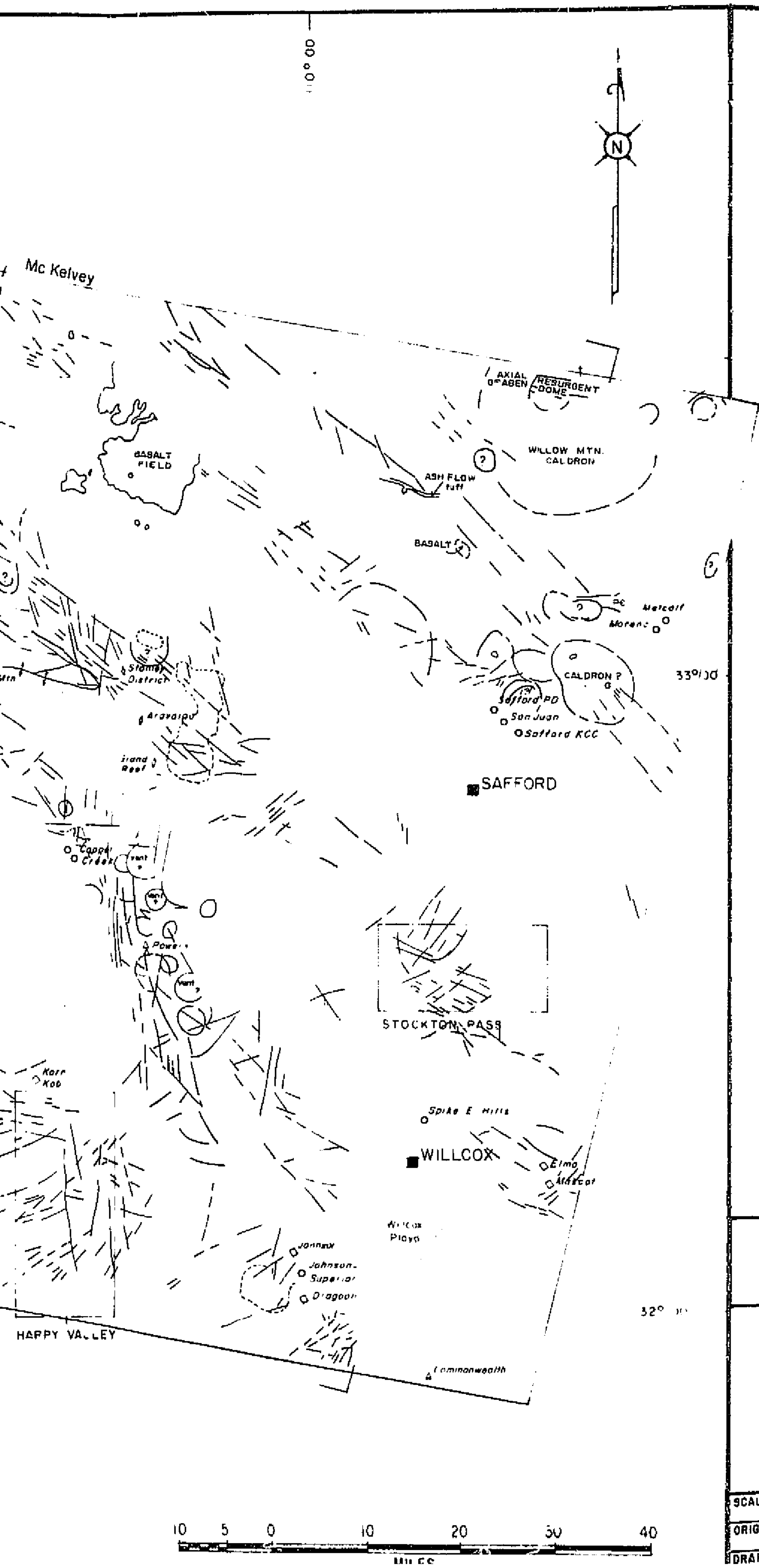


EXPLANATION

- Linear feature
- Circular feature

FOLDOUT FRAME 2

MINERAL DEPOSITS

- Stockwork sulfide (includes porphyry coppers)
- Contact pyrometasomatic
- Veins
- Tertiary epithermal veins

Kennecott Exploration, Inc.
Exploration Services Department

GEOLOGIC FEATURES INTERPRETED FROM ERTS COLOR COMPOSITE IMAGERY

by

G. McKELVEY

RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3 28 74	No FIGURE-11
ORIGINATOR G.M		
DRAFTING idm		REVISED 7-24 75

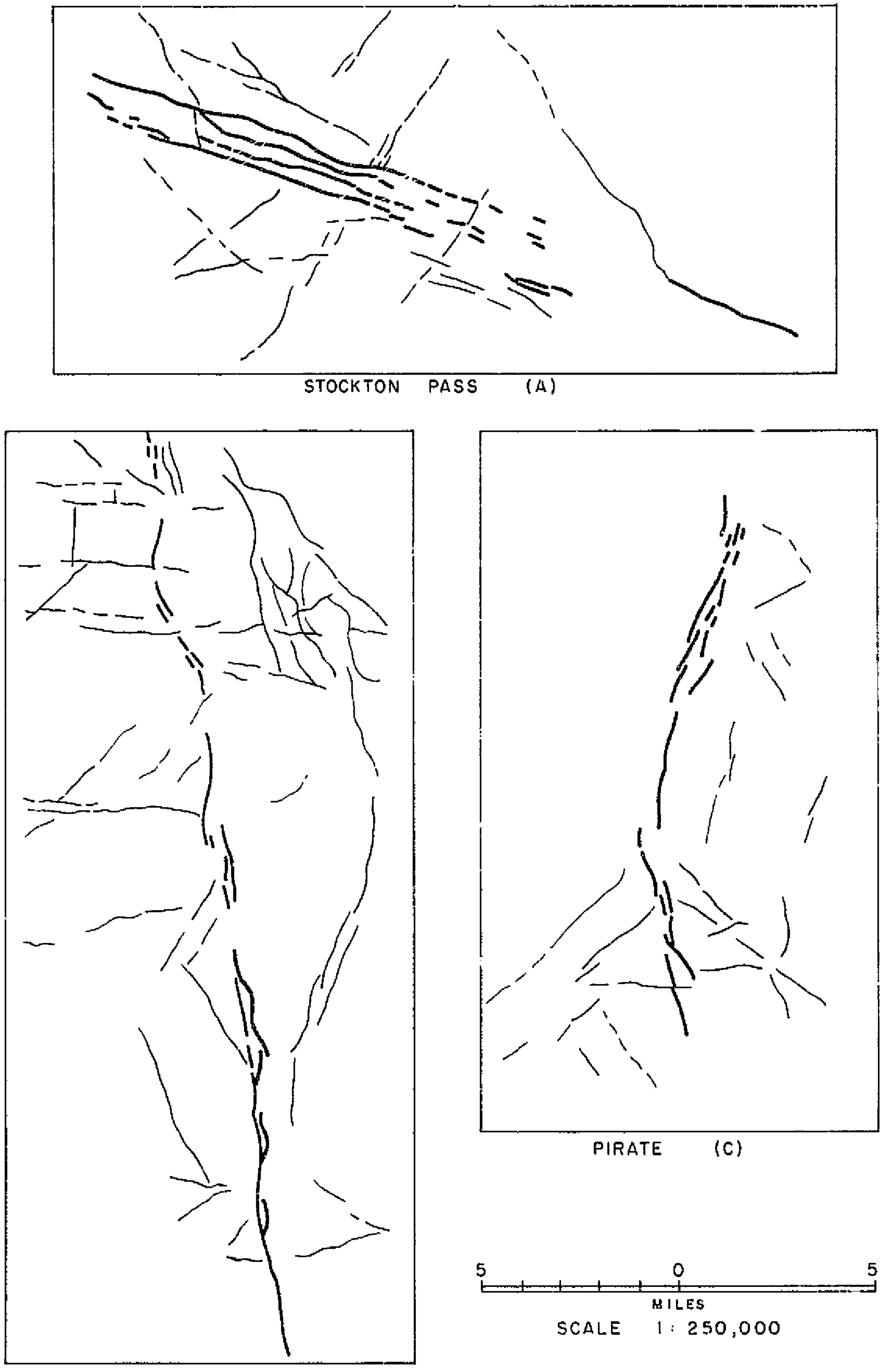
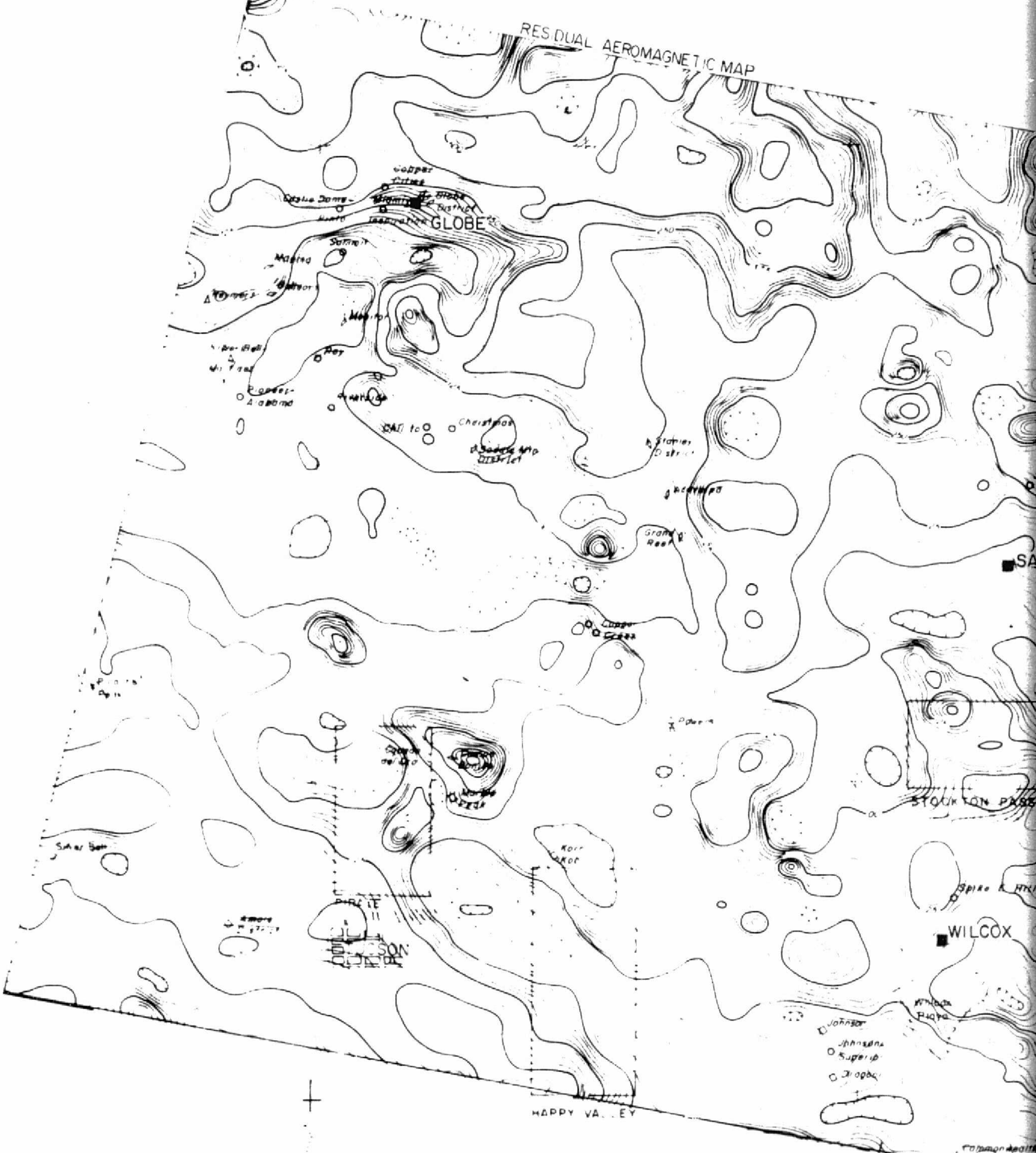


