Geology and Copper Mineralization of the Saindak Quadrangle, Chagai District, West Pakistan

GEOLOGICAL SURVEY PROFESSIONAL PAPER 716-A

Prepared in cooperation with the Geological Survey of Pakistan, under the auspices of the U.S. Department of State and the Government of Pakistan

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By WAHEEDUDDIN AHMED, SHAHID NOOR KHAN, *and*
ROBERT G. SCHMIDT

GEOLOGICAL INVESTIGATIONS IN PAKISTAN

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Folded and faulted Cretaceous and Tertiary strata have been intruded by copper-bearing quartz diorite stocks with many features characteristic of the porphyry copper type

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FOREWORD

In 1956, the Geological Survey of Pakistan and the U.S. Geological Survey began a cooperative program to intensify the mapping and appraisal of the geological resources of Pakistan. The program was initiated under an agreement dated October 1955 between the Government of Pakistan and the International Cooperation Administration, predecessor of the Agency for International Development, U.S. Department of State. It included joint geological reconnaissance of unmapped areas, detailed mapping and appraisal of mineral districts, and development of facilities and staff to increase the capacity of the Geological Survey of Pakistan.

This volume entitled "Geological Investigations in Pakistan" is intended to present some of the more significant results of the cooperative program in Pakistan, which extended from 1956 to 1970. It consists of papers that have been prepared by U.S. Geological Survey geologists and by their counterparts in the Geological Survey of Pakistan, summarizing the investigations believed to be most important for those interested in the geology and resources of Pakistan. More detailed information from these investigations, as well as reports from other studies made during the program, are available from the Geological Survey of Pakistan in Quetta. Much of the regional geological information obtained during this program, and from surveys made earlier, was summarized in a new Geological Map of Pakistan prepared cooperatively and published by the Geological Survey of Pakistan in 1964.

The cooperative program in Pakistan, which directly involved the services of about 110 professional personnel from Pakistan and 43 from the United States, operated successively under the direction of four Directors-General of the Geological Survey of Pakistan and three Chiefs of Party appointed by the U.S. Geological Survey. Program directors for Pakistan were E. R. Gee (1956–59), N. M. Khan (1959–64), A. F. M. M. Haque (1964–69), and A. M. Khan (1969–70). United States participation was supervised by J. A. Reinemund (1956–63), M. G. White (1963–66), and D. L. Rossman (1967–70), each of whom also served as senior geologic consultant to the Director-General.

Geologic specialists provided by the U.S. Geological Survey were supplemented by four mining engineers from the U.S. Bureau of Mines, who provided collateral assistance to the West Pakistan Department of Mineral Development, and by a drilling specialist and an administrative specialist from the Agency for International Development. The Geological Survey of Pakistan, through the Ministry of Industries and Natural Resources, provided counterpart personnel facilities, and services for the program, and arranged cooperative support from the West Pakistan Department of Mineral Development, as well as from the West Pakistan Industrial Development Corporation, Pakistan Council of Scientific and Industrial Research, and other agencies concerned with resource development.

This program would not have been possible without the excellent support of all agencies involved, both in Pakistan and the United States. The geological information and institutional growth obtained through this program should contribute significantly toward orderly economic and scientific development in one of Asia's largest and newest nations.

A. M. Khan

Abdul Mannan Khan, Director-General
Geological Survey of Pakistan

John A. Reinemund

John A. Reinemund, Chief
Office of International Geology
U. S. Geological Survey

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By WAHEEDUDDIN AHMED,[1] SHAHID NOOR KHAN,[1] and ROBERT G. SCHMIDT

ABSTRACT

Hydrothermal mineral veins containing sparse amounts of lead and copper, and metasomatic replacements of country rocks by pyrrhotite, hematite, and pyrite are associated with a group of copper-bearing quartz diorite stocks in the Saindak quadrangle. The alteration and mineralization associated with the copper-bearing stocks include many features characteristic of porphyry copper deposits.

Most of the Saindak quadrangle is underlain by sedimentary and metasedimentary rocks ranging in age from Late Cretaceous to Pleistocene(?). The bedrock is extensively covered by unconsolidated Holocene sediments. The Cretaceous through Oligocene(?) strata are folded and much faulted and form the low mountain ranges along the Pakistan-Iran border in the Chagai District.

The sedimentary rocks are mostly shale, sandstone, siltstone, abundant volcanic conglomerate, and lesser amounts of limestone and limy shale. The stratigraphic section is cut by two major unconformities; the older unconformity truncates Cretaceous beds and preceded the deposition of Paleocene strata, and the younger cuts Eocene and Oligocene(?) beds. This latter surface is overlain by unfossiliferous volcanic conglomerate beds of Pleistocene(?) age.

Parts of the sedimentary section are richly fossiliferous. Ages of the Cretaceous, Paleocene, and Eocene rocks have been confirmed, and several new forms, especially corals, were discovered.

The Cretaceous through Oligocene(?) rocks are folded in a major northwest-trending syncline, locally complicated by drag folds and strike faults. The younger consolidated beds of Saindak Koh have been folded to a much lesser extent but seemingly along the same axis. The more highly folded rocks are cut by many high-angle faults.

Large ridge-forming andesite porphyry sills of Late Cretaceous age are widespread outside the quadrangle but are limited to two small areas within the quadrangle. A group of small diorite stocks was intruded after the post-Oligocene(?) folding, and finally a group of quartz diorite stocks was intruded later than deposition of the nearly horizontal sedimentary rocks capping Saindak Koh.

A zone of low-grade contact-metamorphic rocks about 4 miles wide, mostly albite-epidote hornfels, is related to the quartz diorite stocks, and trends northward through the middle of the mapped area.

Three general types of mineral deposits were found: (1) disseminated copper sulfides in stocks of quartz diorite; (2) metasomatic replacements of limestone reefs by beds of hematite or pyrrhotite, and of volcanic agglomerate and tuff by pyrite; and (3) simple hydrothermal veins containing copper and lead minerals filling some fractures and the openings along some fault planes.

A group of quartz diorite stocks contains small quantities of disseminated copper minerals. Although perhaps leached near the surface, the rock locally contains as much as 1.49 percent copper.

The hematite that has formed by replacing limestone layers and lenses seems to have developed only where the original beds were thin. If similar replacement has taken place where limestone layers are thick, it could have resulted in rich ore bodies of moderate or large size. The pyrrhotite and pyrite replacement bodies do not seem to contain valuable elements in significant quantities.

Most of the mineralized veins are within, or very close to, the zone of low-grade contact-metamorphic rocks. They contain galena, chalcopyrite, quartz, calcite, sideritic calcite, and many oxides that have resulted from surficial alteration of the vein minerals. In some veins, separate zones of copper and lead minerals can be differentiated. No mineral veins of economic significance were discovered.

The information gained in the Saindak quadrangle provides guides for prospecting in other similar rocks in the region. The mineralization at Saindak is definitely related to a group of quartz diorite stocks, and most is found in low-grade metamorphic rocks. The copper-bearing stocks are interpreted to be of the copper porphyry type. Dikes are most abundant in the same general area as the metamorphism and the mineralization. Areas of metamorphosed rocks can be recognized on aerial photographs by their rugged topography, and dikes can also generally be recognized. It is recommended that careful photogeologic studies of the border ranges be made to delineate the most favorable areas for prospecting.

INTRODUCTION

PURPOSE AND SCOPE OF THE STUDY

This report covers the first detailed geologic mapping done in extreme western Pakistani Baluchistan; work was completed in the area of Survey of Pakistan quadrangle 30 G/11, the Saindak vicinity (fig. 1; pl. 1) in 1962. The mapping was undertaken primarily to evaluate the mineral potential of the region, and the quadrangle was chosen because of the presence of minor mineralized veins, replacement deposits, and evidence of hydrothermal activity. The stratigraphy, paleontology, structural and igneous geology, and metamorphism, however, were also studied.

As a part of the fieldwork, all mineral veins in the quadrangle were thoroughly prospected. Test pits were dug at many places where surface exposures were not adequate, and surficial material was stripped from

[1] Geological Survey of Pakistan.

covered veins. Radiometric traverses with a geiger counter were made of most of the veins and over much of the general area of mineralization.

Study of the Saindak quadrangle was supplemented by reconnaissance for mineral veins in the Gurandi Rud area to the south in quadrangle 30 G/12; the Borghar area to the southeast, in 30 G/16; the Harenar area, in 30 G/7; the Kacha-Kirtaka area, in 30 G/6 and

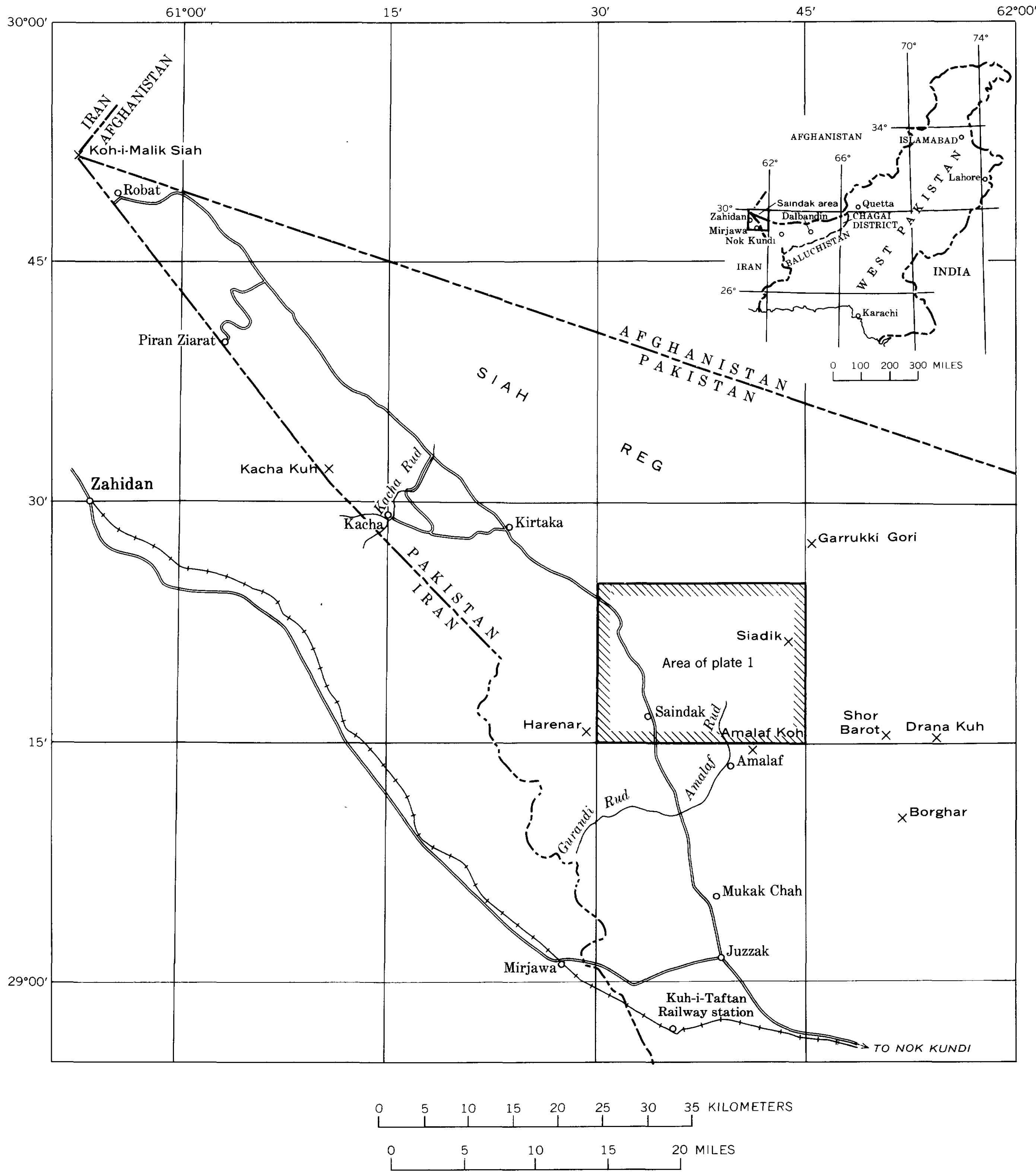

FIGURE 1.—Index map showing location of the Saindak area and related localities, West Pakistan.

