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THE USE OF ERTS-1 IMAGES IN THE SEARCH FOR LARGE SULFIDE DEPOSITS IN THE CHAGAI DISTRICT, PAKISTAN

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15. Supplementary Notes

This is the final report of project titled: Analysis study of multispectral data, ERTS-1, from an area in western Pakistan.

16. Abstract Visual examination of color composites was tested under relatively ideal conditions for direct detection of large hydrothermal sulfide deposits at the large low-grade porphyry copper deposit at Saindak, western Chagai District, Pakistan. The Saindak deposit, in an area of relatively easily eroded folded sedimentary and volcanic rocks, is characterized by an elongate zone of easily eroded sulfide-rich rock surrounded by a resistant rim of hornfels and propylitically altered rock. The geomorphic features related to the Saindak deposit are easily distinguished on ERTS-1 images. Attempts to detect a color anomaly using false-color composites were not successful.

About 36,000 square km (14,000 square miles) of the western Chagai District were examined on false-color composites for direct evidence of large sulfide deposits. New geologic information acquired from the images was used in conjunction with the known geology to evaluate two previously known prospect areas and to suggest seven additional targets for field checking, one of which is proposed on the basis of tonal anomaly alone. The study also showed that Saindak-type deposits are not likely to be present in some extensive areas of the Chagai Distrct; and also that a rim like that at Saindak does not form if regional metamorphism has increased the resistance of the country rock to erosion, as in the Pakistan-Iran border region northwest of Saindak.

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The use of ERTS-1 images in the search for large sulfide deposits in the Chagai District, Pakistan

by

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Abstract

Visual examination of color composites was tested under relatively ideal conditions for direct detection of large hydrothermal sulfide deposits. The large low-grade porphyry copper deposit at Saindak, western Chagai District, Pakistan, is an excellent test site, and the surrounding region would seem a reasonable place to seek similar porphyry copper deposits.

The Saindak deposit is in a very arid part of the Baluchistan desert, in an area of relatively easily eroded folded sedimentary and volcanic rocks. The deposit is characterized by an elongate zone of easily eroded sulfide-rich rock surrounded by a resistant rim of hornfels and propylitically altered rock. As in similar deposits in other desert areas, the Saindak deposit has local patches of red and yellow coloration (here related to the mineral natrojarosite).

The geomorphic features related to the Saindak deposit are easily distinguished on ERTS-1 images. Attempts to detect a color anomaly using false-color composites were not successful.

About 36,000 square km (14,000 square miles) of the western Chagai District were examined on false-color composites for direct evidence of large sulfide deposits. New geologic information acquired from the images was used in conjunction with the known geology to evaluate two previously known prospect areas and to suggest seven additional targets for field checking, one of which is proposed on the basis of tonal anomaly alone. The study also showed that Saindak-type deposits are not likely to be present in some extensive areas of the Chagai District, and also that a rim like that at Saindak does not form if regional metamorphism has increased the resistance of the country rock to erosion, as in the Pakistan-Iran border region northwest of Saindak.

Introduction

All of the western part of Pakistan has been mapped by 1:253,440 photogeologic reconnaissance maps (Hunting Survey Corporation, Ltd., 1960), but probably less than 1 percent of the Chagai District has been mapped in detail. Although this region has been known to have produced small amounts of lead and silver from galena for centuries, as indicated by scattered ancient smelter slag, modern mineral reconnaissance has been spotty and mainly for high-grade deposits; if a porphyry copper deposit had been noticed in the recent past, it might have been passed over as too low grade for consideration.

This investigation is based on the premise that the large low-grade copper sulfide deposit at Saindak in the Baluchistan desert (fig. 1) could be recognized on an ERTS-1 image, that other similar deposits may reasonably be expected in the region, and that ERTS-1 imagery provides a unique and convenient means of evaluating nearby areas for the presence of such deposits.

Mapping and mineral evaluation were conducted at Saindak in 1962 and 1963 because the locality was thought to have some economic mineral potential; the complete results of that study were reported by Ahmed, Khan, and Schmidt (1972). In 1962, after discovery of the copper porphyry deposit, we noted several features of the deposit that lent themselves to optical recognition, and color aerial photography was then suggested as the most practical remote-sensing method (Schmidt, 1968, p. 60).

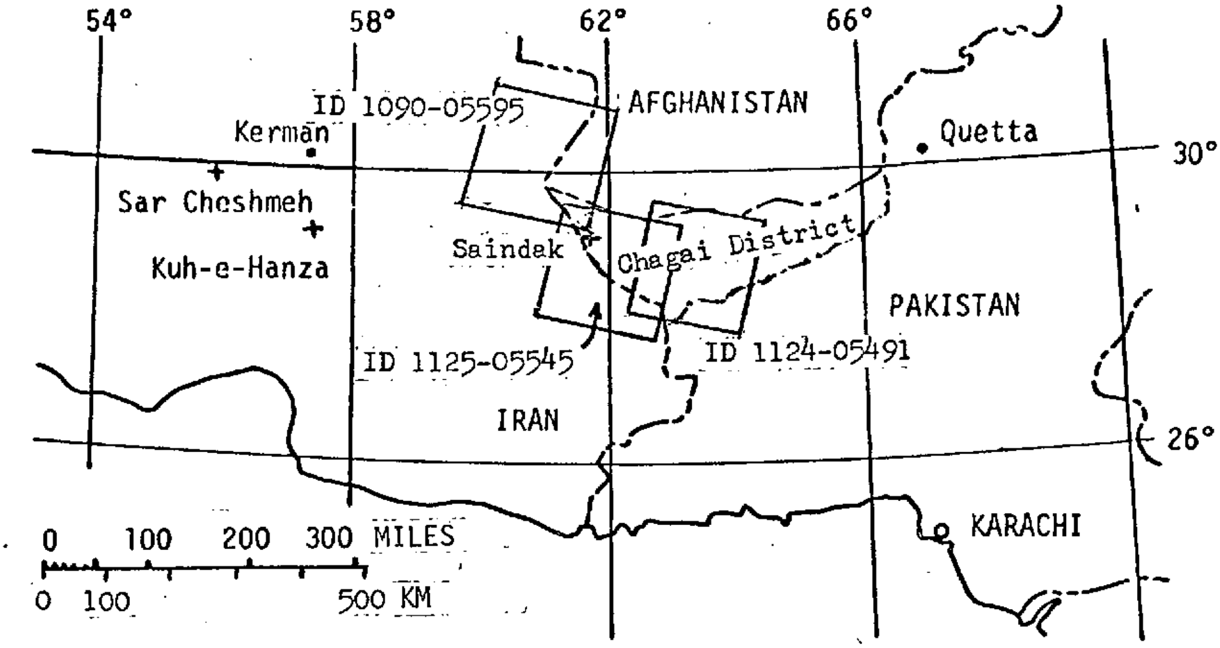

Figure 1.--Index map of the Saindak area, showing ERTS-1 image coverage.

