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CONTENTS

PETROLOGY OF THE ULTRAMAFIC ROCKS AND BRIEF GEOLOGY OF THE ANDIZLIK - ZIMPARALIK AREA, FETHİYE, SOUTHWEST TURKEY

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ABSTRACT. — The ultramafic rocks[1] of the Andızlık - Zımparalık area are mainly harzburgites with subordinate dunites. Pyroxenite and tremolite veins are late-stage features.

The ultramafics show wide variation in degree of serpentinization which is invariably intense near the margins of the body, along fault zones and along internal tectonic contacts.

Harzburgites mainly consist of olivine and orthopyroxene. Various techniques reveal the composition of olivines to vary from Fo_{88} to Fo_{91} and composition of orthopyroxenes from En_{89} to En_{99}. On the other hand, orthopyroxenes of the orthopyroxenite veins vary in composition from En_{85} to En_{91}. Composition of the clinopyroxene from the clinopyroxenite vein is estimated to be $Ca_{43} : Mg_{43} : Fe_{14.}$

Dominant serpentine mineral is lizardite with lesser amount of chrysotile.

GENERAL SETTING

Andızlık - Zımparalık area is situated in Southwest Turkey, 40 km north of Fethiye; it lies at the southeastern end of a large peridotite body extending from the Dat9a Peninsula in the west (Fig. 1). The field itself is bounded by Çal Deresi and Gürleyik Köy in the south, Damdır Köy in the north, Kızlan Mahallesi in the east and Dalaman Çay in the northwest (Fig. 1).

The peridotites are divided into two units as northern and southern units. The northern unit starts from the Dat9a Peninsula and covers an area of 2.100 km². The southern unit is in the north of Fethiye and southeast of Köyceğiz, covering an area of 700 km².

Peridotites in this part are interpreted to be the part of a huge belt coming from Balkans, through Greece, extending along Southern Turkey and going into Iran (Wijkerslooth, 1942; Hiessleitner, 1954; Borchert, 1958; İlhan, 1962; Engin, 1969).

Along Southern Turkey the peridotites are uniform in appearance, but the ages ascribed to various localities vary considerably. Hiessleitner (1954) gives Lower Paleozoic age to the peridotites in Balkans and Greece and correlates those with the Southern Turkey peridotites in general. Borchert (1958) suggests that the peridotites in Greece and Balkans are Mesozoic (Upper Jurassic) and correlates them with the southern peridotite unit. Borchert (1958) further correlates the Upper Cretaceous-Eocene peridotites of Southwest Greece, Crete and Cyprus with those of Mersin-İskenderun

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[1] The ultramafic rocks, as explained in Wyllie (1967), are those with color indices of more than 70, that is rocks containing more than 70 percent of mafic minerals. Ultrabasic rocks are those containing less than 45 percent SiO_2. Most ultramafic rocks are ultrabasic and most ultrabasic rocks are ultramafic, but there are some exceptions. Ultramafic rocks are composed largely of the dark-colored ferromagnesian or mafic minerals—olivine, pyroxenes, hornblends, biotite, phlogopite, serpentine, and opaque minerals. Some of the monomineralic rocks—anorthosite, nepheline kalsilite, akermanite, gehlenite and caicite are ultrabasic but not ultramafic.

and the eastern Anatolian chromite province. İlhan (1962) classifies peridotites in Turkey in three groups and places them all in Mesozoic, but stresses the fact that they were all subjected to various tectonic movements in different age periods.

Gass and Mason-Smith (1963) explain the geologic and tectonic development of Cyprus. They place the mafic and ultramafic rocks of Cyprus as pre-Triassic, but considering the tectonic development they leave them out of the belt which Borchert tried to establish.

The northern and southern peridotite units are separated from each other by mainly Mesozoic rocks in the east. They get closer to each other in the west, south of Köyceğiz they are separated by a zone of disturbance on which Köyceğiz Lake is situated.

The peridotites are mainly harzburgites. Serpentinization is particularly common along the disturbance zones. Dunite and Iherzolite are the less common rock types, while pyroxenite veins and mafic dykes are of subsidiary importance. According to G. van der Kaaden (1960), the pyroxenite veins, mafic dykes and Iherzolites are more common in the northern unit, the southern unit is being richer in chromite deposits. He also suggests that the two peridotite units were emplaced during the Early Paleozoic, their present disposition and tectonic setting being due to alpine movements. Accounts on these two units are given by G. van der Kaaden and Müller (1953), Colin (1962), G. van der Kaaden and Metz (1954), G. van der Kaaden (1959), G. van der Kaaden (1960), Graciansky (1968), Engin (1969).

GEOLOGICAL   SETTING

The area is situated at the southeastern end of the northern peridotite unit and separated from the main mass by the Dalaman Çay.

The field itself is bounded by thrust zones to the south and to the north. The southern thrust zone is very sharp, in places it follows the northern bank of the Çal Deresi with a northwest-southeast trend. This thrust zone can be followed towards the southeast for about 30 km to the Esen Çay valley where it is terminated by a north-south-trending fault along the valley (Colin, 1962). To the northwest the southern thrust zone extends round Dikmen Tepe and passes to Dalaman Çay valley. The zone leaves the field with a northwest trend (Fig. 1). This thrust zone is very sharp and always dips towards the peridotite with an angle varying from 27° to 53°. Slickensides at the contact have measurements which indicate movement in the northwest-southeast direction (056/29, 17 right, 016/53,10 right).

The northern contact of the peridotite is irregular in trend and often ill-defined. The contact dips towards the peridotite with an angle varying from 28° to 44°.

Sedimentary Rocks[2]

The oldest known units in the surrounding sediments are fossiliferous Permo-Carboniferous shales, quartzites, sandstones and limestones. These rocks are mainly in fault contact with other sediments and have no direct contact with the peridotite. They occur at three isolated localities to the west of Kalabak Tepe.

Permian limestones are widespread, though invariably highly fractured. Despite their disturbed nature the Permian limestones dip towards the peridotite along the contact. The Upper Permian is represented by arkoses, their upper surface is taken as the boundary to the overlying Trias.

Triassic rocks are mainly dolomitic limestones and quartzites and are of limited extent in the vicinity of the peridotite.

Brecciated Upper Jurassic and Lower Cretaceous silicified limestones are common along the contact with the peridotite. Bedding is evident at some localities, dipping towards the peridotite. In places these limestones rest uncomformably on Permian limestones but they have normal contact relations with the Triassic dolomitic limestones.

Upper Cretaceous limestones are very restricted, outcropping mainly in the southeastern part of the area.

Eocene in this part is represented by the Nummulitic limestones, Miocene is represented by limestones and flysch formations; together they form the largest sedimentary unit. They are composed of arenaceous and argillaceous limestones and include peridotite fragments and blocks of Carboniferous and Cretaceous limestones (G. van der Kaaden, 1959). They are thinly bedded, very narrowly folded and have fault contacts with the surrounding rocks.

Although the sedimentary units in the north have not been studied in detail, their lithology suggests that they are the same as the Paleozoic and Mesozoic limestones and flysch formations as seen in the south.

Radiolarian cherts, which are red in color and highly fractured, are accounted as blocks in the peridotite and also in the sedimentary units along the northern thrust zone.