30 G/7, west and northwest of the Saindak quadrangle; and in the Piran Ziarat area, shown in figure 1, in quadrangle 30 G/2. No veins of economic significance were found in these areas during the reconnaissance.

PREVIOUS WORK

The Saindak area was first studied geologically by Vredenburg (1901, p. 257–261). His observations remained the most comprehensive until the Colombo Plan Cooperative Project study (Hunting Survey Corporation, Ltd., 1960), during which regional photogeologic maps were prepared at a scale of 1:253,440. These maps included the Saindak area and provided the most useful basic references during this study.

For 2 months in 1943, M. I. Ahmad extensively prospected a lean galena vein on Saindak Koh. He also visited another galena vein near Zonk Nala, 2 miles northeast of Saindak.

The reconnaissance geology of the area southwest of Saindak has been described in a report by Ahmad (1945).

PRESENT STUDY

Two days were spent prospecting near Saindak in October 1961 by S. A. Asad and R. G. Schmidt as part of a reconnaissance of mineralized areas in the Chagai District. As a result of this visit, Survey of Pakistan quadrangle 30 G/11 was chosen for thorough geologic study.

Fieldwork began January 20, 1962, by Waheeduddin Ahmed and R. G. Schmidt and continued until February 19, during which time the copper-mineralized quartz diorite stocks were first noted by Waheeduddin Ahmed. Work was resumed in March by Schmidt, assisted by S. Habib Abbas, continued until April 4, and was again resumed by Shahid Noor Khan and Schmidt from October 18 until November 12, 1962, by which time it was almost completed. A last field visit was made by Shahid Noor Khan in March 1963 to complete mapping an area in the southwest corner of the quadrangle. The detail of our field mapping approached that of standard geologic mapping, but considerable additional time would have been needed to reach that standard, time which we felt was not justified. The laboratory work and most of the report writing were done in the summer and in December of 1962 and in January, February, and March of 1963.

ACKNOWLEDGMENTS

The authors are grateful to Major Khwaja Muhammad of the Chagai Militia at Nushki and to the Chagai Militia Jamedars, Subedars, and Sepoys of the Saindak and Nok Kundi posts who helped make the stay in Saindak more pleasant and comfortable by supplying petrol and bringing food, mail, and messages to the camp from Nok Kundi.

The help provided by S. Habib Abbas in the field and in preparing and examining mineralogic samples in the laboratory is gratefully acknowledged.

Determinations of the albite-anorthite ratios of the plagioclase in several igneous rocks were kindly performed by Mr. Mahfoozul Haque of the Geological Survey of Pakistan. Axinite was identified microscopically by F. L. Klinger of the U.S. Geological Survey.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

The Saindak quadrangle is in extreme western Pakistani Baluchistan, 5 miles from Iran at the closest point, in the Chagai District of Quetta Division. Saindak is about 400 road miles from Quetta (fig. 1). It consists of the old stone fort occupied by the Chagai Militia, a very few substantial stone buildings, and some tents and mud huts.

Saindak, the only settlement in the quadrangle, is reached by 19 miles of good fair-weather road northward from Juzzak on the Nok Kundi-Mirjawa all-weather shingle road. The nearest railroad and telegraph station is Koh-i-Taftan, about 26 miles distant. The nearest markets are the town of Mirjawa, Iran, about 30 miles by road, and Nok Kundi, in Pakistan, 90 miles by road; each town has a small bazar, post office, dispensary, and various civil and military offices, including customs offices. A military telephone line connects Saindak Militia Post with neighboring posts and Nok Kundi.

TOPOGRAPHY AND LANDSCAPE

The Iranian border area near Saindak comprises two general topographic units: the linear folded mountain ranges along the border in the southwest corner of the Saindak quadrangle and the desert plain of Siah Reg extending northeastward to beyond the border with Afghanistan. This plain consists of alluvial fans and plains near the linear ranges, but it is covered to the northeast by ranges of moving sand dunes and ridges. The desert plain is interrupted by small isolated mountain peaks and low ranges, such as Siadik in the eastern part of the quadrangle, Garrukki Gori, just northeast of the mapped area, and the low nonlinear ranges to the southeast that include the peaks Shor Barot, Drana Kuh, and Borghar.

The linear folded mountains in the Saindak region are of three general types: (1) resistant ridges or hogbacks caused by hard layers of limestone or sandstone, such as the prominent limestone ridge west of Saindak Fort; (2) resistant ridges caused by the thick Tanki sills, in places present as limbs of folds and in other places as the remnants of the troughs of synclines, as at the mountain Harenar, 5 miles west of Saindak; and (3) isolated mountains and ranges caused by more resistant rock masses that seem to be generally metamorphosed volcanic agglomerates. Saindak Koh and the other mountain peaks to the east and north of it are probably the most metamorphosed parts of otherwise similar agglomerate layers.

The linear border ranges increase in height and ruggedness northwestward and are probably most rugged in the vicinity of Kacha and the highest Pakistan peak in the area, Kacha Kuh, 7,682 feet. Toward the southeast, the ranges pass into low hills composed of less metamorphosed rock that is transitional to a generally nonvolcanic sequence. The area to the southeast of Saindak, and generally east of Mukak Chah and Juzzak, was described by Vredenburg (1901, p. 253):

> The whole region is occupied by low undulating ranges absolutely destitute of any covering of soil or sand, or alluvium or boulders, or of any vegetation whatsoever. It is impossible to describe the dreary desolation of such a scene.

The linear mountains from Amalaf northwest to Koh-i-Malik Siah are drained by northeast-flowing drainage systems, most of which are dry except for a short time after the rare rainstorms. These dry riverbeds are large, and most are strewn with thick alluvium, though some, such as Saindak Rud about 2–3 miles northeast of Saindak, flow for short distances on bedrock. These riverbeds, despite rather steep gradients, are generally smooth enough to be readily traversed by a jeep and form excellent access routes to most of the area.

Drainage within the Saindak quadrangle appears to be entirely subsequent; the regional drainage is largely subsequent and controlled by the resistant layers of folded beds and sills and by faults, though several of the major streams appear to be antecedent. The most striking antecedent stream seen by the authors was the gorge of Kacha Rud where it cuts through the highly resistant range of volcanic rocks just northeast of Kacha.

A large valley trending about N. 15° W. is 2½ miles east of Saindak Fort. The valley is believed to be related to pyrite enrichment of the country rock and not to faults or erodible beds. It cuts across two major drainage systems as well as some tributaries. We named the whole topographic trough "Sulfide Valley" during field mapping and have continued the use of that term in this report.

CLIMATE, WATER SUPPLY, AND VEGETATION

An exceedingly arid climate prevails over the entire area of western Pakistani Baluchistan, and most of the area west of Dalbandin probably receives less than 5 inches of rainfall annually. The town of Mirjawa, Iran, 20 air miles southwest of Saindak Fort, has an annual precipitation of only 33 mm (1.3 in.), which apparently is the lowest precipitation of record in Iran (Ganji, 1955, p. 275). Because summer temperatures are high, averaging 88°F at Zahidan, 40 air miles northwest of Saindak (Ganji, 1955, p. 296), fieldwork is most effectively carried out between mid-September and mid-April. The January mean temperature is 43°F at Zahidan (Ganji, 1955, p. 296).

The surrounding hills and mountains protect Saindak from sandstorms, but very high winds sometimes make outdoor work impossible. On March 29, 1962, one storm hurled small pebbles as much as 0.2 inch in diameter with great velocity, and to heights of 3–6 feet.

Potable water is available at Saindak Fort from a small karez (a water-collecting tunnel based on an ancient design) and well, but this water is too salty for outsiders' taste. More palatable water may be obtained from other small karezes about 1 and 2 miles up Saindak Rud from the fort. Very salty water seeps to the surface in the bed of Saindak Rud 1–2 miles northeast of the fort. No other water is available within the quadrangle, though the local growth of trees in some of the dry streambeds suggests that ground water may not be far below the surface.

Several small springs, wells, and karezes, of various degrees of salinity, south of Saindak, outside the quadrangle, and as far as Juzzak are described by Ahmad (1945, p. 8, 9). Good fresh water is available at Kuh-i-Taftan railway station, to which it is hauled by train from Mirjawa and stored in a cistern. Good water is also available in quantity from the karez at Kirtaka, about 18 miles northwest of Saindak.

Except for small shrubs and a few herbaceous plants and grasses, most of the region is almost without vegetation. This is particularly true in the desert to the south. In the mountains around Saindak and to the north, small trees grow in a few of the riverbeds, and shrubs are fairly abundant in the higher mountains. Patches of sizable trees, perhaps as high as 15 feet, previously grew where Amalaf Rud spreads out on the alluvial plains and also in the plain south of the hill Siadik, but woodcutting has greatly reduced the vegetation at both of these places. Five small underground charcoal furnaces were noted in the mountains northwest of Saindak, indicating that small trees must have once grown there, but only three or four trees in one streambed remain at present.

An interesting relationship between ground water, vegetation, and sand-dune formation seems to exist at many places in the area. Most of the main karezes, as at Kirtaka and the three near Saindak, are in low mounds of dune sand overgrown with tall coarse grass. It is not clear whether the ground water is retained by the sand and is therefore a result of the presence of the sand, or whether the sand has accumulated as a result of the seepage of water, permitting the growth of the grass, which in turn trapped the windblown sand.

GENERAL GEOLOGY

The Saindak quadrangle comprises two general geomorphic provinces: the rough hilly and mountainous area in the southwest corner in which bedrock is exposed on much of the land surface and the gently inclined alluvial fans and flat pebbly desert, in part covered by sand hills, of the rest of the quadrangle. Bedrock is exposed in only a few small hills in the flat desert area, and almost all the fieldwork was devoted to study of the mountainous part in the southwest corner. All general statements regarding the bedrock geology of the quadrangle refer to this area.

The Saindak quadrangle is underlain by mostly sedimentary and metasedimentary rocks ranging from Cretaceous to Oligocene(?) in age and some younger rocks of Pleistocene(?) age. The bedrock is extensively covered, mostly by unconsolidated sediments of Holocene age. The sedimentary rocks consist mostly of shale, sandstone, siltstone, and volcanic conglomerate, with lesser amounts of fossiliferous, particularly foraminiferal, limestone and limy shale, and various other rocks in minor proportion. Fossils are locally abundant in the Eocene and older rocks.

Two major unconformities divide the stratigraphic section: the Cretaceous-Paleocene unconformity, which is readily mapped in part of the area but is rather obscure in the rest, and the conspicuous unconformity on the west side of Saindak Koh, where consolidated almost flat-lying volcanic conglomerate and sandstone of Pleistocene(?) age rest on shale and sandstone of Eocene and Oligocene(?) age. Folded upper Tertiary gravels are abundant to the northwest near Robat and beyond in Iranian territory, but they have not been found in this quadrangle.

The Cretaceous through Oligocene(?) rocks are folded in a northwest-trending major syncline, locally complicated by drag folding and strike faulting. This major fold was called by Hunting Survey Corporation, Ltd. (1960, p. 349, 358), the Mirjawa synclinorium and also the Saindak syncline. In this report it is referred to as the Saindak syncline. These folded rocks are overlain by the consolidated and only slightly folded beds of Pleistocene(?) age mentioned above, and all are cut by a great many high-angle faults.

