The structure of the oceanic upper mantle and lower crust as deduced from the northern section of the Oman ophiolite

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SUMMARY: The lowermost 7 km of the Oman ophiolite consist of harzburgite, dunite and minor lherzolite of mantle origin overlain by layered gabbros and peridotites of the lower oceanic crust. Detailed structural measurements along three traverses through the ophiolite, complemented by olivine petrofabric determinations on oriented specimens from these traverses, reveal the following geometrical parameters of the spreading process:

(i) The ultramafic rocks of the mantle sequence have all suffered deformation by simple shear at temperatures exceeding 950°C beneath a spreading ridge.
(ii) The tectonite fabric which characterizes the mantle sequence passes upwards with no change in orientation or intensity into the layered gabbros and peridotites at the base of the crust.
(iii) The sense of shear and type of slip system vary at random with depth, reinforcing petrological arguments that the Oman mantle sequence results from the juxtaposition of various mantle 'packages' equilibrated at different depths beneath the ridge.
(iv) No unique kinematic model for the ophiolite can be formulated from the structural data of the three traverses; each traverse has a distinctive geometrical arrangement of the various structural elements relative to the reconstructed ridge directions. Dispersed mineral-layering planes indicate closing directions of magma chambers strung along the ridge.

The concept that ophiolites represent ancient oceanic crust, formed either at a major oceanic spreading centre, or more probably, one sited in a back-arc marginal basin, has been founded on a variety of geological and geophysical reasoning. Accepting this analogy, ophiolites can then be used to gain more insight into the processes of ocean-crust formation. Since the time when the ocean-crust analogy was originally formulated by such workers as Gass (1968) and Moores & Vine (1971) much of this work has concentrated on petrological and geochemical modelling (Refs in Coleman 1977). It is only relatively recently that attention has been paid to the pervasive tectonite fabrics that characterize the ultramafic rocks of the ophiolite suite and their possible relationship to the geometrical parameters of the spreading process (Juteau *et al.* 1977; George 1978; Nicolas *et al.* 1980; Prinzhofer *et al.* 1980; Girardeau & Nicolas 1981; Nicolas & Violette 1982).

Structural studies of ophiolites can augment modelling based on oceanic seismic studies in providing data on the kinematics of the upper mantle beneath spreading centres. Such studies in ophiolites are most meaningful, however, when a complete stratigraphy is preserved (so that a maximum number of structural parameters can be interrelated) and the ophiolite is extensive over a sufficiently wide area to display the extent of the structural pattern. Unfortunately, the structural studies on ophiolites to date suffer by either lacking the complete stratigraphy—e.g. Turkey (Juteau *et al.* 1977) and New Caledonia (Prinzhofer *et al.* 1980)—or, where the total stratigraphy is present, by not being laterally extensive—e.g. Troodos, Cyprus (George 1978) and Bay of Islands, western Newfoundland (Girardeau & Nicolas 1981). The Oman ophiolite has suffered relatively little dismemberment during emplacement, and throughout most of its 500 km length, the complete stratigraphy of the ophiolite is exposed. In this account, structural data, complemented by forty-eight olivine petrofabric diagrams are presented from three traverses through the northern section of the Oman ophiolite. Incorporating the data from a traverse described by Boudier & Coleman (1981) in the southern section of the Oman ophiolite allows an interpretation of the geometrical pattern of spreading from a complete ophiolite representing a ridge-parallel segment of Upper Cretaceous oceanic crust exceeding 300 km in length.

Geological setting

The field relations, petrology and geochemistry of the Oman ophiolite have been the subject of many recent papers (e.g. Hopson *et al.* 1981; Smewing 1980; Alabaster *et al.* 1983). This section is restricted to a brief account of the mafic and ultramafic plutonic rocks at the base of the ophiolite from which the structural measurements were taken. The Oman ophiolite is of Cenomanian age (95 Ma). (Tippit *et al.* 1981) and forms the major part of a 700 km arcuate mountain chain along the southern coast of the Gulf of Oman. It comprises the uppermost nappe of a series of Mesozoic thrust slices overlying the autochthonous Mesozoic carbonate platform of the Arabian shield.