It is widely beleived that peridotite, spilitic rocks and radiolarian cherts generally occur together. Steinmann (1927) was the first to notice this relationship and since then this association is named as "Steinmann trinity".

Although spilitic rocks have not been accounted in the Andızlık-Zımparalık area, Colin (1962) reported occurrences of spilitic rocks which are intercalated with Upper Cretaceous limestones in the southeast of the area near to the southern peridotite unit.

Controversy on the association of the rock units classified in the «Steinmann trinity» is far from being settled. It is widely believed that this association is tectonic rather than genetic. Radiolarian cherts and spilitic rocks are the characteristics of the geosynclinal terranes. During the tectonic uplift of the peridotites (probably in the mush form) on the way to the upper parts in the crust they pass through the geosynclinal terranes and enclose parts of spilitic rocks and radiolarian cherts.

Apparently unfossiliferous sedimentary rocks, lithologically similar to many of the above units are enclosed within the peridotite near both northern and southern contacts. Identification of some of these included blocks as Upper Jurassic to Lower Cretaceous limestones (P. de Graciansky, personal communication) suggests that the peridotite was emplaced subsequently during the Laramide phase of the alpine erogenic movements (Ketin, 1966).

Upper Pliocene and Quaternary conglomerates and marls overlie the peridotite in the east and northeast of the area. They extend away from the area to the north and may be followed to Denizli. These deposits have a northwest-southeast strike and dip at 10° to 20° towards the northeast. Near to the conglomerates and marls, in peridotite, there are magnesite occurrences.

Magnesite is not the usual alteration product of the peridotite and results from the action of CO_2-rich waters. SiO_2 liberated by the reaction crystallizes as opal, near to the magnesite occurrences. The following equation may represent this localized alteration process:

$$3Mg_2 SiO_4 + 2H_2O + 3CO_2 \longrightarrow 3MgCO_3 + H_4Mg_3Si_2O_9 + SiO_2$$
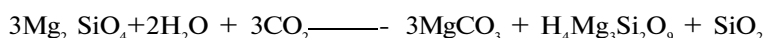
The formation of magnesite appears to be related to recent dislocations and eroded surfaces and occurs after consolidation of the peridotite and after serpentinization. Magnesite deposition takes

place around 250℃ and seldom extends to depths greater than 150-200 m from the surface. Wijkerslooth (1945) considers that the CO_2 necessary for magnesite may be obtained in one of two ways :

a) Rain and surface waters,

b) Juvenile waters associated with asidic magmatism.

Magnesite often occurs where aplitic and pegmatitic dykes cut peridotite. The absence of acidic rocks in the Andızlık-Zımparalık area suggests that CO_2-rich surface waters were probably responsible for the formation of magnesite.

Ultramafic and mafic rocks

The main rock type of the peridotite is harzburgite, composed of forsteritic olivine, orthopyroxene, serpentine minerals and accessory clinopyroxene, chrornite, magnetite and pyrite. Other varieties of the peridotite such as dunite and lherzolite are not easily distinguished in the field.

The peridotites are serpentinized and also weathered. Serpentinization and brecciation are particularly noticeable along fault zones and at the contacts. The breccias are formed of angular fragments which include mafic rocks, peridotite and sometimes chrornite.

Pyroxenites occur as veins cutting the peridotite, they have a thickness which varies from a few cm up to 30-40 cm and can seldom be followed for more than 3-4 m. In some places they have been followed up to 50-60 m.

Pyroxenite veins in the Andızlık and Zımparalık mine areas, which cover an area of 2 km^2, have been studied in detail (Engin, 1969). The dispositions of 114 pyroxenite veins from Andızlık and 34 from Zımparalık were measured and plotted on equal area stereograms, as poles normal to the plane of orientation, produced into the lower hemisphere (Fig. 2).

For the Andızlık area, the stereogram has 10.5 and 7 percent concentrations of the poles in the southwest and southeast parts of the diagram, respectively. The former indicates a 308/54 dip direction and the latter a 027/57 dip direction (027 is the dip direction and 57 is the dip angle).

The Zımparalık diagram shows three heavy concentrations of poles in the southwest and southeast quadrants. The most powerful with a 13 percent concentration lies in the southeast and indicates a 305/60 dip direction, the other two have 7.3 percent concentration of poles and indicate 332/56 and 026/57 dip directions. The two stereograms demonstrate the consistent nature of pyroxenite veins with clear orientations at about 308/54 and 027/57. Pyroxenite veins from other parts of the field have orientations which coincide with one of other two dominant directions. In reality these two directions are the dominant directions of other geologic features such as faults, orientations of chrornite pods etc. in the field (Engin, 1969 and Engin & Hirst, 1970a).

Although many of the pyroxenite veins are made of orthopyroxene and are in fact orthopyroxenite veins, in one place a pyroxenite vein bearing considerable clinopyroxene is known. Orthopyroxenite veins mainly consist of orthopyroxene and include accessory clinopyroxene, amphibole minerals and chrornite.

Mafic dykes are common, forming about 10 percent of the peridotite area, characterized by a rugged appearance, they stand out from the more easily weathered peridotite. Contacts to peridotite are usually sharp and marked by cooked, serpentinized, brecciated or sheared peridotite. The dykes vary from 50 cm to 250 m in thickness and they can be followed for distances of up to 2 km in the strike direction. The main constituents are clinopyroxene, plagioclase feldspar and skeletal ilmenite. The general strike direction of the dykes, despite small variations, is northwest-southeast. The dykes

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AYRINTILI ÇALIŞILMAMIŞ PERIDOTIT
PERIDOTITE NOT MAPPED IN DETAIL

AYRINTILI ÇALIŞILMAMIŞ TORTUL BIRIMLER
SEDIMENTARY UNITS NOT MAPPED
IN DETAIL

Legend:

- al — Alluvium
- Marls
- Conglomerates — Pliocene-Quaternary
- Limestone, flysch — Eocene_Miocene
- Limestone — Upper Cretaceous
- Limestone Lower Cretaceous_Upper Jurassic
- Dolomitic limestone quartzite arkose Triassic
- Limestone — Permian_Permo_Carboniferous
- Radiolarian chert
- Amphibolite
- Magnesite
- Basic dyke
- Peridotite
- Individual chromite outcrop
- Group of chromite outcrops
- Breccias
- Dip direction and angle
- Lineation
- Joints
- Faults
- Spot height