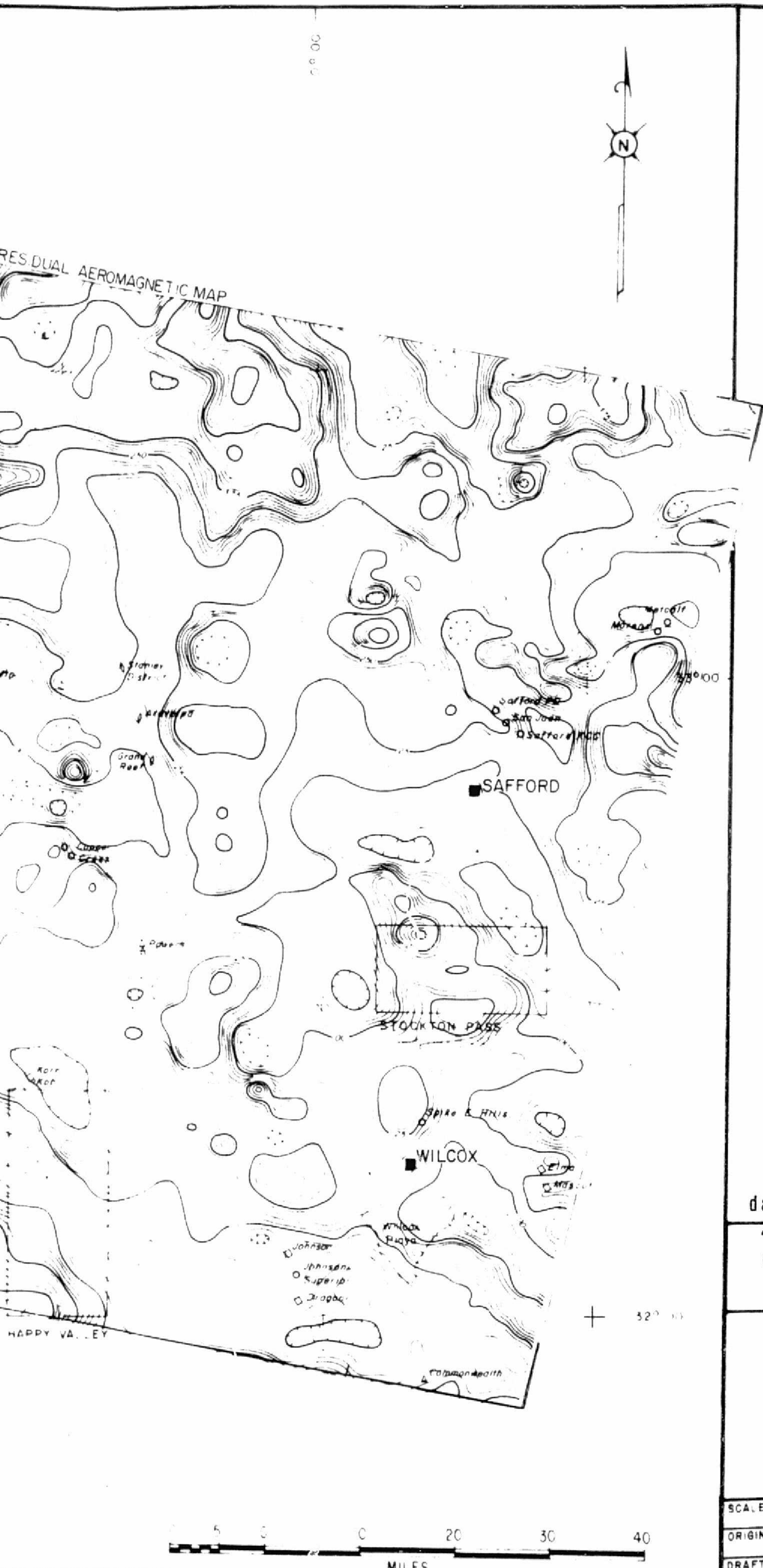
FIGURE 12
THREE MAPPED FAULT ZONES FOR COMPARISON
WITH RESULTS FROM ERTS INTERPRETATIONS
(see FIGURES 5 thru 11)



FOLDOUT FRAME

Base Image Frame 1102-17274
Covering most of RAY TEST AREA, ARIZONA

5 0 20
MILES



EXPLANATION

FOLDOUT FRAME 2

MINERAL DEPOSITS

- o Stockwork sulfide (includes porphyry coppers)
- ◇ Contact pyrometasomatic
- Veins
- Δ Tertiary epithermal veins

data from Sauck et al (1969)

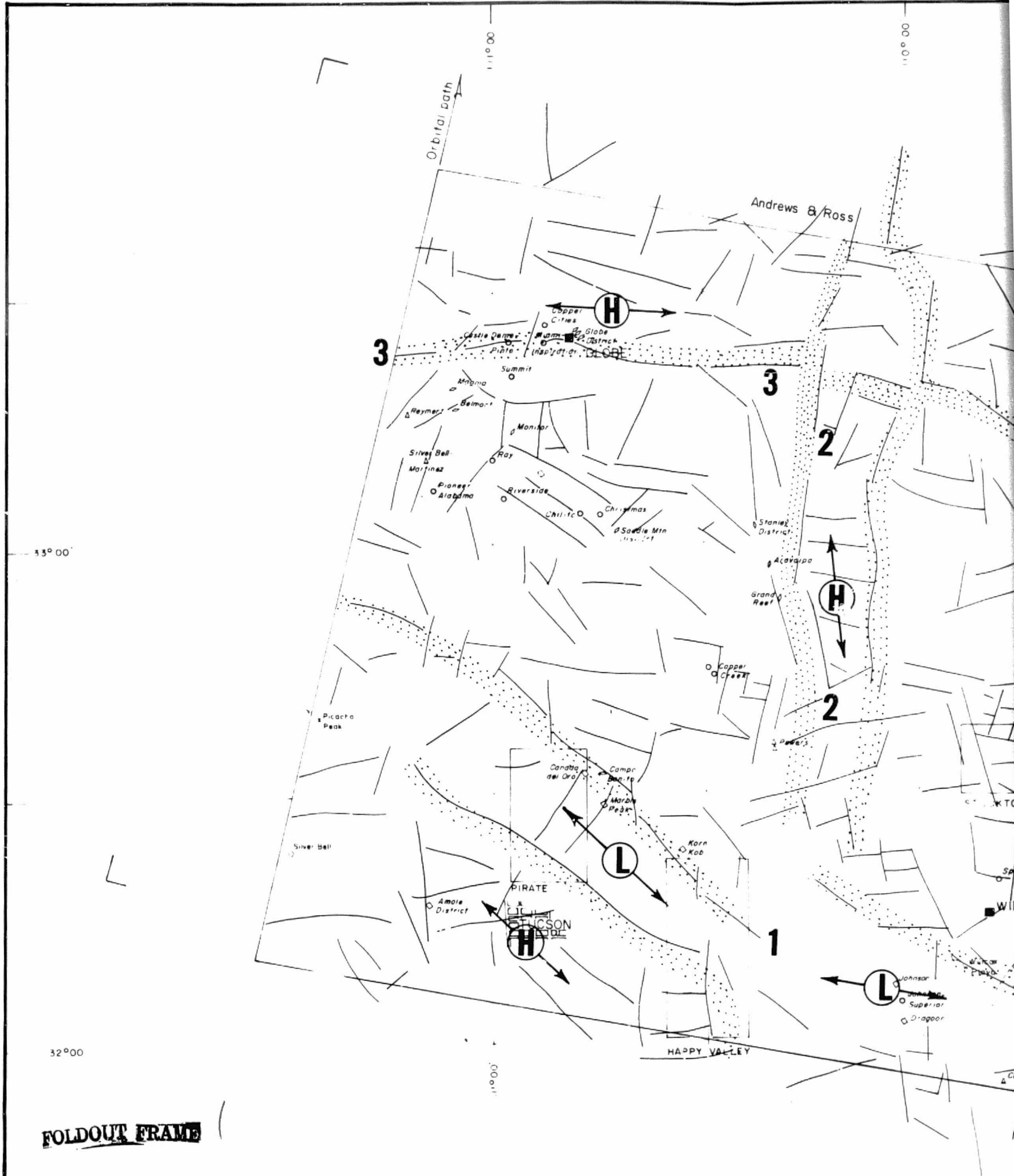
Kennecott Exploration, Inc.
Exploration Services Department

RESIDUAL AEROMAGNETIC MAP

OF

RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3 28 74	No FIGURE-13
ORIGINATOR		
DRAFTING jdm		REVISED 7 24 75



FOLDOUT FRAME

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Covering most of RAY TEST AREA, ARIZONA