The discovery in 1967 of a major porphyry copper deposit at Sar Cheshmeh, near Kerman in Iran (fig. 1), and the subsequent discovery of several more deposits, including those in the vicinity of Kuh-e-Hanza to the southeast and those to the northwest of Sar Cheshmeh, has increased interest in the entire Chagai District as a potential source of minable copper. Examination of the deposit at Saindak was recently resumed by the Geological Survey of Pakistan (Khan, 1972).

This study was made on three overlapping bulk 9.5-inch images (see fig. 1). False-color composites were prepared by reproducing positive transparencies of the multispectral scanner bands 4, 5, and 7 on yellow, magenta, and blue transparent foils in various combinations. Foils of various color densities were made, and one set was then selected to give both optimum differentiation of geologic units and enhancement of the difference between eolian sand and other near-white geologic features. Toward the end of the study, digitally processed false-color composite transparencies and prints of image ID 1125-05545 (fig. 1) were provided by Ralph Bernstein of the IBM Corporation, and these composites had much better resolution of small-scale features and tonal variations than the foils made from bulk-processed material.

In part of the western Chagai District, areas of high porphyry copper potential are generally the same areas that are partly mantled by dune sand, and discrimination of favorable target areas is very difficult in those places where the patches of eolian sand are abundant. An experiment now underway will test classification-type digital image enhancement as a method of identifying the tonal anomalies related to hydrothermal alteration.

Areas of interest were examined in conjunction with photogeologic reconnaissance maps, and recognition of mapped geologic units on the images was generally easy. An excellent impression of relative topographic relief can be obtained from the images, because ERTS-1 images in the Chagai region are all made at approximately 11 a.m. local time (roughly 10 a.m. sun time), resulting in similar sun elevation and similar shadow enhancement. The relative topographic relief apparent on the images combined with the photogeologic maps is a powerful interpretive tool, and the synoptic view of whole regions emphasizes features not noted in the examination of conventional aerial photographs. No modern topographic maps were available to me for this investigation.

The images show that faults and other linear features abound in the region, and much structural plus some stratigraphic information can be extracted directly from them. Although some of this information would be required in a mineral exploration survey, such studies were not an objective of this project. No study was made of those parts of the images in Iran and Afghanistan.

Regional geology

The areas of interest in the Mirjawa range--the folded mountains along the Pakistan-Iran border (Hunting Survey Corporation, Ltd., 1960, pl. 1)--and in the northern Chagai Hills have somewhat different regional geology. The rocks of both areas, however, are of Cretaceous to Quaternary age (Hunting Survey Corporation, Ltd., 1960, maps 17, 18, 21, and 22).

The Mirjawa range area, which includes the Saindak deposit, has mostly folded (along northwest trends) and much faulted sedimentary and volcanic-sedimentary strata containing relatively small amounts of intrusive and extrusive igneous rock. The detailed description of the Saindak area (Ahmed, Khan, and Schmidt, 1972) is fairly representative of the geology of this border region. Cretaceous sedimentary rocks represent a wide variety of marine and continental depositional environments; lower Tertiary rocks are mostly shallow marine, and upper Tertiary-Quaternary strata are largely of continental origin.

Regional metamorphism, probably related to granitic intrusions 40 km (25 miles) west of Saindak in Iran, was noted in the field a few kilometers west of Saindak and at many places northwestward from Saindak along the Mirjawa range.

In the Nok Kundi region, a western section of the Chagai Hills (fig. 2), folding and faulting are also present, but folding lacks the strong linear pattern characteristic of the Mirjawa range. Intrusive rocks are more abundant, however; several volcanic necks are conspicuous, and volcanic cones and probably plug domes are present, as well as the dormant volcano Koh-i-Sultan. Recently dried or still weakly flowing sinter-depositing warm springs, plus a few fumaroles, suggest that hydrothermal activity is still going on.

In the northern Chagai hills area east of Koh-i-Sultan, irregular felsic intrusions of stock to batholithic dimension (Chagai intrusions of Late Cretaceous to Eocene age) are surrounded by horizontal to gently folded strata of the Sinjrani Volcanic Group, assigned a Cretaceous age by Hunting Survey Corporation, Ltd. (1960, p. 294). Over half of the areas of Chagai intrusions, and also some of the adjacent gently dipping volcanic strata, are cut by great swarms of dikes of intermediate composition.