EGE DENIZI
Aegean Sea

BALIKESIR
IZMIR
AYDIN
DENIZLI
MUGLA
FETHIYE

Datça yarımadası
Datça Peninsula

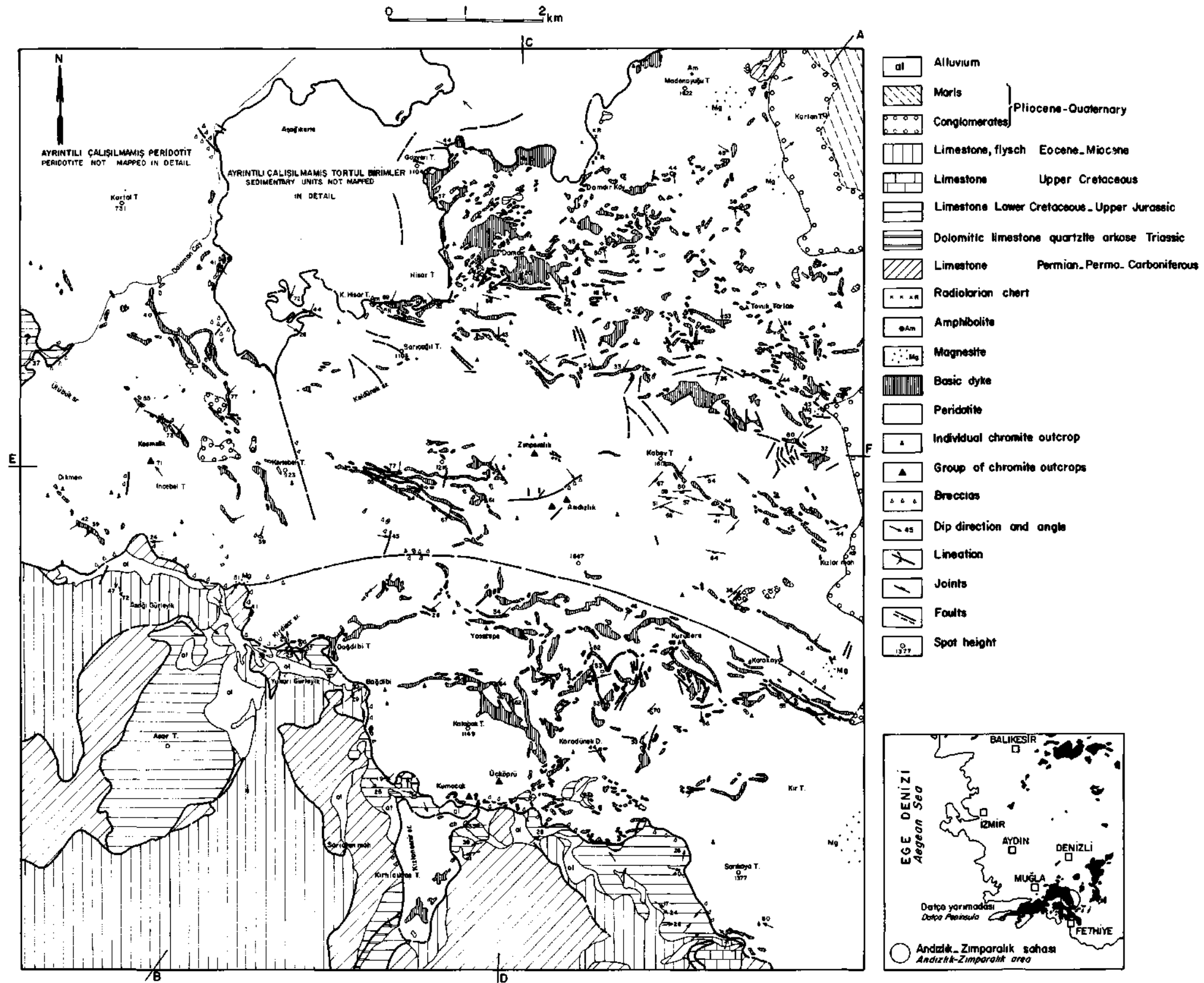Andızlık_Zımparalık sahası
Andızlık-Zımparalık area

Fig. 1 - General geology of the Andızlık-Zımparalık area. Sedimentary units in the south were modified from an unpublished map by P. de Graciansky (personal communication).

are limited to the peridotite body. Only in one locality (G. van der Kaaden, 1959) does a mafic dyke transgress to the surrounding sediments, this is on the western continuation of the peridotite, near Datça.

The dykes are heavily concentrated in the north and south of the field. The petrology and chemistry of the mafic dykes will form the subject of a separate paper.

Chromite occurrences

Chromite, ubiquitous as an accessory mineral in the peridotite, is also concentrated into economically viable deposits. The chromite deposits in the field are mainly of podiform type, the ore grading from disseminated through nodular to massive varieties. The matrix of the chromite is serpentine, serpentinized harzburgite-dunite or in some cases tremolite and chlorite.

The chromite bodies, though in places shapeless, are in general in the form of elongated, lenticular pods. The position of some of the chromite bodies as they are seen on the gallery walls is shown in Figure 3. The size of the individual pods varies from 1 to 2 m, up to 50 m in length and the thickest parts from 0.50 to 7-8 m.
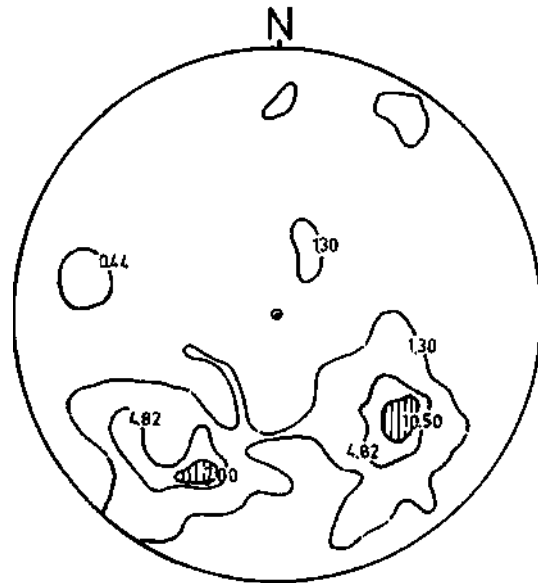
Boundaries between chromite and the surrounding rocks are mostly very sharp, the peridotite is heavily serpentinized and brecciated. On the fault planes slickensides are common indicating differential movement.

In the Üçköprü and Sarıkaya mine areas (Fig. 1) the contact between the chromite and the enclosing dunite or harzburgite is sharp and primary in some cases and gradational in others. Primary magmatic contact relations are, however, of very restricted occurrence.

114 pyroxenite veins from the Andızlık mine area.

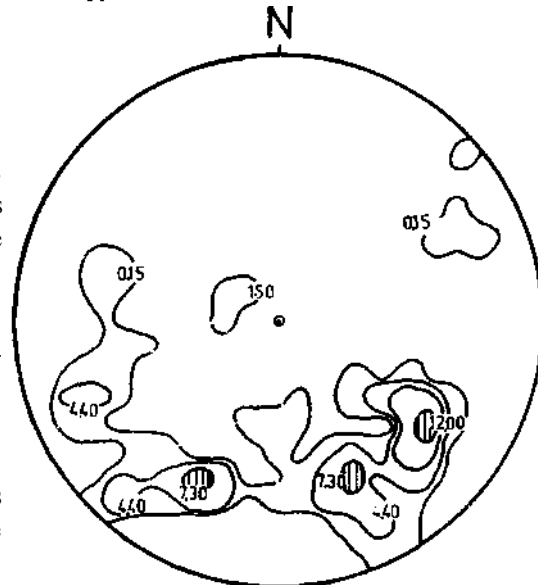34 pyroxenite veins from the Zımparalık mine area.
Fig. 2

Stratiform or banded chromites occur in very limited amount. They form 3-4 mm-thick bands of anhedral to subhedral chromite grains. They cannot be followed for more than 1 to 2 m in the strike direction.

Nodular chromite in the serpentine matrix, is widespread. The nodules vary in size from a few mm to 2-3 cm in length and up to 1 cm in diameter at the thickest part. The nodules are a miniature counterpart of the chromite pods. The nodules consist of about 50 percent of the specimen.