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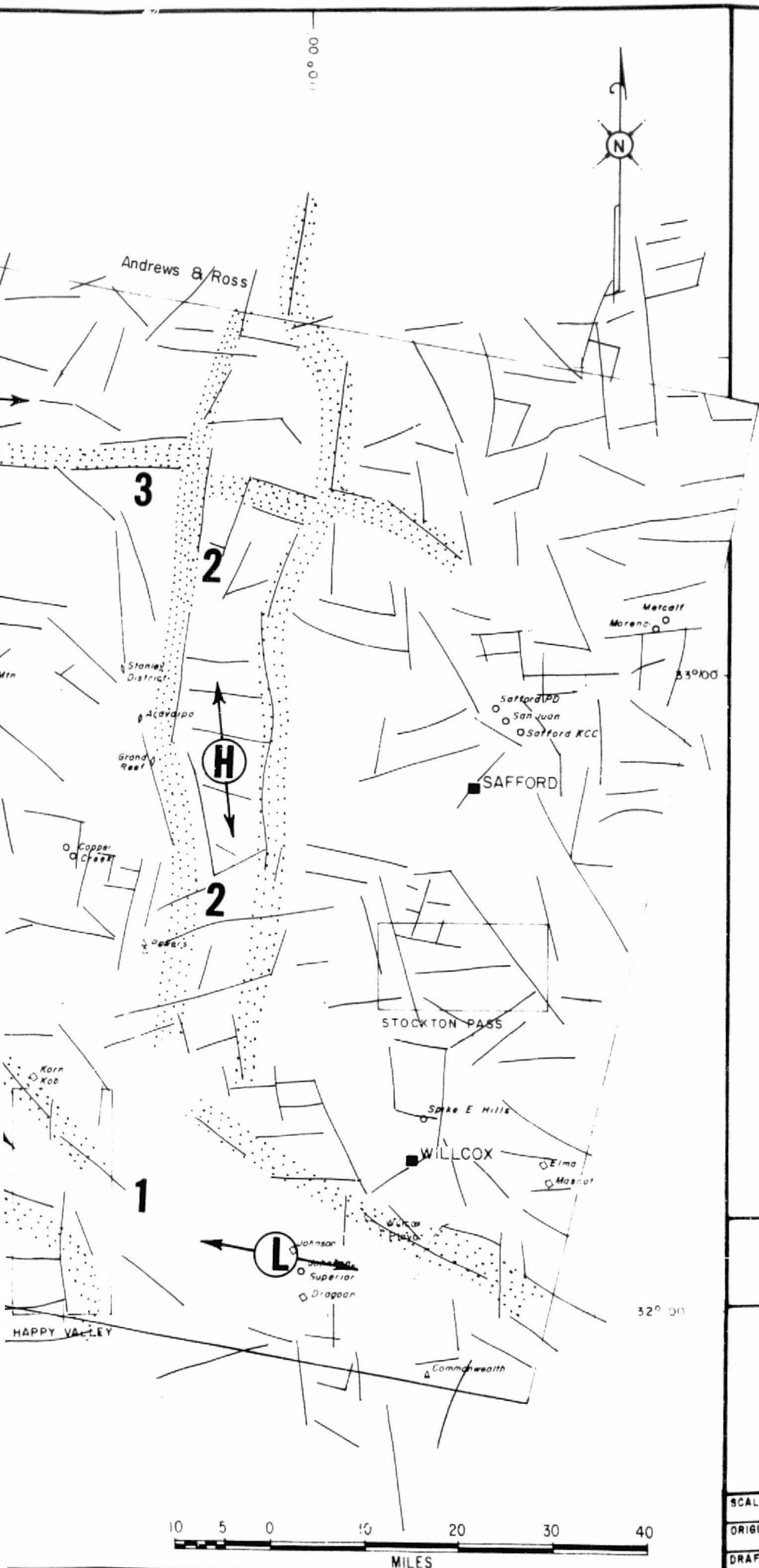
MILES



EXPLANATION

(H) Regional magnetic highs

(L) Regional magnetic lows

1,2,3 Text references

Aeromagnetic linear feature

Continuous low-frequency gradient

Source - Aeromagnetic map of Arizona (Sauck, Sumner & Wold, 1969) with the earth's regional field removed

FOLDOUT FRAME 2

MINERAL DEPOSITS

- o Stockwork sulfide (includes porphyry coppers)
- Contact pyrometasomatic
- Veins
- Δ Tertiary epithermal veins

Kennecott Exploration, Inc.
Exploration Services Department

INTERPRETATION OF STRONGER AEROMAGNETIC LINEAR FEATURES

R. ANDREWS and H. P. ROSS
RAY TEST AREA, ARIZONA

SCALE as shown	DATE 3. 28. 74	No FIGURE-14
ORIGINATOR R.A. and H.P.R.		
DRAFTING jdm		REVISED 7-24-75

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Interpretation and Evaluation of ERTS Imagery
from the Ok Tedi Area, Central New Guinea

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2300 West 1700 South
Salt Lake City, Utah 84104

June 1974
Final Report

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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7. Author(s) Robert W. Bamford		8. Performing Organization Report No.
9. Performing Organization Name and Address Kennecott Exploration, Inc. 2300 West 1700 South Salt Lake City, Utah 84104		10. Work Unit No. 11. Contract or Grant No. NAS5-21769
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Type III 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Naive interpretation of bulk processed ERTS imagery for the Ok Tedi area permitted accurate definition of three contrasting geotectonic terranes and the mapping of many major folds, faults, and volcanic features therein. Meaningful ratings of the different terranes for porphyry mineralization potential were established based on their structural complexity and/or evidence for igneous (volcanic) activity. Specific guides to individual centers of porphyry mineralization, e.g., the Mount Fubilan (Ok Tedi) and Freida prospects, however, were not established.

Use of limited ground-acquired geologic information with the ERTS imagery permits resolution of imagery mapping for terranes of moderate structural complexity. This mapping could be of significant utility to future porphyry search in New Guinea and possibly other areas.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Porphyry copper deposit New Guinea Geotectonic terrane Mineral exploration	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	6	

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PREFACE

This report discusses work accomplished by Kennecott Exploration, Inc. under its ERTS-1 project entitled, "Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery," PR-510, Contract NASA-21769. Research on the Ok Tedi Test Site, one of the six test sites investigated under this contract, examines the usefulness of imagery to mineral exploration geologists, and analyzes the tectonic framework in which the very young Ok Tedi deposit is found. Two other reports on this test site are:

Bamford, Robert W., 1974, Band Reflectance Ratio Maps From ERTS-1 Data Over Two Copper Prospects in New Guinea -- Appendix IX

Prindle, R. O., Lyon, R. J. P., Haenggi, W. T., and Erskine, M. C., 1974, Tectonic Interpretation of ERTS-1 Imagery of the Ok Tedi, Papua New Guinea Test Site -- Appendix VI

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Kennecott Exploration Services 2300 West 1700 South, Salt Lake City, Utah 84104 • Phone 801 486 6911 • TWX 910 925 5624

INTERPRETATION AND EVALUATION OF ERTS IMAGERY FROM THE OK TEDI AREA, CENTRAL NEW GUINEA

SUMMARY

Naive interpretation of bulk processed ERTS imagery for the Ok Tedi area permitted accurate definition of three contrasting geotectonic terranes and the mapping of many major folds, faults, and volcanic features therein. Meaningful ratings of the different terranes for porphyry mineralization potential were established based on their structural complexity and/or evidence for igneous (volcanic) activity. Specific guides to individual centers of porphyry mineralization, e.g., the Mount Fubilan (Ok Tedi) and Freida prospects, however, were not established.

Use of limited ground-acquired geologic information with the ERTS imagery permits resolution of imagery mapping for terranes of moderate structural complexity. This mapping could be of significant utility to future porphyry search in New Guinea and possibly other areas. In the broadly folded, limestone-rich terrane containing the Mount Fubilan porphyry prospect, for example, small (2-5 km diameter) intrusions which include all known centers of mineralization, can be recognized as circular topographic highs which, within thicker limestone sections, may be surrounded by a yet larger (5-15 km diameter) circular or semicircular depression.

An additional attempt to establish a specific guide to porphyry mineralization is to be made using computer techniques to investigate possible changes in the spectral properties of vegetation due to the presence of anomalous metal contents in soils over deposits.

INTRODUCTION

The purpose of work on ERTS imagery from the Ok Tedi area in central New Guinea was to determine if geologic or other information derived from ERTS imagery provides useful guides to porphyry copper mineralization. The area contains one prominent porphyry deposit, Mount Fubilan, and several prospects.

Work reported here includes a naive geologic interpretation and an evaluation of this interpretation based on comparison with known geology. Types of bulk processed imagery used included 1:1,000,000-scale, MSS-7, black-and-white prints and standard, 1:1,000,000-scale, MSS, color-composite transparencies. Principal scenes worked with were E-1027-00081 and -00084, and E-1028-00134 and -00140. In addition, a mosaic of 12 scenes at

1:1,000,000 scale, which centered on the Ok Tedi area and covered the width of the island between 140° and 144°30' east longitude, was used to extend some of the interpretation. Interpretive maps were constructed on transparent film overlays to the imagery. The interpreter is an exploration research geologist with six years experience in mineral exploration, one and one-half of which were spent in the Ok Tedi area. Background in imagery interpretation includes academic and general work experience with conventional aerial photographs and SLAR imagery.

In line with the nature of the Ok Tedi study area, discussion emphasizes the potential value of satellite-acquired imagery to exploration for porphyry mineralization in remote tropical areas characterized by poor access and very limited availability of geologic and cartographic information.

NAIVE INTERPRETATION

Results obtained in the naive imagery interpretation (i.e., interpretation without reference to previous work) fall into three principal categories: (1) definition of contrasting geologic terranes or tectonic zones (based on differences in structural and/or lithologic character shown by differences in relief, landforms, and/or drainage texture); (2) designation of specific geologic features with unambiguously recognizable geomorphic character (e.g., volcanic features, anticlines and synclines, and major linear "fault zones"); and (3) delineation of a variety of tonal and geometric patterns of unknown character.

Three principal geologic terranes or tectonic zones were distinguished. The southernmost terrane (area 1, Fig. 1 overlay) occupies the southern two-thirds of New Guinea within the area covered by the 1:1,000,000 scale imagery mosaic and, as is the case for all three terranes defined in this work, probably extends to the west-northwest and east-southeast significantly beyond the limits of the study area. It is characterized by extremely low relief, low elevations, broadly meandering streams, and a low drainage density. These characteristics suggest terrane 1 has experienced comparative tectonic stability for a significant period of geologic time, probably tens of million of years.