All folded rocks are intruded by many dikes, most of which have intermediate to basaltic composition. Large prominent andesite porphyry (Tanki) sills in Upper Cretaceous rocks and truncated by the pre-Paleocene unconformity are widespread in the border area but are of limited extent in the quadrangle. A group of early dioritic stocks and a group of later quartz diorite stocks were intruded after post-Eocene folding. The quartz diorite has produced a zone of thermal static metamorphism without stress effects and appears to be later than the nearly horizontal consolidated beds of Pleistocene(?) age on Saindak Koh.

Veins containing some galena, chalcopyrite, quartz, calcite, sideritic calcite, cerussite, malachite, cuprite, hematite, and goethite, are common in part of the area. In some veins, lateral zonation of copper and lead minerals can be distinguished. Parts of some of the quartz dioritic intrusive bodies contain sparse disseminated copper minerals.

Most of the sedimentary rocks are marine-laid clastic material intercalated with abundant coarse volcanic debris and a few submarine lava flows. Moderately persistent layers and discontinuous lenses of limestone and limy shale are found at many horizons in the stratigraphic section and serve to date most strata rather closely, except for the post-middle Eocene rocks. Fossils in the Paleocene rocks and older Eocene rocks are forms indicative of shallow bottom conditions. The younger Eocene rocks contain many shallow-water pelecypods and grade upwards into unfossiliferous, probably terrestrial red beds.

Some of the older Cretaceous rocks in the extreme southwest corner of the quadrangle seem to be part of the same monotonous flysch-type sequence of shale, volcanic sand, and nonfossiliferous shaly limestone found northwest and south of the quadrangle.

The geologic history of the area may be summarized as follows:

1. Deposition of thick flysch-type deposits of shale, volcanic sandstone, and thin unfossiliferous shaly limestone. Deposition in shallow water of shale, sandstone, and reef limestone containing fossils of Cretaceous age, intercalated with abundant volcanic debris and perhaps thick flows or crystal tuffs.

   Deposition of a nonfossiliferous red-bed sequence of conglomerate, arkosic sand and grit, sandstone, and shale.

   The relative dates of these three events are unknown, but they occurred in Cretaceous time.
2. Intrusion of very large andesite porphyry sills.
3. Folding, uplift, and erosion.
4. Submergence and deposition of Paleocene sedimentary rocks, accompanied by volcanic activity and deposition of large volumes of coarse conglomer-

atic debris. The deposition of coarse volcanic material continued into Eocene time and finally included two submarine flows.

5. Intermittent cessation of volcanism and deposition of fine limy shales and fossiliferous reefs in a littoral environment during Eocene time.
6. Emergence and deposition of red shale, siltstone, and sandstone, probably during Oligocene time.
7. Folding, much faulting, probably intrusion of diorite stocks, uplift, erosion, and local deposition.
8. Resumption of volcanism and deposition of a thick volcanic conglomerate, probably during Pleistocene time.
9. Intrusion of quartz diorite stocks causing metamorphism of the country rocks in an area east of Saindak probably during Pleistocene time. Late phases of this intrusion probably included the injection of many dikes of diverse composition but perhaps mostly diorite, and the introduction of mineralizing solutions. The solutions caused rock alteration and deposited copper in the quartz diorite. In the country rock they entered along faults and fractures and deposited large barren siderite veins followed by small lean veins of copper-lead minerals accompanied by calcite and quartz.
10. Uplift and erosion, local relatively deep weathering of susceptible rocks such as the pyrite-rich volcanic rocks east of Saindak Koh.
11. Vertical displacement along major faults, probably as continued movement on old fault surfaces, causing rejuvenation of erosion of deeply weathered rocks and dissection of older Holocene unconsolidated gravels.

STRATIGRAPHY

The stratigraphic nomenclature within the area covered by this report has not yet come under consideration by the Stratigraphic Committee of Pakistan and is therefore subject to change. The nomenclature used is that proposed in the report of the Hunting Survey Corporation, Ltd. (1960). The stratigraphic units described by them in their reconnaissance survey were substantiated by detailed study during this project, except for certain minor changes in boundaries and the reassignment of rocks underlying a large part of the area from a Paleocene to a Cretaceous age. The reassignment of age was based on positive identifications of several collections of fossils from areas that could not have been easily covered in a reconnaissance study and from rocks that generally contain meager fossil remains.

Rocks older than Cretaceous are not known in the border ranges region; the nearest reported in the recent reconnaissance survey of adjacent Iran (Bartolucci, 1959) are the Paleozoic rocks near Kuh-i-Bazman, 90 miles southwestward.

CRETACEOUS ROCKS

SINJRANI FORMATION

The thickest and by far the most complex stratigraphic unit in the region is the Sinjrani Formation, comprising a great variety of lithic types. The complexity of the formation as presently mapped strongly suggests that additional study will lead to subdivision; this study, however, will have to be done outside the Saindak quadrangle, where more complete stratigraphic sections and less disturbed rocks are available.

The Sinjrani Formation consists of (a) flysch-type sedimentary rocks including intercalated shale, siltstone, and unfossiliferous calcareous grit and shaly limestone; (b) thick layers of mixed volcanic agglomerate and tuff; (c) a mixed assemblage of volcanic tuff and sand and perhaps some welded tuff, interbedded with shale, siltstone, conglomerate, agglomerate, and small lenticulur reefs or massive lenses of fossiliferous limestone; and (d) red beds of shale, sandstone, and conglomerate. Identifiable fossils were found in the quadrangle only in the reefs of fossiliferous limestone and in some nearby limy beds in shales. The reefs are not predominantly coralline. Northwest of Saindak, near Kirtaka and Kacha, hippuritids locally are fairly common in red beds similar to those described here.

The relative ages of the four general lithic types are not known. The flysch-type rocks and the red beds seem to be the least structurally disturbed in the mapped area. Determination of relative ages will require detailed studies of other areas in the border ranges.

Flysch-type sedimentary sequence

A thick sequence of gently folded fine clastic beds of shale, siltstone, nonfossiliferous limestone, and probably volcanic tuff and sand is found in the southwest corner of the quadrangle; it is exposed in much greater thickness, perhaps many thousands of feet, about 6 miles south of the quadrangle. Alternating beds of shale and sandstone, siltstone and volcanic sand, shale and calcareous sand, or other combinations are each a few inches to a few feet thick. Some layers of shale contain agglomerate pebbles and boulders, and in one place, small channel fillings of white arkosic tuff were found. The layers of shale, siltstone, and grit are various shades of greenish gray and light brown. The volcanic sand layers are dark gray and, most characteristically, grayish green and dark green.

The very thick section of interbedded sandstone and shale 40 miles northwest of Saindak, crossed by the road leading to Piran Ziarat, is generally similar to this facies of the Sinjrani Formation and is probably of the same age.

The flysch-type sedimentary sequence is presumed to have been deposited in deep water. No megafossils were found.

Volcanic agglomerate and tuff

Hard, dark-green to almost black, compact volcanic agglomerate and beds of light-gray and grayish-green tuff or tuffaceous sand are common in the Kacha area, 23 miles northwest of Saindak, and in the quadrangle east of Saindak. In the eastern part of the Saindak quadrangle, agglomerate and tuff are found only in the hill known as Siadik and in some very small mounds 2 miles southeast of Siadik. Most of the outcrops are covered by black desert varnish, and the low mounds are partly covered by dune sand.

Most of Siadik and all the low mounds consist of agglomerate, perhaps some flow rock, and minor beds of light-colored tuff, all slightly metamorphosed to hornfels. The west end of Siadik, is conspicuously light in color and is mostly a very thinly bedded hornfels, presumably the result of metamorphism of tuffaceous shale.

The very regular layering of the tuffaceous layers at the west end of Siadik and at Kacha suggests deposition by water, probably in a lake or sea; otherwise, the environment of deposition is not known.

The age of these beds at Siadik is unknown, but Hunting Survey Corporation, Ltd. (1960), includes them in the Cretaceous, along with the rocks of large areas to the east. Similar rocks at Kacha are overlain by reddish-brown conglomerate that contains *Hippurites* locally, though not immediately, above the volcanic rocks discussed here.

Mixed assemblage of volcanic and sedimentary rocks

A mixed assemblage of rocks consisting of a variety of volcanic and sedimentary types includes small layers and lenses of fossiliferous limestone and marl and is definitely dated as Late Cretaceous (see below). The lithologic complexity of the mapped rock unit is matched in the southwestern part of the quadrangle by the extreme structural complexity. Folding is intense, and one fold axis plunges almost vertically; faults are very abundant, and some fold axes may be faulted. Compared structurally with the simply folded flysch-type rocks outcropping to the southwest, this assemblage appears to be older.

Volcanic rocks predominate in this assemblage and include green volcanic sands and grits, thick layers of agglomerate and conglomerate, tuffaceous shale, and some dark-grayish-green layered rocks; these layered rocks appear to be crystal tuffs, but part of them may be flows or a peculiar sheeted intrusive (welded tuff?). The facies was observed along the west side of the quadrangle where considerable sedimentary material and volcanic sand are interbedded in the northwest corner of the outcrop area, and along the northeast side of the ranges where shale layers and shaly volcanic conglomerate layers are interbedded in a thick section of volcanic agglomerate. Along the northeast edge of the ranges southeast of Saindak Rud, the same layers are finer and are sand and shale in large part, probably mostly volcanic in origin, with various amounts of included volcanic conglomerate pebbles and boulders. Southeast of the Saindak Rud, fossiliferous limestone reefs and lenses are common, and several collections of Late Cretaceous fossils were made. The total thickness can be approximated only near Amalaf Rud, where it appears to be 1,500–2,000 feet.

Red beds

Along the northeast side of the ranges, at the foot of the hills, and especially as low mounds fringing the ranges, beds of red shale, sandstone, and conglomerate crop out locally for more than 8 miles. Just southeast of Saindak Rud, conglomerate is rather abundant in the section; it is also found at many places farther to the southeast.

The pebbles in the conglomerate are composed of a variety of igneous rocks and a noticeable number are vein quartz, jasper and chalcedony; hence, they are quite different in composition from the simple types of volcanic conglomerates common elsewhere in the area.

No limestones or fossils of any kind were found in these red beds. Their age is judged from close association with the fossil-dated assemblage of volcanic and sedimentary rocks described in the previous section, and by the general association of very similar red beds containing *Hippurites* 20–30 miles to the northwest. These red beds are presumed to be the strata near Saindak which Vredenburg considered (1901, p. 257) to be of Siwalik age. These are definitely not equivalent to the very young Tertiary and Quaternary gravels that flank these ranges 20–40 miles to the northwest.

Although the thickness of this facies was not measured, it probably is on the order of 2,000–3,000 feet.

Fossils

Many collections were made from Upper Cretaceous rocks in the Saindak quadrangle, all from limestone reefs and limy beds in the mixed assemblage. Conclusive dating was provided from one collection on the west side of the syncline (loc. R–33–A) and by two along the east side (locs. R–206, R–223); five other collections indicated a probable Late Cretaceous age (locs. SN–55, R–39, R–218, R–230, R–273, R–276).

Rudistids were identified from two collections, and 10 species of corals, constituting a new reef coral fauna for southern Asia, were listed in a collection from locality R–223. The closest affinities of two *Neithea* identified in the collection from locality R–33–A are with the Senonian fauna of Iran described by Douvillé (1904). Fossil lists are given below.

Locality SN–55, R–276 (Examined by K. N. Sachs, Jr., July 15, 1963)
- Foraminifera:
  - Unidentifiable miliolids
- Others:
  - Miscellaneous pelecypod(?), and sponge(?) fragments
  - Possible rudistid

If rudistids are present, then this sample can be assigned to the Cretaceous.