The lowermost unit of the ophiolite consists of up to 7 km of ultramafic tectonites. The dominant

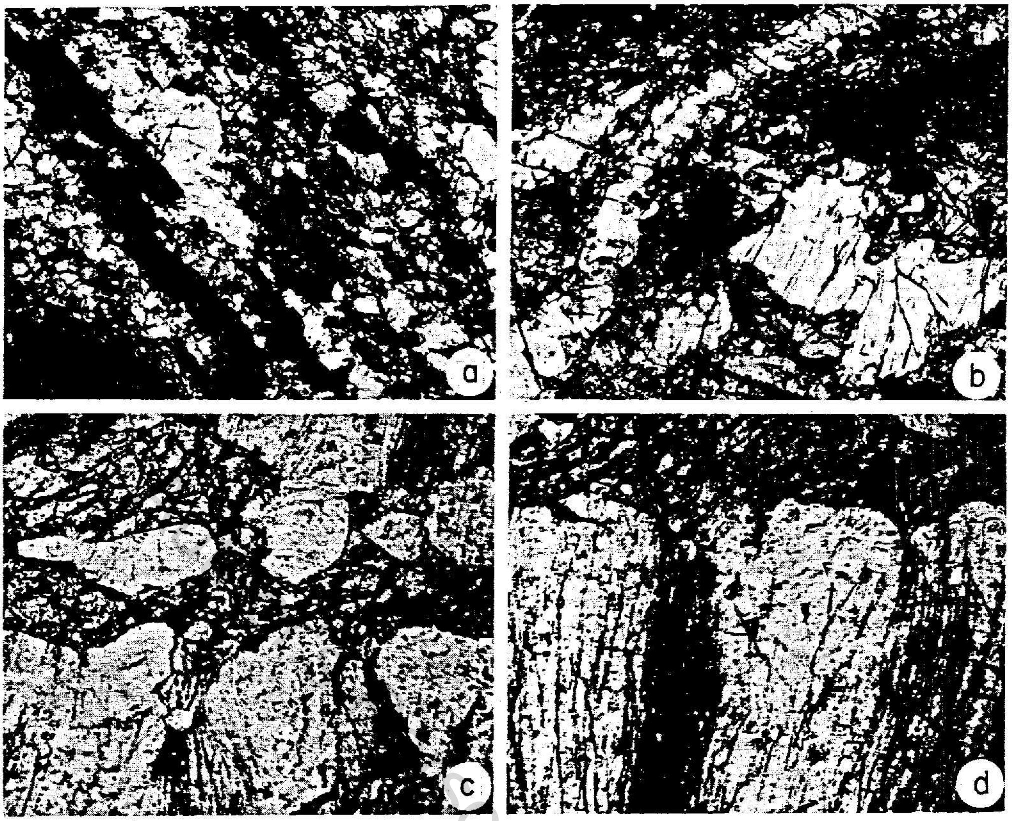

FIG. 1. (a) Harzburgite, Wadi Jizi. Tectonite foliation in harzburgite running from top left to bottom right. Elongate olivine crystal just left of centre with kink-band boundaries recording dextral shear sense with respect to orientation of photograph. Crossed nicols. (Width of photograph 3.5 mm). (b) Harzburgite, Wadi Jizi. Olivine fabric wrapping around enstatite porphyroclast. Crossed nicols. (Width of photograph 3.5 mm). (c & d) Base of layered sequence, Wadi Ragmi. Tectonized layered gabbro with foliation parallel to long dimension of photograph. Pull-apart fractures in plagioclase oriented perpendicular to lineation. PPL (Width of photograph 3.5 mm).