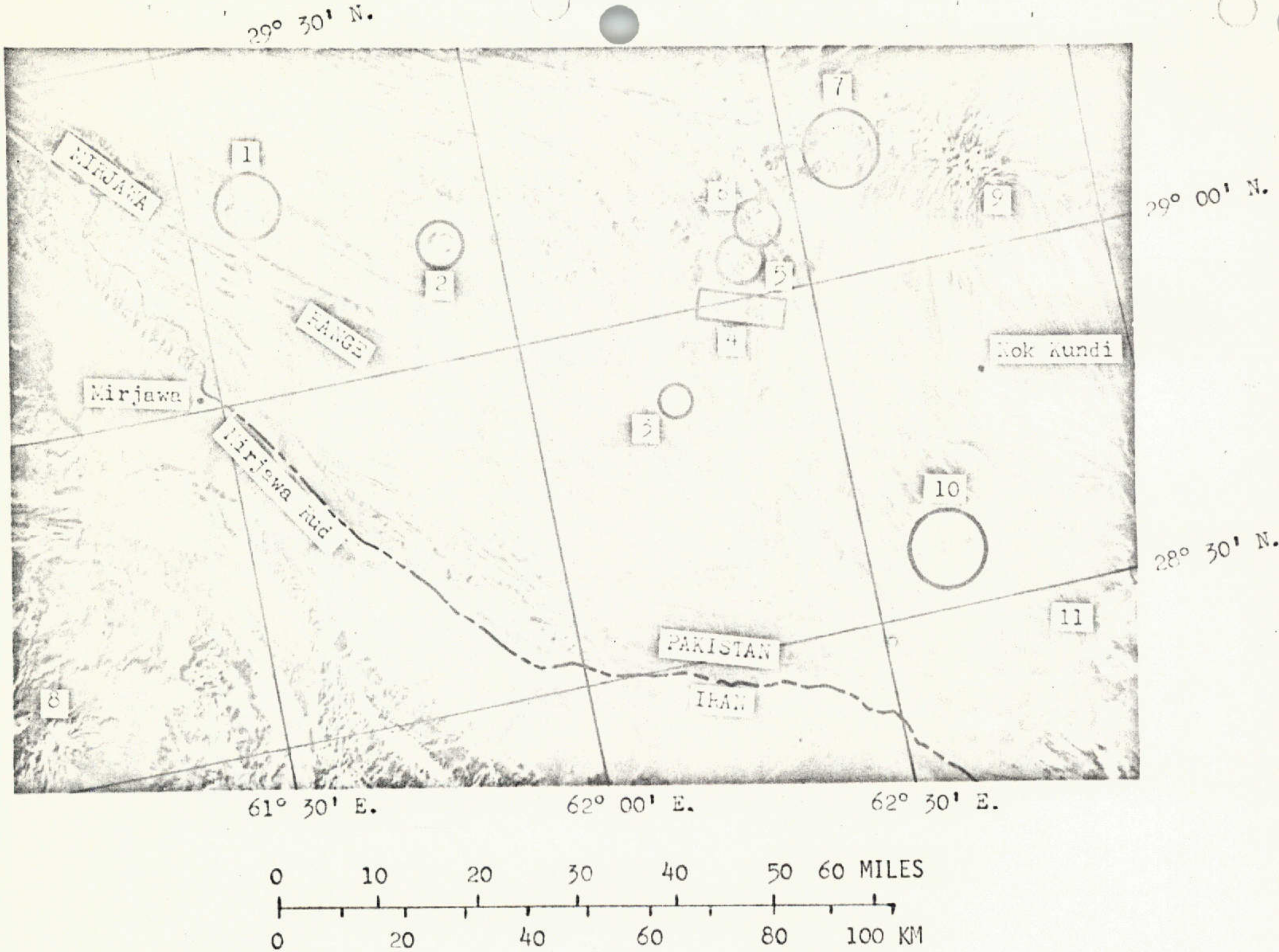

Figure 2.--Annotated northern part of ERTS-1 image ID 1125-05545, MSS band 5. Numbered localities are 1, Saindak porphyry copper prospect; 2, Boghar Nawar locality; 3, Koh-i-Dalil railway station area; 4, Mashki Chah onyx marble deposits, light-toned spots along axis of rectangle: 5, Mashki Chah SW. locality; 6, Mashki Chah NE. locality; 7, Amir Chah copper prospect; 8, volcano Kuh-i-Taftan; 9, volcano Koh-i-Sultan; 10, two small salt surfaced playas; 11, northwest edge of major playa, Hammun-i-Mashkhel. International boundaries are approximately located.

Economic geology

At Saindak, a group of small copper-bearing porphyritic quartz diorite stocks cuts northward across the entire folded lower Tertiary and part of the Cretaceous stratigraphic section. The stocks may be cupolas on a single barely exposed granitic body 8 km (5 miles) long and as much as 1.5 km (1 mile) wide. The group of stocks is surrounded by zones of contact metamorphism and hydrothermal alteration (simplified section in fig. 3). The stocks are enclosed in a sulfide-rich envelope that contains as much as 15 percent pyrite; the envelope in turn is surrounded by a zone of propylitic alteration in which pyroclastic rocks in particular are altered to a hard, dark epidote-rich hornfels. Rather little is known of the most highly altered central part of the deposit, but pervasive sericitic alteration, some hydrothermal biotite, and fluid inclusions are abundant in quartz grains. Many of the fluid inclusions contain halite crystals, and some gas-rich inclusions suggest formation of the quartz under near-boiling conditions (J. T. Nash, written commun., 1973).

The pattern of hydrothermal alteration and the general characteristics of the copper sulfide mineralization are typical of porphyry deposits, but only detailed geological mapping plus extensive exploration drilling, such as the program now underway by the Geological Survey of Pakistan, can establish whether the deposit is of economic significance.

