GEOLOGY AND ECONOMIC POTENTIAL FOR CHROMITE IN THE ZHOB VALLEY ULTRAMAFIC ROCK COMPLEX, HINDUBAGH, QUETTA DIVISION, WEST PAKISTAN

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ABSTRACT

The ultramafic rocks making up the Zhob Valley igneous complex have yielded small amounts of metallurgical-grade chromite since the early part of the century. From 1968-1970 a cooperative study undertaken by the Geological Survey of Pakistan and the U. S. Geological Survey, under the auspices of the Government of Pakistan and the Agency for International Development, evaluated the chromite potential of the Zhob Valley area and provided data for effective exploration.

The Jung Tor Ghar ultramafic rock mass, covering an area of about 45 square miles, is a thrust-fault block completely surrounded and underlain (?) by sedimentary rocks as young as Late Cretaceous in age. The igneous rocks were thrust from the northwest along an east-trending, north-dipping fault in Late Cretaceous or Paleocene time and were peneplaned, dissected, and deeply laterized by mid-Eocene time.

The ultramafic rocks consist of interlayered harzburgite and dunite and a cross-cutting dunite here called transgressive dunite. Layered structure passes without discernible deviation from the interlayered harzburgite-dunite through the transgressive dunite. The lowest rocks

in the mass, composed mainly of transgressive dunite, grade upward into the interlayered rock about 3,000 feet above the fault block base. The upper transgressive dunites tend to form interconnecting linear networks and probably a few pipe-like structures.

The transgressive dunite is thought to have formed by action of water derived from the underlying sedimentary rocks; the water heated by the hot ultramafic rock (at the time of emplacement) altered the pyroxene to olivine and talc, and, with lowering temperature, to serpentine. Other interpretations are possible.

Virtually all the chromite in the Jung Tor Ghar lies in or immediately above the masses of transgressive dunite. This fact provides a key to chromite exploration: The most favorable zone for prospecting lies in the vicinity of the upper contacts of the transgressive dunite masses where they are flatly dipping; if the transgressive dunite masses are steeply dipping or pipe-like, the chromite tends to be more centrally located.

The Jung Tor Ghar is believed to contain enough unmined chromite at practical minable depths to equal or exceed that mined to date but the individual deposits are likely to be small.

INTRODUCTION

The present investigation was started in November 1967 to determine the economic potential of the chromite-bearing ultramafic rocks near the town of Hindubagh, West Pakistan. The work was done jointly by members of the Geological Survey of Pakistan and the U. S. Geological Survey under the auspices of the Government of Pakistan and the Agency for International Development.

The investigation concerns a group of igneous rocks collectively called ultramafic rocks or ophiolites that are characterized by having an unusually high proportion of magnesium and an abnormally low proportion of silica. The ultramafic rocks studied form the Jung Tor Ghar (range) which is an isolated part of the Zhob Valley igneous complex (Bilgrami, 1964). A larger igneous mass, in the Saplai Tor Ghar-Nasai area, crops out to the east, outside the mapped area. Ultramafic rocks are the only source of chromite.

Chromite is an oxide mineral of variable composition with the formula $(Mg, Fe^{++})O\ (Cr, Al, Fe^{+++})_2O_3$. High aluminum chromite is a valuable refractory owing to its high melting point. Chromite high in chromium is the only economic source of chromium used in metallurgy. Other elements associated with some ultramafic rocks are nickel and platinum.

The great scientific importance of ultramafic rocks stems from the fact that they have probably formed at great depths. They undoubtedly hold decipherable information of fundamental importance concerning the genesis of igneous rocks and the composition of the earth at considerable depths. However, at present there is wide divergence of geologic opinion on the origin and geologic history and on interpretation of rock relations of ultramafic rocks. This is probably due to two factors: inadequate geologic mapping, and lack of recognition of fundamental processes involved in the formation of these rocks.

The present investigation emphasized systematic mapping of rock relations and structures and their relation to chromite deposits and has resulted in the recognition that most of the chromite in the Jung Tor Ghar occurs under certain specific geologic conditions. This knowledge provides a sound basis for future exploration. The work has revealed the need to develop new field mapping techniques and methods of portrayal in illustrations. It has also shown that certain geologic processes may be of greater importance than here-to-fore believed, and that these need to be evaluated under controlled laboratory conditions.

Geography

The Hindubagh area is in the western part of West Pakistan near the Afghanistan border (fig. 1). It is near the center of a folded Alpine-type mountain belt extending from the Arabian Sea northward and eastward as a hugh regional flexure, known as the Central axis, to the Himalayan mountains, of which it is structurally a part. The Zhob River Valley, north of the complex, is a major topographic feature. Nearly 10 miles wide at Hindubagh, the valley floor is gently concave from the middle and sweeps evenly down valley to the east. The climate is arid; annual precipitation is about 8 inches, falling mainly as snow between December and March. The summers are hot and dry. The area is barren except for sparse low thorny bushes and grass. A few ancient juniper trees grow at high altitudes near the southern end of the mapped area. Fox, rabbit, mice, porcupine, and other small animals are sparsely present, as are small birds resembling quail, and crows, hawks, and vultures. Scorpions, centipedes and a few

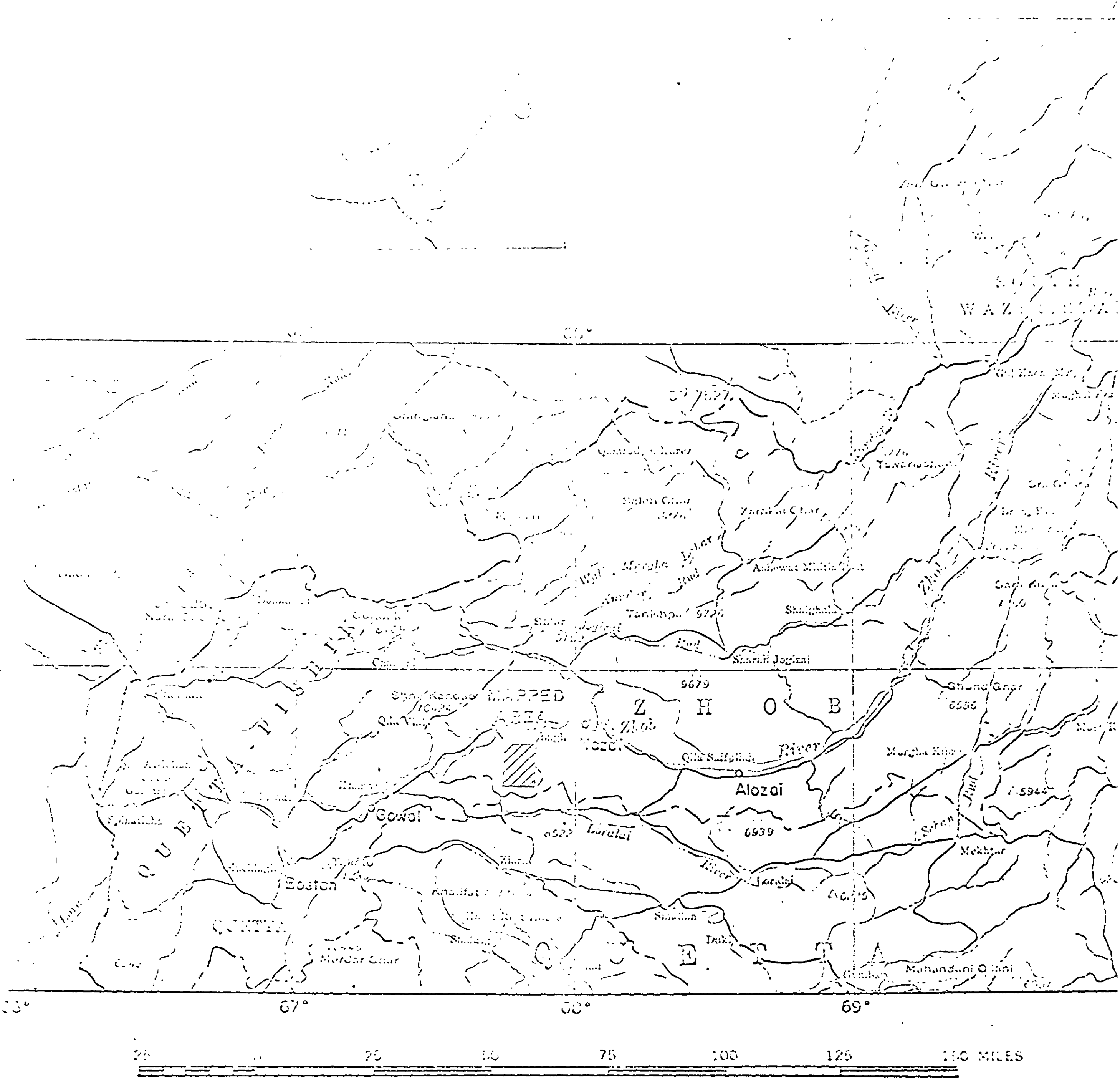


Figure 1. INDEX MAP SHOWING LOCATION OF REPORT AREA

snakes, including cobra, are indigenous. Goats and sheep graze throughout the area. Springs are common in the valleys (nalas) near the base of the mountains, and these supply limited water for a few small farms and settlements. Although some springs flow throughout the year, many dry up during the hot summer months, and resume their flow even without additional rainfall as the temperature falls. Commonly magnesium-rich spring deposits accumulate as flat, grass covered, terraces.

Hindubagh is the largest settlement near the area and has a population of several thousand persons. It is the site of the local military establishment and has a high school and a hospital. A government rest house is maintained there, and Hindubagh is the railway shipping point for the chromite mined in the area. A narrow gauge railway from Fort Sandeman connects with a standard gauge track at Bostan. A surfaced all-weather road connects Hindubagh to Quetta, 74 miles to the southwest.

Farming is increasing both in amount and in use of modern methods. Tractors are being used in increasing numbers. In the absence of timber, most of the buildings are constructed of dried clay, bricks, or stone. Many of the people are permanently or intermittently engaged in some phase of chromite production. A large network of roads has been built and is maintained by the mining company for haulage of chromite.

The Zhob Valley has long been occupied by man, and ruins of ancient structures and fortifications are widespread throughout the area. Several old stone fortifications are about one mile southwest of Hindubagh.

Acknowledgements

During the course of the investigation which extended over almost 2 years, the members of the party were provided with excellent living quarters in Hindubagh at the headquarters of the Pakistan Chrome Mines, Ltd. Initially this was under the direction of Dr. S. A. Bilgrami and later during 1969 under the direction of Mr. A. Farooqi, General Manager. In addition, at times repairs to vehicles were made in the shops of the company and on several occasions transportation was provided to the party members when their vehicle was being repaired. For several periods the company provided quarters for the party members, and in many other ways the members of the mining company individually and collectively were of great assistance. In particular, the assistance of Messers Mohiuddin, Ahmed Saeed Hasni, Ismail Yusfi, and Syed Reza Shah is gratefully acknowledged. Both Dr. Bilgrami and Mr. Farooqi deserve special thanks for their kind assistance.