The origin of nodular chromite is controversial. Reviewing the works on nodular chromite, Snelgrove (1968) concludes that nodular chromite js of early magmatic fractional crystallization. A widely held theory suggests that early chromite crystallizing in the upper parts of a magma chamber

sinks and rolls down the banks of silicate, increasing heat during the descent causing corrosnn and resulting in formation of nodular chromite (Borchert, 1964). This theory, however, does not explain why nodular chromite is only related to alpine peridotites. Nodular chromites are one of the characteristics of the alpine type peridotites and are not known where chromites are classified as stratiform types (Thayer, 1960). Clearly the tectonic history must have a role in the formation of nodular chromite.

The nodules are generally composed of imperfectly formed crystals. According to Snelgrove (1968) there are not any significant compositional changes in the nodules of the nodular chromite from the Hindubagh deposits, West Pakistan. From center to the margin he gives the unit cell edge of the chromite as 8.30A° for the center and 8.34A° for the margin of the nodule. However, a change of 0.04A° in the unit cell edge should indicate significant changes in the composition.

Fig. 3

Thayer suggests that chromite may have separated from the peridotite magmas as globules which settled on the floor of the magma chamber. Bowen (1928) has pointed out that the unmixing of liquids take place by the formation of globules. In discussing the possible mechanism for the formation of nodular chromite Bilgrami (1964) says that the possibility of liquid immiscibility in chromite-rich melts should be considered. Bearing Bowen's findings in mind, Bilgrami says if these globules were generated from the unmixing of the liquids which existed in the natural magmas and were preserved, they may explain the formation of nodular chromites.

The orientation of chromite pods is regular, mainly either northwest - southeast or east-northeast - west-southwest. As the geology, mineralogy and chemistry of the chromites have formed the subject of other papers, here they will not be dealt with any further (Engin, 1969; Engin & Hirst, 1970a; Engin & Aucott, 1971).

Other rock types known in the peridotite are those of light-green colored irregular tremolite veins filling cracks in the chromite pods and those of amphibolite xenoliths which are known in some places in the north along the thrust zone.

MINERALOGY AND PETROLOGY OF THE ULTRAMAFIC ROCKS

The ultramafic rocks are mainly serpentinized harzburgites with limited dunite, pyroxenite, tremolite and amphibolite.

Harzburgite

The harzburgite is mainly composed of olivine and orthopyroxene together with minor amounts of clinopyroxene, chromite and some alteration-product minerals in the altered specimens. The representative fresh-hand specimen is black to dark-green in color, individual crystals are not easily seen with the naked eye. In altered specimens olive-green rounded olivine, lath-like pyroxene and pin-head chromite crystals can be distinguished.
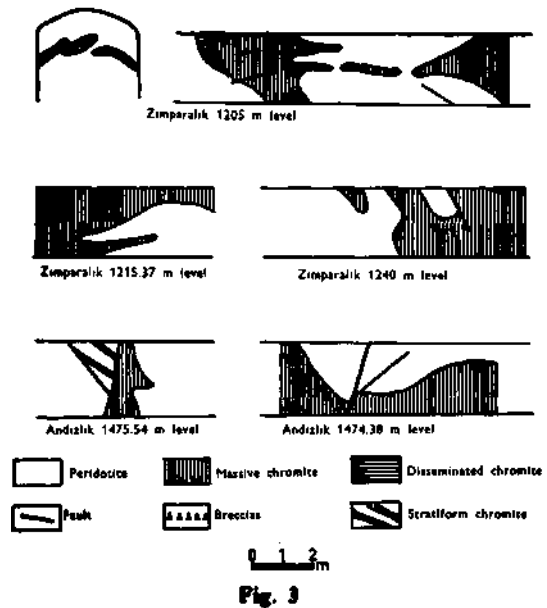
In many places the harzburgite is highly serpentinized, the degree of serpentinization varying from zero to fully serpentinized. In general the peridotite is over 50 percent serpentinized (Engin & Hirst, 1970b).

The dominant mineral in the harzburgite is olivine comprising up to 82 percent of unserpentinized specimens. Specimen F251 is the least altered, modal analysis by integrating point counter gives olivine 82 percent, pyroxene 18 percent and chromite 0.4 percent.

Olivine. — Olivine is anhedral, of fine to medium grain size, up to 2 mm in length and has second-order birefringence. Cleavage is not developed well but in some grains it is possible to see imperfectly developed cleavages (010), (100). The optic axial angles are equal to or greater than 87. In most specimens olivine is partially or completely altered to serpentine, individual grains being surrounded by a serpentine rim.

In the less serpentinized harzburgites lamellae are common accompanied by undulose extinction. Undulose extinction my still occur in olivines which are free from the lamellar structure. The occurrence of such lamellae in olivine is explained by Turner (1942) as the result of translation gliding. Brothers (1960) has suggested that these features might be the result of gravity deformation by a load of overlying crystallites.

Microscopic studies indicate that lamellae develop parallel to (100) and are optically homogenous. Challis (1967) has analyzed spots on those lamellae by electron microprobe. Analyses have shown that chemistry of each band is not significantly different from the other. On the development of the lamellae structure Challis accepts that the weight of the overlying crystals may have an important role particularly in suitably oriented crystals, but main factor is the crystallization pressure. Stresses imposed by growth of overlying and surrounding crystals in a largely monomineralic rock could produce the deformation during the later stages of crystallization.

Examining the olivine structure it is seen that (100) is the plane of greatest atomic density, so (100) is structurally the most likely glide plane and deformation lamellae develop parallel to (100), the most likely glide direction is (001). If the second set of lamellae to develop the most likely second plane on the theoretical consideration is the plane of second greatest atomic density (010).

Raleigh (1967) has also indicated that lamellae structure in olivine parallel to (100) in naturally deformed olivine result from translation gliding.

In the Andızlık-Zımparalık area the lamellar structure may thus have been formed during the tectonic emplacement of the peridotite or as a result of the internal pressure set up during serpentinization (Engin & Hirst, 1970b).

The olivines include chromite crystals and are themselves included within chromite and pyroxene.

Although it is rare, but in fresh harzburgite specimens granulated olivines situated along the crystal boundaries with triple junction can be seen indicating secondary generation of olivine in limited amount, as explained by Ragan (1963, 1967) on Twin Sisters dunite.

The olivines in 10 peridotite specimens from different parts of the peridotite have been analyzed by electron probe. Results reveal the olivine composition to vary from Fo_{88} to Fo_{91}. Traverses made in the same olivine grain reveal no obvious zoning, results are given in Table 1.

Orthopyroxene. — Orthopyroxene is the second most abundant mineral in the harzburgite, the content ranging from 8 to 25 percent, but mostly 14 percent. The Orthopyroxene occurs as lath-like, subhedral to euhedral crystals with a grain size reaching 5-6 mm in length. They have low first and second order birefringence and the optic angle gives values from 77° to 80°. On the basis of optical

identification the orthopyroxenes are either enstatite or bronzite. Bronzites show very faint, light brown pleochroism and are optically negative, while the enstatite is non-pleochroic and optically positive.