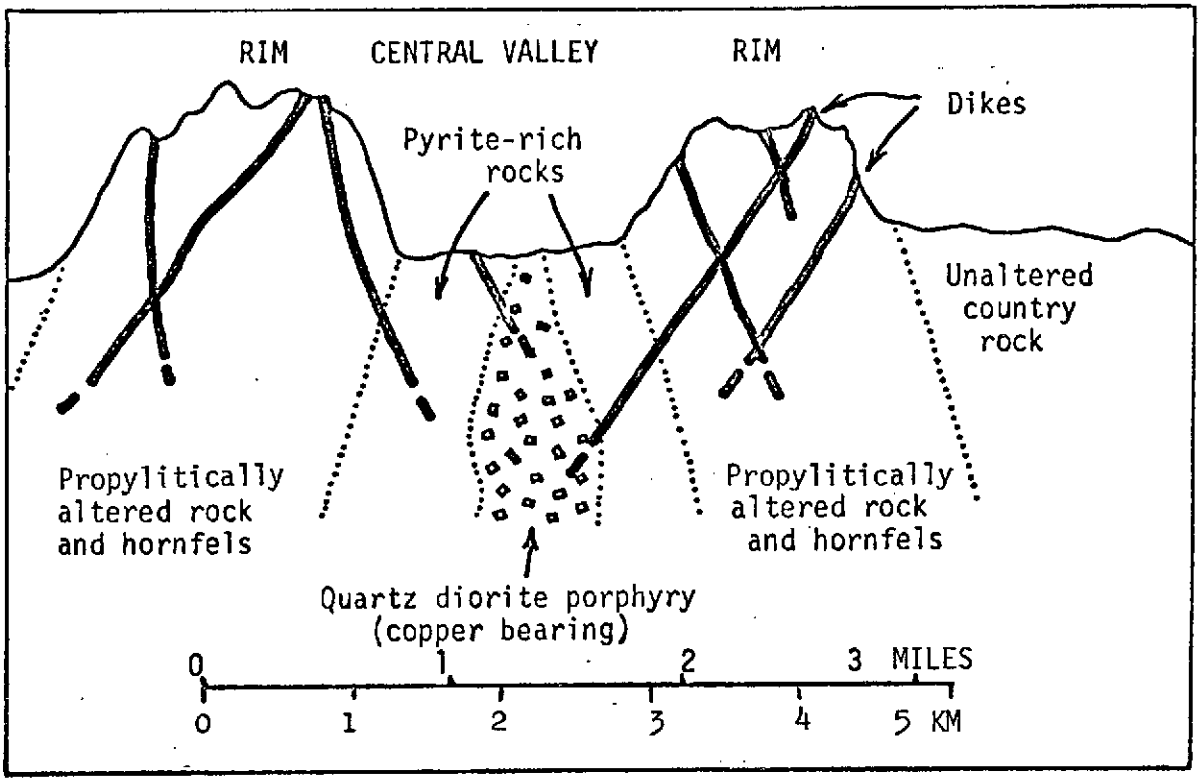

Figure 3.--Hypothetical cross section of Saindak-type porphyry copper deposit. Vertical scale exaggerated.

The quartz diorite stocks cut several formational units; the hornfels, therefore, is derived from conglomeratic sandstone, siltstone, and mudstone, which contain various proportions of incorporated pyroclastic material. Limestone in the zone of alteration has been changed to marble and hematite-rich, sulfide-rich, and silicate-rich tactite. Magnetic anomalies associated with the deposit (Farah and Nazir Ullah, 1973) suggest that magnetite rather than hematite is the iron oxide at deeper levels. Quartz-diorite dikes are common and locally abundant within the alteration zones and are easily identified on aerial photographs. Veins containing sparse lead and copper minerals are also common within the limits of the alteration.

The sulfide-rich zone including both the intrusive porphyry stocks and the adjacent pyrite-rich country rock has been eroded out to form a light-toned valley (figs. 2 and 3). Desert soils associated with many porphyry copper deposits the world over have distinct red and orange color anomalies, and this is true at Saindak as well, where the mineral natrojarosite has been identified in the pigmented material. In the central valley at Saindak, however, wind-blown and alluvial grains considerably dilute or cover much of the colored soil.

In plan view, this valley is encircled by a symmetrical rim of hills more rugged than the surrounding region and darker in tone (Ahmed, Khan, and Schmidt, 1972, fig. 2). This hornfelsic rim, generally corresponding to the resistant zone of propylitic alteration, forms the outer boundary of the whole exploration target.

Expression of the Saindak deposit on ERTS-1 images

The linear central valley and the surrounding hornfels rim of the Saindak deposit form a distinct feature on ERTS-1 images (fig. 2). The north end of the valley and rim are cut off, perhaps by a border fault, and covered by broad alluvial fans. Abundant dikes easily seen throughout the area on aerial photographs are too small for recognition on ERTS-1 images.

The light tone of the interior valley is distinctly visible both on single bands and on color composites, but I could detect no color anomaly on the false-color composites.

Both the central valley and rim are displaced left laterally by a major east-trending fault. The fault was mapped in 1961-62, but the significant displacement of the sulfide-rich zone was noted first by Khan (1972). Both the fault and the displacement of rim and central valley are easily identified on the ERTS-1 image.

Evaluation of potentially mineralized areas

using ERTS-1 image data and existing geologic data

Old data from photogeologic maps (Hunting Survey Corporation, Ltd., 1960), various old prospect descriptions, and personal recollections were used, together with new information from the ERTS-1 images, to reevaluate several areas where copper minerals were known to occur or where hydrothermal alteration had been reported. Moreover, the photogeologic maps and the images were used together to suggest several new localities that are considered to deserve prospecting in the field. The photogeologic maps provided the locations of copper mineral occurrences, especially copper-lead veins, and of magnetite or hematite skarn bodies, with or without copper minerals, indicating extensive hydrothermal alteration. (A dike swarm at Saindak is particularly dense near the center of mineralization and similar concentrated dike swarms may also be favorable features.) As I examined the images, I looked for features such as a rim that might correspond to a zone of propylitic alteration, an indication that the stock weathers to a lower profile than surrounding rocks, and a light tone suggesting either leucocratic rocks, hydrothermal alteration, or weathering and bleaching of rocks containing abundant pyrite.

(Of the potentially mineralized areas evaluated here, one previously known prospect (Amir Chah) and two new suggested targets for field checking (Mashki Chah NE. and Mashki Chah SW.) were also included in the area studied by classification-type digital data processing of the 4 channels of ERTS-1 MSS data. Preliminary evaluation of the results of the classification shows that the apparent reflectance of the light-toned anomalies of none of the three sites matches the classes established in the known mineralized area at Saindak. This is believed to mean that the low central valleys at all three sites are mostly mantled by alluvium and eolian sand, and I have not modified my recommendations in this report because of the new information.)

Evaluation of old prospect areas

Amir Chah locality [29°08'-13' N., 62°31'-36' E. (fig. 2)].--Disseminated weak copper mineralization is present in a granodiorite(?) stock (Schmidt, 1968, p. 60), and small lean copper-bearing veins occur in hills a short distance to the west of the stock. The image shows that the central area of intrusive rock is topographically low and, though partly mantled by dune sand, I think enough bedrock is exposed to indicate it has a light tone. Except rocks to the east, which are younger volcanic rocks, the surrounding more rugged dark areas, especially to the southwest and northwest, are interpreted to be hornfelsic zones of alteration, perhaps forming a fairly complete rim of hills; hornfels was formerly reported at only one locality on the northwest side. A hematite skarn with stains of malachite is also known on the northwest side (Hunting Survey Corporation, Ltd., 1960, p. 449).