Previous investigations

The Zhob Valley Complex has received little attention in the way of detailed investigation. The area comprising the Jung Tor Ghar was first mapped at a scale of 1 inch=4 miles and described by Vredenburg (1904). Subsequently, Fermor (1916) briefly described the chromite deposits and the history of mining. He also determined the reserves of chromite in the Zhob Valley Complex as 63,400 tons for the entire area between Gowal and Nasai. Hayden (1917, p.12) also described the chromite deposits, based on information derived from Fermor's visit. Reports on the mining of chromite are given in a number of annual and other reports of the Geological Survey of India.

In recent years the Zhob Valley Complex was again mapped at a scale of 1 inch=4 miles by the Hunting Survey Corp., Ltd., Toronto, Canada (1960, map Nos. 26, 27); and the geology, structure, and tectonic setting were described in some detail (1960, p. 136, 338-339, and 370).

Chemical analyses of a few chromite deposits from the Jung Tor Ghar were discussed by Bilgrami and Ingamells (1960). Subsequently, Bilgrami (1964) published analyses of some 20 chromite samples and discussed their chemistry along with the chemistry of chromite from other parts of the Zhob Valley Complex. Distribution of chromium and trace elements in the chromites of the Zhob Valley was discussed by Bilgrami (1961).

Asrarullah (1960-62) mapped part of the Zhob Valley Complex which includes the Jung Tor Ghar, but his work has not been published. Farah (1964) made a gravity survey in the western and eastern parts of the Zhob Valley Complex; the Jung Tor Ghar was not covered by this survey. On the basis of four hand specimens, Shams (1964) discussed the possible origin of some of the structures in chromite-bearing serpentinites in the Zhob Valley Complex.

The chromite deposits of the Jung Tor Ghar were the subject of mineralogical studies and studies of cost of concentrating low-grade chromite ore by Bogue (1961a, b).

Bilgrami and Howie (1959, 1960) and Bilgrami (1956; 1960; 1963a, b; 1968; and 1969) also have discussed different aspects of the Zhob Valley Complex, particularly chromite; some of their work concerns the area covered in this report.

Other investigators include Khan and Weinert (1951); and Quadir, Rehman and Khundkhar (1956).

The ultramafic rocks which are the main subject of this investigation, have been named the Zhob Valley Igneous Complex by Bilgrami (1964). The complex consists of a number of isolated masses of ultramafic rocks that crop out along the south side of the Zhob-Quetta valleys from Gowal, 3 to 4 miles southwest of Khanozai, on the southwest to a point beyond the Nasai area on the east (fig. 1). The topography is more or less controlled by the type of underlying rocks. Most of the ultramafic rocks are somewhat more resistant to erosion than are the sedimentary rocks, and form mountains. The area under investigation, called the Jung Tor Ghar, is surrounded by sedimentary rocks of Triassic to Cretaceous age, and stands out as high, rugged, bare rust-colored mountain peaks. The highest and most rugged is Ush Ziarat, which is 9,900 feet above sea level, about 3,000 feet above the general level of the valley. Saplai Tor Ghar lies to the east and is lower and less rugged, although the east end, the Nasai area, consists of bold rugged mountain slopes composed of gabbroic and ultramafic rocks. The smaller ultramafic masses scattered along both sides of the Zhob Valley are lower and are more rounded than are the larger masses of the Jung Tor Ghar and Saplai Tor Ghar.

The mountain slopes over most of the Jung Tor Ghar are rugged, irregular and cliff-forming. At several places an old rolling upland surface is present on the upper slopes of the higher peaks in the Jung Tor Ghar. A correlative surface in the eastern part of the Saplai Tor Ghar extends eastward to the Nasai area.

Present investigation

The survey party has included at one time or another the following: Zaki Ahmad, Hasan Farooq, Rab Nawaz, Hamidur Rahman, who are members of the Geological Survey of Pakistan, and Darwin L. Rossman, U. S. Geological Survey. Zaki Ahmad has been the party chief for the Geological Survey of Pakistan staff. He personally did a large part of the field work. Most of the geologic mapping on the southern half of the area is his work. In addition, he accompanied Rossman on many traverses. He also has supervised the field and laboratory work of the other members of the party. Mr. Rahman mapped independently in the southern end of the area. He also did most of the sample preparation for analysis and cleaned more than 400 samples during the course of investigation. Rab Nawaz and Hasan Farooq were assigned to the investigation for only a short period. Their mapping on the west, north, and southeast sides of the Jung Tor Ghar has been incorporated in the geologic map. Rossman has covered most of the area either during the initial mapping or later where additional information was needed. Most of the writing and map compilation was done by him.

The staff members of the Geological Survey of Pakistan have all consistently supported the investigation in every way possible, and owing to their cooperation and effort the work has gone forward smoothly, efficiently and on schedule.

Field mapping started in November 1967 and continued until December

15 when the weather became too severe. Mapping started again in April 1968 and continued until June when it was recessed for initial report preparation. The work was resumed in September and continued until the basic geologic map was completed in mid December. Field checking and some further mapping was done in the spring and fall of 1969. All field work was done from headquarters in Hindubagh.

Geologic mapping

The ultramafic rock consists of varying proportions of pyroxene and olivine. The rock type, at one extreme, includes harzburgite composed of olivine and as much as 40 percent pyroxene; the other extreme is dunite, which contains less than 5 percent pyroxene. All gradations exist between the harzburgite and dunite, but on the other hand, rather sharp but still gradational contacts exist even between two rocks of contrasting intermediate compositions. Such rock boundaries are evident, both in the field and on aerial photographs, by contrasts in color or tone, rock surface texture, and by topographic expression. The pyroxene-rich rocks are the darkest and roughest, and comprise the most rugged outcrops, topographically. Generally, however, the rocks grade almost imperceptibly and the mapping of the rock distribution and structures is probably as difficult as any encountered in the field of geology.

Because of the limited time available, the rocks were separated into two units only: harzburgite and dunite. This could not be done where rock of intermediate composition had distinctly visible boundaries and lay between obvious harzburgite and dunite units. Under such circumstances, an intermediate rock unit has been shown and designated as dunite "a."

Dunite is present as: Thinly laminated dunite, transgressive dunite, dunite interlayered with harzburgite, and possibly as dunite intrusive into the above rock types. In addition in certain areas, particularly near the border of the complex, the rocks are extensively altered and structurally intermixed. These rock units could not be separated, and areas containing them have been designated as harzburgite-dunite.

The area is rugged mountain-desert with virtually complete rock exposure. Consequently, many rock relations can be seen on the aerial photographs. The entire area has been covered on foot with some thoroughness. The north face and part of the east face on Ush Ziarat, as well as part of the north faces of the two unnamed mountains lying 9,000 and 15,000 feet north of it, were too steep to map.

Geologic mapping also has proved to be somewhat less accurate in a few places on the tops of the mountains where an ancient rolling topographic surface remains. Erosion here is negligible and most of the slopes are covered with a thin veneer of rubble. The total area involved, however, is less than one square mile.

The entire area was thoroughly photographed in more than 400 35-millimeter color photographs. These have been used to check and refine the geologic map.

Most of the actual rock masses shown on the geologic map were eventually mapped by detailed study of the aerial photographs and from the knowledge gained from the field data. It was found that 3 to 5 hours of concentrated effort was needed to work out the geology on each stereo pair of photographs and 8 to 10 hours additional time was required to transfer the data to the topographic base map. Actual plotting was done with a plotter which used the principles of the Kail plotter. The position of mapped features was plotted with sufficient accuracy to conform to the topographic features.

A greater source of error is found in the actual interpretation of the rock units. This is due to the gradational nature of the rocks which, when shown as separate units, gives a false impression of the geologic relations present. Probably no two persons could plot the geology of the area alike in detail or even agree completely on how to map or what to call some of the trasitional units. In fact, the writer could not replot the data shown on figure 2 a second time in the same detail, although the gross relations would remain the same. Interpretation, in general, is based upon the ability to see; and areas of shade, poor lighting, unclear relations, or any other reason producing less than optimum seeing conditions, faulty interpretation is to some extent inevitable. Undoubtedly it is this inability to see relations which has caused so many divergent opinions on the genesis of chromite and associated ultramafic rocks throughout the world.

Field checking has shown, however, that there is good agreement between outcrop and map over most of the area. In general it is believed that the map can be relied upon within the limits of the scale employed.

Compositional layers present throughout the complex are relatively easier to map than are the rock units because less interpretation is involved. In some areas layers are difficult to see but, in general, layers could be definitely seen at close enough intervals to show a consistent and actual structure. Although well-layered, it has not been possible to recognize, follow, or map any specific horizon throughout the complex.

GEOLOGY

Sedimentary rocks

Triassic to Cretaceous rocks

The consolidated sedimentary rocks in the mapped area belong to the Alozai Group, the Loralai Limestone, and the Parh Group and range from Triassic to Cretaceous in age (figs. 2,3). They are exposed along the margins of the main ultramafic body in the Jung Tor Ghar. Because of the limited time available, and because the main emphasis of the investigation was on the study of the ultramafic rocks and associated chromite deposits, no effort was made during the present survey to map these formations separately.

Rocks of the Alozai Group, named by the members of the Hunting Survey Corporation, Ltd., Canada (1961, p. 69), after the village of Alozai in the Survey of Pakistan topographic sheet 39 B/10, are exposed in the northern and eastern part of the mapped area (fig.2; Hunting map no. 26 Most of these rocks are soft and form a terrain of relatively low topographic relief. The high proportion of shale and soft limestone distinguishes the Alozai from the overlying cliff-forming Loralai Limestone.

The Alozai Group consists mainly of interbedded limestone and shale, and subordinate sandy ferruginous limestone in the lower part of the succession. Generally the limestone is pale gray to blue gray or almost black, and weathers to light gray or buff. It is fine grained and argillaceous. The limestone beds in the group, as a whole, are thin bedded.

The shale is mainly pale gray and dark gray and is flaky, fissile, or blocky, and highly calcareous. The bedding in the shale is generally obscure. Sandstone is a minor component in the group but is nevertheless conspicuous. It is calcareous, dark gray, ferruginous, and coarse grained.

The Alozai Group is the oldest sedimentary unit exposed. Its upper contact, with Loralai Limestone, is conformable and transitional, and is placed below the cliff-forming limestone (Hunting, 1961, p. 72).