The second terrane distinguished (area 2, Fig. 1 overlay) lies immediately to the north of terrane 1 and is a narrow (60-70 km in width), west-northwest-trending zone characterized by moderate to high relief, broad, open folds and prominent linear structures with mostly west-northwest trends, and a low to moderate drainage density. It is a linear fold belt with relatively simple structural character and probably is mostly underlain by layered rocks. Volcanic effusive centers occur in the eastern part of the belt and provide evidence of recent, local(?), igneous activity which appears to be mostly confined to the belt. If the igneous activity were characteristic, terrane 2 might be assigned a high potential for porphyry mineralization since such deposits are widely considered to be related in origin to subvolcanic stocks. Because some of the volcanic features occur near the boundaries of terrane 2, however, and in part disrupt and conceal the characteristics by which the different terranes are distinguished, their designation as unique features of terrane 2 remains somewhat tenuous.

The third and most northerly terrane (area 3, Fig. 1 overlay) is characterized by significant "textural" heterogeniety on the imagery, and might alternately have been separated into two or more distinct geological or tectonic units. Treated as a unit, terrane 3 is distinguishable from terrane 2 by its characteristic heterogeniety and by a much higher drainage density, both of which imply greater structural complexity. Relief is quite similar to that of terrane 2 throughout, except for the presence of prominent alluvial flats along major drainages. West- to west-northwest-trending structural linears (probably fault zones) are prominently developed near, and closely parallel, the boundary with terrane 2. The presence of igneous rock can be inferred for this terrane because of its complexity, but cannot be directly identified on the imagery.

EVALUATION OF NAIVE IMAGERY MAP

Evaluation of the naive imagery map has been based primarily on comparison with the 1:1,000,000-scale geologic map of Papua New Guinea (Australia Bureau of Mineral Resources, 1972). Other maps used in the evaluation were the 1:5,000,000-scale Tectonic Map of Australia and New Guinea (Geological Society of Australia, 1971) and the 1:250,000-scale geologic map from Bärr, et al. (1961, Geological Results of the Star Mountain Expedition: Nova Guinea, Geology, v. 4, p. 39-99). The latter facilitated initial evaluation of the extreme northwestern part of the naive imagery map, where the imagery coverage extends into West Irian.

Comparison of the naive imagery-derived map with known geology indicates:

1. Terrane 1 (Fig. 1 overlay) corresponds to within ± 5 km along its northern boundary to uniform, relatively flat-lying Quaternary terrestrial clastic sediments. These make up the uppermost units in a thick (up to 5,000 meters) sequence of mostly conformable, Mesozoic to Holocene shelf sedimentary rocks (platform cover) on pre-Mesozoic basement, which comprise part of an epicontinental extension of the Australian craton (e.g., see Tectonic Map of Australia and New Guinea).

The general character of terrane 1, then, is reasonably defined in the naive interpretation (page II), and, on the basis of such interpretation, a very low potential for porphyry copper mineralization could be assigned to this terrane. In the absence of regional geologic information, such work done prior to initiating a ground search for porphyry mineralization in the region might effect a significant savings in time and effort.

2. Terrane 2 (Fig. 1 overlay) corresponds, within ± 5 km along its southern boundary and generally to within less than ± 10 km along its northern boundary, to a fold belt containing mostly Tertiary and Mesozoic marine and Tertiary terrestrial clastic sedimentary rocks. Surface exposures are dominated by a thick (approximately 1,000 meters) Middle Tertiary limestone unit. The low drainage density characteristic of this terrane results from the predominance of internal drainage in the limestone. Reference to the Tectonic Map of Australia and New Guinea shows this area corresponds closely to a zone of locally intense Miocene to Quaternary deformation in platform cover or miogeosynclinal sediments and basement rocks along the Miocene(?) cratonic margin. More than 16 small hypabyssal or subvolcanic stocks of Plio-Pleistocene age occur uniquely in this terrane in the western half of the study area while several (more than 6) Quaternary volcanic effusive centers occur within or near the eastern half. Because the terrane appears to be more deeply eroded toward the west, it is possible that the stocks in the west and effusives in the east are of related origin. The Mount Fubilan porphyry copper deposit of Plio-Pleistocene age occurs within one of the above-mentioned stocks.

Terrane 2, then, which is shown to be permissive for porphyry and other types of major hypogene copper deposits, can be readily distinguished from adjacent terranes and assigned at least a fair porphyry potential based specifically on naive mapping using ERTS imagery. It is doubtful, however, that the true (high) potential for mineralization of this terrane could have been convincingly established on the basis of imagery interpretation alone. Utilization of ground-acquired geologic information in conjunction with the imagery to establish the geomorphic characteristic of specific geologic units of importance to exploration (e.g., the limestones and intrusions), however, would permit resolution of imagery mapping within this terrane to a degree that such mapping could be of significant utility to future porphyry search in New Guinea (see nos. 4, 5, and 6 below). Imagery mapping thus may be useful in extrapolation of prospective areas after a mineral potential has been identified on the ground.

3. Terrane 3 (Fig. 1 overlay) corresponds, within ± 10 km along its southern boundary, to an igneous metamorphic terrane which is possibly largely oceanic in character (i.e., may represent an oceanic eugeosynclinal

or paleo-island arc environment). The southerly part of terrane 3 is overlain mainly by Mesozoic marine clastic sedimentary and volcanic rocks, mostly metamorphosed, and Tertiary volcanic rocks. Numerous ultramafic bodies and several Late-Middle Tertiary calc-alkaline intrusions occur in these rocks. The area is structurally complex. Major structures are west-northwest-trending transcurrent faults. A significant porphyry copper prospect, the Freida, occurs closely associated with one of the calc-alkaline intrusions near one of the transcurrent faults.

As with terrane 2, then, naive imagery mapping of terrane 3 defined a broad area which, if only because of its obvious geologic complexity, could be initially defined as possibly permissive for porphyry mineralization. Subsequent reference to geologic data from even limited surface reconnaissance would establish the presence of calc-alkaline intrusive and extrusive rocks (e.g., by observation in stream float) and should further increase interest in the area. The complexity of the area, however, would make it difficult to significantly improve the resolution of the naive imagery mapping in this terrane by using ground-acquired geologic information to establish geomorphic or tonal recognition criteria for, e.g., intrusions. Follow-up detailed imagery mapping, therefore, would probably be of limited utility preliminary to exploration in such terrane compared, for example, to its utility in terrane 2.

4. Criteria for recognition of intrusions can be established with a reasonable degree of confidence for terrane 2, but remain very tenuous for terrane 3. In terrane 2, smaller (2-5 km diameter) intrusions emplaced in flat-lying clastic sedimentary and thinner limestone units often form circular features which are commonly topographic highs, e.g., feature A (Fig. 1 overlay). In terrane dominated by thick limestone units these appear as subdued topographic highs within a pronounced and abrupt topographic depression (sink hole?), e.g., feature B (Fig. 1 overlay). Unfortunately, most of the small intrusions known within terrane 2 (Fig. 1) are partly to completely obscured by cloud cover in the imagery. Many of these, however, do exhibit the above-described geomorphic character in 1:50,000-scale SLAR imagery of the Mount Fubilan area. Applying these criteria for intrusion recognition to the ERTS imagery, additional (unmapped or subsurface) intrusions can be tentatively hypothesized at locations C, D, E. F, and G (Fig. 1 overlay).

5. Major folds and a fair number of prominent high-angle faults were accurately mapped in the naive interpretation (cf. Fig. 1 and Fig. 1 overlay). Noteable exceptions were an inability to map much of the prominent Lagaip and Freida fault zones (Fig. 1), although a number of paralleling structural linears were defined. In addition, a variety of structural linears not

corresponding to established structural trends (e.g., northeast-trending linears in the east part of terrane 3, Fig. 1 overlay) were identified on the imagery as probable significant structures.

6. Drainage maps and alluvium maps which would be of considerable value to a first-pass reconnaissance program in New Guinea-type terrane can be derived from ERTS imagery. Drainage maps of adequate detail (scale up to approximately 1:50,000) and location accuracy ± 1 to 2 km) for use in a helicopter-supported stream sediment sampling program can be produced. Areas with bedrock at the surface can be distinguished from areas wider than 2 km containing recent sediments to aid the planning and interpretation of reconnaissance work.

PROBLEMS

Errors in locations of latitude and longitude ticks on imagery of up to 9 km (9 mm on 1:1,000,000 scene) are noted (e.g., see longitude ticks on E-1028-00134 and -00140). These show up as offsets in coordinate grids established for adjacent lines of imagery.

Repetitive coverage of the Ok Tedi test area was very limited, and, as a result, the amount and type of information which could be evaluated in this work was significantly less than it might have been. Cloud cover obscures the immediate Mount Fubilan (Ok Tedi) porphyry deposit area in all available scenes.

Contrast and tonal quality vary significantly for different spectral-band images for a given scene and make evaluation of differences in spectral response of various features extremely difficult. Part of this problem could have been solved by compensating for differences in initial exposure during image processing. Under existing circumstances, however, evaluation of spectral signatures would probably best be carried out by computer manipulation of ERTS data (see below).

ADDITIONAL WORK

ERTS imagery data in computer-compatible tape format for the Ok Tedi area have been requested from NASA to facilitate investigation of possible changes in the spectral properties of vegetation due to the presence of metals in soils over known mineral deposits. The computer processing of the ERTS data will utilize established programs designed to yield comparable reflectance ratios at any specified location for each of the four MSS spectral bands. Time requirement for completion of this work will be about one month after we receive the tape.

Following Plates Not Silmed

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Band Reflectance Ratio Maps from ERTS-1 Data over Two Copper Prospects in New Guinea

Robert W. Bamford
Kennecott Exploration, Inc.
2300 West 1700 South
Salt Lake City, Utah 84104

December 1974
Final Report

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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7. Author(s) Robert W. Bamford		8. Performing Organization Report No.
9. Performing Organization Name and Address Kennecott Exploration, Inc. 2300 West 1700 South Salt Lake City, Utah 84104		10. Work Unit No.
		11. Contract or Grant No. NAS5-21769
		13. Type of Report and Period Covered Type III
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

ERTS-1 computer-compatible MSS raw data were used to generate approximately 1:20,000-scale shadeprints, band ratio prints, and cluster analyses for two prospect areas containing porphyry-type copper mineralization in western Papua New Guinea tropical rain forest terrain. The purpose of this work was to see if theoretically feasible vegetation reflectance anomalies might be detected. Such anomalies would be related to plant stress caused by excessive base-metal contents in soils over mineralization.