Dark areas around the Amir Chah pluton suggest a hornfels rim much more extensive than was known before, and though meager, this new information reinforces the idea that this pluton fits a Saindak-type porphyry model.

Kacha (Kachao) area [29°29' N., 61°19' E. (fig. 4)].--A local zone of metamorphism was interpreted on conventional aerial photographs and selected for immediate field examination by S. N. Khan and Schmidt in 1962. Although this reconnaissance trip accomplished much less than we had hoped, it did establish that sparse copper-lead veins are present within this aureole (Schmidt, 1968, p. 60). Because the zone interpreted as low-grade metamorphic rock may be equivalent to the hornfels rim at Saindak, and especially as there are mineralized veins within it, this target was examined carefully on the image in hope that a sulfide-rich core might be visible. No indication of a core was seen and no hornfels rim can be distinguished on the image because of the low-grade regional metamorphism.

If this is indeed a Saindak-type feature, erosion has probably not yet exposed the sulfide core, and it is problematical just how much can be learned from field examination of the surface alone.

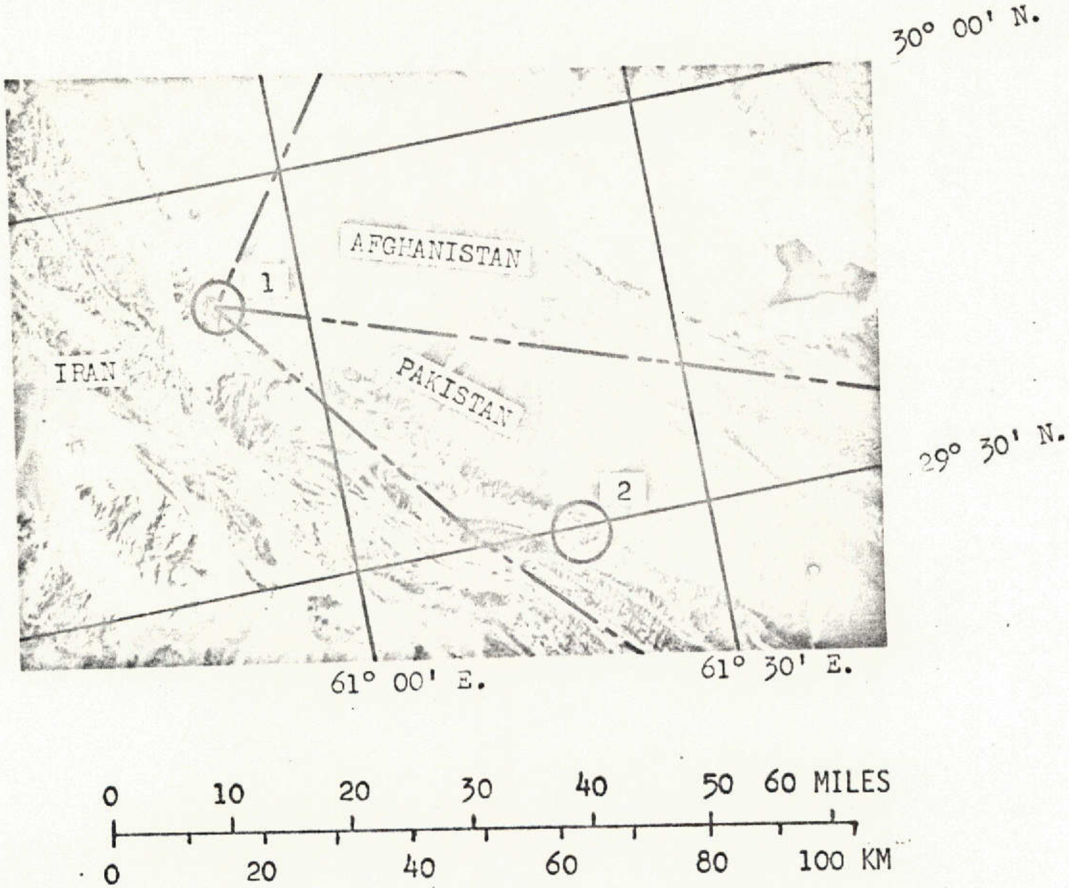

Figure 4.--Annotated southeastern part of ERTS-1 image ID 1090-05595, MSS band 5. Numbered localities are 1, Koh-i-Malik Siah; 2, Kacha (Kachao) prospect area. International boundaries are approximately located.

Evaluation of known stocks

Many areas known to contain stocks were examined on the images; four were considered to have features favorable for associated hydrothermal activity.

Koh-i-Malik Siah /29°51' N., 60°52' E. (approximate coordinates) (fig. 4)/--This mountain peak, located where the boundaries of Pakistan, Iran, and Afghanistan intersect, is within an area of many known mineral veins and small skarn deposits. Nearby Jali Robat, Afghanistan, is known as an old smelter site and has a large slag pile, perhaps pre-British (Nagell, 1967, p. 68).

False-color composites of the area were examined, especially for evidence of hydrothermal alteration. An east-west elongate light-toned area about 1 km (0.6 mile) long on the southeast flank of the mountain Koh-i-Malik Siah is suggestive of a zone of hydrothermal alteration. It is located approximately at the contact of the intrusive stock that forms the mountain and the surrounding Robat Limestone, and it is close to reported small copper mineral occurrences and hematite or magnetite bodies of the skarn type. Several dikes cut the limestone.

The light-toned area lies near the tip of the sharp western point of Pakistan, and the light area may be found to actually lie partly or entirely in Iran. Despite the indeterminate geographic location, the combination of favorable geologic features make this an area deserving more field checking.

Koh-i-Dalil railway station /28°53' N., 62°14' E. (fig. 2)/.--The area considered includes four small intrusive stocks mapped by Hunting Survey Corporation, Ltd. (1960, map 18). The northernmost of these is near the center of a radiating dike swarm. The ERTS-1 image indicates a small topographically rugged area about 3 km (2 miles) northeast of this stock. No light-toned areas are visible. Though this site has rather few favorable features, it is worth checking in the field because it is easy to reach from the main road and is located less than 10 km (6 miles) from the railroad. The northeasternmost mapped stock should be examined, and the rugged hills 3 km northeast from that stock should be checked for hydrothermal alteration, for traces of mineralization, and also for related unmapped intrusive bodies.