Although the Alozai Group of Hunting (1961, p. 72) includes rocks ranging in age from Permo-Carboniferous to early Liassic, in the mapped area it is no older than Triassic. During the present investigation fossils collected from the southern part of the mapped area were identified by paleontologists of the Oil and Gas Development Corporation (1968, written commun.) as Halobia sp. and Daonella sp. of Triassic age.

The Loralai Limestone, named by Hunting (1961, p. 189) after the town of Loralai in the Survey of Pakistan topographic quadrangle 39 B/11, is exposed in a narrow strip in the southwestern and east-central part of the mapped area.

According to Hunting (1961, p. 189), the formation ranges in thickness from 500 to 2,000 feet.

The Loralai Limestone consists of dark, fine-grained limestone. The beds are regular and range from an inch to one foot in thickness. At some places the upper beds of limestone are light gray and contain fossil algae and oolites. Shale is subordinate in amount. It is gray, splintery, hard, and calcareous. The shale is most abundant among the lower strata.

The Loralai Limestone is more resistant to erosion than the underlying rocks of the Alozai Group and the overlying Parh Group, and in consequence forms prominent ridges.

According to Hunting (1961, pp. 190-191), the Loralai Limestone represents all of the Jurassic period from the late Liassic onward.

The term Parh was first used by Blandford (1891) for "the rocks of the Parh Range." Vredenburg (1909) used "Parh limestone" for a prominent white limestone in part of the Cretaceous sequence. For the purpose of the present mapping the term "Parh Group" is best suited; it refers to only the lower and middle parts of the Cretaceous succession and represents an Early to middle Cretaceous age.

The Parh Group consists of limestone, marl, shale, and volcanic rocks. They are nearly constant in lithology and general appearance. They are exposed all along the margins of the mapped area. The limestone is porcellaneous or sublithographic, white, light gray, pink or red. The beds are generally regular, smooth faced, and tabular, ranging from 2 inches to a foot in thickness.

The marl is red and green and is thin bedded. It weathers to a nodular surface. The shale is characteristically calcareous, splintery, hard, maroon, light and dark green, and may be blotchy. Gray or light-gray chert is a common associate of marl and limestone. The chert weathers black or rusty red.

The volcanic rocks of the Parh Group are exposed chiefly in the northern and eastern parts of the mapped area. These rocks are mainly dark green and maroon basaltic and andesitic lavas, some of which have pillow structure. Many of them are porphyritic and vesicular. Flow breccia, agglomerate, and tuff are also present.

In the mapped area, rocks of the Parh Group are underlain conformably by the Loralai Limestone. The upper contact is not exposed. According to the Hunting report (1961, p. 236), the Parh Group represents the whole of the Cretaceous Period.

Quaternary unconsolidated and cemented gravels

Gravels derived from rocks of the complex fill all the major valleys and form hugh alluvial fans which spread out nearly across the Zhob Valley. In profile they appear to be perfectly straight when seen from a distance. Most of the material is angular and fragmental. Sand sizes and finer material are notably lacking nearly everywhere. Chromite concentrate in stream-wash is rare, but the reason for lack of fine sand and chromite is not known.

An older, strongly cemented gravel composed of material derived from the rocks of the complex is widespread throughout the area. It was deposited upon a dissected peneplane but the exact age is not known. The gravels once covered the south side of the Saplai Tor Ghar to a depth of several hundred feet above the general level of the peneplane. Gravel remnants are still present on top of the peneplane and in the ancient stream valleys. The cemented gravel is remarkably resistant to weathering and erosion and appears to be as strong as most concrete.

Similar cemented gravel associated with ultramafic rocks is widespread throughout the world and all masses of ultramafic rock known to the author are associated with some cemented gravels, and it is believed likely that the cementing material is magnesium carbonate derived from the ultramafic rocks by weathering processes.

Metamorphic rocks

Metamorphosed rocks of the Parh group crop out along the northwest part of the Jung Tor Ghar for a distance of about 3½ miles. Over most of this distance the contact between the metamorphosed rocks and the ultramafic rocks shows some faulting, but at one place where Naik Nala crosses the contact (northwestern corner of the mapped area), the contact is essentially unfaulted. The metamorphosed rocks were originally a lime-rich sediment that has been recrystallized to a hornblende gneiss. At the contact the gneiss contains garnet crystals nearly one centimeter in diameter, and abundant hornblende. Biotote appears a few tens of feet from the contact, with the disappearance of the hornblende, and grades outward into rocks containing sericite. This sericite-rich zone, which is as much as 1,000 feet wide away from the contact, grades into unmetamorphosed rocks belonging to the Parh Group.

The zone that contains the hornblende varies in width. In the area of Naik Nala and southward for about one mile, the zone may be as much as 300 to 400 feet wide; farther south but north of the area where Khuta Sur Nala crosses the hornblende-bearing zone, it is not much more than 100 feet wide and grades into sericitic rock that extends from a few tens to several hundred feet farther west. The hornblende gneiss is dark colored and resists erosion; consequently the rock is readily distinguished on aerial photographs and in the field.

The relations just described strongly suggest that the metamorphosed rock crystallized by heat from the ultramafic rock and that the original contact relations are still preserved. However, it should be pointed out that the metamorphism could have taken place if a hot block of igneous rock was thrust over the sediments and thus the relations may not represent an intrustion of magma, and this is thought to be the case (see page 35). A description of the ultramafic rock in contact with the metamorphosed rock is included under the heading of thinly laminated dunite.

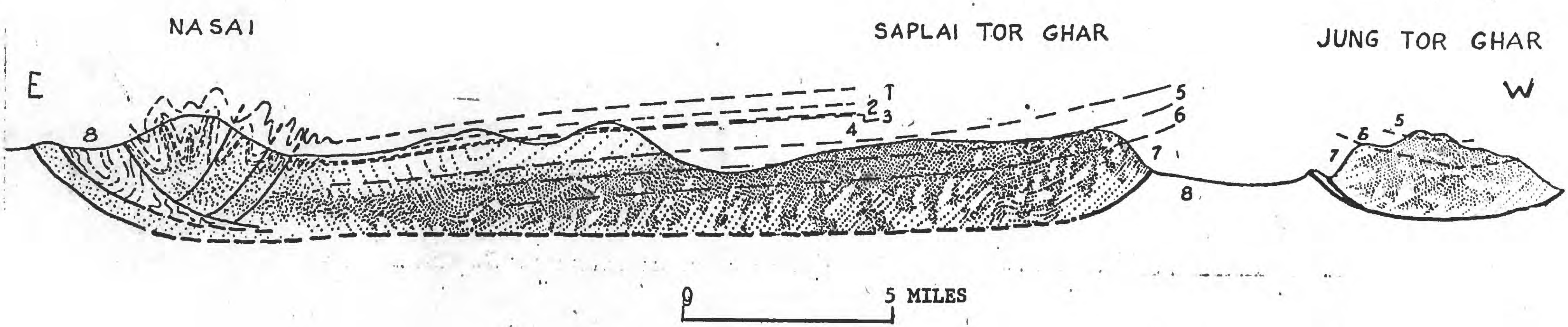
Igneous rocks

Jung Tor Ghar complex

The designation Jung Tor Ghar complex is used in this report to refer to the isolated block of ultramafic rock that makes up the Jung Tor Ghar. It is, however, part of the Zhob Valley igneous complex, the name first used for the entire complex by Bilgrami (1964); the names Jung Tor Ghar complex and Saplai Tor Ghar complex as used in this report are not proposed as formal geologic names.

The Jung Tor Ghar complex is an elliptical mass about 10 miles long in a north-south direction and 4 miles wide. It is in fault contact with sedimentary rocks on all sides except the northwest, where it is in contact with metamorphosed sedimentary rocks. The faults dip steeply under the ultramafic rocks on all sides. Similar structural relations between the metamorphic and ultramafic rocks exist on the northwest corner of the Saplai Tor Ghar and another mass of ultramafic rocks lying immediately northwest of the Jung Tor Ghar. Figures 4 and 5 show diagrammatically the interpreted relations of the igneous rocks to underlying sedimentary rocks and to each other.

All the ultramafic rocks consist of olivine and pyroxene (both orthorhombic and monoclinic) in varying proportions, except dunite which may be pyroxene free. As mapped, rock with less than 5 percent pyroxene is termed dunite; where it contains more than this amount it has been shown on the map as harzburgite. Rock containing



1.- Gabbro
2.- Mafic gabbro
3.- Pyroxenite
4.- Dunite
5.- Harzburgite (barren)
6.- Pipelike dunite zone
7.- Transgressive dunite zone
8.- Triassic-Cretaceous sedimentary rocks