No correlations between reflectance anomalies and known mineralized areas were detected in this work. However, atmospheric corrections and, hence, reflectance calculations have not been made. Such refined data might reveal coherent reflectance anomalies not resolved in the raw data.

17. Key Words (Selected by Author(s))	18. Distribution Statement
band reflectance ratio map porphyry copper New Guinea ERTS-1 imagery	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	6	

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28-i

PREFACE

This report discusses work accomplished by Kennecott Exploration, Inc. under its ERTS-1 project entitled, "Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery," PR-510, Contract NASA-21769. Research on the Ok Tedi Test Site, one of the six test sites investigated under this contract, examines the usefulness of imagery to mineral exploration geologists, and analyzes band reflectance ratio measurements over two copper prospects in this test site. Two other reports on this test site are:

Bamford, Robert W., 1974, Interpretation and Evaluation of ERTS Imagery From the Ok Tedi Area, Central New Guinea -- Appendix VIII

Prindle, R. O., Lyon, R. J. P., Haenggi, W. T., and Erskine, M. C., 1974, Tectonic Interpretation of ERTS-1 Imagery of the Ok Tedi, Papua New Guinea Test Site -- Appendix VI

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SUMMARY

ERTS-1 computer-compatible MSS raw data were used to generate approximately 1:20,000-scale shadeprints, band ratio prints, and cluster analyses for two prospect areas containing porphyry-type copper mineralization in western Papua New Guinea tropical rain forest terrain. The purpose of this work was to see if theoretically feasible vegetation reflectance anomalies might be detected. Such anomalies would be related to plant stress caused by excessive base-metal contents in soils over mineralization.

No correlations between reflectance anomalies and known mineralized areas were detected in this work. However, atmospheric corrections and, hence, reflectance calculations have not been made. Such refined data might reveal coherent reflectance anomalies not resolved in the raw data.

INTRODUCTION

Modifications of reflectance spectra of vegetation due to anomalous base-metal contents of the soils (or other media) which provide plant nutrients have been documented in a variety of studies (Canney, 1970; Howard, et al., 1971; Press, et al., 1972; and Yost, 1971). The most common changes documented are an increase in reflectance at about 550 nm, which is a yellowing or form of chlorosis, and/or a decrease (or less commonly an increase) in reflectance in the near infrared which is generally attributed to structural changes in leaf mesophyll. If such changes were of sufficient magnitude and were manifest over sufficiently large areas, it is possible that they could be detected by satellite-borne, multispectral scanners such as those carried by ERTS-1.

The purpose of the experiment described in this report was to test the possibilities (a) that base metal-induced vegetation reflectance anomalies exist over porphyry prospects in western Papua New Guinea tropical rain forest and (b) that these anomalies can be defined using ERTS-1 computer-compatible MSS data. Computer manipulation of the MSS data was considered essential in the experiment in order to maximize resolution and reproducibility of the data and to permit use of channel ratioing and clustering techniques to aid definition of anomalies.

METHOD

ERTS-1 multispectral scanner (MSS) data in computer-compatible tape (CCT) format were acquired for scene E-1028-00134 which covers an area in Papua New Guinea containing a number of porphyry prospects. Only two of these, however, Kennecott's Tifalmin prospect and Carpenteria Exploration's Freida prospect, were sufficiently free of cloud cover during data acquisition to provide adequate data for remote sensing investigations. Work to date has been confined to the Tifalmin prospect, since basic ground-acquired geological and geochemical data, though limited, are available for that site only.

Data manipulations were carried out using an interactive computer (PDP-10) at Stanford University in cooperation with R. J. P. Lyon and F. R. Honey of the Stanford Remote Sensing Laboratories. The program used, designated RIPPER (Honey, 1974; and Honey, et al., 1974), permits data from the CCT to be read, shadeprinted, ratioed, and clustered.

Specific output generated in the current study was MSS 4, 5, 6, and 7 shadeprints; MSS 4/7, 4/5, 7/5 reflectance ratio prints (with minimum values of ratios subtracted and step intervals selected to maximize print contrast in areas of interest); and cluster analysis prints (MSS 4, 5, 6, and 7 data clustered using a $\pm$14% gate width). A complete set of these data were derived for each of two centers of copper mineralization, the Olgal-Futik and Unfin areas of the Tifalmin prospect. A single line print page (approximately 1:20,000 scale and covering an area about 3.8 by 5.4 km) provided adequate coverage of each mineralized area and adjacent surroundings to facilitate definition of reflectance anomalies (if any) within that area (see figures). All shadeprints and ratio prints in this study were color coded to aid interpretation using brown to yellow colors of graduated density. Dark colors were used for delineation of low reflectance or ratio values with lighter colors being used for delineation of higher values. Cluster analyses were coded using progressively darker colors to define progressively smaller (more anomalous) areas.

Figures 1 and 2 are examples of part of data generated for the Olgal-Futik and Unfin mineralized areas, respectively. Figures 1-A and 1-B are uncolored MSS 7 shadeprints for these areas showing the locations of the mineralized intrusions and principal drainages. Copper geochemistry over the mineralized intrusions commonly averages 1,000 to 2,000 ppm in creek outcrop, rock chip samples, and about 500 ppm in ridgetop soil and rock samples which are frequently oxidized and leached. Systematic geochemical grid sampling, however, has not been completed for these areas.

RESULTS

The MSS raw data shadeprints, band ratio prints, and cluster analyses for the Olgal-Futik and Unfin areas do not appear to provide evidence of correlation between reflectance anomalies and known mineralized areas.

Explanations for the lack of detection of reflectance anomalies include the possibilities that (a) reflectance modifications may have taken place as suggested by previous work (see introduction) but are of insufficient magnitude to be resolved in ERTS-1 MSS data and (b) vegetation assemblage over the mineralized area may have adapted to the base metal-anomalous soils by survival of tolerant species only and thus may not be significantly more stressed than surrounding vegetation. Work to test these tentative explanations is desirable but is not practical at present due to the remoteness of the test locality. It should also be noted that atmospheric corrections have not yet been made, hence reflectance calculations have not been attempted. Such refined data could possibly reveal reflectance anomalies not resolved by the raw data. Lack of information on areas of black-body or other calibrated reflectances precluded determination of an atmospheric correction factor.

REFERENCES

Channey, F. C., 1970, Remote detection of geochemical soil anomalies, in Geology Volume, 2nd Annual Aircraft Program Review (Houston, Texas: NASA) p. 1-8.

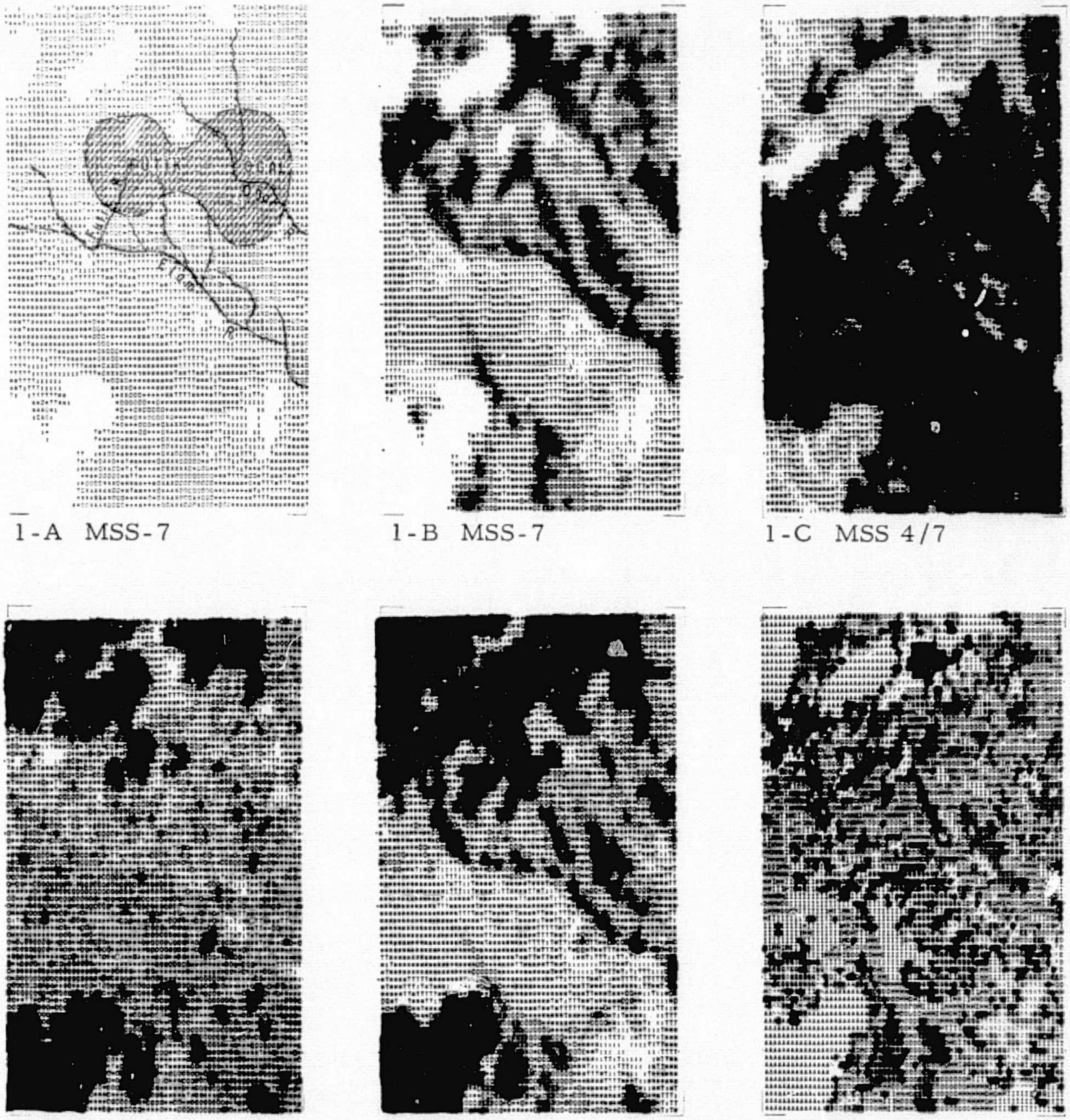
Honey, F. R., 1974, RIPPER: An interactive program for reading ERTS CC tapes: Stanford RSL Tech. Rept., no. 74-10 (preprint), 23 p.