Table - 1

Forsterite content (Mol percent) of olivines from harzburgites determined by electron microprobe

No.	Fo	Fo	Fo	Fo	Fo	Fo	Fo (Average of E. Probe analyses)
F19	88	88	88	88			88
F29	87	87	88	88	87		87
F44	88	88	89				88
F54	91	91	91	91	91	91	91
F68	89	89	90	90	88		89
F169	88	88	88	87	87		88
F206	87	87	87	87	87		87
F124	88	88	88				88
F215	88	87	88	88	88		88
F251	88	89	89	89			89

In many sections the cleavage traces of the orthopyroxenes suggest that crystals are bent or broken. Many orthopyroxene laths are divided into sharply defined sections of different optical orientation with boundaries known as kink bands. These bands become more irregular with increasing deformation until the crystals actually rupture and are torn apart along the sector boundaries. This structure has been produced artificially by deformation of pyroxenite at pressures of 5000 bars/cm^2 and 800°C. The kink bands are attributed to translation gliding during rotation about the (010) axis (Turner, Heard & Griggs, 1960). This may be the result of internal pressure imposed during the expansion resulting from serpentinization.

The orthopyroxenes include thin clinopyroxene exsolution lamellae which are mainly parallel to the 110 cleavage trace. The lamellae show high birefringence and have oblique extinction. In some sections they are not strictly parallel to the cleavage trace. The exsolution takes place such that the lamellae and host have common b and c axes and (100) plane. This is the only plane on which the clinopyroxene and orthopyroxene have similar structure and might thus be expected to give the lowest energy interface between the two structures. This may also explain why the lamellae develop along the (100) plane and appear parallel to the (110) cleavage trace in thin sections. Bown and Gay (1959) give methods of identification of exsolutions in pyroxene crystals by X-ray techniques.

Hess (1960) considers that the exsolution plane may also be related to the ease of migrations of ions in the structure, rather than to difference between the two structures.

Morimoto and Takonami (1969) studied the augite exsolution lamellae in pigeonite and have indicated that they are parallel to (001) and (100) planes. It is a rather special case to have two different sets of lamellae in the same specimen. According to Morimoto and Takonami (1969), the crystallization of the original pigeonite was followed upon cooling by exsolution of augite plates parallel to (001), by further cooling the pigeonite inverted to hypersthene which exsolved fine lamellae of another augite parallel to (100).

The harzburgites generally show a poikilitic texture, orthopyroxenes enclosing rounded olivine, chrome spinel and rare clinopyroxenes. Serpentinization of the orthopyroxene may be seen in many sections, they are partly or completely altered to bastite.

Hess (1952) and Kuno (1954) have shown that orthopyroxenes exhibit ideal solid solution, the unit cell parameter varying regularly with Mg content. Zwan(1954) showed that the d spacings (10 3 1) and (0 6 0) (Fig. 4) change systematically.

Hancock (1964) plotted the spacing (0 6 0) against the spacing (10 3 1) for a series of low-alumina orthopyroxenes from Hess (1952). He established a straight line relationship from which the molecular percent En could be estimated in the range En_{40} to En_{100} (Fig.5).

Separated orthopyroxenes from ten harzburgite specimens have been examined by X-ray diffraction over the angular range 50° to 64° 26, using CuKa radiation and added silicon as internal standard. Duplicate scans were made for each specimen and the average spacings (103 1) and (0 6 0) used to determine composition from the curve produced by Hancock (1964), d values and corresponding En values are listed in Table 2. Results indicate that orthopyroxenes vary in composition from En_{89} to En_{99}, in agreement with their optical identification as enstatite and bronzite.

Clinopyroxene. — Clinopyroxenes are very minor in amount, in some specimens they are completely absent while in others 1 or 2 grains can be seen. In some specimens from the western part of the field around İncebel Tepe there is a slight increase in the amount of clinopyroxene to 3-4 percent, but insufficient to term the rock Iherzolite. They occur as subhedral to euhedral crystals with well developed cleavage (110) and oblique extinction. Clinopyroxenes are identified as diopsidic augite. The Clinopyroxenes are the least altered silicate minerals in the harzburgite, although they show slight signs of alteration to a light green chlorite and tremolite.

Cfiromite. — Accessory chromite, about 1 percent, is generally found in the harzburgite. In the weathered specimens pin-head chromite crystals are easily seen. In thin sections they are reddish brown to reddish dark brown, although they are mostly anhedral corroded crystals in some cases euhedral forms have been preserved. The chromite crystals are usually enclosed in olivine or
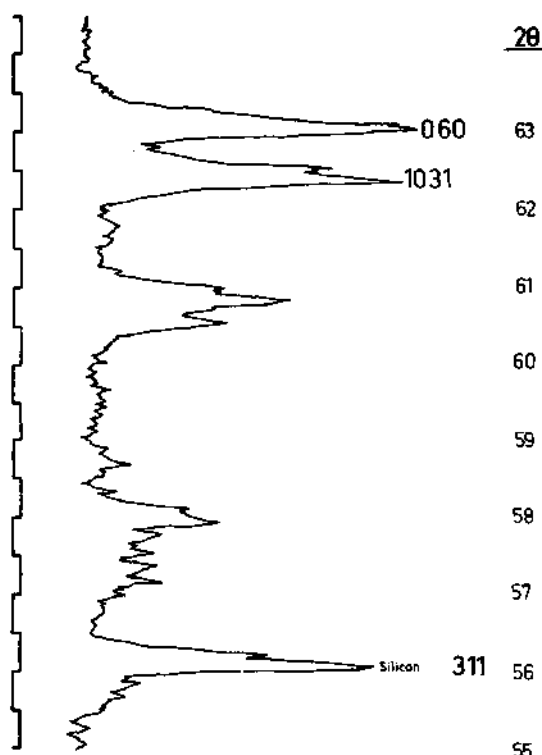

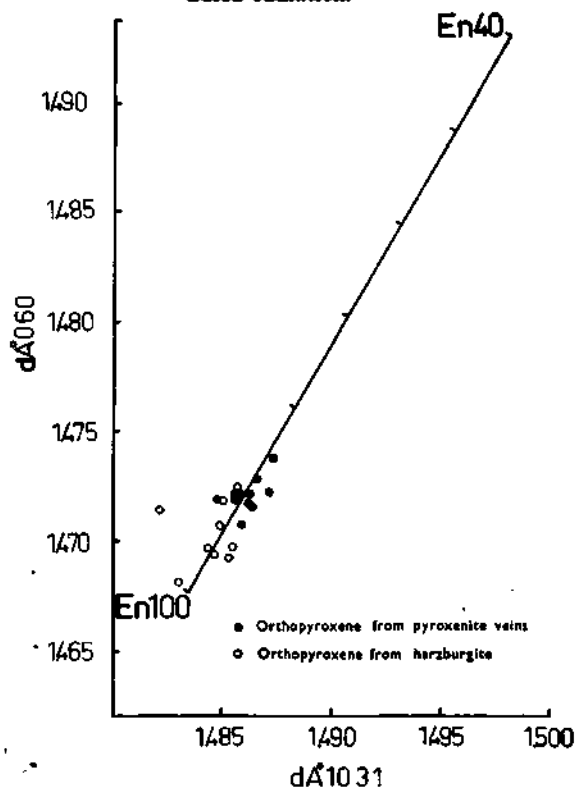Fig. 4 - Diffractometer record of orthopyroxene, CuKa radiation.

Fig. 5 - Orthopyroxene X-ray determinative curve (Hancock, 1964).