Figure 4.- Inferred cross section, Jung Tor Ghar-Nasai area

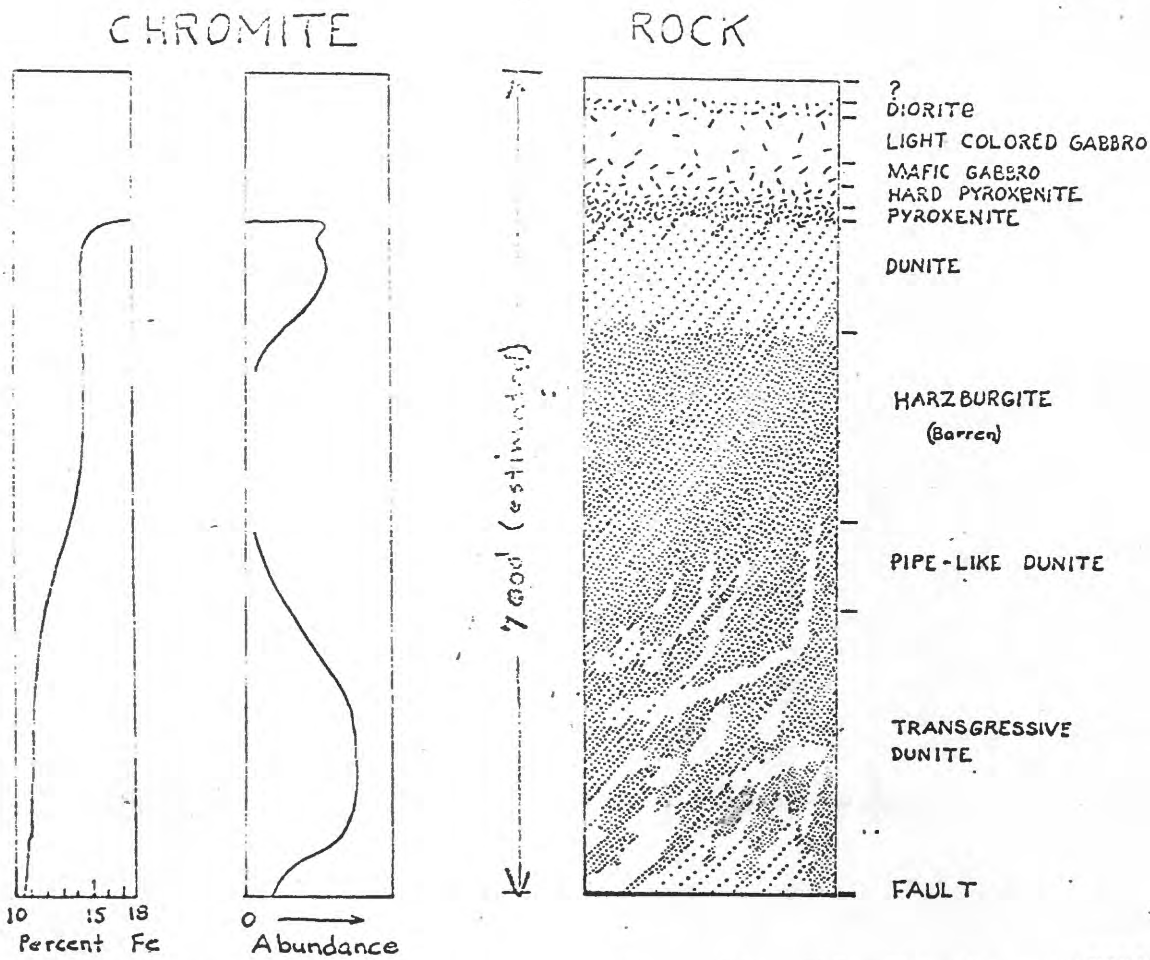


Figure 5.- Inferred rock succession Zhob Valley igneous complex

more than 50 percent pyroxene is not present in amounts large enough to permit mapping at the scale used. Spatially, the dunite is most abundant near the lowest contact, but dunite is present in large amounts in all but the structurally highest rock and is also present as layers within harzburgite.

The ultramafic rock contains a consistent layering formed by varying proportions of olivine and pyroxene, called layers in this report. The way that these layers formed is not known but they are universally present in all bodies of ultramafic rock of the Alpine-type of any size, and it is certain that their origin is important in understanding the genesis of these rocks. Generally investigators attempt to distinguish between primary layering produced by mineral seggregation into flat tabular units similar to sedimentary beds which formed by crystal accumulation, and secondary layering, some of which is certainly the result of rock flowage. In this report no distinction is made because the origin is not known and it is likely that layers of more than one mode of origin are present. Most workers generally hold the concept that chromite layers are primae facie evidence of primary layers. This is not necessarily true of chromite layers found in the Alpine-type complexes, as can be convincingly demonstrated from field relations.

In the Jung Tor Ghar, layers may be tracable for a few hundred feet to perhaps several thousand feet, but none can be traced for the full length of the complex. They appear to end both by grading and by pinching out. Probably the phenomenon of grading is as common or more so than that of pinching out.

The term "layered structure" becomes essential to the description of the relation of the layering to the various rock units. It refers to the structure produced by the layering rather than to the layers themselves. The distinction is an important one and the reader is cautioned to observe the difference in this report, since the layered structure may pass through several rock types even though no one individual layer may do so.

The structure produced by the layering in the Jung Tor Ghar may be seen on figure 2 from the cartographic pattern used, the measured layering attitude, and on the cross sections, and is described under the section on structure. In practice, it is generally impossible, to actually trace the layering across a dunite zone because evidence of layering in the dunite is vague at best. Exceptions exist, and some crosscutting layered structures are distinct enough to show up on photographs. One such zone lies 3,300 feet west of mine 166 and is indicated on the geologic map (fig. 2).

Harzburgite.--The harzburgite, typically, is relatively resistant to erosion and forms bold rugged land forms. In general it is darker colored than dunite and can be distinquished by this characteristic as well as by its bold outcrop pattern. Typically it is less altered than associated dunite.

Figure 6. Map of part of the Jung Tor Ghar area, showing graphically, relations between interlayered harzburgite-dunite (dark) and transgressive dunite (light). The linear structure shown indicates the layered structure. (Location shown on Fig. 2)

Same scale as geologic map

The most massive, coarse grained and pyroxene-rich harzburgite occupies the north-central part of the area, and there the rock has a uniform texture. Mineral compositional layering, although present, is difficult to see. An internal fabric is produced by the tendency for the pyroxene crystals to be disposed with their long directions parallel to the plane of the layering. Lineation is present but it is difficult to see. In the central part of the mapped area on top of Ush Ziarat, the harzburgite consists of alternating thin layers of harzburgite and dunite, and has the best developed layering, and could be mapped as a separate unit. The thinly layered rocks grade downward on all sides of Ush Ziarat into a zone of crosscutting dunite. Harzburgite shown elsewhere throughout the mapped area characteristically grades into dunite both along and across the strike of the layers. In places, in the southern part of the area and around the borders of the Jung Tor Ghar, the rock mapped as harzburgite is simply a dark phase of the dunite that contains a relatively larger amount of pyroxene. This rock was mapped as harzburgite because it helps show the structure and rock relations.

In thin section typical harzburgite is medium grained and has a hypidiomorphic-granular texture. All rock specimens examined were more-or-less altered to brucite and antigorite. In some rocks the alteration is complete but in most some unaltered material remains.

The orthorhombic pyroxene ranges from En 93 to En 80 and the olivine from Fo 96-85 as follows:

Orthorhombic pyroxene
Total number of specimens - 47

Class interval - Enstatite molecule	percent of specimens
80-81	5
82-84	5
85-87	13
88-90	76
91-93	2

Olivine

Total number of specimens 47

Class interval - Forsterite molecule	percent of specimens
80-81	0
82-84	0
85-87	17
88-90	58
91-93	11
94-96	14

The accuracy of the measurements, done by standard immersion methods, is estimated to be about 1 percent and 2 percent for the pyroxene and olivine, respectively, but in both, the normal composition is about En 88-90 and Fo 88-90 for the pyroxene and olivine respectively. The wider scatter in the measurements for olivine is probably due to the characteristics of this mineral which make accurate measurement more difficult.

Monoclinic pyroxene is also present in much of the harzburgite. Generally the amount is less than that of the orthorhombic pyroxene but may constitute half of the pyroxene present in a few places. The monoclinic pyroxene can be distinguished in the hand specimen from the orthorhombic variety because of the color contrast of green and brown respectively. Most of the monoclinic pyroxene has a maximum index of refraction of 1.69-1.705 making it a magnesium-rich diopside. The calcium content has not been determined.

The harzburgite probably formed in the upper parts of the mantle as one of the initial rocks in the complex. Such rock is regarded by many investigators as being a segregated product from a basaltic magma, and this origin seems likely for the harzburgite in the Zhob Valley igneous complex.

Dunite.--Dunite is composed of more than 95 percent olivine, the remainder being pyroxene and accessory chromite.

Several types of dunite are present in the area. These are dunite interlayered with harzburgite; dunite showing a thinly laminated characteristic; transgressive dunite; and probably a fourth type which is believed to be intrusive.

Interlayered dunite: Throughout the complex the harzburgite is interlayered with dunite. The dunite layers range from a fraction of an inch to a few tens of feet in thickness and may extend laterally for hundreds of feet. Layers terminate both by pinching out and by grading into pyroxene-bearing rocks. From a distance, areas such as cliff faces or mountain sides, show that the dunite appears to be composed of over lapping lenticular masses, but generally this relationship is difficult to verify close up as the tapering ends appear to grade into harzburgite. The overlapping feature is not very evident on the geologic map, but this is due to the scale. The best example of interlayered dunite is on the upper rolling surface of Ush Ziarat where tens of thousands of layers are present. Contacts with harzburgite are moderately sharp and rarely exhibit evidence of disruption. There appears to be nothing particularly unusual about these contacts. In places where thick dunitic layers are present, the contact with harzburgite consists of closely spaced thin layers of dunite which become fewer towards the main harzburgite. There is little if any evidence of injection in the dunite layers, or is tectonic movement evident in most places.

It is not always possible to distinguish between the interlayered dunite and the transgressive dunite in those places where the transgressive dunite is parallel to the layering. Generally the transgressive dunite is light colored and more highly altered than the interlayered dunite. A little chromite is associated with the interlayered dunite but no large chromite deposits are found in it. In a few places where thin chromite layers are present in the interlayered dunite, tearing, folding, distortion, and faulting are evident, but these features are not particularly common, although they do show that the interlayered dunite and harzburgite have undergone some differential movement. The interlayered dunite appears to be structureless in outcrop unless some pyroxene is present, but undoubtedly a parallel fabric of the olivine grains is present in places.

The interlayered dunite has an allotriomorphic texture and medium grain size. As far as could be determined by optical methods, the included olivine is the same as that in the harzburgite described above and contains about 88-90 percent of the forsterite molecule. The origin is believed to be similar to that of harzburgite described above.

Intrusive dunite and diapirs.--Here and there, intrusive dunite masses may be present in the Jung Tor Ghar. Most masses lie structurally high in the layered succession above the transgressive dunite (see below). Several crop out on the rolling upland surface of the mountain 9,000 feet due north of Ush Ziarat, and some crop out on the east face of Ush Ziarat just about at the top of the zone containing the transgressive dunite. Generally the masses of intrusive dunite are fairly small, and measure less than 1,000 feet in diameter. Contacts with enclosing rocks are fairly sharp and crosscutting. Layering is absent. In outcrop the rock weathers to a reddish brown, is dense and breads with a conchoidal fracture. Typically the intrusive dunite has more chromite scattered through it than any other type, but none, so far as known, contains enough to be minable. The chromite masses are present as swirls, sheared-out masses, thin veils of chromite grains, and irregularly shaped masses, all generally less than one inch thick and a few feet long. The chromite is fine grained and composed of crushed grains. All these features suggest that the rock has undergone strong differential movement in the solid, and lend credence to the belief that the geologist can recognize truly intrusive dunite in the field where it is present.

There is no evidence of recrystallization of the intruded rocks, which are to some extent serpentinized, and it is obvious that the temperature of intrusion must have been less than 500° C. for above that temperature serpentine can no longer exist.

The olivine in dunite believed to be intrusive has the same composition as that found in the other dunites described. The origin and actual existence of intrusive dunite is in some doubt. It is possible that it represents either transgressive dunite (see below, p. 35) or a mobilized part of the interlayered dunite. As no chromite deposits of consequence are known to be associated with it, and it represents a minor rock type, its economic importance is believed to be slight.