Honey, F. R., Prelat, A., and Lyon, R.J.P., 1974, Stansort: Stanford remote sensing laboratory pattern recognition and classification system: Stanford RSL Tech. Rept., no. 74-4 (preprint), 9 p.

Howard, J. A., Watson, R. D., and Hessin, T. D., 1971, Spectral reflectance properties of Pinus Ponderosa in relation to copper content of the soil-- Malachite Mine, Jefferson County, Colorado, in Proc. 7th Symposium Remote Sensing Environment (Willow Run Laboratories: Ann Arbor, Michigan), p. 285-296.

Press, N. P., and Norman, J. W., 1972, Detection of orebodies by remote-sensing the effects of metals on vegetation: Inst. Mining and Metall. Trans., Section B, v. 81, p. 166-168.

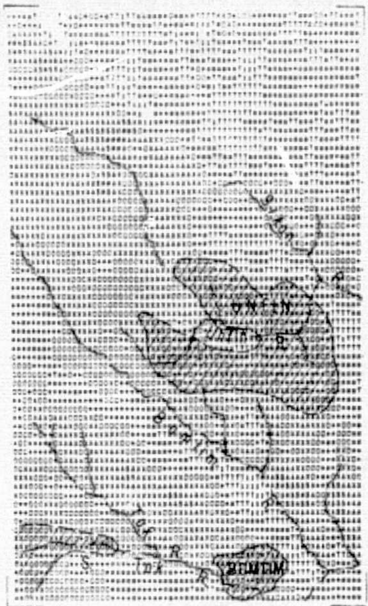
Yost, E., and Wenderoth, S., 1971, The reflectance spectra of mineralized tree, *in* Proc. 7th Symposium Remote Sensing Environment (Willow Run Laboratories: Ann Arbor, Michigan), p. 269-284.



1-A MSS-7 1-B MSS-7 1-C MSS 4/7

1-D MSS 4/5 1-E MSS 7/5 1-F Cluster analysis

Figure 1: Examples of computer-generated, hand-colored prints of ERTS-I MSS data for the Olgal-Futik area, Tifalmin prospect, P.N.G. (approximate scale of images 1:76,000 or 1 cm = 0.76 km). Various prints are: (1-A) Uncolored MSS shadeprint showing approximate location of mineralized intrusions (cross-hatch) and principal drainages, (1-B) MSS 7 shadeprint, (1-C) MSS 4/MSS 7 ratio print, (1-D) MSS 4/MSS 5 ratio print, (1-E) MSS 7/MSS 5 ratio print, and (1-F) cluster analysis for all MSS bands. All prints in this figure cover the same geographic area.

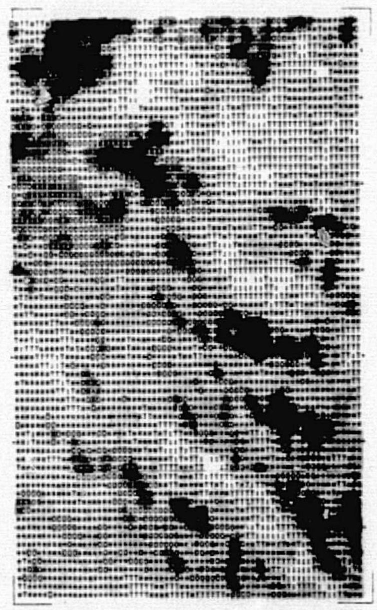


2-A MSS-7

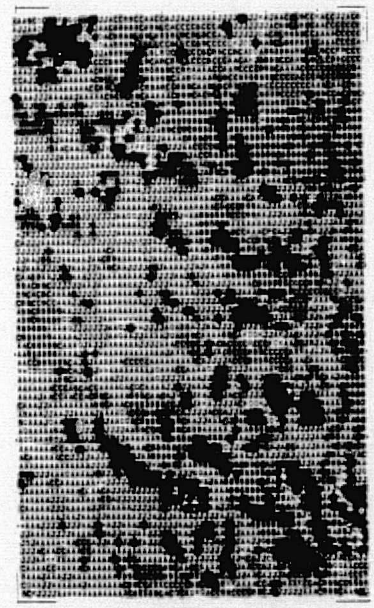
2-B MSS-7

2-C MSS 4/7

2-D MSS 4/5



2-E MSS 7/5



2-F Cluster analysis

Figure 2: Examples of computer-generated, hand-colored prints of ERTS MSS data for the Unfin area, Tifalmin prospect, P.N.G. (approximate scale of images 1:76,000 or 1 cm = 0.76 km). Various prints are: (2-A) Uncolored MSS 7 shadeprint showing approximate location of mineralized intrusions (cross-hatch) and principal drainages, (2-B) MSS 7 shadeprint, (2-C) MSS 4/MSS 7 ratio print, (2-D) MSS 4/MSS 5 ratio print, (2-E) MSS 7/MSS 5 ratio print, and (2-F) cluster analysis for all MSS bands. All prints in this figure cover the same geographic area.

RECOGNITION OF THE GEOLOGIC FRAMEWORK OF PORPHYRY COPPER DEPOSITS ON ERTS-1 IMAGERY

Interpretation of One Frame of U-2 Infrared Imagery in Gila County, Arizona

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Decamber 1974
Final Report

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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16. Abstract

U-2 underflight infrared photography was used as an aid in interpreting ERTS-1 imagery and was found to be highly useful in its own right in reconnaissance exploration. A geologic interpretation from one image is compared to previous mapping and the appearance of formational rock units is described.

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PREFACE

This report discusses work accomplished by Kennecott Exploration, Inc. under its ERTS-1 project entitled, "Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery," PR-510, Contract NASA-21769. Research on the Ray Test Site, one of six test sites investigated under this contract examines the usefulness of imagery to mineral exploration geologists and is reported more fully in the following appendices:

Appendix I -- Haenggi, W. T., and Erskine, M. C., 1974, Tectonic Interpretation of ERTS-1 Imagery of the Ray, Arizona Test Site

Appendix VII -- Allan, J. W., Andrews, R. K., Ross, H. P., and Wilson, J. C., 1974, Recognition of the Geologic Framework of Porphyry Copper Deposits on ERTS-1 Imagery, Ray Test Site, Arizona

This report describes how the underflight infrared photography may be used in reconnaissance in a specific area of this porphyry copper province.

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INTERPRETATION OF ONE FRAME OF U-2 INFRARED IMAGERY IN GILA COUNTY, ARIZONA

SUMMARY

U-2 underflight infrared photography was used as an aid in interpreting ERTS-1 imagery and was found to be highly useful in its own right in reconnaissance exploration. A geologic interpretation from one image is compared to previous mapping and the appearance of formational rock units is described.

INTRODUCTION

As a preliminary part of the ERTS-1 program, several flight lines of color infrared imagery of the study areas in Arizona and Nevada were provided to Kennecott Exploration for geological evaluation. This imagery was taken June 27, 1972 from a U-2 aircraft flying at an altitude of 65,000 feet. Positive transparencies with a 9 by 9-inch image area at a scale of 1:125,000 were produced. Table 1 shows sensor data for the U-2 infrared imagery and comparative data for 35-mm panchromatic (Kodachrome) imagery taken previously for use in reconnaissance mapping.

Table 1

IMAGERY DATA

	U-2 Infrared Imagery	Panchromatic Imagery
Image area	9 x 9 inches	35 x 24 mm
Image scale	1:125,000	1:62,500
Sensor	RC-10 metric camera	Leica camera
Lens focal length	6 inches	24 mm
f Stop	8	Not recorded
Shutter speed	1/500 sec.	Not recorded
Filters	Kodak Wratten No. 12	None
Film	Aerochrome infrared 2443	Kodachrome
Spectral band	500-900 nm	310-680 nm

The purpose of this report is twofold: (a) to clarify features of infrared imagery that might be confusing to the viewer, and (b) to emphasize the value of the imagery as an exploration tool, especially in searching for covered porphyry copper deposits.

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INTERPRETATION OF THE U-2 COLOR INFRARED IMAGERY

Probably the greatest difficulty with interpreting geology from the infrared imagery is the psychological effect that the coloration has on the photo interpreter. The appearance of the imagery is sufficiently different from what the eye is accustomed to that a mental adjustment is necessary before an interpretation can be made. To assist the interpreter in making this adjustment, photo 1994 was compared with Kodachrome imagery of the same area to permit the identification and description of features peculiar to the infrared imagery. Photo 1994 was selected mainly because it covers an area containing most rock types and formational units common to southeast Arizona. The area also contains the Saddle Mountain mining district and the Banner mining district which includes porphyry copper deposits at Chilito and Christmas. Figure 1 is an index map of Arizona. Figure 2 is a geologic map of the area by Willden (1964). Figure 3 is a positive black-and-white contact print of photo 1994.

Many rock units have much the same color on the infrared imagery as on the panchromatic. The relative reflectivity of limestones, tuffs, and acidic intrusive and extrusive rocks seems to remain constant through the visible and near-infrared part of the spectrum. Consequently, these rocks appear nearly white on both types of imagery.

Red, which is produced by the reflection of infrared light, is not an obvious additive color associated with any of the rock units on the infrared imagery. This indicates that the reflectivity of infrared light relative to the reflectivity of the visible part of the spectrum is quite low. Quartzites, which appear brown on the infrared imagery, seem to have stronger infrared reflectivities than other rock types. Table 2 compares colors of various rock units as they appear on both types of imagery.

Rocks commonly show greater color continuity on the infrared imagery than on the panchromatic. Color variations attributed to staining and weathering are generally not detected by the infrared film; consequently, rock units can usually be identified and traced more readily. For example, a thin tuff that has been stained by a nearby weathering basalt flow might be indistinguishable on the panchromatic imagery but contrasts sharply with the basalt on the infrared. Similarly, a white limestone that weathers red might be interpreted as two units on panchromatic imagery, expecially if weathered outcrops are separate from unweathered ones. On the infrared imagery, however, limestones, both weathered and fresh, usually appear near-white.