Table - 2

En content of orthopyroxenes (Mol percent) from harzburgites and pyroxenites determined by X-ray diffractometer

No.	$dA°$ 10 3 1	$dA°$ 0 6 0	En
(a) orthopyroxenes from harzburgites :			
A22	1.4851	1.4718	91
F4	1.4844	1.4694	95
F18	1.4821	1.4713	94
F200	1.4855	1.4697	94
F214	1.4848	1.4706	93
F216	1.4857	1.4723	89
F223	1.4847	1.4693	95
F245	1.4831	1.4681	99
F249	1.4853	1.4692	95
(b) orthopyroxenes from pyroxenites :			
A18	1.4859	1.4721	89
A34	1.4865	1.4728	87
A54	1.4874	1.4738	85
A55	1.4856	1.4722	89
A76	1.4857	1.4719	90
Z3	1.4863	1.4722	89
Z14	1.4872	1,4723	88
Z25	1.4863	1.4717	89
F15	1.4849	1.4719	91
F20A	1.4859	1.4707	92
F36	1.4864	1.4715	90

orthopyroxene. Microprobe analyses on some of these accessory chromites have revealed a slight compositional zoning although nothing is detected on episcopic study (Engin & Aucott, 1971).

Dunite

Dunites are of very limited extent and their distinction from harzburgite is difficult in hand specimen. Normal contacts between chromite and the enclosing rock do however involve dunite which is usually heavily serpentinized. The dunite is composed of olivine and minor chromite and is usually heavily serpentinized, pyroxene content may reach 0.3 volume percent.

Serpentinites

The peridotite is in general serpentinized to over 50 percent. Around the chromite bodies, adjacent to mafic dykes and along the tectonic zones the peridotites are generally fully serpentinized. The sheared serpentinites are composed of a mass of small serpentine flakes showing undulose extinction. The serpentine texture is controlled by the original rock type and the degree of post-serpentinization. In the serpentinized peridotites minerals are usually surrounded by a thin serpentine zone. Serpentinization starts from the margin and advances towards the center where relict olivine may still be seen. Serpentinized olivines form brownish-green mesh-textured serpentine with small euhedral magnetite crystals or magnetite dust, occurring along cracks and representing iron liberated during the serpentinization process. The rims of this mesh-textured material are composed of fibrous serpentine which is length slow and termed a serpentine by Tertsch (1922) and Francis (1954).

Arda (1970) has studied the serpentine minerals in the northern Amanos Mountains, Southern Turkey, and was able to divide the development of serpentine minerals according to their structural characters as a_1 primary mesh serpentine, a_2 secondary mesh serpentine, a_3 tertiary mesh serpentine and quaternary serpentine parallel to the tectonic development of the area. Similar divisions were also made by Lauder (1965) in the Dun Mountain, New Zealand, but not necessarily related with the tectonic development of the area.

The «hourglass» structure is quite common. In this structure the collar and the core are both composed of a serpentine. Late stage chrysotile veins fill cracks resulting from shearing, and cut across the previously formed serpentine.

Orthopyroxene is altered to bastite during serpentinization but original crystal outlines are often well preserved. This feature has been used to argue against volume increase during serpentinization. In many of these relict orthopyroxenes clinopyroxene exsolution lamellae can still be seen. The bastite is length slow a serpentine.

The main polymorphs of serpentine are chrysotile, antigorite and lizardite.

Chrysotile consists of fibers of the order of 200A° in diameter. Electron microscope studies reveal that chrysotile has a morphology similar to that of a hollow tube.

Whittaker (1953) has recognized three varieties of chrysotile from single fiber studies: Clinochrysotile, parachrysotile, orthochrysotile. Ortho and parachrysotile are orthorhombic while clinochrysotile is monoclinic. In clino and orthocrysotile the fibers are curved about the a axis while parachrysotile has curvature about the b axis. Lizardite has a platy morphology and is disordered in three ways:

a) The crystals are macroscopically bent about more than one crystallographic axis.

b) Some layers are rotated relative to the others by 180°.

c) Some layers are displaced.

Antigorite exhibits both platy and fibrous morphology. It is a single layered serpentine with c and b dimensions similar to those of lizardite but with a larger a parameter, in many cases approximating 40 A°.

Serpentines from the Andızlık-Zımparalık area have been investigated using an X-ray diffractometer. Scans were made over the angular range 6°-65°, 2@ using CuK a radiation, again peak positions were corrected by means of known peaks from silicon which was added as an internal standard. The d spacings have been correlated with values derived by Whittaker and Zussman (1956), they are given in Table 3. The existence of the (060) reflection at 1.547-1.532A^0 and of the (2 0 8) reflection at 1.502-1.507, Figure 6, suggests that the serpentine is mainly lizardite. The presence of the (2 0 4) reflection at 2.09A°, the (2 0 6) reflection at 1.749A^0 and the (2 0 2) reflection at 2.45A° suggest that chrysotile is also present.

No peaks specifically attributable to antigorite could be identified in the diffraction patterns. The absence of antigorite was checked by comparison with diffraction pattern of a fibrous antigorite (picrolite) from the Durham University, Geology Department collection (Fig. 6-7).

Many workers accept that antigorite is found where shearing has taken place (Hess *et at,* 1952; Francis, 1956; Wilkinson, 1953). But Deer, Howie and Zussman (1963) suggest however that antigorite may be found where there is no evidence of shearing. The chemical environment may have an important influence on the formation of serpentine pseudomorphs. Hess *et aI.* (1952) have suggested that in general olivine yields chrysotile and enstatite yields antigorite. However although the harzburgite contains enstatite there is no evidence for antigorite in the serpentinized varieties.

Table - 3

d spacings of serpentines

dA°	WZ* Intensity	A2 dA°	Intensity	F58 dA°	Intensity	Z72 dA°	Intensity	F75 dA°	Intensity	F101 dA°	Intensity	F142 dA°	Intensity	hkl
7.360	vs	7.300	100	7.312	100	7.335	80	7.360	100	7.355	100	7.317	100	002
4.580	m	4.564	20	4.550	25	4.541	18	4.580	16	4.585	16	4.576	14	020
3.660	vs	3.652	90	3.653	90	3.659	100	3.658	39	3.664	90	3.659	98	004
—				2.827	6									
2.617	w					2.620	17							201
2.498	s	2.495	31	2.498	24	2.490	51	2.495	90	2.502	58	2.505	28	202
—				2.455	16			2.457	6	2.461	5			202
2.340	mw													203
2.150	mw	2.147	9			2.150	16	2.148	11	2.149	9	2.149	8	204
—		2.093	9											204
1.968	w													205
1.830	w													008
1.797	w					1.794	7	1.796	8			1.799	6	206
—		1.749	19									1.749	6	106
1.739	mw													110
1.640	w													207
1.534	s	1.537	16	1.532	24	1.532	25	1.535	18	1.536	16	1.539	24	060
1.504	m	1.502	7	1.503	6	1.507	7	1.507	5	1.503	7	1.506	6	208
1.464	w													

* WZ d spacings of serpentine from Whittaker and Zussman (1956), p. 117, column 22.

Some serpentinites from the Andızlık-Zımparalık area have been heated to 1200°C in the differential thermal analysis apparatus. The following reactions may be identified (Fig. 8). The serpentine loses H_2O- at 104°C-113°C, iron is oxidized at 250°C-327°C and structural water lost from lizardite at 644°C-675°C. In some specimens a further endothermic reaction was observed at 687°C-720°C, this possibly relates to the loss of structural water from chrysotile. Further heating resulted in an exothermic reaction at 811°C-821°C which subsequent diffraction examination suggested was attributable to the formation of olivine and enstatite.