The source of the intrusive dunite is not known, but it is suggested that, because of its position just above the zone containing the transgressive dunite, that it may represent some part of them which had become mobilized and intruded upward to its present position. No evidence indicates that the intrusive dunite represents a separate later intrusion; it most probably is simply a mobilized part of some of the rocks in the Jung Tor Ghar complex. It has not affected the serpentine of the enclosing rocks and cannot therefore have been intruded as a dunite magma.

The intrusive dunite may be a diapiric intrusion. However, the intrusive dunite bodies are not associated with any descernable circular structures . No other evidence for the presence of possible diapirs was found, although the investigators were vigilant in their search.

internal rock disposition is sufficiently clear in the mapped area that diapiric masses of any size would likely to be evident. That they are not suggests that diapirs are not abundant or are absent.

Thinly laminated dunite: An unusual and, in fact, unique (in the writer's experience) type of dunite occupies the contact area in the northwest part of the Jung Tor Ghar. The rock, a thinly layered or laminated dunite, occupies a zone that coincides with the part of the complex that is believed to preserve an original basal contact. The rock in outcrop is a dirty gray-green-brown. It is dense, not particularly altered, or broken or sheared to any great extent. The zone ranges from a few hundred feet wide in the southernmost part to more than 1,000 feet wide in the middle; is exposed for a distance of about 16,000 feet, and probably extends under cover for another 5,000 feet to the south. It grades into interlayered harzburgite and dunite to the east and is penetrated from the north and south by the transgressive dunite.

In the field it is difficult to determine just what there is about the rock which makes the thin laminations. They show up between parallel, more easily eroded lamallae containing serpentine, and vary slightly from one another in color. Elongate masses of green pyroxene are preferentially, but sparsely present in certain layers. The lamallae suggest that they are the result of differential movement along which some serpentinization has taken place.

At the contact of the complex, the thinly laminated dunite in places merges with a dense black rock which in thin section is seen to be composed of a fine felt of serpentine. Other dunite collected from a few feet from the contact is only slightly altered. The fact that the rock contains fresh olivine indicates that either the rock was never serpentinized or has subsequently undergone temperatures above 500^{o} C., forming new olivine. Because the olivine is fine grained and has a sugary texture, it may have formed later by recrystallization from serpentine minerals.

The thinly laminated dunite has a strong laminar element, and the crystals are elongate and do not show a cumulate texture, suggesting that the rock has undergone considerable differential movement. If this is the case, a certain amount of recrystallization must have taken place because the olivine crystals are not unduly broken or shattered.

The thinly laminated dunite, occurring as it does just above the metamorphic rocks, probably represents a basal part of the mass. It may not, however, have crystallized in that particular place, as it could equally well be a portion of solid block brought from greater depth, and thus from much hotter conditions, by thrust faulting. The writer does not believe that the thinly laminated dunite and metamorphic rocks represent an original magmatic contact zone.

<u>Transgressive dunite</u>: In outcrop transgressive dunite appears to have formed from the harzburgite-dunite. The distribution of transgressive dunite is very similar to that produced in altered bedded rocks where they have been transformed by hydrothermal solutions that penetrated for varying distances along fractures and beds and

permeated from them through the enclosing rock and for varying distances. Boundaries between the transgressive dunite and the harzburgite are gradational over many feet. Figure 7 diagramatically illustrates some characteristics of the contact. Many boundaries are very irregular and preferentially extend along some layered horizons. In other places the boundaries are straight and regular; in some places the transgressive dunite has the same pattern as a dike which may be tens of hundreds of feet thick and extends across layered rocks, including other transgressive dunite. In such places it can be distinguished by color contrast resulting from differential alteration. An unusual and geologically important feature is that the layered structure, present as a regular through-going structure in the complex, extends through and across the transgressive dunite masses with little or no deviation. The general relations are depicted in figure 6. Some of the transgressive dunite zones are obvious major features and one, for easy reference, is given the informal name of Ush Ziarat transgressive dunite zone in this report. The zone extends diagonally from the west-central part of the area to the northeast side. It cannot be traced further in either direction, because it merges with other transgressive dunite masses at each end. Although extensions of the zone cannot be recognized, there is some suggestion that the zone is present in the western part of the area, and that it does, in fact, extend clear across the Jung Tor Ghar. Another zone which is broader and not clearly defined appears to branch from the Ush Ziarat transgressive dunite zone at a point just west of the place marked as area "D" on figure 2, and to extend from this place at about N.20 E. to the position of area "C". At this point the zone is cut by a major fault but many continue on the northeast to pass just west of area "A" and on to the northern edge of the complex.

Typically the transgressive dunite is serpentinized and appears white on aerial photographs, but the alteration is far from complete in most places and some unaltered olivine can generally be found.

The general outcrop pattern of the transgressive dunite is evident from the geologic map and figure 7. It forms a wide zone around the ultramafic complex. The zone is wider on the south end of the complex than it is at any other place, and the rocks there are also more altered. The upper part is only exposed on Ush Ziarat where the top of the transgressive dunite-bearing zone is about 8,700 feet above sea level. A similar situation may also exist on the top of the mountain, Tsukai, near the west edge of the area, but the change to harzburgite at about 8,700 feet is less evident than it is on Ush Ziarat.

In many places the boundary between the transgressive dunite and the pyroxene-bearing rock consists of one or more concentric zones on the order of a few hundred feet wide, each of which may be distinct and mappable. They are commonly more clearly discerned on aerial photographs than they are on the ground because a larger area can be seen and compared in the same view. In places the zones have fairly definite boundaries. Many zones have a rhythmic relationship, that is, they may repeat like a series of concentric waves. The concentric zones form from variations in the proportions of pyroxene and olivine,

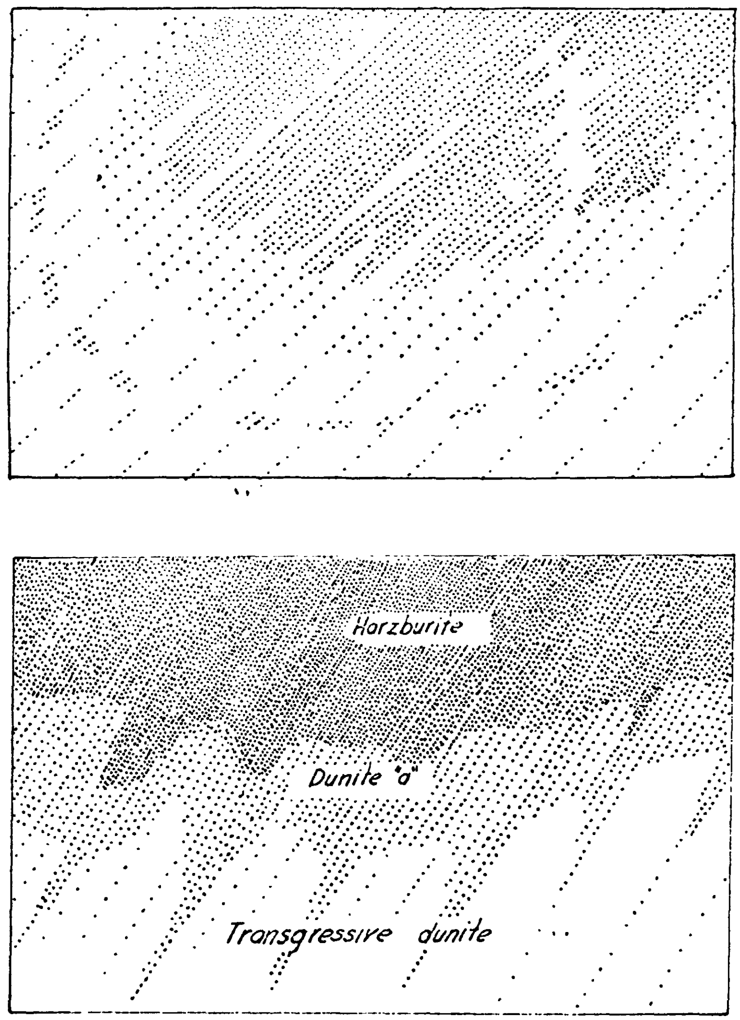


Figure 7.- Diagrammatic sketches of general geologic relations at the boundary of transgressive dunite and harzburgite. The transitional zone, dunite "a" may be several hundred feet wide. Linear pattern indicates plane of layering. Scale of features shown in the diagram may range from 10-200 feet to the inch.

and are made visible by the resulting changes in color and physical characteristics of the rock. In a few places these zones produce a rim or ring of resistant material. This rim may be all that remains and it stands out as an isolated unit in an area of transgressive dunite. More commonly the material within the zone is rather uniform but in some zones the amount of pyroxene and hence the color and ruggedness of outcrop may grade across the zone. The grading may be in either direction, i.e., it may contain the most pyroxene at the outer margin and grade to less toward the harzburgite, or it may become greater. Most commonly a single gradational zone is present, with the amount of pyroxene increasing toward the harzburgite. In places this zone between the transgressive dunite and the harzburgite is wide and distinct enough to present a problem in mapping. In such places the zone containing the intermediate rock has been mapped as dunite "a."

The origin of the transgressive dunite is of fundamental concern in explaining both the rock relations and the geologic history of the chromite. That the transgressive dunite has formed before the time the layering formed is evident because if it had been intruded later, it could not contain the layered structure that it now obviously does. The fact that the dunite preferentially follows along favored layered horizons, on the other hand, implies that the dunite is younger than the layering, for it could not have followed along layers if they were not yet in existence. If the dunite is intrusive, masses the size of those present would have deformed and disrupted the structure of the surrounding rocks to such an extent that it would certainly be detected in the field. In addition, the transgressive dunite fails to show evidence of internal rock flowage, as would be expected from an intrusive dunite. Another possible origin is that the transgressive dunite might actually have been intruded at the time the differential movement was taking place, and that the process continued after the dunite was injected. This has the same objection that movement of such magnitude as would reasonably seem necessary to form the layers would obliterate the transecting relationships of the dunite. Moreover, it is scarcely conceivable that intruded dunite would have the gradational contacts with the harzburgite, where the pyroxene content grades over a zone which in many places is several hundred feet across.

The transgressive dunite may have originated by some sort of transformation process. Such a mechanism would explain all the rock relations observed with respect to the transgressive dunite.

To understand the possibilities of such a process requires a brief review of the laboratory investigations of the system $MgO-SiO_2-H_2O$ carried out by Bowen and Tuttle (1949). These investigators showed that olivine is readily prepared hydrothermally from a stoichiometric mixture of MgO and SiO_2 at a temperature of 500° or higher, and at any water vapor pressure from 2,000 lb/in^2 to 40,000 lb/in^2 without going through a fluid phase. Enstatite is also readily formed from stoichiometric mixtures of the same materials at temperatures of 700° or higher and at water vapor pressures above 5,000 lb/in^2. Talc can be similarly formed at 800° and from 6,000 to 40,000 lb/in^2 water vapor pressure.