Locality R–33–A (Examined by N. F. Sohl, June 19, 1962)
- *Neithea* aff. *N. subgranulata* Münster
- *Neithea* aff. *N. striaticostata* Goldfuss
- *Exogyra* sp. (smooth)
- *Capulus* n. sp.
- Indeterminate turriculate and naticid gastropods

The collection is definitely of Cretaceous, not Paleocene, age. The closest affinities of the identified fossils are with the Senonian fauna of Iran described by Douvillé (1904). Douvillé noted similar *Neithea* from beds below those he assigned to the Maestrichtian. However, *Sphenodiscus* or *Indoceras*, an ammonite restricted to the Maestrichtian, is reported from one of his so-called Senonian localities.

Age assignment of the collection rests primarily on the species of *Neithea*. Compared with known faunas, they are Late Cretaceous types common from the Coniacian to the Maestrichtian. The specifically indeterminate smooth *Exogyra* substantiates a Cretaceous age, but such types are known to occur at many horizons. The *Capulus?* is a large species not reported in the literature.

Locality R–39 (Examined by K. N. Sachs, Jr., Mar. 11, 1963)
- *Orbitoides* sp. cf. *O. media* (d'Archiac)

Many poorly preserved specimens in this sample resemble *O. media*. On the basis of this identification, the age assigned would be Late Cretaceous. The poor preservation of these specimens and some signs of decomposition around their borders suggests a possibility of reworking; however, evidence is insufficient to state definitely that this is the case.

Age: Late(?) Cretaceous

Locality R–273 (Examined by J. W. Wells, May 20, 1963)
- *Actinacis* sp. cf. *A. sumatrensis* (Tornquist)
- *Periseris* sp.
- Age: Probably Late Cretaceous

Locality R–230 (Examined by J. W. Wells, June 20, 1963)
- *Actinacis* sp. cf. *A. sumatrensis* (Tornquist) (like specimen from R–223)
- Age: Probably Late Cretaceous

Locality R–206 (Examined by J. W. Wells, June 20, 1963)
- *Actinacis* sp. (Not *A.* sp. A)
- *Thamnasteria* sp. (Range of genus: Triassic to Cretaceous)
- Rudist fragments
  - Material poor
- Age: Late Cretaceous

Locality R–218 (Examined by J. W. Wells, June 20, 1963)
- *Cladocora* sp. (Range of genus: Late Cretaceous to Holocene)
- Dasycladacean calcareous algae
  - Material poor
- Age: Late Cretaceous(?)

Locality R–223 (Examined by J. W. Wells, June 20, 1963)
- *Columnactinastrea* sp. nov. aff. *C. rennensis* Alloiteau (Santonian, Europe)
- *Columnactinastrea* sp. nov.
- *Periseris* sp. A. (Range of genus: Middle Jurassic to Cretaceous)
- *Periseris* sp. B.
- *Actinacis* n. sp. A.
- *Actinacis* sp. aff. *A. sumatrensis* (Tornquist) (Late Cretaceous, Indonesia)
- *Nefocoenia* sp. (Range of genus: Late Cretaceous, Europe)
- *Elasmophyllia* sp. cf. *E. deformis* (Reuss) (Late Cretaceous, Europe)
- *Hydnophora* sp. A. (Range of genus: Cretaceous to Holocene)
- *Hydnophora* sp. B.
- Hippuritid fragments
- Age: Late Cretaceous. A new reef coral fauna for southern Asia, unrelated to previously described Late Cretaceous coral faunas from this region.

Locality R–223 (Examined by N. F. Sohl, Aug. 2, 1963)

Two species of rudistids represented by fragmental material are present in the collections. Positive identification of both must await better preserved material. One species belongs in the radiolite group hinging around the genera *Osculigera-Vautrina*. Both are restricted to the Maestrichtian of Syria, Turkey, and Iran. The second species is a caprinid but indeterminate with the material at hand.

PALEOCENE AND EOCENE ROCKS

JUZZAK FORMATION

Within the Saindak quadrangle, the Juzzak Formation is a fairly sharply defined unit consisting of shale, sandstone, siltstone, and shaly limestone; it rests unconformably on Cretaceous rocks and is overlain conformably by Eocene volcanic conglomerates. The distinct angular unconformity separating these strata from those of Late Cretaceous age contrasts with the contact in adjacent Iran, described by Bartolucci (1959, p. 25, 27) as conformable and gradational. Almost all the Juzzak Formation is of Paleocene age, but in part of the quadrangle the top of the formation is as young as middle Eocene; however, these beds cannot be mapped separately.

Marked gradational facies and thickness changes can be noted as the outcrop of this unit is traced around the Saindak syncline. Along the west side of the syncline, west and south of Saindak, the formation is fairly consistent, comprising from top to bottom:

2. Gray shale containing pebbles and layers of volcanic sand; thickness as much as 2,000 feet. Near the top are lenses of reef limestone; fossils of middle Eocene age (locs. R–14, R–27).
1. Shale and siltstone with 6-inch to 10-foot-thick limestone ribs, dark colored, very fossiliferous; alternating units of gray shale, grayish-brown siltstone, and brown sandstone containing a few cobbles of volcanic rocks. Each unit is as much as several hundred feet thick, but the entire sequence is about 2,000 feet thick.

Near the west edge of the mapped area, at localities R–55 and R–55A, collections of fossils suggest proximity to the Paleocene-Eocene boundary. Northwestward, the uppermost shale pinches out, and the volcanic conglomerate of the overlying Saindak Formation rests directly on a siltstone layer. This siltstone, traced northwestward and around the apex of the syncline, grades into limy nummulitic shale and thin limestone ribs, and the older shale-siltstone-sandstone sequence grades into gray shale. Thus, at the northwest apex of the syncline, the Juzzak Formation is composed entirely of gray shale and silty shale containing Foraminifera and algae of Paleocene age near its base (loc. R–271) and at the very top of the succession a few thin shaly nummulitic limestone beds of Eocene age (loc. R–269). Along the east side of the fold, southeastward toward Saindak Rud, limestone beds and lenses are common. Locally near Saindak Rud, limestone beds a few inches to 6 feet thick are very abundant, and they make up as much as a third of the total thickness of the formation at that place.

Just southeast of Saindak Rud, the formation is hidden beneath the long trough of Sulfide Valley. Half a mile southeast of the junction of Sulfide Valley and Saindak Rud the formation is considerably metamorphosed, the half dozen or so thin limestone layers (2–12 in. thick) being locally completely replaced by hematite. These layers can be traced for half a mile east of Sulfide Valley through a marble facies into foraminiferal limestone enclosed in shale, where the unit is cut off by a fault. In the next two fault blocks, only a tactite zone indicates the probable position of the metamorphosed limestone-bearing beds and hence the probable position of the Juzzak Formation.

Beyond the tacite and thence southeastward to Amalaf Rud, the whole formation is perhaps only 100 feet thick. About 30 feet consists of beds of calcareous grit interbedded with 70 feet of limy shales containing abundant small Foraminifera and algae of Paleocene age (loc. R–217). The unit is underlain by volcanic sand, shale, and conglomerate in which there are scattered limestone lenses of Cretaceous age. It is overlain by volcanic conglomerate and agglomerate containing limestone lenses of Eocene age.

Southeast of Amalaf Rud the unit is not well marked; it consists of a thin shaly layer containing a few local limestone lenses and forms a narrow valley between underlying and overlying volcanic conglomerates. Foraminifera and algae of Paleocene age were collected from locality R–227. The unit may pinch out to the south.

The Juzzak Formation overlies Cretaceous rocks with marked unconformity along the west side of the Saindak syncline; this relationship persists around the northwest apex of the fold. Along all the northeast flank of the fold, the formations appear conformable within this quadrangle.

Fossils

Certain layers in the Juzzak Formation contain abundant medium- and large-size Foraminifera, smaller, however, than the "giants" found in the beds of Eocene age. *Discocyclina* is perhaps most abundant; small types of *Assilina* and *Nummulites* were also common. The alga *Distichophlax biserialis* was identified by K. N. Sachs in several collections (locs. R–217, R–227, R–271, R–275); this species is regarded as a good Paleocene index fossil in the Middle and Far East. Complete lists of types identified are given below:

Locality R–14 (Examined by K. N. Sachs, Mar. 11, 1963)
- *Nummulites* sp.
- *Alveolina elliptica* (Sowerby)
- Age: Eocene

Locality R–27 (Examined by Waheeduddin Ahmed, Jan. 1962)
- *Lockhartia*
- *Alveolina* (small)
- *Discocyclina*
- *Nummulites perforata*?
- Age: Early middle Eocene

Locality R–27 (Examined by K. N. Sachs, Mar. 3, 1963)
- *Nummulites* sp. cf. *N. discorbinus*
- *Alveolina elliptica* (Sowerby)
- *Discocyclina* sp.
- Age: Middle Eocene

Locality R–249 (Examined by K. N. Sachs, July 15, 1963)
- Foraminifera:
  - *Nummulites* sp.
  - *Discocyclina (Discocyclina)* sp.
- Algae:
  - Several unidentified forms
- Insufficient fauna for dating

Locality R–249 (Examined by E. B. Fritz, Mar. 25, 1963)
- Age: Possibly Paleocene

Locality R–53 (Examined by K. N. Sachs, Mar. 11, 1963)
- *Discocyclina (Discocyclina)* sp. cf. *D. (D.) ranikotensis* Nuttall
- *Kathina nammalensis* Smouth & Haque
- *Operculina* sp.
- Age: Paleocene

Locality R–55 (Examined by Waheeduddin Ahmed, Jan. 1962)
Small forms, probably Paleocene type

Locality R–55 (Examined by K. N. Sachs, Mar. 11, 1963)
Alveolina elliptica (Sowerby) (abundant)
Alveolina elliptica var. *flosculina* (rare)
Discocyclina (Discocyclina) dispansa Sowerby
Discocyclina (Aktinocyclina) alticosta? Nuttall
Nummulites sp.
Operculina sp.

The presence of *Alveolina elliptica* var. *flosculina* in sample R–55 suggests an Eocene age rather than Paleocene. However, its rarity could well mean close proximity to the Paleocene-Eocene boundary. This species is abundant in sample R–55A which seems certainly to be of Eocene age.

Age: Eocene

Locality R–55–A (Examined by K. N. Sachs, Mar. 11, 1963)
Alveolina elliptica var. *flosculina Silvestri* (rare)
Discocyclina (*Discocyclina*) sp. cf. *D.* (*D.*) *dispansa* Sowerby (common)
Nummulites sp. (small specimens, abundant)
Age: Probably early Eocene

Locality R–269 (Examined by K. N. Sachs, July 15, 1963)
Foraminifera:
Miscellaneous unidentifiable small forms
Assilina sp.
Nummulites obtusus? Sowerby
Discocyclina (*Discocyclina*) sp.
Alveolina elliptica (Sowerby)
Age: Eocene

Locality R–271 (Examined by K. N. Sachs, July 15, 1963)
Foraminifera:
Unidentifiable miliolids
Amphistegina sp.
Discocyclina (*Discocyclina*) sp.
Algae:
Distichophlax biserialis (Dietrich)
Distichophlax sp.
Age: Paleocene

Locality R–275 (Examined by K. N. Sachs, July 15, 1963)
Foraminifera:
Unidentifiable miliolids
Rotalia? sp.
Algae:
Distichophlax biserialis (Dietrich)
Distichophlax sp.
Age: Paleocene

Locality SN–63 (Examined by K. N. Sachs, July 15, 1963)
Foraminifera:
Nummulites sp.
Miscellanea miscella (d'Archiac & Haime)
Discocyclina (*Discocyclina*) sp.
Algae:
Distichophlax biserialis (Dietrich)

Nummulites resembling *N. obtusus* from the Eocene of India are abundant in this sample. This fact, coupled with the extreme rarity of *Distichophlax biserialis,* which is the characteristic Paleocene index, suggests that the sample could possibly be younger than Paleocene.