Aslaner (1971) has also studied the D.T.A. pattern of serpentines from the tskenderun-Kinkhan area, Southern Turkey. He gives the endothermic reaction value for lizardite-chrysotile at 637°C-715°C and 790°C-802°C for antigorite. Apart from the diffractometer technique, D.T.A. technique is probably a better way of determining the presence of antigorite in the serpentinites. Aslaner also points out that there is not an exothermic reaction recorded for antigorite.

Artan(1970) gives endothermic reaction value for chrysotile-asbestos at 690°C-695°C from the Zara region, Central Anatolia.

Pyroxenite veins

Pyroxenites occur as veins; they constitute a very minor fraction of the entire peridotite mass but are known throughout the area. The pyroxenite veins are mainly composed of orthopyroxene, although a single vein bearing considerable clinopyroxene is known.

Orthopyroxenile veins. — In these veins orthopyroxenes constitute 60 to 85 percent of the rock with crystals up to 7 mm in length, mostly subhedral; subsidiary clinopyroxene, olivine and very minor chromite comprise the remainder of the rock. Kink bands are strongly developed in the orthopyroxenes and clinopyroxene exsolution lamellae are common. The orthopyroxenes are of two
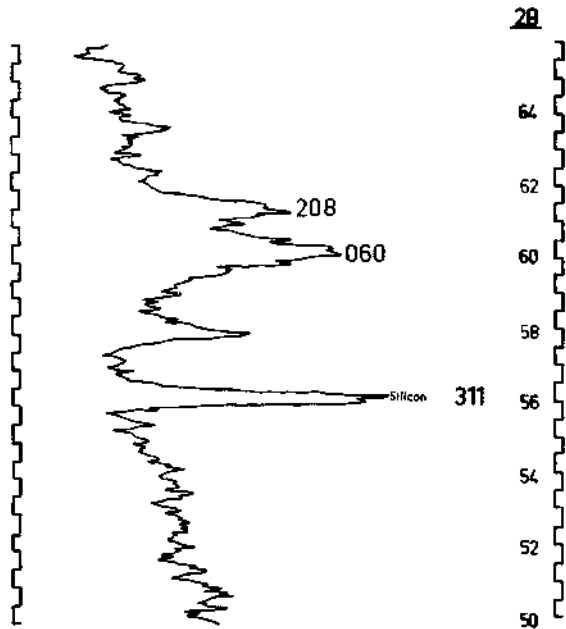
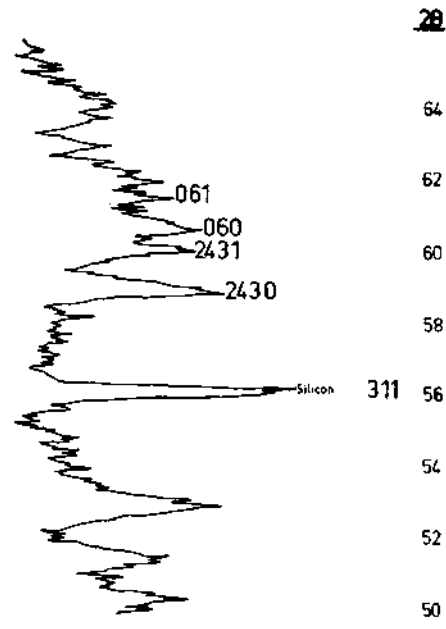Fig. 6 - Diffractometer record of lizardite, CuKα radiation.

Fig. 7 - Diffractometer record of antigorite, CuKα radiation.

kinds: enstatite and bronzite. The optic axial angle was measured at 77° in one specimen. Many of the orthopyroxene crystals are crushed into smaller fragments along the crystal boundaries where they are also partly altered to bastite.

The clinopyroxene occurs as lath-like crystals, in parts altered to tremolitic amphibole and pale green chlorite. Olivine is rare comprising no more than 1-2 percent, chromite constitutes about 0.1 to 0.2 volume percent of the rock.

Orthopyroxenes from the pyroxenite veins have been examined by X-ray diffraction using the methods described previously (Fig. 5). Table 2 indicates that the orthopyroxenes vary from En_{85} to En_{91}.

According to Bowen and Tuttle (1949) water vapor, saturated with SiO_2 streaming through cracks in the peridotite at temperatures above 650°C, could convert the wallrock to pyroxenite. The orthopyroxenes of the harzburgites range from En_{89} to En_{99}; they are thus more Mg-rich than those of the pyroxenites which is in agreement with Bowcn and Turtle's findings that they may have **been** generated from peridotite at a late stage.

Clinopyroxenite vein. — This type of vein was only found in one locality. The vein is 7 cm thick, can be followed about 3 m. It has a sharp contact with the peridotite, though the boundary is marked by a thin serpentinized zone in the peridotite.

Clinopyroxene constitutes about 60 percent of the rock, the other minerals are orthopyroxene, olivine and altered varieties of these minerals.
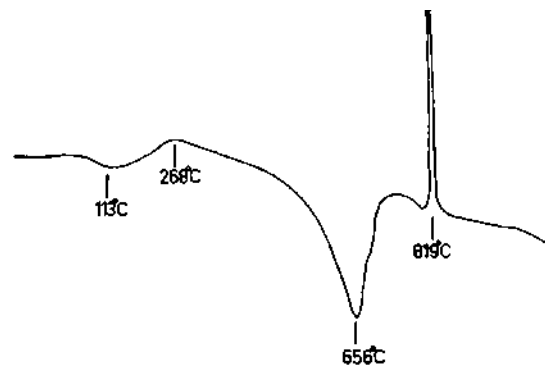

Fig. 8 - Differential thermal analysis (D.T.A.) record of serpentine.

The clinopyroxenes are subhedral ranging up to 1.5 cm in length, they show polysynthetic twinning and an optic angle of 55°. In places they are partly altered to tremolite and chlorite.

Hand-picked clinopyroxene crystals were examined by X-ray diffraction using CuKa radiation following the technique of Brown (I960). The Ca: Mg: Fe ratio of the clinopyroxene was estimated as Ca_{43}: Mg_{43}: Fe_{14} from the position of the (0 6 0) and (6 0 0) reflections (Fig. 9). This composition was determined by plotting b (=6. d_{060}=8.92686) and a sin b (=6.d_{600}= 9.3723) values on the pyroxene part of the $CaSiO_3$-$MgSiO_3$-$FeSiO_3$ triangular diagram (Brown, 1960).

Fig. 9 - Diffractometer record of clinopyroxene CuKα radiation.

Tremolite veins

Tremolite occurs as light green fibrous crystals in veins traversing the chromite ore bodies in an irregular manner. These fibers are 6-7 mm long forming subhedral crystals. They are colorless in thin section and show second order birefringence. The veins include minute chromite crystals. Some of the tremolite has been altered to talc.