The reactions are reversible, and olivine (fosterite) can be changed to serpentine at temperatures less than 500° but not above, because it is stable in a water vapor above that temperature. The same effects were found to take place in naturally formed rocks and minerals and that the presence of iron in them tended to lower the temperature of transformation.

It was shown that water vapor was very effective in the solution of silica and in its transport. Enstatite is readily converted to talc at about 650°, and the talc is accompanied by a second-generation olivine. The authors state: "If...we had a molten mixture of forsterite and enstatite with some water dissolved, it...would consist only of... crystals of forsterite and enstatite. As it cooled further nothing would happen until curve III was encountered (650 ca) when enstatite would be transformed to talc and a second generation of forsterite. At curve II (500°ca) serpentine would form and either forsterite or talc would be left in excess..." He further states (p. 459-460):

> "In an ultramafic complex it is not unusual to find pipes and dike-like masses of one rock type in another, that have been interpreted as indicating intrusion of the material of the pipe or dike as a liquid magma. Sometimes the age indications afforded by these "intrusives" are contradictory; that is, pyroxenite dikes may cut dunite, and dunite may cut pyroxenite, all in the same mass..."

> "On an earlier page we pointed out that silica was abstracted from some of our charges by water vapor and that when it was imperative that no change of composition of the charge should occur special precautions were necessary to prevent this transport of SiO_2. The loss of SiO_2 can occur even when no free SiO_2 is present. Thus after heating synthetic enstatite at 725°C and 22,500 lbs/in^2 pressure of water vapor for 2 days it was found that some of the enstatite was transformed to forsterite, when

no precautions were taken against removal of silica by water vapor. It seems possible, therefore, that if a crack formed in a mass of rock consisting mainly of orthopyroxene, and if water vapor unsaturated with SiO_2 streamed through the crack the rock adjacent to the crack could be converted to a type consisting mainly of olivine, which might appear to be a dike in the pyroxenite. A fracture zone serving in the same capacity as the postulated crack might become a pipe of dunite..."

"In short our observations suggest that the mutual "intrusion" of ultramafic types in such complexes, often giving contradictory indications of time of "intrusion," is really due to hydrothermal (pneumatolytic) rearrangement of material, taking place largely within the mass itself, though the water and perhaps small amounts of other substances were of extraneous origin.

"Such "intrusives" would not extend beyond the borders of the ultramafic complex and this appears to be the relation observed."

The similarity of the field relations observed in the Jung Tor Ghar to the process postulated by Bowen and Tuttle is remarkable. The Jung Tor Ghar complex probably consists of rocks differentiated from a magma of basaltic composition that solidified in place in the upper part of the mantle. Mountain-building movements attendant upon forming the Alpine-type mountain chain probably resulted in southward thrusting which brought the still hot segment of the differentiated ultramafic mass up over strata of the Parh Group (fig.). It seems reasonable, in the light of Bowen and Tuttle's investigation, that water from the underlying sedimentary rocks penetrated along fractures and permeated the rock where the water was heated to about 650°. Silica was extracted from the enstatite transforming it into talc and second generation olivine, forming the transgressive dunite. Further cooling allowed reaction of water vapor and olivine to form serpentine and brucite.

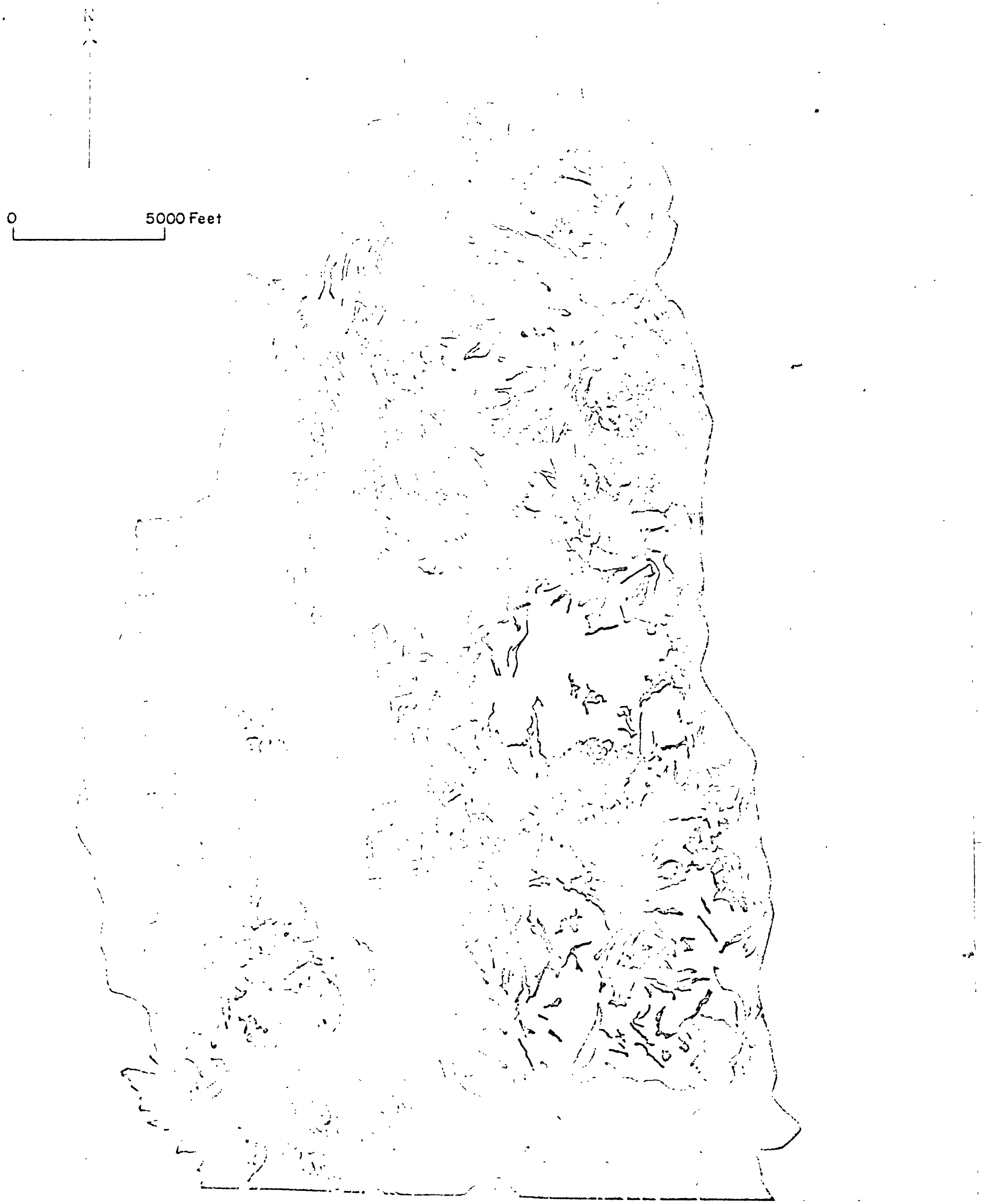


Figure 8.- Distribution of transgressive dunite (dark) in harzburgite in the Jung Tor Ghar. Surronding rocks are sedimentary

These processes can be related to specific features mapped. As might be expected, the greatest amount of transgressive dunite is found in the lower part of the complex where the amount of water would logically be the greatest. It also accounts for the increased amount of serpentinization found there because the rock would reasonably be expected to be cooler there than at the center of the mass.

The Ush Ziarat transgressive dunite zone appears to represent a major access route of water into the central and higher parts of the mass, and water not only penetrated along the zone but extended out along other fractures and along favorable layered horizons for distances on the order of several miles.

The concentric gradational zones which make up the boundary between the transgressive interlayered dunite and the harzburgite-dunite appear to result from its incomplete transformation, and were dependent upon the physical conditions extant at that particular place and time. Where the boundary is relatively sharp, the ability of the water vapor to extract silica probably decreased sharply over a short distance. The presence of concentric zones at rock boundaries suggests that the access of water vapor or other physical conditions which might modulate the process.

Essentially all the features observed in the field related to the transgressive dunite can be explained by the process attendant upon the action of water vapor on dunite and enstatite. As the process is established beyond doubt, is reasonable geologically, and can be expected to take place as a major process, the writer concludes that the general framework for the origin of the transgressive dunite follows the process as outlined.

Age

The rocks of the Zhob Valley igneous complex were thrust over sedimentary rocks as young as Cretaceous and are overlain unconformably by limestone of Eocene age. The emplacement of the complex, therefore, must have taken place sometime between Cretaceous? and before the end of the Eocene. Later faulting along the north side of the Zhob Valley brought in serpentinized ultramafic rock during Miocene time and thus emplacement probably took place over a long interval of time. However, the ultramafic rock probably was brought in as a solid, and the actual age of crystallization remains unknown.

Dikes and volcanic rocks

A few doleritic dikes are present in the area but are not abundant; they are not related to the origin of the chromite, nor are they likely to effect its mining. The largest dike-bearing zone extends discontinuously from the west contact of the complex at Sur Nar Nala to the south end of the Jung Tor Ghar. At the north end a single dike is present which is on the order of 100 feet thick, and is the thickest dike in the area. Farther south, the dike zone consists of several dikes. The enclosing rock has been serpentinized for a few feet on each side of the dike, but there is no evidence that the ultramafic rock was recrystallized to form new olivine. In a few places paper-thin seams of crysotile asbestos have formed in this serpentinized zone, but at no place is crysotile present in any significant amount.

A few small dikes of pyroxenite were noted in the southern part of the area, but the amount is small and unmappable on the scale of the map.

Basaltic rocks have intruded the bordering sedimentary rocks in a number of places. They show a preferential distribution with respect to the contact, as most are found near it. The rock is dark brown to gray in outcrop. The margins are dark colored and hard but the central core is soft and easily eroded. Similar rocks are widespread to the south and east of the Saplai Tor Ghar and Nasai areas.

Interstratified agglomerates and extrusive flows are widely present in the Cretaceous sedimentary rocks and are confined to the vicinity of the igneous complex.

Structure

Layered structure

The structure produced by the layering is relatively open, easily seen and reasonably well established and mapped. The layering in the northern part of the Jung Tor Ghar strikes north. The layering in the western part dips steeply or at intermediate angles to the east, but becomes progressively flatter to the east. Farther south, starting a short distance south of Khüta Sur Nar, the layers form a south-trending, gently south plunging anticlinal fold. In the southern part of the area near the contact, the structure is somewhat more complex and a number of small folds, disturbed layers, and faulted rock slices are present.