lithology (more than 80%) is harzburgite with a very uniform mineralogy of 80% olivine (Fo_{91}), 17–19% orthopyroxene (En_{91}), 1% chrome spinel and 0–2% clinopyroxene ($Wo_{45}En_{51}Fs_4$). On a centimetre scale, a ratio segregation into more dunitic and pyroxenitic layers is common. A tectonic foliation, defined by the planar orientation of orthopyroxenes is generally parallel to this layering. Chrome spinel lineations are also commonly visible within the foliation plane. A pronounced shearing fabric, associated with the emplacement of the ophiolite affects the lowermost 100–200 m of the harzburgite tectonite. The harzburgites unaffected by emplacement have a microscopic porphyroclastic to mylonitic texture; sub-boundaries in olivine (Fig. 1a) are oriented oblique to the foliation in sections cut perpendicular to the foliation and including the lineation (*xz* plane of Nicolas & Poirier (1976)), indicating deformation by simple shear, as typical of other ophiolite harzburgites (Prinzhofer *et al.* 1980; Girardeau & Nicolas 1981).

Throughout the harzburgite tectonite, sharply defined bodies of dunite (Fo_{91-92} + accessory chrome spinel) are encountered. For the most part, the dunites are concordant with the harzburgite foliation and possess a parallel tectonite fabric. They vary in size from layers 1–2 cm thick to pods with long axes up to 500 m long and thicknesses up to 50 m. In the upper part of the harzburgite tectonite, however, dunite generally appears as random, wispy stringers in harzburgite. In Oman chrome spinel concentrations are restricted to the dunite pods.

Apart from the dunite/chromite bodies in the harzburgite tectonite, a series of more mafic and ultramafic lenses, veinlets and dykes also appear. These bodies are most numerous in the uppermost 50 m of the harzburgite tectonite where they are represented by gabbro, wehrlite and pyroxenite. With increasing depth, these three petrological types persist but in decreasing abundance. At depths exceeding 2 km, olivine norites predominate and in the lowermost 1 km, websterites are most common. These bodies vary from being strictly concordant, with a tectonic fabric parallel to the enclosing harzburgite, to being sharply discordant and completely undeformed. Boudier & Coleman (1981) have proposed an explanation for this relationship by a mechanism where dykes are emplaced sequentially into the harzburgite and are then progressively rotated into the plane of the foliation.

Layered gabbros and peridotites, up to 3.5 km in total thickness, rest with a sharp contact on the harzburgite tectonite. The layers are organized in cyclic units up to 200 m thick, in which the most common sequence is dunite–wehrlite–olivine gabbro–pyroxene gabbro. The thickness of layers varies from several tens of metres to only a few millimetres. In lateral extent, layers rarely exceed 0.5 km and often pinch out after only a few metres. Cumulate* textures, generally adcumulate, and a strong igneous lamination, particularly in gabbroic types, characterize these layers.

The contact between the uniform harzburgite tectonite and the petrologically more diverse layered sequence is an easily mappable, planar boundary that can be traced throughout the length of the ophiolite. The petrology of the lowermost layers resting directly on the harzburgite tectonite varies considerably along the strike of the contact; in terms of the cyclic unit described above this may be anything from dunite to pyroxene gabbro. The mineralogy of the dykes cutting the uppermost harzburgite tectonite matches the phase assemblage developed at the base of the layered sequence. Regardless of whether the harzburgite tectonite is overlain by gabbro or peridotite, the cyclic pattern of layering described above characterizes the layered rocks up sequence.

Although this contact marks a sharp petrological break, the pervasive tectonite fabric of the harzburgite does not die out here but can be traced upwards into the layered rocks without any significant change in orientation or intensity in all the three areas studied. The tectonized layered rocks show a flattening of all constituent minerals and a lineation on the foliation plane defined by olivine and plagioclase elongation. In thin section, pyroxenes are severely fractured; olivine shows a similar wavy substructure to that noted in the harzburgite, with kink-band boundaries oriented at a high angle to the foliation; and plagioclase shows a distinctive pull-apart planar fabric perpendicular to its elongation (Fig. 1c & d). The tectonite fabric overprinting the base of the layered sequence becomes weaker upwards; tectonized cumulates alternate with non-tectonized rocks up sequence and eventually the tectonite fabric dies out completely, some 100–200 m above the base of the layered sequence.