Mashki Chah NE. /29°06' N., 62°24'-28' E. (fig. 2)/.--This area, 10 km (6 miles) north of Mashki Chah, includes a pluton shown on the reconnaissance photogeologic map (Hunting Survey Corporation, Ltd., 1960, map 22). The ERTS-1 image indicates that the intrusive rock forms a northeast-trending topographic depression and that the surrounding terrain is generally higher and more rugged than that of the pluton. Iron skarns such as the "Zibri Kaur occurrence" have been reported in the area (Rizvi and Hussain, 1972) but, lacking exact locations, I do not know if they are related to this pluton. Evaluation of the significance of the light tones at this site is complicated by the abundance of wind-blown sand. This field-check target seems relatively favorable.

Mashki Chah SW. [29°03' N., 62°24' E. (fig. 2)].--Like the Mashki Chah NE. locality, this is a small pluton mapped by Hunting Survey Corporation, Ltd. (1960, map 22). The pluton appears on the ERTS-1 image to be very light toned, topographically low, and surrounded by higher, more rugged dark hills.

Several small iron skarns with associated quartz porphyry have been described 2 km (1.3 miles) to the southeast (Hunting Survey Corporation, Ltd., 1960, p. 448-449, figs. 280-282, map 22), and some of those reported by Rizvi and Hussain (1972) are in the general area. The pluton seems unusually light toned, suggesting hydrothermal alteration, although wind-blown sand may be a partial factor in the tone. This seems the most favorable field-check target considered in this investigation.

Evaluation of tonal anomalies

An area east of Saindak and west of Koh-i-Sultan between 29°00' and 29°22' N. and 61°45' and 62°15' E. includes so many light-toned areas that the significance of individual patches is difficult to assess. Geologic information is available from photogeologic maps and the results of field reconnaissance for mineral resources. Dune sand is common and creates a problem in interpretation, and over much of the area the outcrops tend to be poorer than in regions both east and west of here.

The most conspicuous light-toned anomaly is a small "granitic stock of Chagai intrusions" at 29°07'40" N., 62°10' E., pictured by Hunting Survey Corporation, Ltd. (1960, fig. 37). Some of the small light-toned spots may be areas of calcareous sinter. The crescentric ridge at Boghar Nawar (fig. 2) (29°10' N., 61°55' E.) has the general form of a hornfels-type rim but was mapped by Hunting Survey Corporation, Ltd. (1960, map 21), as an intrusive rock.

Skarn-type mineral occurrences have been reported in this general region (Rizvi and Hussain, 1972), but the locations are not known to me. The presence of both skarns and numerous small intrusive bodies suggests that the area is favorable for prospecting. Although examination of composites did not result in selection of any targets for field examination in this general area, use of the color composites in the field might expedite a mineral reconnaissance. This is an area where discrimination between tonal anomalies caused by hydrothermal alteration or by breakdown of sulfide minerals would be of maximum usefulness, and it has been selected for an experimental test of digital classification of image data.

The northern Chagai Hills region, east of the mountain Koh-i-Sultan, on image ID 1124-05491, was studied somewhat differently than the areas to the west. I first examined the foil composite for tonal anomalies without comparing it with photogeologic maps; then the most conspicuous tonal anomalies not obviously related to sand or alluvium were evaluated using the maps and all other data available to me.

On this image, little wind-blown sand was noted within the area of interest, in contrast to the areas to the west, and it is reasonably certain that none of the tonal anomalies, except perhaps numbers 15 and 16 (fig. 5) are in alluvium. No hornfels rims seem evident around any intrusive bodies in the Chagai Hills; perhaps the Sinjrani Volcanic Group rocks are so indurated that any differential weathering of hornfels is not conspicuous.

Following are brief descriptions of the tonal anomalies, identified by numbers keyed to figure 5. Evaluation of the anomalies is inhibited by the lack of mineral reconnaissance data in the region. Anomalies 3, 4, and 5 are considered good field-check targets, the rest are of secondary importance. Unless otherwise noted, all geologic mapping cited is by Hunting Survey Corporation, Ltd. (1960, maps 22 and 23).