Faults

Except in the northwest part of the Jung Tor Ghar complex, the rock is in fault contact with the surrounding sedimentary rocks. At most places the faults dip under the complex. In the northwestern part of the area, the same fault system probably lies slightly farther west of the contact and includes a slab of metamorphosed rock. The contact around the north end of the complex is visible except for a short distance, and it is evident that the Jung Tor Ghar is an isolated thrust-fault block. In the southwestern part of the area, these faults are present as an imbricate structure. In many places not only in the Jung Tor Ghar but also in the southern part of the Saplai Tor Ghar and the Nasai area, a parallel fault, which includes a septum of serpentine, is commonly present a few hundred feet out into the sedimentary rocks. Its presence is so widespread that the relation is not accidental, but the reason for and mechanism of emplacement are not understood.

A system of east-striking faults crosses on the north end of the Jung Tor Ghar. The faults dip south at low angles and those observed show a sense of right-lateral displacement. They are probably more extensive than shown on the geologic map and some may extend completely across the north end of the complex. They probably are related to the major thrust fault system that underlies the complex.

A fault of possibly major displacement extends across the southeast part of the Jung Tor Ghar. The fault strikes northeast and dips steeply to the west. Rocks to the southeast of it are darker colored and more massive; because the rocks are different on each side of the fault, it is believed considerable displacement may have taken place. However, the order of magnitude of displacement could not be established

The Ush Ziarat transecting dunite zone is remarkably straight; its pattern on the geologic map suggests that it follows a fracture zone that may extend across the Jung Tor Ghar. The actual fault break itself has not been observed; if this actually is a fault zone, then the fault is older than the time at which the transgressive dunite formed.

CHROMITE DEPOSITS

Chromite in the Jung Tor Ghar is widespread and only a few areas are without some deposits. Figure 2 shows the general distribution. The largest deposits appear to lie about midway between the base of the Jung Tor Ghar faulted block of ultramafic rock and the uppermost occurrence of transgressive dunite about at 8,700 feet altitude. The geologic map shows clearly that the chromite is found preferentially near the structural tops of individual masses of transgressive dunite although a few irregular shaped masses of chromite are present within the transgressive dunite.

The shape of deposits varies from area to area and reflects local geologic conditions. In the northern part of the Jung Tor Ghar where the layering is pronounced and regular, and the transgressive dunite crosses the layered structure at low angles, the chromite deposits are essentially parallel to the layering, are tabular, and are restricted to a narrow "stratigraphic" interval. Few if any chromite deposits lie in the thinly laminated dunite. On the other hand, where the transgressive dunite is at larger angles to the layering, the chromite masses, although still lying parallel to the layering, are arranged in an echelon pattern. Figure 9 shows the general relation.

Ore control is less evident where the transgressive dunite makes up more than half of the total rock by volume, as it does around the border areas and in the southwest quarter of the Jung Tor Ghar. Even in these areas the chromite tends to be beneath isolated masses of harzburgite, however.

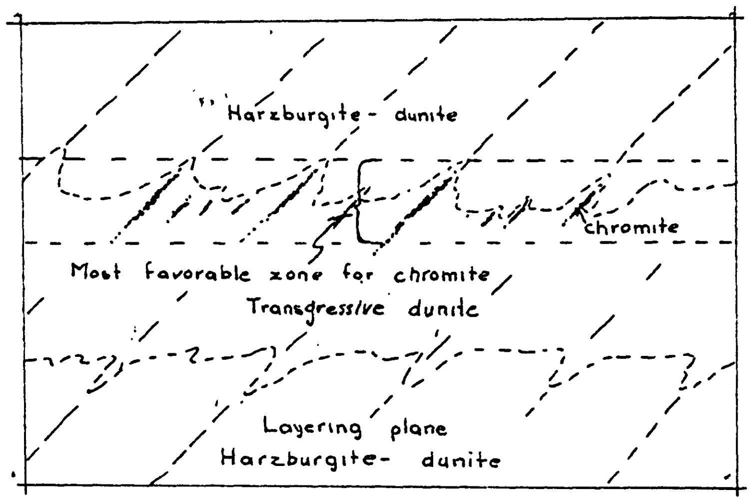


Figure 9.- Geologic relations of harzburgite, transecting dunite, and chromite. The chromite tends to lie along the layering planes but is disposed in a zone near the top of the transgressive dunite. Scale of features shown in the diagram may range from 10-200 feet to the inch

In some of the chromite deposits, the chromite mass is very elongate. These elongate masses are fairly abundant in the northern part of the Jung Tor Ghar, where many plunge steeply northeast along the plane of layering. They may have axial ratios as extreme as 1:10:100, the longest dimension being downward. Most of these elongate deposits show evidence of having undergone strong differential movement parallel to their length. Pipelike deposits have not been noted in the Jung Tor Ghar but have been observed in the Saplai Tor Ghar and Nasai areas. Although chromite deposits have not been observed to lie along the axis of a fold in the Jung Tor Ghar, an outstanding example of this relationship is present at mine 153 in the central part of the Nasai area, and other deposits having these features are probably present in the Jung Tor Ghar (Offield and van Vloten, 1966, p. 5).

Nodules of chromite ranging from 0.2 inch to nearly 2 inches in diameter are present in many places in the Jung Tor Ghar; they preferentially lie in the lower parts of the chromite-bearing zone that is present at the top of the transgressive dunite. Generally, but not everywhere, the disposition of the chromite nodules fails to reflect the layered structure by its distribution. Nodular chromite has been widely described, illustrated, and discussed throughout world literature, and little new information can be added from the observations made during the present investigations. Excellent specimens of nodular chromite are present at mine 166; nodules are particularly well shown in the deposits on both flanks of the valley containing mine 153.

The size of the chromite deposits so far mined indicates that very large deposits in the million ton class probably will not be discovered;

rather it can be predicted that most of the deposits will range from one to several thousands of tons.

A large amount of disseminated chromite is present in mine dumps and as unmined material. This probably equals the total amount of chromite mined in the area to date. This disseminated material may have potential for profitable exploitation if mined and handled efficiently. It is likely that a 50 ton per day mill to concentrate the disseminated chromite could be kept in operation for a great many years on the disseminated material available.

Economic potential

The Jung Tor Ghar contains hundreds of chromite deposits at the surface and geologically there is every reason to believe that the number of chromite deposits underground should not change for any practical mining depth within the limitations imposed by the geologic features described. Thus it is believed that the area holds the possibilty for containing ore deposits close enough to the surface for practical mining that the total potential tonnage will exceed that already mined. Although the Saplai Tor Ghar area to the east has not been geologically mapped in as much detail, it is evident from the history of recovery and from the reconnaissance traverses made, that the area has as great a potential per unit area as the Jung Tor Ghar. In fact the deposits in the Saplai Tor Ghar have proven, on the average, to be somewhat larger than those so far discovered in the Jung Tor Ghar. Many deposits are also present in the Nasai area. It is believed that systematic exploration will undoubtedly find a considerable amount of ore, and production could be increased for many years to come.

Analysis of chromite samples is still in progress. In general, however, the chromite in the Jung Tor Ghar meets the standards for metallurgical-grade chromite.

Description of deposits

Considering the large number of chromite deposits in the area, it is neither practical nor desirable to describe them all. However, a few have been selected to illustrate on more specific terms some of the geologic relations to be expected and how exploring for chromite in the Jung Tor Ghar might be undertaken.

One area in the northeastern part of the Jung Tor Ghar, called area A in this report, clearly shows the relation between chromite deposits and the enclosing rocks. The area centers around a northwest-trending ridge which is underlain by a huge mass of transgressive dunite. Figure 10 shown the geologic relations present and outlines the boundary between the overlying harzburgite and the transgressive dunite. Structural contours drawn on this boundary strike northwest and dip 14° NE under the main ridge, but the boundary reverses dip in an adjacent ridge to the north. Major faults cut off the transgressive dunite on the north.

Almost 50 prospects and three mines, 166, 135, and an unnamed mine near the north edge of area A, lie in a zone at the boundary between the harzburgite and the transgressive dunite, and it is evident that this zone is the most favorable for the occurrence of chromite. Layering in the area has about the same strike but a steeper dip (15° -20°) than the

Figure 10.- Geologic map of area A showing transgressive durite (da) and harzburgite hz-du and the zone most favorable for chromite (cross hatched). Structural contours shown on chromite-bearing zone at boundary between harzburgite and transgressive durite. Explanation of symbols and location shown on figure 2

transgressive dunite-harzburgite boundary. Because the strike of the layering and the boundary between the transgressive dunite and harzburgite are nearly parallel, most of the chromite deposits in area A resemble a normal "stratified" succession. Detailed examination shows, however, that the chromite layers die out upward in the harzburgite and downward in the transgressive dunite.

The area designated on figure 2 as area B is 9,000 feet south of mine 135 on the east flank of Jung Tor Ghar (fig. 11). It consists of a chromite-bearing zone trending due south that crops out at an altitude of 8,250 feet for a distance of about 1,500 feet along the upper contact of a transgressive dunite mass. However, the transgressive dunite masses in this general area are wide-spread, and chromite deposits lie at the structural tops of many of them. For this reason the pattern of chromite distribution simply shows a large number of widely scattered deposits. At area B two relatively large deposits from which a few thousand tons of chromite has been mined lie along a flat south-trending chromite zone. The most northerly mine still contains a considerable amount of disseminated chromite at the surface. An exploratory tunnel has been driven westward toward the deposit from a point to the east and about 100 feet below the surface workings but apparently failed to intersect the chromite. The second mine to the south consists of a large pit, and another pit which is nearly as large lies near the southern end of the zone. There are numerous other workings, and from a distance it is apparent that they all lie along a

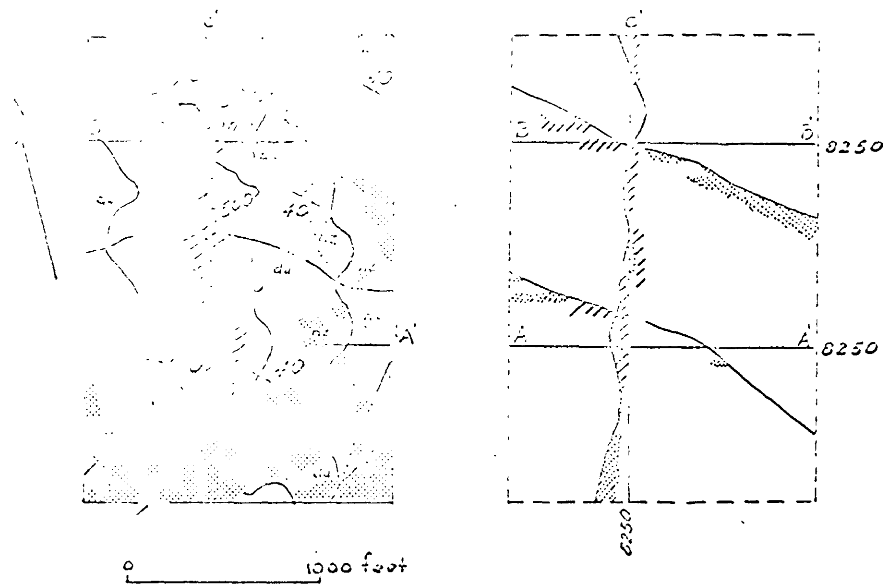


Figure 11.- Geologic map and cross section of area B showing zones most favorable for chromite (cross hatched). Explanation of symbols and location shown

consistent zone. The regional strike of the layering is almost east and the dip is 30°-70° N. From the general pattern of distribution it seems that the chromite-bearing zone is nearly horizontal. It is evident, however, that the zone lies at a fairly large angle to the layering, whatever the dip of the chromite. All individual chromite masses, with the possible exception of the most northerly, lie parallel to the layering.