Age: Paleocene or Eocene

Locality R–217 (Examined by K. N. Sachs, July 15, 1963)
Foraminifera:
Unidentifiable miliolids
Amphistegina? sp.
Miscellanea miscella (d'Archiac & Haime)
Nummulites sp.
Discocyclina (*Discocyclina*)
Algae:
Distichophlax biserialis (Dietrich)
Age: Paleocene

Locality R–227 (Examined by K. N. Sachs, July 15, 1963)
Foraminifera:
Unidentifiable miliolids
Nummulites sp.
Assilina? sp.
Discocyclina (*Discocyclina*)
Algae:
Distichophlax biserialis (Dietrich)
Distichophlax sp.
Age: Paleocene

EOCENE ROCKS

SAINDAK FORMATION

The Saindak Formation of Eocene age is made up of two general parts. The lower consists of volcanic debris, mainly water-laid conglomerate, sandstone, and agglomerate, and several conspicuous beds, lenses, and massive reefs of limestone. The upper part consists of soft gray shale, siltstone, sandstone, marl, and thin layers of limestone. Most of the formation was deposited under marine conditions, but there is a suggestion of a gradual upward change from shallow water to very shallow water, or even an intertidal environment.

The lithology of the lower volcanic part of the formation is generally the same throughout the quadrangle. Volcanic conglomerate 1,500–3,000 feet thick contains layers of coarse agglomerate, fine volcanic sand and shale, and conspicuous lenses, layers, and reefs of gray nummulitic limestone from which two collections of Eocene-age fossils were taken west of Saindak (locs. R–250, R–263). Two submarine lava flows near the top of the lower part of the formation are found in the northern part of the bedrock area (described in the section on "Volcanic Rocks").

The upper, nonvolcanic part of the Saindak Formation is about 1,500 feet thick and is rather uniform in lithology. Marly shales and shaly limestone layers are abundant near the base wherever it was mapped and are generally richly fossiliferous. West of the Saindak Fort the base is marked by a gray limestone bed 30–40 feet thick that rests directly on volcanic conglomerate and makes a conspicuous ridge. The limestone bed is overlain by nummulitic shale locally containing abundant echinoids, pelecypods, large gastropods, and corals (locs. R–10, R–12, R–22, R–52, R–95). Northwestward, a lens of volcanic conglomerate 200–300 feet thick overlies the gray limestone and separates it from the overlying gray shale and marls; about 3 miles northwest of Saindak the gray limestone pinches out. Northwest of Saindak Rud, the nonvolcanic part of the formation gradually becomes less sandy and more marly; southeastward, sandstone and siltstone increase in abundance. Near Amalaf Rud a thick section just overlying the volcanic conglomerate contained much conglomerate as well as the usual thin layers of nummulitic limestone.

At every place examined, the top of the formation is sparsely fossiliferous and consists of gray siltstone, shale, and sandstone. It is distinguished from the overlying Amalaf Formation strictly on the basis of the transitional color change through a thickness of 10–100 feet from gray and grayish brown to the dominantly reddish brown of the Amalaf. Stratigraphically, the highest collection taken was at locality R–131–A about 1,000 feet northwest of Saindak Fort. The Saindak Formation is conformable with the underlying Juzzak Formation.

Fossils

Shallow-water forms are very abundant near the bottom of the upper, nonvolcanic part of the Saindak Formation. Excellent collecting sites are found west of Saindak Fort where large foraminifers and echinoids weather free from soft limy shales (locs. R–10, R–12). Farther north, corals and very large gastropods are also common (locs. R–22, R–52). Gastropod specimens found at these localities were poor; pelecypods included small stone borers.

The youngest collection from which diagnostic fossils were identified came from near the top of the formation at locality R–131–A, close to Saindak Fort. The two identified species of Foraminifera were judged by Sachs to be middle or late Eocene in age. Poorly preserved pelecypods and gastropods and other nondiagnostic materials are fairly common from this locality and in the overlying beds below and just above the top of the Saindak Formation. The four molluscan genera mentioned by Vredenburg (1901, p. 261) (discussed under Amalaf Formation) probably came from the top beds of the Saindak Formation.

Complete lists of types identified are given below.

Locality SN–51 (Examined by K. N. Sachs, July 15, 1963)
  Foraminifera:
    Nummulites obtusus Sowerby
    Discocyclina (*Discocyclina*) *dispansa*? Sowerby
  Age: Eocene

Locality R–263 (Examined by K. N. Sachs, July 15, 1963)
  Foraminifera:
    "*Lockhartia*" sp.
    Nummulites obtusus? Sowerby
    Assilina exponens Sowerby
    Alveolina elliptica (Sowerby)
  Age: Probably Eocene

Locality R–95 (Examined by K. N. Sachs, Mar. 11, 1963)
  Nummulites obtusus? Sowerby
  Assilina sp. cf. *A. papillata* Nuttall
  Age: Middle or late Eocene

Locality R–131–A (Examined by K. N. Sachs, Mar. 11, 1963)
  Nummulites obtusus? Sowerby
  Assilina sp. cf. *A. papillata* Nuttall
  Age: Middle or late Eocene

Locality R–10 (Examined by A. F. M. M. Haque, Dec. 19, 1961)
  Foraminifera:
    Assilina exponens
    Nummulites perforatus
    Nummulites cf. *catsi*
  Echinoids:
    Conoclyperes sp.
    Metalia sp.
  Pelecypods:
    Spondylus sp.

All are present in the Khirthar Formation in other parts of West Pakistan. *Spondylus* and *Mithka* have also been reported from rocks of the Laki Formation. A middle Eocene age is indicated.

Locality R–10 (Examined by Waheeduddin Ahmed, Jan. 1962)
  Foraminifera:
    Nummulites irregularies
    Nummulites obtusus
    Assilina exponens?
  Age: Same as Khirthar Formation (middle Eocene)

Locality R–10 (Examined by K. N. Sachs, Mar. 11, 1963)
  Assilina sp. cf. *A. papillata* Nuttall
  Nummulites gizehensis (Forksal)
  Nummulites obtusus Sowerby
  Age: Middle Eocene

Locality R–12 (Examined by K. N. Sachs, Mar. 11, 1963)
  Assilina papillata Nuttall
  Nummulites gizehensis (Forksal)
  Age: Middle or late(?) Eocene

Locality R–22 (Examined by K. N. Sachs, Mar. 11, 1963)
  Assilina sp.
  Nummulites obtusus Sowerby
  Discocyclina sp.
  Age: Middle Eocene

Locality S–250 (Examined by E. B. Fritz, Mar. 1963)
  Nummulites sp.
  Discocyclina
  Miscellanea spp.
  Alveolina sp. *elliptica*? (Sowerby)
  Age: Paleocene, near Eocene contact?

Locality S–250 (Examined by K. N. Sachs, July 15, 1963)
  Foraminifera:
    Miscellaneous unidentifiable small forms
    Assilina sp.
    Nummulites obtusus? Sowerby
    Discocyclina (*Discocyclina*) sp.
    Alveolina elliptica (Sowerby)
  Age: Eocene

Locality R–52 (Examined by P. M. Kier, Jan. 11, 1963)
  Macrooneustes speciosus Duncan and Sladen; reported by Duncan and Sladen from the Khirthar Formation.

The material submitted is not well preserved, and there are too few specimens. Very little is known of the ecology of these echinoids, except that they probably lived in shallow water on a soft substratum.

Locality R–52 (Examined by J. W. Wells, June 20, 1963)
"*Antillia*" *octoformis* Gregory. Upper Ranikot Formation
Stylophora sp. (Range of genus: Eocene to Holocene)
Astrocoenia sp. cf. *A. duncani* (Gregory). Upper part of upper Ranikot Formation

OLIGOCENE(?) ROCKS

AMALAF FORMATION

The Amalaf Formation of probable Oligocene age is a red-bed sequence of shale, siltstone, and sandstone. It is in the center of the Saindak syncline and is the youngest unit remaining in the fold. These beds were assigned to the "base of the Nari" by Vredenburg (1901, p. 261, figs. 11, 15) on the basis of fossils found near the Saindak-Amalaf formational contact and identified by Noetling. The same red beds were named the Amalaf Formation and were assigned to the Oligocene on the basis of Noetling's correlation by the Hunting Survey Corporation, Ltd. (1960); the volcanic rocks topping Saindak Koh were also included in this formation. The present study has shown that these volcanic rocks of Saindak Koh are clearly from a postfolding depositional period and should be assigned to a separate formation.

Rocks of similar lithologic composition and containing Nummulitidae, *Alveolites*, Lamellibranchia (*Pecten*), and Gastropoda were reported from an area about 40 miles to the west, in Iran, by Bartolucci (1959, p. 29). These were described as the youngest marine strata in the region.

The Amalaf Formation consists of reddish-brown shale, siltstone, sandstone, and thin gray and grayish-green beds of the same lithic types; the shales are gypsiferous. These strata are well exposed on the northwest and north sides of Saindak Koh where the red sandstone was quarried for use in Saindak Fort. Along Saindak Rud, a few thin stringers of shelly sandstone and rubbly limestone are found, and these contain several types of poorly preserved Mollusca, a type of *Ostrea* being the most common. Northwest of Saindak Rud the formation is very poorly exposed, and most of it is covered by alluvium. Southeast from Saindak Koh, at the edge of the quadrangle, the formation is entirely metamorphosed to a very low grade gray hornfels; only a few small layers of reddish material remain in the very southeast corner of the mapped part of the formation. Just outside the quadrangle, however, the unmetamorphosed red-bed lithology described above is resumed. The formation as defined in this study contains no volcanic material.

From 1,500 to 2,000 feet of the formation is found in the quadrangle, but the total thickness is not known because the top has been removed by erosion.

Fossils

None of the fossils seen in the field during this study were regarded as diagnostic. Except for *Turritella,* fossil preservation was very poor; therefore, nothing has been added to our knowledge of the age of the Amalaf Formation since Noetling's work. Dating is entirely based on several species of four genera (*Cardita, Corbula, Natica,* and *Turritella*) found near the base of this formation, or more probably near the top of the underlying nonred strata (Saindak Formation), by Vredenburg and assigned to "the base of Nari" by Nooeting (Vredenburg, 1901, p. 261). Unfortunately, Vredenburg did not list the species in his report.

Other exposures of the Amalaf Formation were mapped by the Hunting Survey Corporation, Ltd., 25–45 miles to the southeast (1960, map sheets 17, 18, 21), but these outcrops were not seen by the authors. Perhaps better paleontologic data may be found in that area.

PLEISTOCENE(?) ROCKS

KAMEROD(?) FORMATION

The gently folded volcanic boulder conglomerate and lesser amounts of pebble conglomerate, sandstone, and grit capping Saindak Koh and various other hills in the quadrangle are tentatively correlated with the Kamerod Formation described from other parts of the region and mapped in the same structural position within the Saindak syncline 30 miles to the southeast by the Hunting Survey Corporation, Ltd. (1960, p. 165–168 and map sheet 21). These beds are not an upper part of the Amalaf Formation separated by a horizontal thrust fault, as described by Hunting Survey Corporation, Ltd. (1960, p. 74, figs. 17, 19).

The Kamerod(?) Formation in the Saindak quadrangle rests unconformably on the folded and eroded surface of the Cretaceous to Oligocene(?) strata. Rocks of the Kamerod(?) Formation seem to be slightly folded, probably by late folding of the Saindak syncline, and they are partly metamorphosed and cut by basaltic and other dikes and by mineral veins. Maximum dip observed on the folded beds, part of which may be initial dip, was 30° at the northeast end of Saindak Koh.

The Kamerod(?) Formation appears to have been deposited on a rather irregular surface. The oldest strata were deposited in valleys or depressions on the old surface and consisted of gravel, clay-pebble conglomerate, grit, sand, red shale, and volcanic grit; a few 6-inch layers of black calcareous shale were found. These clastic sedimentary materials fill the valleys, where they are as much as 100 feet thick. They are overlain by coarse volcanic agglomerate that generally rests directly on the Amalaf Formation between the old valleys.