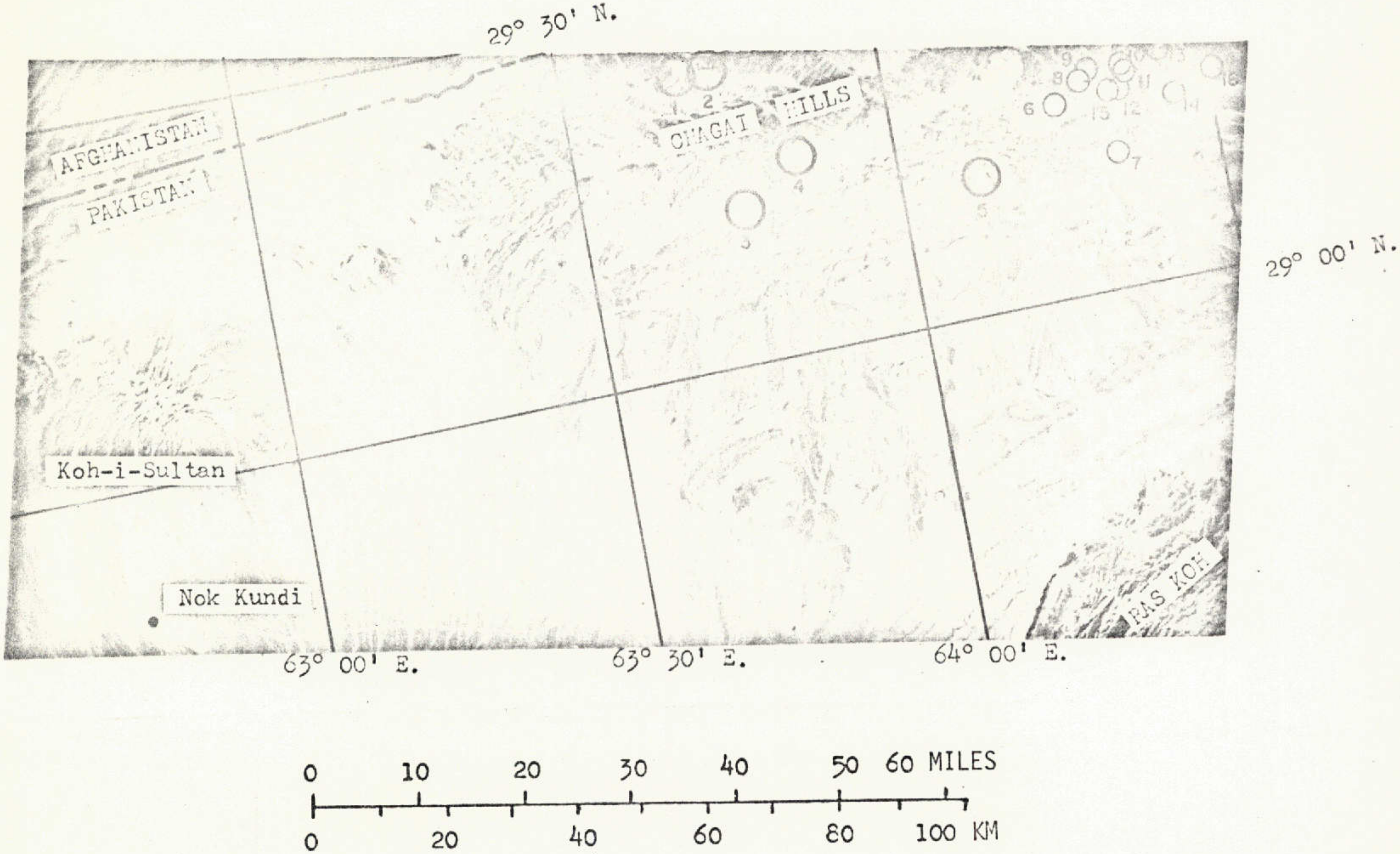

Figure 5.--Annotated northern part of ERTS-1 image ID 1124-05491, MSS band 5. Numbered localities are tonal anomalies selected from false-color foil composites and are described in the text. International boundaries are approximately located.

1. 29°24'30" N., 63°41'30" E.--This moderately distinctive circular area, about 1 km (0.6 mile) in diameter, is 1.3 km (0.8 mile) east of the peak Malik Tezanan (elevation 7679 feet; 2335 m). The anomaly is on the edge of, but entirely within, an area mapped as Chagai intrusions. No copper mineral occurrences near the locality are known to me. There is some possibility the light tone is the result of topographic slope angle relative to sun position.

2. 29°24' N., 63°44' E.--This very light toned anomaly is 1.6 km (1 mile) E-W and 0.8 km (0.5 mile) N-S. It straddles a contact of Chagai intrusions to the north and recent alluvium to the south. No copper mineral occurrences near this locality are known to me. This anomaly may owe some of its light tone to slope angle relative to sun position.

3. 29°12'40" N., 63°45'40" E.--A distinct elliptical anomaly about 1 km (0.6 mile) E-W and 0.6 km (0.4 mile) N-S occurs on the west side of Dargan Rud, in an area mapped as Sinjrani Volcanic Group, but close to a large mass of Chagai intrusions; it probably represents a small stock that has not been mapped separately. An area of hydrothermal alteration and pyrite enrichment was reported to be near Pincashi Nala, less than 3 km (2 miles) to the southeast (Nagell, 1967, p. 39-40).

4. 29°16' N., 63°51' E.--Perhaps the most distinct light-toned anomaly in the Chagai Hills, this irregular area is about 3 km (2 miles) across and lies mostly within what has been mapped as Chagai intrusions. Nagell (1967, p. 38) reports minor amounts of chalcopyrite, bornite, and malachite in a fracture traced over 1.6 km (1 mile) within the anomaly area. Nagell also mentioned an old smelter site here. This is the only tonal anomaly in the Chagai Hills that I know to have closely associated copper mineral occurrences.

5. 29°11'20" N., 64°07'40" E.--An elliptical light-toned area 2 km (1.3 miles) long in a N-NE direction is near Chahilgazi Rud. When transferred from the ERTS-1 image to the geologic map, this anomaly was found to fit the mapped Chagai intrusive pluton almost exactly. No nearby mineral occurrences are known to me from scientific literature, but there have been reports in the popular press of magnetite deposits "at Chahilgazi" in the general region. The magnetite is presumably in skarn-type deposits.

The anomalous areas listed below,

6. 29°16' N., 64°16'20" E.

7. 29°11'20" N., 64°21' E.

8. 29°17'20" N., 64°18'40" E.

9. 29°17'50" N., 64°19'40" E.

10. 29°18'10" N., 64°22'20" E.

11. 29°17'20" N., 64°22'50" E.

12. 29°16'20" N., 64°22'30" E.

13. 29°18'30" N., 64°26'40" E.

14. 29°14'50" N., 64°27'20" E.,

the largest of which is 2.3 km (1.5 miles) in greatest dimension, are each within, or mostly within, areas mapped as Chagai intrusions. (Slight overlap of areas 7, 13, and 14 into areas of Sinjrani Volcanic Group may be due to poor registration or generalization of map boundaries.) The only copper mineral occurrence known to me to be close to any of these localities is weak malachite staining in granodiorite near the mountain Duganan (somewhere between anomalous areas 12 and 14), reported by Poughon (1961, p. 32-34). Poughon did considerable reconnaissance in this region, and his failure to note more than this one copper occurrence is rather discouraging.

Two anomalous areas that fall on the geologic map in places mapped as subrecent gravel, alluvium, etc., are,

15. 29°16'20" N., 64°21'20" E.

16. 29°16'20" N., 64°31' E.

Area 15 is probably different in tone from adjacent alluvium areas and is more likely to be a pediment surface on Chagai intrusions. The identification of area 16 is problematical. Both areas are best considered as lower priority field-check targets, as would be anomalous areas 6-14 in this same region.