A third area, area C lies 6,000 feet west of mine 166 on the west slope of the Jung Tor Ghar. (fig. 12). The area contains a chromite-bearing zone that has enough potential to make its description desirable; it represents one of the few places where the transgressive dunite and related chromite deposits are nearly parallel to the layering. The chromite deposit lies along a transgressive dunite that cuts across the layering in the central part for a few feet, but is parallel to the layering at each end. The layering dips steeply to the east and strikes north. The north end is cut by an east-trending fault that dips about 30°S. It is believed that the zone has been displaced in such a way that the northern extension lies about 500 feet to the east. A truck road crosses the south end of the zone in the bottom of a steep mountain gulley. The south end of the dunite zone is covered in the vicinity of the road and the nature of the southern termination could not be determined.

The chromite is present as layers, most of which lie a few feet above the structural top of the dunite zone. Most of the chromite layers are thin, and the deposits are probably not large.

Area D includes a chromite-bearing zone at the top of a transgressive

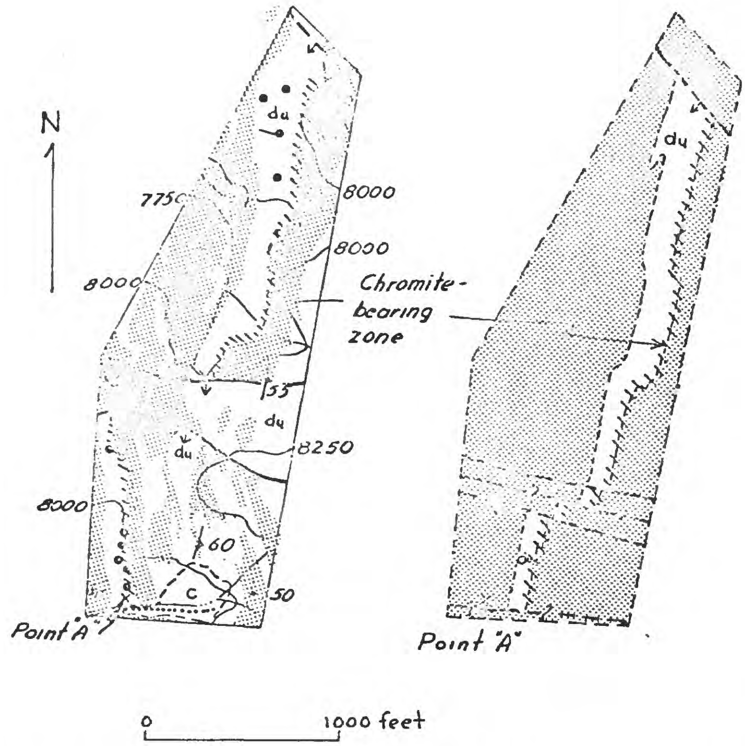


Figure 12.- Geologic map of area C showing zone most favorable for chromite (cross hatched). Outline figure on right shows inferred location of chromite-bearing zone at level of point A (about 7800 feet above sea level). Explanation of symbols and location shown on figure 2

dunite in and to each side of the major stream, Sur Nar, on the west side of Jung Tor Ghar, 5,500 feet N. 60°W. of the top of Ush Ziarat (Fig. 13). The zone is extensive and chromite crops out along it for at least 1,000 feet; other mines lie along it farther south. The mine developed on it is one of the most productive in the Jung Tor Ghar at present (1969) and deserves consideration as an area for exploration. Layering in the area strikes north and dips 10°-15°E. The boundary of the transgressive dunite in the vicinity of the mine appears to be almost parallel to the layering, but careful detailed mapping may show that it is not, for the same zone 1,000 feet to the south trends sharply across the layering for a distance. The transgressive dunite is connected on the north to the Ush Ziarat transgressive dunite.

Physical exploration

The results of the investigation show that there is a logical and systematic way to undertake the search for chromite in the Jung Tor Ghar and other areas containing transgressive dunite. Because most of the chromite lies in a zone near the top of the transgressive dunite masses, the zone must be recognized and its position and shape determined before it can be explored. The three steps of exploration include: (1) Assessment of entire area for chromite potential. (2) Establishment of position and shape of zones (near the top of the transgressive dunite) favorable for containing chromite. (3) Planning of physical exploration activity based upon the results obtained in (1) and (2).

The first step, assessment of the area has been partly done in the Jung Tor Ghar and is more or less evident from the distribution of chromite as shown on figure 2. The same regional type of mapping is desirable in the Saplai Tor Ghar in those areas containing transgressive dunite. How-

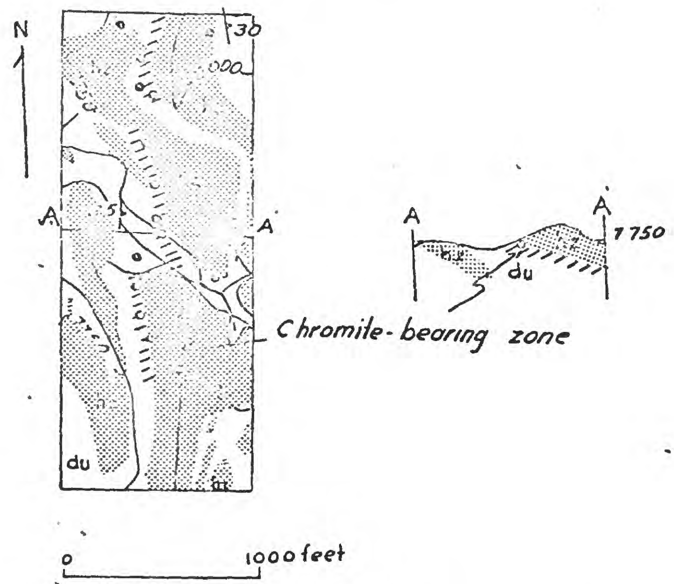


Figure 13.- Geologic map and cross section of area D showing lithologic relations and zone most favorable for chromite (cross hatched). Explanation of symbols and location shown on figure 2

ever further detailed assessment should continue, in order to determine priorities and to provide knowledge needed to carry out the required geological work.

The second step, the establishment of the shape and position of the zone most favorable for chromite can only be done by careful field work and is the most important activity of the three steps.

Planning will be straight forward once all available geologic data is at hand. It should include engineering considerations as well as geological ones.

Areas A to D, described above, are used to illustrate the general procedure for exploration. Area A has some of the clearest geologic relations and most evident ore controls known in the Jung Tor Ghar. It is also the most promising for containing chromite and is probably the best area for initial exploration. Areas B and D are also of considerable economic potential but are difficult to understand geologically, and exploration should be delayed until experience is gained on geologically simpler deposits. Area C is the simplest geologically and the easiest explored, but its economic potential is not great.

The most favorable zone for chromite in area A is well established and is shown by plan, cross section, and structural contours on figure10. Optimum physical exploration is almost self evident. Diamond drilling is impractical because of lack of water and the difficulty of and accessibility to drilling sites. On the other hand, tunneling is relatively inexpensive in the area and access to portal sites is good.
The initial tunnel should be driven parallel to the strike (northwest) and so located on the boundary zone that it will pass about midway between mines 166 and 135. Crosscuts driven at 100-to 150-foot intervals

in both directions from the tunnel will throughly explore a part of this zone. Should the results prove encouraging, similar parallel tunnels can be driven so that eventually the entire zone is explored. The mountain to the north can be similarly explored but there the strike is more westerly and the dip is horizontal or to the south.

Exploration of area B is geologically difficult, and physical exploration should be delayed until experience has been gained in areas A and C. However, chromite deposits are numerous, and systematic exploration is merited. The first work should be the geologic mapping at a suitable scale of the entire area included in figure 11, the objective being the determination of the shape and position of all areas favorable for the presence of chromite by criteria discussed for area A. Many irregular shaped masses of transgressive dunite are present; chromite will probably be found at the tops of some of them. The geologic work already done suggests that the main zone containing chromite may be horizontal, but this is not certain. Plans for physical exploration can only be made following the detailed geological mapping.

Physical exploration of area C (fig. 12) will be the simplest of the four areas discussed. The chromite is in a zone at the structural top of a transgressive dunite which is nearly parallel to the layering. A single tunnel driven northward from near the level of the road at the south end of the zone, with suitably spaced cross cuts, will effectively explore the zone. A south-dipping east striking fault will probably be reached a few hundred feet from the portal. This fault and other parallel faults a few tens of feet farther north have probably offset the chromite-bearing zone about 500 feet to the east. North of these faults the transgressive dunite and some associated chromite extends northward for at least 2,000 feet, with only minor right-lateral displacements.

Physical exploration in area D should start with systematic surface and underground geologic mapping to determine the shape and position of the top of the major transgressive dunite, which is the zone containing the chromite. Mapping should include all of the area outlined in figure 13. The data obtained should suggest the best method for physical exploration. Because the chromite zone dips at low angles to the east, it is likely that some diamond drilling can be done efficiently from the level of Sur Nar, east of the surface outcroppings which has a small but continuous flow of water. Underground workings should follow the strike of the transgressive dunite to the south and north of the workings, and lower levels can be explored from east-trending inclines and north- and south-trending tunnels extending from it.

The above examples briefly outline the general method of carrying out the search for chromite in the Jung Tor Ghar; the method is applicable to the entire area. It is also equally valid for those deposits in the Saplai Tor Ghar which are related to the transgressive dunite that dips less than 60°. With steeper dips the chromite deposits tend to become more centrally located within the masses of transgressive dunite, and in places they may even become pipelike in shape.

There are no known chromite deposits in the interlayered dunite-harzburgite above the zone containing the transgressive dunite; chromite in the dunite above the interlayered harzburgite-dunite is only exposed in the Nasai Area and is not discussed here.

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