Much of the upper part of Saindak Koh is coarse, probably andesitic volcanic agglomerate, slightly metamorphosed, except for parts of the west end of the mountain which seem unmetamorphosed.

The caps of two small hills about 3¾ miles N. 75° W. of Saindak Fort are interpreted to be part of the same formation. They consist of rhyolitic breccia and tuff, perhaps welded tuff, and unconformably overlie the older, folded Sinjrani Formation.

As the top of the formation has been removed by erosion, no total thickness is known, but about 500 feet of the formation remains on Saindak Koh.

No fossils were found in the formation in the Saindak quadrangle, although the thin layers of black calcareous shale near the base at the northeast end of Saindak Koh looked favorable for fossil remains. Dating is, therefore, only tentative and based on physical relationships. The slight metamorphism and the mineral veins suggest an age older than Pleistocene. The volcanic materials may be related to the early Koh-i-Sultan volcanics, as defined by the Hunting Survey Corporation, Ltd. (1960, p. 168, 182).

HOLOCENE DEPOSITS

OLDER HOLOCENE DEPOSITS

Terrace gravel and alluvial-fan deposits related to the present drainage pattern, but occupying higher positions along the valleys and generally dissected by the present streams, are roughly classified as older Holocene. Probably some conglomerates that should be assigned to the Kamerod(?) Formation have been included in this unit. There is a continuous gradation to younger alluvial deposits.

Most of the material considered as older Holocene is gravel and coarse conglomerate, although some finer clastic strata are found. Only slight cementation is present in most of the beds, but at a few places a caliche-type calcareous cementation has resulted in a well-indurated rock.

The gravels consist of metamorphosed and unmetamorphosed material, mostly volcanic rocks and limestone, but minor amounts of many other lithic types may be found. The ratio of limestone to volcanic rock depends upon the bedrock dominant in the drainage basin. Saindak Rud and Amalaf Rud, the longer drainage systems, now carry abundant coarsely crystalline white marble and pieces of gray slate derived a few miles west of the quadrangle, and pieces of these rocks are fairly common in some of the older Holocene gravels.

The thin cap on the low hill just south of Saindak Fort contains huge boulders as much as 10–20 feet long, composed of volcanic conglomerate. These boulders are believed to be talus blocks that slid down Saindak Koh, when it was a more extensive and less eroded mountain, as they appear too large to have been transported by water.

No indigenous fossils are found in these strata, but reworked intact middle Eocene Foraminifera are locally fairly common, and fossils of other ages are probably present.

HOLOCENE ALLUVIUM AND DUNE SAND

Younger Holocene deposits in the Saindak quadrangle consist of alluvium and dune sand. The alluvium of boulders, gravel, sand, and clay is found in streambeds throughout the mapped area and almost completely covers the wide alluvial-fan area in the middle of the quadrangle. One small patch of dune sand was mapped on the south edge of Saindak Rud; a few other patches of dune sand along Saindak Rud were too small to map.

The alluvium consists of locally derived material. The coarser fragments are mostly volcanic conglomerate, as this is the most abundant erosion-resistant rock in the area. Where limestone is locally abundant in the drainage system, it contributes considerably to the coarse detritus. As discussed above, the through-flowing drainage systems carry pieces of white crystalline marble and gray slate derived from the large area of metamorphosed rocks a few miles west of the quadrangle. Fragments of these rock types form a small, but conspicuous, part of the alluvium of Saindak Rud and Amalaf Rud and their alluvial fans.

The moving sandhills in the northeast corner of the quadrangle are part of a large belt 7–10 miles wide and at least 50 miles long that extends beyond the border into Afghanistan. The dunes are mostly separate transverse sand ridges along the margins of the belt, but some appear to be modified barchans. In the middle of the belt the same transverse ridges are found, but they merge with a sand platform of unknown thickness generally obscuring the underlying alluvium. Scattered depressions or windows through the sand expose the alluvium base, and half a mile east of the quadrangle the limestone hill "Garrukki Gori" protrudes through the sand platform. The dunes migrate from northwest to southeast.

The mapped patch of dune sand along Saindak Rud is nonmigratory. The peculiar coincidence and perhaps interrelationship between dune patches, coarse grass, and ground water is discussed in the section on "Climate, Water Supply, and Vegetation."

INTRUSIVE ROCKS

Four general types of intrusive igneous rocks, representing a great range of composition and age, are found in the Saindak quadrangle. The most conspicuous are the Tanki sills in the southwestern and southeastern part of the quadrangle, which are thick dark layers of massive resistant rock that form many high ridges south and west of the area mapped. Rather inconspicuous, but important geologically, are several stocks of diorite intruded before metamorphism, and a group of quartz diorite stocks that appear to have been responsible for the metamorphism. In addition, the whole area is cut by dikes and small sills of diverse ages and compositions.

TANKI SILLS

The Tanki sills were named by M. I. Ahmed (1945) who, however, believed them to be flows. These rocks are in layers thousands(?) of feet thick, and form the most conspicuous mountain ridges south and west of the mapped area. The rocks were first described by Vredenburg (1901) who was unsure of their classification but seemed to favor calling them sills. The Tanki sills were included in the Shor Koh intrusions, a group of dikes, sills, and lenticular stocks, by the Hunting Survey Corporation, Ltd. (1960, p. 282–284).

The Tanki sills are andesite porphyry in which the small phenocrysts of feldspar and augite compose as much as half the volume of the rock. The groundmass is either very fine or made up of microlites. Metamorphism has locally converted most of the augite to chlorite and the plagioclase to porphyroblastic albite.

The intrusive relationship of these andesite porphyry rocks is not generally observable; basal contacts are common and easy to see, but upper contacts are rare. Six miles directly south of Saindak, outside the quadrangle, two distinctly separate sills join a thicker stock-like mass, and where they join, the igneous rock cuts squarely across the ends of the sedimentary beds. The metamorphic effects on the wallrocks are limited to slight baking from a few inches to 6 feet from the contact.

Typical Tanki sills are found within the quadrangle only at the extreme southwest corner. Similar type rocks 2.5 miles northward, on the western edge of the quadrangle, are believed to be of the same origin, although no conclusively intrusive contacts could be located there. Porphyritic rock of Amalaf Koh, in the southeast corner of the quadrangle, is also judged to be of the same group of sills. The lower contact was baked and the upper contact was not found. The Tanki sills are in Cretaceous rocks, and they may be truncated by the pre-Paleocene unconformity; if so, their age is rather closely limited.

DIORITE

Four small stocks, or groups of stocks, of diorite are alined northward from Saindak Fort, and a fifth stock is 4 miles to the east-northeast. Outcrops of the southernmost group, about 1 mile north of the fort, consist of two large bodies and three small masses; other stocks to the north are known from one or two exposures. The first group of stocks north of Saindak Fort, and the next to the north, consist of a hornblende diorite porphyry in which most of the phenocrysts are small hornblende crystals. The matrix is fine grained and cloudy, and contains a few ghostlike grains of plagioclase judged to be porphyroblasts of albite developed by weak metamorphism; the grains are too indistinct for positive identification. The third and fourth stocks in the north-trending line, and probably also the fifth stock to the east, are considerably metamorphosed. No hornblende is found, and porphyroblastic plagioclase is well developed. Chlorite, calcite, and epidote are present in these rocks. All five stocks are considered to be of the same age; presumably post-Oligocene, pre-Pleistocene.

Diorite stocks in the southwest corner of the quadrangle have been tentatively included in this same category.

QUARTZ DIORITE

Seven small stocks of quartz diorite were mapped along a north-south line 2–3 miles east of Saindak Koh, following the topographic low called "Sulfide Valley." Several small irregular dikes of the same quartz diorite are between the main stocks, and all the bodies are believed to be part of the same intrusive mass. This intrusive mass is believed to have metamorphosed the relatively broad zone surrounding the stocks. The contact-metamorphic effects include the metasomatic replacement of limestone by hematite or by pyrrhotite and other minerals and introduction of pyrite into the pyroclastic and volcanic sedimentary rocks of Sulfide Valley. The intrusive phase is also presumed to have been responsible for the lead- and copper-mineral veins that are most prevalent in the adjacent metamorphic rocks.

Certain large andesite porphyry dikes and sills, particularly some that seem to have had noticeable metamorphic effects on the wallrocks, are believed to be offshoots of the same quartz diorite intrusive body. The relationship of the andesite porphyry dike swarm that cuts both country rocks and quartz diorite stocks near the southern end of Sulfide Valley to the stocks themselves is not clear; perhaps the dikes represent a final intrusive phase after the upper parts of the stocks had solidified.

The quartz diorite is a uniformly fine grained phanerite composed of dominant andesine (averaging about 60 percent albite) and biotite, hornblende, and 5–10 percent quartz. The biotite is in part an alteration product of hornblende.

Small amounts of copper were found in many places in the quartz diorite bodies within the pyrite-bearing area shown on plate 1, but none was noted in those stocks along the west edge of the zone. On the usual surface exposure, both hydrothermal solutions and weathering have probably contributed to the thorough alteration of the rock.

Generally, only faint traces of malachite can be seen in outcrops or hand specimens, but at one location fresh rock contains grains of chalcopyrite. The quartz diorite stocks as a copper resource are discussed on pages A18–A19.

Because of the low relief of Sulfide Valley and the relatively deep weathering, the contacts of the quartz diorite with the surrounding rocks are not easily studied. Some of the contacts of the northernmost stock seem to be gradational from 10 to 20 feet into the adjacent metasedimentary rocks.

DIKES AND SILLS

The small dikes and a few small sills can be generally divided into five main groups:

1. Old, mostly andesite porphyry dikes, injected after folding but before metamorphism. In some of these dikes the degree of alteration is so intense that the original composition can only be presumed, and in most of these altered dikes, the principal feldspar visible is porphyroblastic and probably albitic in composition. In some dikes, augite is, or was, present as the original mafic mineral, but hornblende is more common. Some of these dikes are believed to be offshoots of the diorite stocks, and some of the basalt dikes also appear to be of the same age.
2. Relatively unmetamorphosed dikes and sills, mostly andesite porphyry, part or all of which may be related to the intrusion of the quartz diorite stocks. Plagioclase and hornblende are the common phenocrysts; the hornblende is generally fresh but locally is chloritized. Porphyroblastic feldspar is not common, but is present in several dikes. Augite seems to have been the original ferromagnesian mineral in only one specimen.
3. A few large quartz diorite porphyry dikes, some of which cut the quartz diorite stocks. The dikes are believed to be distinctly younger than the stocks. They have coarse hornblende and plagioclase phenocrysts and are made conspicuous by their light color. A little quartz is present in most samples; it tends to be embayed and surrounded by narrow reaction rims.
4. Two large serpentinized mafic dikes in the northern part of the outcrop area appear to be a unique type. Of unknown age, they both trend in a northwest direction following no general fault or dike direction. They are locally conspicuous features and range from 10 to perhaps 30 feet in thickness.
5. Young basalt dikes of varying composition are found over the entire area. Because of their freshness (such as an almost unaltered olivine-rich dikelet cropping out near the west edge of the area), some of these dikes are believed to be very young, whereas others are partly or entirely decomposed by alteration and may be older. Two small pipelike fresh basalt dikes 2.7 miles northwest of Saindak Fort contain abundant phenocrysts of augite and biotite and a multitude of fine specks of magnetite. Basalt flows are intercalated in tilted conglomerate beds, probably of the Kamerod Formation, at the edge of the mountain range, 65 miles to the northwest at Hurmok in Iran. These conglomerates are composed of pebbles of Eocene limestone. The fresh basalt dikes at Saindak may represent the same period of igneous activity.

VOLCANIC ROCKS

Much volcanic material is interbedded with the marine sedimentary rocks of the Saindak region and most of it is water laid.