Other observations relevant to mineral resource evaluation

In addition to use of the color composites for evaluation of light-toned sites and known small intrusive bodies as potential large sulfide deposits, certain miscellaneous information from the ERTS-1 images can be used to assign regional mineral evaluation priorities.

Other possibilities in the Mirjawa Range

Inspection of the ERTS-1 image and the photogeologic map indicates no other likely sites in the unmetamorphosed border range area southeast of Saindak, except the Koh-i-Dalil railway station locality, and I would give other prospecting here a low priority. The entire region west of the mountain range Ras Koh and south of the railway line seems to hold little promise for hydrothermal mineral deposits of either porphyry copper type or vein type.

Relationship of Mashki Chah onyx marble deposits to a major fracture zone

The general westward trend of the calcareous sinter deposits southwest of Mashki Chah (fig. 3) is well shown by Hunting Survey Corporation, Ltd. (1960, map 18), but the close alignment of these hot-spring deposits is more conspicuous on the ERTS-1 image. The near-perfect alignment of most of these along a distance of 16 km (10 miles) strongly suggests that they are related to a major deep fracture zone that channeled recent hydrothermal solutions. Feeble activity of some springs that still deposit a little calcareous sinter suggests that some hydrothermal waters may still flow at depth, though not in sufficient volume to reach the surface. Exploration drilling of the fracture zone for a water or steam source of hydrothermal energy, or possibly for hydrothermal metal deposits, should be carefully considered.

Playas and possible related saline deposits

The playas of the western Chagai District, particularly Hamun-i-Mashkhel (fig. 2), are potential sources of evaporites and brines, because they drain regions that were successively blanketed by volcanic ash from the Holocene volcanoes Kuh-i-Taftan (Iran) and Koh-i-Sultan (fig. 2). Examination of digitally enhanced false-color composites of image ID 1125-05545 shows that much of the dune sand being transported southeastward between the Mirjawa ranges and Nok Kundi ultimately reaches Hamun-i-Mashkhel. Whether most of this is deposited in the playa, thus tending to dilute the saline materials, or is carried southeastward to supply the large dunefield beyond Hamun-i-Mashkhel, I do not know. In any case, saline accumulation in Hamun-i-Mashkhel must be strongly affected by the location of the playa directly in the course of a major sand-transport route.

Two small salt-surfaced playas were noted at 28°35' N., 62°36' E. and 28°35' N., 62°40' E. (fig. 2) in a generally unvisited area southwest of Nok Kundi. These playas lie within the same course of sand transport as Hamun-i-Mashkhel. They should be inspected as potential sources of evaporites and brines, because they have formed from waters draining entirely from the generally volcanic terrane south and southwest of Koh-i-Sultan.

Miscellaneous geologic observations

Metamorphic isograds

During mapping at Saindak in 1962, it was determined that the grade of regional metamorphism increased westward into Iran, but the trend of this regional gradient northwest and southeast of Saindak was only generally understood. The easternmost evidence of regional metamorphism was seen in the field about 6 km (4 miles) southwest of Saindak (fig. 2) coinciding with more induration and considerably more resistance to erosion, a change that is easily recognizable and mappable on the ERTS-1 image. This line of change in erosional resistance is an isograd close to a threshold of recognizable metamorphic effects and cuts across folds and sedimentary strata at an angle. Its trend near Saindak, as determined from the image, is N. 12° W.

Former high lake stand

In the valley of Mirjawa Rud, above and below the town of Mirjawa, Iran (fig. 2), a tonal change in part of the alluvial fans seems to parallel the topographic contour. This tonal change can be identified on bulk processed prints, but it is distinctive only on enhanced color composites. This feature is limited to those parts of fans that seem least modified by any recent alluvial activity; that is, the oldest undisturbed parts of fans. These undisturbed upper parts of the fans are dark, presumably from a long period of accumulation of desert varnish, contrasting with the "active" upper parts of fans and all fan deposits below the "tonal contour," which are lighter toned and presumably without varnish.

With no topographic data except the old Survey of India map (1916), I suspect that the elevation of the tonal line is about 150 m (500 ft) above the valley bottom at Mirjawa and that the elevation of the line increases slightly northwestward; the line is more closely parallel to the elevation of the dry stream channel than to a horizontal plane.

It is proposed that at a relatively recent time in geologic history the valley of Mirjawa Rud was lower toward the northwest end, was dammed in the lower part of the valley, and was water filled to the level of the tonal line. The dam may have been the particularly large and active fan on the south side of the valley at 62°30' E. Tectonic tilting of the valley probably emptied the lake, and the exceedingly arid conditions may have slowed the restoration of desert varnish in the lower parts of the fans.

Conclusion

Tonal and topographic features associated with the test area at the large hydrothermal sulfide (porphyry copper) deposit at Saindak are easy to recognize on ERTS-1 images, but no color anomalies were recognized on sandwiched-foil false-color composites or on digitally enhanced false-color film composites.

Surrounding regions were evaluated using composite images in close conjunction with photogeologic maps and field mineral reconnaissance data. Seven sites, not formerly regarded as potential prospects for large sulfide deposits, were selected as new field-check targets; and some other information believed to be relevant to exploration for geothermal energy, evaluation of playas for evaporites, and mapping of metamorphic isograds was obtained as a result of this study. Unfortunately, no significant appraisal of the techniques used is possible until field checks are made of the targets suggested.

In the Chagai region, the use of color composites for direct detection of large sulfide deposits is probably considerably more reliable where there is little wind-blown sand, as in the Mirjawa ranges and the northern Chagai Hills, and less dependable in the Nok Kundi region where eolian sand is widespread. Because the Nok Kundi region is a geologically favorable area, it would be very desirable to apply a method capable of better discrimination. Tests of classification-type digital image enhancement techniques are now underway in another study.

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Appendix

Titles of published articles that were the result of SR 181:

Schmidt, R. G., 1973, Use of ERTS-1 images in the search for porphyry copper deposits in Pakistani Baluchistan: Nat. Aeronautics and Space Adm., Symposium on significant results obtained from the Earth Resources Technology Satellite-1, Goddard Space Flight Center, March 5-9, 1973, v. 1, sec. A, p. 387-394.

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