It appears possible that primary magmatic water of the peridotite magma has been concentrated in the neighborhood of the chromites, pneumatolitic and hydrothermal activity causing the formation of tremolite veins along fractures. A possible reaction is:

$$3MgSiO_3 + 2CaMgSi_2O_6 + SiO_2 + H_2O \longrightarrow Ca_2Mg_5Si_8O_{22}(OH)_2$$
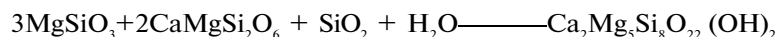
Three hand-picked tremolite specimens have been examined by X-ray diffraction and their d spacings compared with the values recorded by Dunham et al. (1958) (Table 4).

Amphibolites

The amphibolites which occur locally as xenoliths within the ultramafics have well-developed schistosity and are shiny black in hand specimen. They are composed of amphibole, plagioclase, opaques and apatite. Amphiboles comprise 80 to 85 percent of the rock, they are greenish-brown in color with light brown to brown pleocroism. The grain size is around 1 mm. They are identified as hornblende and show strong orientation along the longer dimensions of the rhombohedral sections. They are characterized with their 124° and 56° cleavage traces (110, 110).

Plagioclase is interstitial to the amphibole and is heavily saussuritized, this makes it difficult to identify the plagioclase optically.

From the chemical analyses of amphibolites (Engin, 1969) normative plagioclase composition has been calculated to An_{54-63} Ab_{46-37} (labradorites). From the analyses of amphibolites the amphibole composition computed to fit pargasite (Engin, 1969).

The opaque minerals comprise black anhedral crystals of ilmenite, oriented parallel to the schistosity. Six-sided to round, fine-grained apatite crystals occur as inclusions in the hornblende as well as interstitial to hornblende and ilmenite.
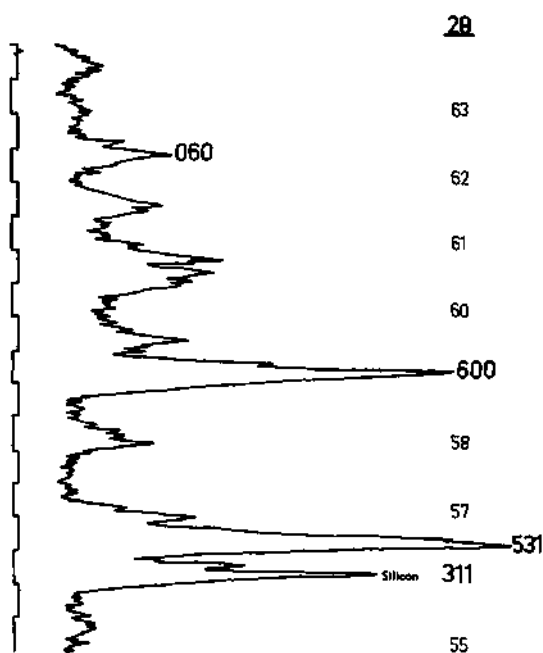
Table - 4
d spacings of tremolites

DPCJ*		F139B		ZU45		AU3		
dA°	Intensity	dA°	Intensity	dA°	Intensity	dA°	Intensity	hkl
—	—	9.025	19	8.99	22	9.035	11	020
8.43	s	8.432	83	8.425	92	8.457	65	110
5.10	w	5.094	18	6.088	7	5.101	9	130.001
4.89	m	4.855	22	4.879	8	4.778	10	$\bar{1}11$
4.52	m	4.502	27	4.524	18	4.517	16	040
4.22	w							
4.01	vw							
3.88	m	3.873	27	3.877	8	3.883	6	$\bar{1}31$
3.38	s	3.377	38			3.371	11	150.041
3.27	s	3.270	62	3.268	64	3.277	43	240
3.11	s	3.129	100	3.131	100	3.132	100	310
3.00	vvw							
2.94	s	2.935	60	2.934	33	2.938	42	$\bar{1}51$
2.80	w	2.809	24	2.809	28	2.810	17	330
2.74	vw	2.740	25	2.740	16	2.737	10	$\bar{4}21$
2.70	s	2.703	72	2.696	47	2.703	38	151
2.59	s	2.589	34	2.586	19	2.590	13	$\bar{1}12.061$
2.53	s	2.540	42	2.540	23	2.540	10	$\bar{2}02.002$
2.41	vvw	2.411	10	2.416	5			$\bar{1}32$
2.38	vw	2.386	16	2.384	11	2.387	7	350.400
2.33	w	2.337	36	2.336	22	2.338	22	$35\bar{1}$
2.298	vw	2.296	12	2.284	6			420.071
2.270	vw							
2.205	vvw					2.202	3	
2.182	vvw							
2.162	m	2.160	23	2.158	14	2.165	8	171.261
2.040	w	2.043	8			2.037	6	081.280
2.015	w	2.018	13					202
1.958	vw	1.963	7					$28\bar{1}.190$
1.934	vvw							
1.889	vw	1.897	4	1.898	5	1.899	9	
1.865	vw	1.865	11					$460.\bar{1}91$
1.837	vw							
1.808	vw							
1.746	vw			1.759	4			
1.686	w	1.686	7					$003.\bar{2}82$
1.648	w	1.651	7	1.649	7			$210\bar{1}$
1.635	vvw					1.640	4	
1.616	vw	1.616	7					
1.578	w							
1.555	vvw							
1.529	vw							
1.511	w	1.514	10					
1.501	vw	1.504	13	1.503	6	1.504	6	
1.468	vw							
1.455	vvw	1.457	10					
1.435	m	1.442	14			1.440	13	
1.362	vw							
1.340	vw							
1.333	vw							

* DPCJ Chrome tremolite from Hangha, Sierra Leone, Dunham, Phillips, Chalmers & Jones (1958) p. 40.

Amphibolites are not part of the peridotite but were incorporated during the tectonic emplacement, probably from the Menderes crystalline, schists.

CONCLUSION

The peridotite of the Andızlık-Zımparalık area is mainly serpentinized harzburgite. Serpentinization in general is around 50 percent. Fresh harzburgite is composed of forsteritic olivine, orthopyroxene, some clinopyroxene and chromite. In the serpentinized specimen dominant serpentine mineral is lizardite with mixture of some chrysotile. Plagioclase is not present in the peridotite, although examination of the system $CaO\text{-}MgO\text{-}Al_2O_3\text{-}SiO_2$ shows that it is not possible to arrive at an enstatite, diopside, forsterite, spinel assemblage without involving anorthite. Yoder and Tilley (1962), however, showed that the anorthite-forsterite assemblage is not stable at very high load pressure, while Rothstein (1961) has also suggested that high pressure causes depression of liquid's temperatures to the point where the spinel and diopside field converge.

Bowen and Tuttle (1949) investigated the system $MgO\text{-}SiO_2\text{-}H_2O$ at temperatures ranging up to 900°C and pressures up to 15,000 1b per sq. inch. They concluded that there is no possibility of existence of serpentine magma below 1000°C.

Lack of contact-metamorphism, intense brecciation and serpentinization indicate that the peridotite was cool and in a solid state when it was emplaced in its present position. The peridotite is believed to have been generated near the crust-mantle boundary where the peridotite crystallized. Tectonic uplift associated with the alpine orogeny raised the body to a mid-crustal position. This was followed by high-temperature hydrothermal formation of pyroxenite, tremolite and serpentinization. Expansion resulting from serpentinization probably provided the impetus for continued uplift to the present level in the crust, this probably took place during the Laramide phase of alpine orogeny.

ACKNOWLEDGEMENTS

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