Abundant volcanic sand and conglomerate are found intercalated with sedimentary rocks of Cretaceous and Eocene age, and the Paleocene-age rocks contain some cobbles, pebbles, and layers of sand of volcanic origin. Some of the Cretaceous rocks may be welded tuff, flows, or an intrusive body; the field relationships we found were not sufficient to identify them properly. Thick volcanic conglomerate and agglomerate layers in the Eocene section consist mostly of coarse material with some fragments several feet long. Mafic flows extruded under water are found in a narrow zone in rocks of Eocene age.

The slightly folded rocks of the Kamerod(?) Formation capping Saindak Koh and covering the tops of several high hills to the south are mostly andesitic volcanic agglomerate. Compact rhyolitic breccia and tuff with some coarse fragments, regarded as part of the Kamerod(?) Formation, cap each of two hills in the area of outcrop of Cretaceous rocks about 3½ miles west and 1 mile north of Saindak.

The volcanic rocks of the Kamerod(?) Formation were not examined in detail. The rhyolite contains small quartz phenocrysts. Most of the presumed andesite is dark colored—shades of maroon, reddish brown, and purple where relatively unmetamorphosed, and greenish gray to black where metamorphosed; it contains various amounts of small plagioclase and mafic phenocrysts.

The flows in an area 3–6 miles northwest of Saindak are interlayered near the top of the volcanic sequence in the Saindak Formation. The flows were probably extruded beneath the sea. Their exceedingly rubbly nature and the great abundance of hydrous minerals are compatible with this view. Two separate flows were mapped. The older one crops out for 1 mile and is as much as 200 feet thick. The younger, several hundred feet stratigraphically above it, may be many hundreds of feet thick at its thickest northern end and is exposed for more than 3 miles.

The composition of these flows is believed to be andesitic. The flows are exceedingly rubbly and amygdaloidal; some of the material is scoriaceous. A crude blocky structure seen at a few places somewhat resembles pillow structure, but is perhaps a type of spheroidal weathering that has developed inward from regularly spaced cracks. Chlorite and zeolites are abundant in places and fill vesicles and cracks between blocks. Chalcedonic silica and crystalline quartz fill many openings in the flows, and various types of agate and chalcedony are very abundant in the dry streams draining the outcrops. Most of this material seems too cracked to be of any use as a lapidary material, however.

STRUCTURAL GEOLOGY

Folds and faults on a large scale characterize the geologic structure of the Saindak quadrangle. Three main periods of folding have affected the rocks of the area: (1) at the close of the Cretaceous Period; (2) sometime after the middle Eocene (probably post-Oligocene); and (3) relatively late, probably Pleistocene. Little evidence of the last folding was noted within the quadrangle. Most faulting appears to have taken place at the same time as the second period of folding, although faulting may have accompanied all three stages of folding.

FOLDS

The dominant geologic structure in the Saindak area is the large northwest-trending syncline called both Mirjawa synclinorium and Saindak syncline by Hunting Survey Corporation, Ltd. (1960). Saindak syncline is used in this report. This roughly symmetrical fold is clearly defined in the Tertiary rocks but is not as conspicuous in the older rocks that have been subjected to more complex two-stage folding. Many other narrower, tighter folds in Cretaceous rocks parallel the Saindak syncline on the southwest side; two of these cross the southwest corner of the quadrangle.

The Saindak syncline disappears a few miles northwest of the quadrangle but extends for 40 miles southeast of it, as shown on geologic maps Nos. 17, 18, 21, and 22 of the Hunting Survey Corporation, Ltd. report (1960). Slight recurrence of folding on the same fold axis followed deposition of the Kamerod(?) Formation, both in Saindak Koh and about 25 miles to the southeast. Many small drag folds are found in the softer, less competent middle Eocene shales near the axis of the syncline north and northwest of Saindak; drag folding in the older Tertiary rocks is fairly common.

FAULTS

About 150 faults were mapped in the field during this study, although not all these faults have been included on the geologic map. Probably hundreds more were noticed in the field but were of too small displacement to be recorded.

The faults can be divided into two general groups, one group related to the first period of folding and the other group related to the second period.

Faults in the tightly folded Cretaceous rocks shown in the southwest corner of plate 1 strike N. 20° E. (a few N. 30° E.) nearly perpendicular to the folding, and N. 60° W., or parallel to the folds. A very few faults trend about 45° to the fold axes.

Faults appear to be more abundant in the Tertiary rocks, because significant offsets are more readily recognized. In these rocks a great many faults strike at an angle of about 45° to the northwest-trending fold axis. There are also several strike faults, some faults that are normal to the fold axis, and some faults that change direction from one form to another. Some pre-Paleocene faults may have been rejuvenated during later Tertiary time. The evidence for this is the continuation of faults from Cretaceous into Tertiary rocks, with a change in fault direction near the contact (see the northeast-trending fault about 3 miles north of Saindak Fort and the east-west fault half a mile south of the fort). In the northeast limb of the Saindak syncline southeast of cross section *B–B′* (pl. 1), the north-trending faults cross the Cretaceous-Tertiary contact without deflection, suggesting that all these faults formed when the Saindak syncline formed.

The planes of almost all faults are so nearly vertical that, except where otherwise noted, they are regarded as vertical. Perhaps four faults with intermediate dips were seen during the entire survey. Most younger faults in the quadrangle show consistent right-lateral movement, but in the area of section *A–A′* (pl. 1) some faults show left-lateral movement.

Direction of movement was not determined on most of the faults; but where slickensides were seen on the surfaces, the grooving was nearly horizontal.

Horizontal displacement on these faults generally ranges from a few feet to as much as 3,000 feet, and in the great east-west fault just south of Saindak and bounding Saindak Koh, the horizontal left-lateral offset is 1 mile. Part of the actual displacement on this particular fault is vertical, however, and the south side is upthrown.

The unconformity at the base of Saindak Koh was described by Vredenburg (1901, p. 260) and Hunting Survey Corporation, Ltd. (1960, p. 357–359, figs. 17, 19), and interpreted as a fault, probably because there has been a considerable amount of differential movement at the unconformity surface at a few places, one of these being a readily accessible point near Saindak Fort marked by conspicuous slickensides. The "disconformity" was noted by Ahmed (1945, p. 5).

The localized differential movement on the unconformity in Saindak Koh is due to the late, probably Pleistocene, folding of the Saindak syncline after deposition of the nearly horizontal sedimentary and volcanic beds. Near the northeast end of Saindak Koh, the capping rocks dip 25° SW, which seems mostly the result of late folding (pl. 1, section *C–C′*).

JOINTS AND ROCK CLEAVAGE

No analysis was made of the abundant joints in the Saindak region that cut all but the unconsolidated youngest rocks. The commonest systems seem to parallel the north-south and east-west fault directions. Very striking systems of columnar joints and sheet structures cut the Tanki sills 2–5 miles south of the quadrangle.

Neither fracture nor flow cleavage was noted in the area of metamorphic rocks east of Saindak, as outlined on plate 1, which seem to have developed without any evidence of stress. In the extreme southwest corner of the quadrangle, near the synclinal mountain capped by Tanki sills, slight flow cleavage has formed in the argillaceous rocks as part of a zone of regional metamorphism developed to the west.

METAMORPHISM AND METASOMATISM

A zone of metamorphic rocks trends northwestward through the middle of the Saindak quadrangle (pl. 1), surrounding the group of quartz diorite stocks. It forms an elongate area. The north end is covered by Holocene alluvium, and the south end terminates less than a mile south of the quadrangle. The grade of metamorphism is low, and most of the rocks are albite-epidote hornfels. This zone probably corresponds to the "zone of propylitic alteration in which chlorite, epidote, and minor carbonates are developed" described by Lowell around the Kalamazoo porphyry copper ore body in Arizona (Lowell, 1968, p. 651). Intense pyritization of the country rocks has taken place in a smaller envelope within the propylitic zone and immediately surrounding those quartz diorite stocks which also contain anomalous quantities of copper; this probably corresponds to Lowell's "pyrite zone" (1968, p. 649, fig. 4). Outcrops of pyritized country rock are widespread in Sulfide Valley where almost all the rocks contain a little and a few contain as much as 15 percent sulfide (as described under "Economic Geology").

Small patches of epidote-garnet-calcite-specularite tactite within the albite-epidote hornfels seem to reach the hornblende-hornfels facies as defined by Turner and Verhoogen (1960, p. 511–520); however, this assemblage may be only a reflection of locally different rock composition in an otherwise generally similar metamorphic environment. The small localities where tactites have formed and garnets and various iron-rich silicates have developed extensively seem to be limited to the limestone beds in the original sedimentary section. At other places the limestone beds have been metasomatically replaced by hematite, and still others have been enriched by as much as 20 percent pyrrhotite.

The albite-epidote hornfels is generally a darker rock that tends to form much higher hills than the unmetamorphosed rock of similar composition. In contrast, the pyritized rock in Sulfide Valley, although bordered to the east and west by the hills of albite-epidote hornfels, has eroded to rounded forms of low relief.

The metamorphic zone as shown on plate 1 was mapped on the basis of the following simple field criteria:

1. Formation of new minerals, of which only epidote is recognizable at the edge of the zone.
2. Hardening of shales to a dense porcelaneous hornfels, and hardening of agglomerate to a massive rock that breaks across the original fragments rather than around them.
3. Change in color of agglomerate from reddish brown to greenish gray, dark green, and, in some places, almost black; change of reddish-brown shale to gray hornfels and red sandstone to quartzite.
4. Conversion of limestone to marble.

The fringe of the metamorphism, as so defined, is in places sharp, but at others, difficult to locate. The metamorphic changes used as criteria in the field seem to have developed a little more readily in the volcanic conglomerate and agglomerate than in the ordinary shale, siltstone, and limestone, and the boundaries tend to bend inward when crossing bands of the nonvolcanic rocks, although this is not particularly evident at the scale of plate 1.

Unrecrystallized fossils were collected from limestone lenses well within volcanic agglomerate in which the metamorphic criteria described above were quite clearly developed. The many small sporadic patches within volcanic conglomerate north and northwest of Saindak that seem just slightly metamorphosed made mapping difficult. These were not sharply enough defined to be separately mapped, but one such spot must be noted. In the northwestern part of the area, one small limestone reef was found to have been completely replaced by hematite and constitutes a very small tonnage of rather rich iron ore (pl. 1, loc. SN–60). It is not clear what has caused the replacement at this particular place, but the greater abundance of dikes in the area and indications of low-grade metamorphism suggest that this may be part of a separate zone of metasomatism.

The metamorphic rocks were also briefly studied by examination of thin sections, and this study confirmed the general relationships mapped. Characteristic minerals of the metamorphosed zone are poikiloblastic albite, chlorite, epidote, biotite, and, as shown on some slides, hornblende and specular hematite. The tactites include, in addition, coarse-grained calcite and specularite, garnet that is probably andradite, and a variety of dark-green ferrous silicates, including stilpnomelane.

Where iron-sulfur metasomatism has resulted in introduction of pyrrhotite, calcite of the limestone beds has been largely replaced by chlorite and hornblende. Axinite is found with calcite in small veinlets that cut the pyrrhotite-bearing beds.

Flow cleavage in the rocks in the southwest corner of the quadrangle is at the extreme edge of a zone of regional metamorphism. This zone extends westward into Iran, at least to the vicinity of Zahidan. The degree of metamorphism as indicated by the perfection of flow cleavage increases steadily westward toward the Iranian border for a distance of 3 miles. Similarly metamorphosed rock was also observed by us along the western edge of the ranges in Iran at about the same latitude, as well as farther northwest along the road to Zahidan.

Regional metamorphism in adjacent Iran, as described by Bartolucci (1959, p. 50–51), seems to have a spatial relationship to the Zahidan granite stocks, although he has concluded, on the basis of cleavage directions, that the stocks were not the metamorphosing factor.