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Table 2

COMMON COLOR OF LITHOLOGIC UNITS ON PANCHROMATIC AND INFRARED IMAGERY

Rock Type or Unit and Age	Color	
	Panchromatic Imagery	Infrared Imagery
Unconsolidated Sediments (Q)	brownish-gray (varies somewhat with composition)	variable (color indicates composition)
Rhyolite (T)	light orange to light pinkish-brown	white
Ash Flow Tuff (T)	white (except where stained)	white
Andesite (Tk)	green to reddish-purple	yellowish-green to green
Basalt (Tk)	reddish purple to dark brown	dark green to black
Diorite and Quartz Diorite (Tk)	tan to light orange	near-white
Pinkard Formation (Cretaceous sediments) (K)	red-brown to light brown	light orange
Naco Limestone (D)	light bluish-gray	white
Escabrosa Limestone (M)	light bluish-gray	white
Martin Limestone (D)	light brownish-gray	white
Abrigo Limestone (C)	light reddish-brown	white
Bolsa Quartzite (C)	dark red-orange	golden brown to brown
Diabase (pC)	dark gray-green to dark red-brown	dark green
Dripping Spring Quartzite (pC)	light orange	golden brown to brown
Pioneer Formation (pC)	dark purplish-brown	golden brown to brown
Oracle Granite (pC)	tan to light orange	light yellowish-brown
Pinal Schist (pC)	greenish-gray to brown	dark gray-green

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The most obvious peculiarity of infrared imagery is the appearance of vegetation. Since most plants strongly reflect infrared light, they appear red to magenta on the infrared imagery. Hence the color addition to rock units caused by a cover of vegetation produces an appearance quite different from what the eye normally sees. In areas with a moderate to dense cover, the color addition is usually so strong that color differentiation of rock units is virtually impossible.

Regional Photogeologic Interpretation

The U-2 infrared imagery provides an excellent means for rapidly interpreting and compiling the regional geology of an area. The 1:125,000 scale is ideal and radial distortion is minimal. A photogeologic interpretation can be traced with only minor modification onto an AMS topographic base that has been enlarged to 1:125,000 scale.

Figure 4 illustrates some of the geologic data that can be traced from the U-2 imagery. It is considerably more detailed than a geologic map produced by surface methods alone (compare with Fig. 2). By having prior geologic knowledge of an area and by consulting available geologic maps, interpretations can be completed in a very short time. Dikes, joints, and areas containing pervasive sulfide mineralization are especially suited for mapping from the imagery. Limonites, which have high infrared reflectivities, give a yellow to yellow-orange tint to rocks containing oxidized sulfides. Regional attitudes of stratified units can be determined quite accurately. Dips can either be estimated from the imagery or obtained from previous geologic maps.

Application to Exploration for Covered Porphyry Copper Deposits

Regional photogeologic interpretation with emphasis on postmineral (post-Laramide mineralization) geology is particularly useful in the evaluation of areas for possible covered porphyry copper deposits. A particularly useful approach is to emphasize specific geologic features on the photographs by use of color overlays. Such features as Laramide intrusions, postmineral cover, and mineralization can be individually traced from the photographs to produce overlays. Any one or a combination of these overlays can then be viewed with the imagery in stereo to emphasize the three-dimensional distribution of that feature(s). This can greatly assist the interpreter in projecting mineralized zones, favorable host rocks, structures, dike swarms, and other features into covered areas and in many cases determine where cover might be relatively thin.

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REFERENCE

Willden, R., 1964, Geology of the Christmas quadrangle, Gila and Pinal Counties, Arizona: U.S. Geol. Survey Bull. 1161-E, p. E1-E64.

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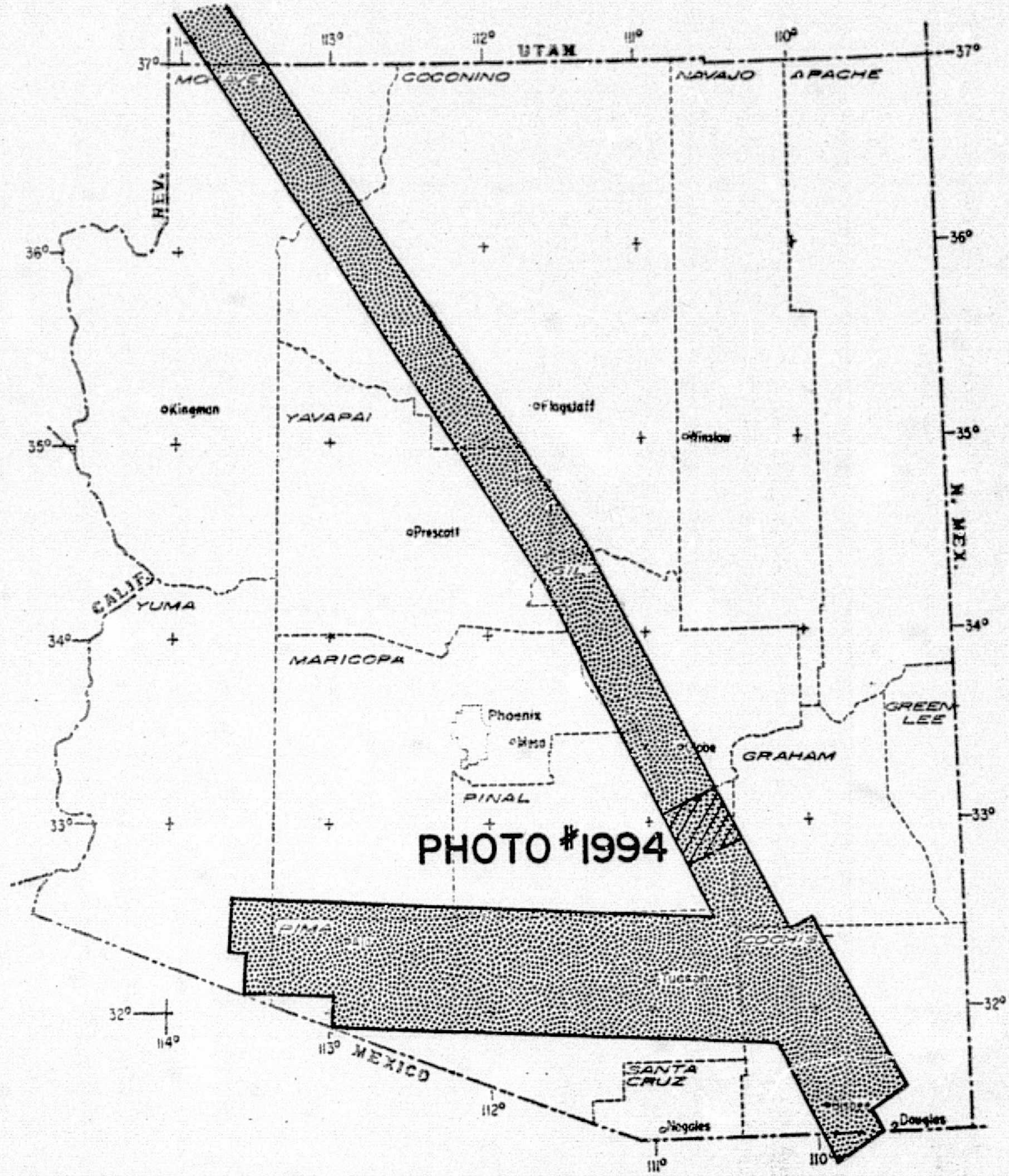
FIGURE I



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INDEX OF U-2 COLOR INFRARED IMAGERY