ECONOMIC GEOLOGY

The Saindak quadrangle was selected for study in preference to other areas in the northern and western Chagai District because of the abundance of small deposits of ore minerals and of evidence of hydrothermal action on the rocks of the area. Many new veins of lead and copper minerals were found in the course of the survey, but, unfortunately, all are very small and for the most part do not deserve further investigation. Of particular interest are intrusive stocks and their adjacent wallrocks that contain small amounts of disseminated copper minerals that may constitute a minable resource. These deposits, discussed under "Disseminated Copper Sulfides," seem to fit the general pattern of the classical porphyry copper deposit.

The lead and copper veins of the Saindak area were mentioned by Vredenburg (1901, p. 260). One vein in Saindak Koh and the Zonk vein northeast of Saindak Fort were described by Ahmad (1943); the report included descriptions of extensive prospect pits dug in the Saindak Koh vein during a period of 2 months. The vein on Saindak Koh was also described by Hunting Survey Corporation, Ltd. (1960, p. 455), and another lead-copper-bearing vein 4½ miles east of Saindak was mentioned.

Small hematite deposits, metasomatic replacements of limestone or marble, northeast of Saindak were first reported by the Hunting Survey Corporation, Ltd. (1960, p. 448).

The locations of ore-mineral showings found during the course of this survey are indicated on plate 1. The primary ore minerals are galena, chalcopyrite, and hematite, and there is an even greater variety of secondary minerals as a result of surficial weathering. Pyrite, pyrrhotite, calcite, and epidote are also very common minerals in the area as a result of metasomatism and metamorphism.

Three general types of mineral deposits were found: (1) disseminated copper sulfides in stocks of quartz diorite, (2) metasomatic replacements of limestone reefs and beds by hematite or pyrrhotite, and of volcanic agglomerate and tuff by pyrite, and (3) simple hydrothermal veins containing copper and lead minerals filling some fractures and openings along some fault planes.

DISSEMINATED COPPER SULFIDES

Small amounts of chalcopyrite and secondary copper minerals are visible in many of the exposures of quartz diorite in Sulfide Valley. Scattered preliminary sampling indicates a wide range in copper content and suggests that the most "interesting" area may be within the southernmost body mapped (between field reference Nos. R–149 and R–152). We have found only a little data indicating that mineralization penetrates the closely adjacent wallrocks also.

Each copper-stained quartz diorite body was sampled at least once, and seven surface samples of about 15 pounds each were taken and analyzed. From north to south, these analyses were: R–110, 0.5 percent; R–148, 0.01 percent; R–150, 0.03 percent; R–149, 0.01 percent; R–129, 0.5 percent; R–96, 0.8 percent; R–152, 0.03 percent (M. A. Wahid, Geol. Survey of Pakistan, analyst).

The most thoroughly sampled stock is the southernmost one from which four samples, R–96, R–129, R–149, and R–152, were collected by us; later, two additional samples were taken by R. H. Nagell. One of Nagell's samples was taken roughly 500 feet southeast of R–149, and one perhaps 200 feet northwest of R–96. These samples contained 0.26 and 1.49 percent copper (Chauhan, Geological Survey of Pakistan, analyst), but we do not know which came from which location.

Additional surface sampling and a program to test these rocks at depth by drilling was recommended. Four exploration holes were later drilled by the Geological Survey of Pakistan; some of the results of this drilling have been noted by Schmidt (1968, p. 58). We were not able to decide how much surface leaching may have taken place or to judge the possibilities of secondary enrichment at depth, but a secondary enriched zone at depth is possible and must be taken into consideration in any future exploration plans in the area.

The pessimistic outlook for the occurrence of copper we expressed earlier (Khan and others, 1964, p. 178) was based on preliminary consideration of field data, and further study has resulted in the more optimistic recommendations presented in this report.

METASOMATIC REPLACEMENT DEPOSITS

Earthy red hematite and black specular hematite have partly or completely replaced thin beds of limestone (loc. R–287, pl. 1) and small lenticular limestone reefs (locs. R–58, SN–60, pl. 1). The resultant hematite is high grade, probably containing only small amounts of alumina and secondary silica as impurities. Small spots of malachite stain are rather common in the hematite. Although the hematite bodies may contain appreciable iron, the size of the deposits is negligible. The hematite beds at location R–287 range in thickness from 1 inch to 1 foot. Several beds were followed for 1,000 feet; eastward, they grade into marble, and westward, the exposures pinch out or are covered by alluvium and weathered rock.

Hematite has replaced an outer rim 10 feet thick of a reef 40 feet in diameter at location R–58; the center of the reef is a coarse recrystallized white or gray marble. A trench made by prospectors exposes the deposit on two sides. Another similar, but smaller, deposit about 100 feet to the southeast has a thinner shell of hematite surrounding the marble core. Other similar small hematite bodies in the area were indicated by float blocks of hematite in the gullies.

A reef that seems to have been completely replaced by hematite was found at location SN–60, where it forms a small, but conspicuous, black hill. A generous estimate of the ore available might be 5,000 tons.

Pyrrhotite has replaced most or all limestone beds in the pyrrhotite-bearing area outlined on plate 1, 2½ miles northeast of Saindak. The limestone beds are completely metamorphosed and recrystallized for a length of 1,500 feet, and minerals found in addition to pyrrhotite are calcite, epidote, and garnet. Small amounts of chalcopyrite are probably also present, as the weathered rocks contain small malachite stains. No nickel was detected spectroscopically, and the presence of nickel would not be expected in pyrrhotite formed in this fashion.

In places the metamorphosed rocks in the pyrrhotitized zone are cut by veinlets of calcite and axinite.

Pyrite has formed by metamorphic or hydrothermal action in metamorphosed volcanic agglomerates, conglomerates, and tuffs in a zone (Sulfide Valley) 2,000 feet wide and extending north-south about 4 miles (pl. 1). Pyrite is found as small disseminated grains irregularly distributed in the metamorphic rocks and in places makes up 15 percent of the total rock; 5 percent is a rough estimate for the entire zone.

Relatively deep weathering has taken place in parts of the areas underlain by pyrite- or pyrrhotite-rich rocks, particularly in the central part of Sulfide Valley, where gently rounded low topographic forms contrast with the higher sharper hills of barren rock on each side (fig. 2). In many places in this valley a saprolitic material has formed, and fresh rock specimens are exceedingly difficult to obtain, thus increasing the difficulty of prospecting. At some localities a relatively soft spongy material remains, preserving much of the original rock texture but few of the minerals. At other localities a soft structureless soil overlies a hard, horizontally layered crusty rock that completely resisted our attempts to penetrate it more than a few inches with prospect pits. Throughout the area are layers and pockets of bright-red and bright-yellow powdery materials in the soil; these are used by local people for dyeing wool and are named, respectively, "gulik" and "mak." (See also Vredenburg, 1901, p. 278–279). These powders were analyzed by J. J. Matzko, U.S. Geological Survey, and found to be principally natrojarosite. Sporadic exposures of these bright materials are found throughout the areas of sulfide-rich rocks and serve as reliable indicators of the mineralized rock beneath.

HYDROTHERMAL VEINS

A great many small lean hydrothermal veins are found in the Saindak quadrangle, mostly in the area east of Saindak Koh. The locations of the more important veins are shown on plate 1. These veins contain small amounts of galena, chalcopyrite, and many oxidized minerals; malachite and cuprite are common, whereas azurite and red, orange, and yellow lead min-

FIGURE 2.—Sulfide Valley, looking east. Rounded weathering forms of sulfide-bearing rock in foreground contrast with dark rugged metamorphic rocks without sulfide in background.

erals are sparse in the oxidized surface exposures. Some of the red material has been identified as phoenicochroite and some of the orange as wulfenite (John Matzko and Mary Mrose, U.S. Geol. Survey, analysts). Common gangue minerals are calcite, sideritic calcite, quartz, limonite, and hematite. Traces of manganese oxides are found in most of the veins. Almost all the veins are along vertical faults in metamorphosed volcanic agglomerate or conglomerate and in various dike rocks; only a few are in minor irregular fractures or in unmetamorphosed sedimentary rocks.

The "Zonk" vein (pl. 1) appeared to be distinctly zoned, lead minerals being present toward the northern end, both lead and copper minerals in the middle, and copper minerals near the southern end.

One sample of galena from a vein on the east side of Sulfide Valley (R–106) contained 0.09 percent silver or 1.8 ounces per ton (C. L. Burton, U.S. Geol. Survey, analyst). The same galena also contained 200 parts per million chromium (J. L. Harris, U.S. Geol. Survey, analyst). Pieces of litharge, the lead-rich slag resulting from an ancient method of extracting silver from lead-silver ores, were found near Saindak Rud, and they indicate that this smelting process was probably used here in the past. The amount of silver obtained and the source of the ore are not known.

Barren siliceous veins and sideritic calcite veins are found on many of the major faults. The deposition of thick veins of sideritic calcite by fissure filling or replacement of gouge and perhaps part of the vein walls was an early stage of mineralization and preceded deposition of all the ore minerals.

Small veins of chalcocite stained with malachite, in some places associated with calcite but in others mostly without gangue, are found in the volcanic rocks of Cretaceous age. Only some of those noticed during the fieldwork are shown on plate 1 near the west edge. Small specimens of very high grade ore can be removed from the veins which are short and narrow. These copper-bearing veins in Cretaceous rocks do not seem to be part of any general mineralizing phase, and they are regarded as having no economic significance.

SUGGESTIONS FOR FURTHER INVESTIGATIONS

The copper-bearing quartz diorite stocks in the Saindak quadrangle are interpreted to be of the copper porphyry type, embodying many of the features described by Lowell (1968). Only a systematic exploration program can determine the quantities and grades of copper-bearing material present, and only careful evaluation can determine whether mining will be advantageous despite the extremely remote location and scarcity of water.

Further investigation of the copper resources of the Saindak quadrangle should consist of very detailed field mapping of the stocks and, at least, of the enclosing pyrite-zone envelope, and extensive surface sampling, perhaps on a closely spaced grid, of the stocks and, to some extent, of the enclosing rocks also. The mapping and sampling can then be the basis for planning a program of exploratory drilling.

Other mineral deposits of this type are possible in western Pakistani Baluchistan; prospecting for such deposits is strongly advised, especially in the area from Saindak northwestward to the border of the country.

On the basis of experience in the Saindak mineralized area, the most rapid and inexpensive method of seeking new areas to prospect is by examination of the terrain either from aerial photographs or from a low-flying aircraft. The metamorphosed (propylitized) zones should be recognizable as hills that are higher, sharper, and more resistant to erosion than the surrounding area, and in places by an abundance of dikes and even dike swarms.

Recognition of sulfide-enriched areas, such as Sulfide Valley, on aerial photographs would greatly simplify prospecting, but we could see nothing distinctive about the valley on the black and white photographs of the Saindak area. Where well exposed, the sulfate-rich soils mantling the sulfide-bearing rock stand out on color aerial photographs (Jerome, 1966, p. 82–83) and when viewed from an aircraft. Where these soils are diluted by surface material and are not easily seen, their recognition on photographs might be enhanced by examination with selected colored filters (Schmidt, 1968, p. 59).

More thorough mineral exploration of the region must include methods capable of detecting both unrecognized and hidden deposits—airborne and surface geophysical methods and especially types of geochemical exploration that have proved useful in very arid climates.

Near Saindak, hematite has replaced material in the thin layers and small lenses of limestone included within the metamorphic zone; similar replacement by hematite or magnetite may be present in some other metamorphosed locality where thick limestone layers, abundant in many places in the region, were originally present.

The vein deposits of lead and copper in the Saindak quadrangle are very lean; but in a mineralized area where the veins have greater extent, these deposits might be of some importance and should be examined. Although no cinnabar was found in our mineral reconnaissance, geologic conditions in the area are favorable for its presence, especially near the large centers of hot-spring activity farther east in the Chagai District.

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