Research geologist: L.F. Barrett

August, 1973

Kennecott Exploration, Inc.
Exploration Services Department

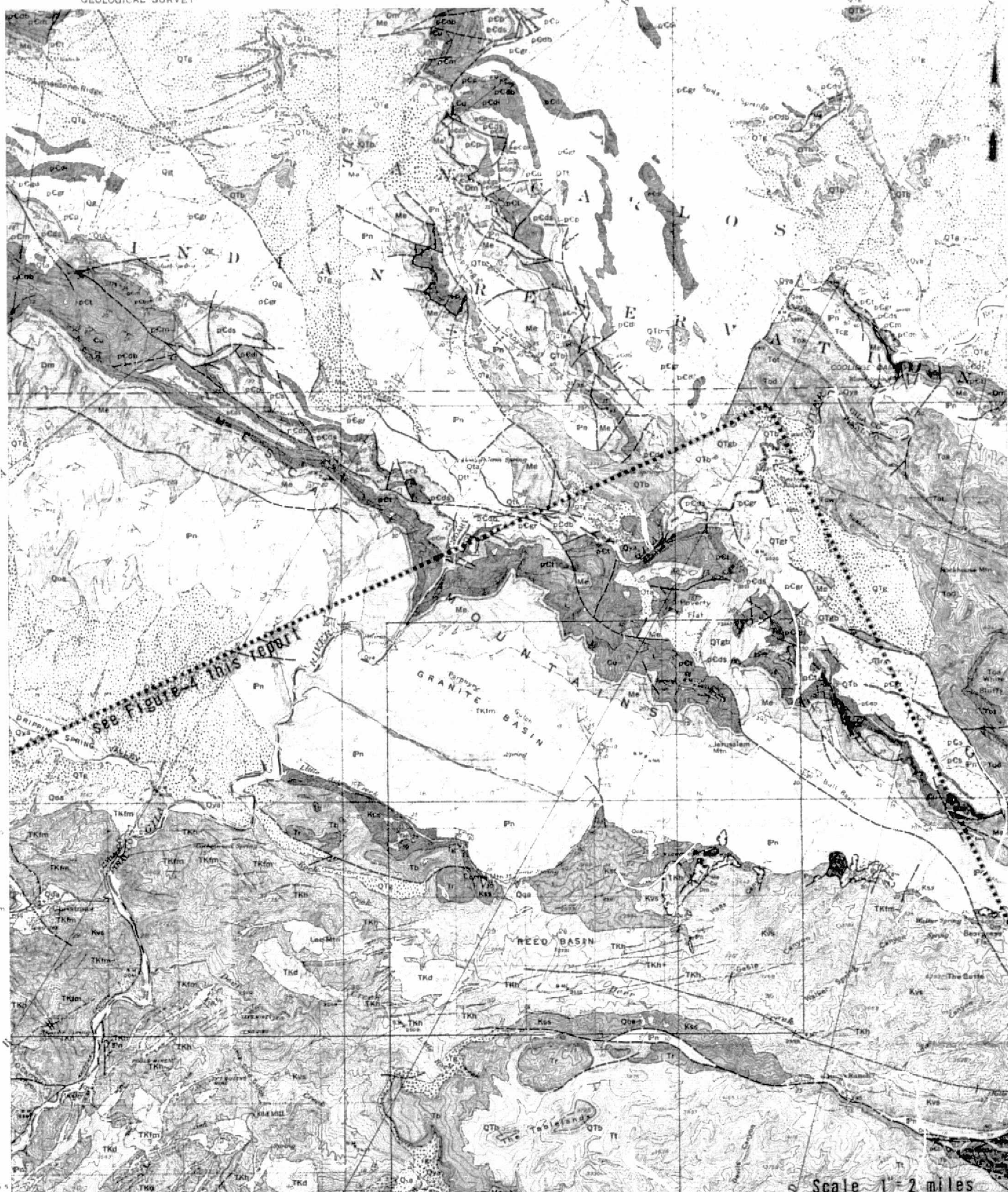
ARIZONA INDEX

SCALE	NO.
ORIGINATOR	
DRAFTING	REVISED

31-6

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

FIGURE-2



Base map by Topographic Division
U.S. Geological Survey, 1915

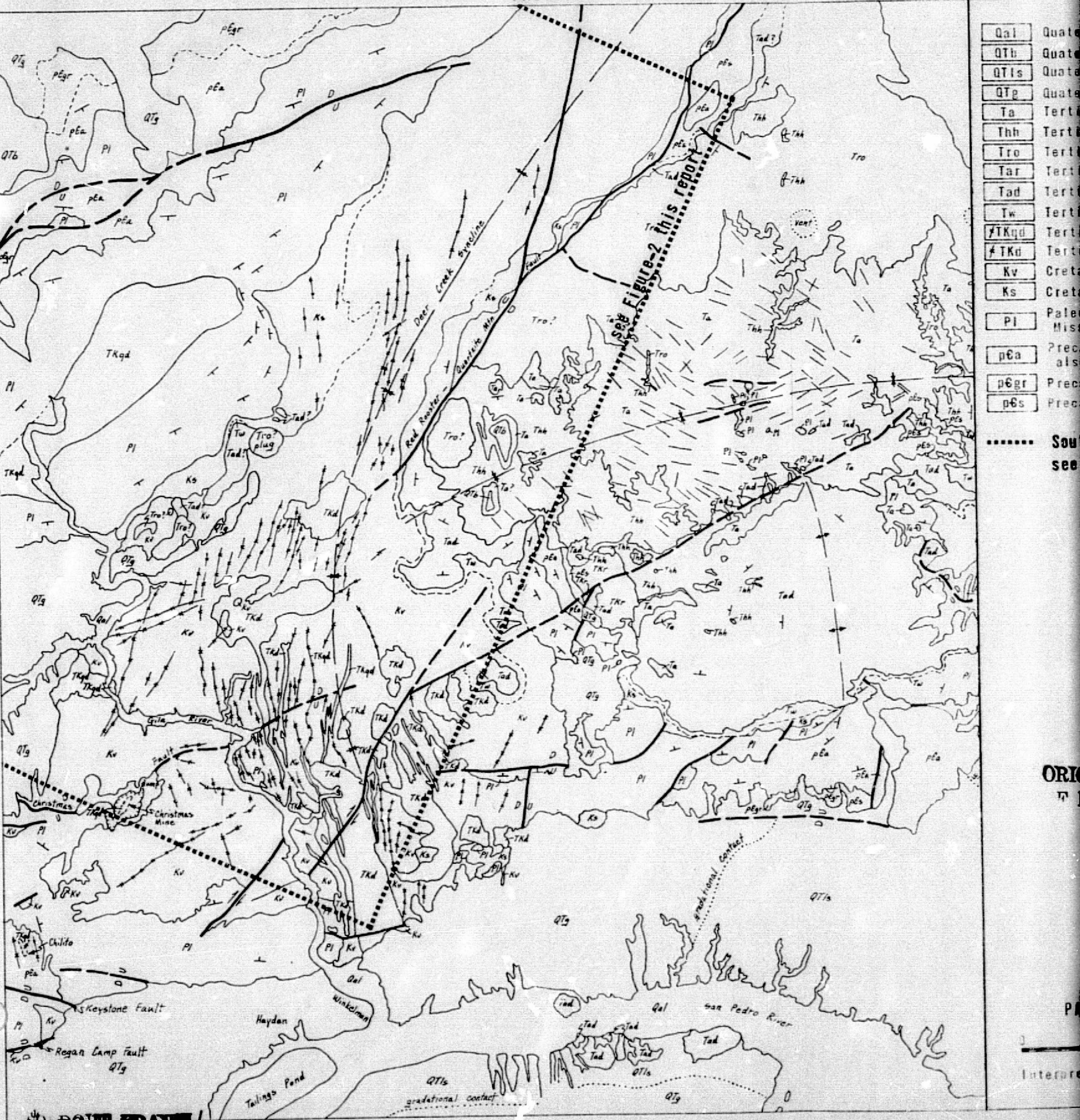
Geology by Ronald Willden 1959-61

GEOLOGIC MAP
OF
CHRISTMAS QUADRANGLE, ARIZONA
(see USGS Bull. 1161, Plate 1)

Scale: 1 : 2 miles

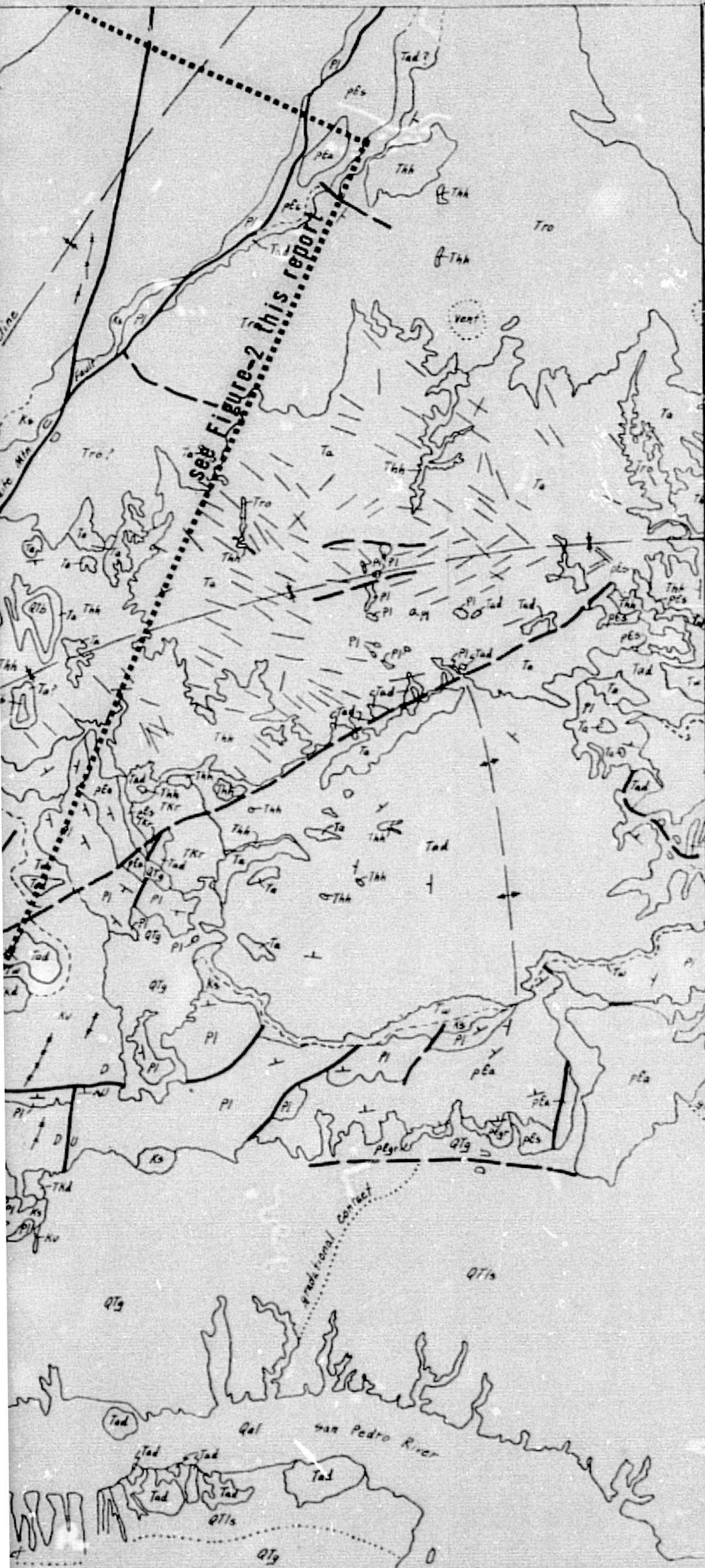
AERIAL PHOTOGRAPH no. 1994
of
O'CARROLL CANYON, ARIZONA

PHOTOGEOLOGIC INTERPRETATION



PHOTOGEOLOGIC INTERPRETATION

FIGURE 4



EXPLANATION

Qal	Quaternary alluvium
QTb	Quaternary-Tertiary basalt
QTls	Quaternary-Tertiary lake sediments
QTg	Quaternary-Tertiary gravels
Ta	Tertiary Apsey Conglomerate
Thh	Tertiary Hells Half Acre Tuff
Tro	Tertiary rhyolite-obsidian
Tar	Tertiary Aravaipa Tuff
Tad	Tertiary Depression Canyon Andesite
Tw	Tertiary Whitetail Conglomerate
TKqd	Tertiary-Cretaceous quartz diorite porphyry
TKd	Tertiary-Cretaceous diorite
Kv	Cretaceous andesite
Ks	Cretaceous sediments
Pl	Paleozoic limestones, includes: Pennsylvanian Naco, Mississippian Escabrosa, Devonian Martin, and Cambrian Abrigo
p€a	Precambrian Apache Group and intercalated diabase; also includes Cambrian Bolsa Quartzite
p€gr	Precambrian Oracle Granite and intercalated diabase
p€s	Precambrian Pinal Schist and intercalated diabase

······· Southern portion of Geologic map (figure-2 this report) see U.S.G.S. bull. 1161-plate-1

N

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FOLDOUT FRAME 2

KENNECOTT EXPLORATION SERVICES

PHOTOGEOLOGIC INTERPRETATION

PARTS OF PINAL AND GILA COUNTIES, ARIZONA

0 2 4 6 8

scale in miles

Interpretation by L.F. Barrett

July, 1973

GRD illus. no. 1973 - 102

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