The layered sequence passes upward with a loss of igneous lamination and the abrupt incoming of metabasaltic dykes into isotropic gabbros and plagiogranites, varying in thickness from 50–200 m. The ophiolite stratigraphy is completed by a sheeted dyke swarm, 1.5 km thick, and 1 km of largely pillowed volcanics.

The choice of a geometrical reference frame

In order to relate the structural measurements described later in this paper to processes at present-day oceanic spreading centres, a rigid geometrical reference frame for the Oman ophiolite has to be chosen. All measurements need to be referred to a palaeohorizontal plane, the direction of the ridge and the side of the ridge which the ophiolite represents.

There are several possible choices for a palaeohorizontal plane in the Oman ophiolite:

(i) depositional planes in sediments and volcanics;
(ii) a plane perpendicular to the orientation of the dyke swarm and intersecting the dyke swarm parallel to strike;
(iii) major lithological contacts within the ophiolite; and
(iv) the plane of magmatic layering.

All these choices depend upon certain assumptions being made with regard to the dynamics of the spreading process. It is the object of this discussion to decide which is geologically the most valid.

Depositional planes in pillowed volcanics can frequently be steeply dipping and this is borne out in the field where flow orientations may change dramatically over a short distance. The dip of pelagic sediments within and above the volcanic pile should be a reliable palaeohorizontal indicator; however, in practice, the occurrence of such outcrops is sparse in Oman and, as they occur near the top of the ophiolite, are often a considerable distance from the structures of interest in the gabbros and peridotites.

*This term is used here in a purely descriptive, non-genetic sense.

A strike section normal to the mean orientation of the dyke swarm assumes that dykes are intruded vertically along the ridge and that any departure from the vertical in the outcrop is due to emplacement tectonics alone. This would appear to be a fair assumption.

Based on the analogy with horizontal discontinuities between the four seismic layers of the oceanic crust, the major lithological contacts within the ophiolite could be used as palaeohorizontal planes. However, as noted by Nicolas & Violette (1982), the scale of resolution of oceanic seismic data is such that an uneven contact at a mapping scale in an ophiolite could quite easily be approximated to a planar contact. In Oman, the lithological contact which most closely approximates a plane of fixed orientation is that between the harzburgite tectonite and the layered sequence; i.e. the petrological 'Moho'. Lithological boundaries within the layered sequence have been used as a palaeohorizontal plane by Prinzhofer *et al.* (1980), Girardeau & Nicolas (1981) and Nicolas & Violette (1982). This assumption is based on models of magma chambers beneath spreading ridges such as those of Greenbaum (1972) and Casey & Karson (1981) which show the plane of magmatic layering inclined towards the ridge axis but lithological boundaries as horizontal. In Oman, this discordance is not observed. A model proposed by Smewing (1981) for the origin of the layered sequence shows layers forming by *in-situ* crystallization against the arcuate walls of a sub-crustal magma chamber which steepen progressively from flat-lying near the base of the chamber to sub-vertical at the margins. Certainly in Oman, the correlation of the plane of magmatic layering/lithological boundaries in the layered sequence with a palaeohorizontal plane would be incorrect.

Regarding the choice of ridge direction, the following possibilities have been proposed by Nicolas & Violette (1982).

(i) orientation of sheeted dykes;
(ii) a direction at a high angle to transcurrent faults, interpreted as transform faults;
(iii) the intersection between planar fabrics of igneous and tectonic origin in the layered rocks and tectonites; and
(iv) a direction at a high angle to chrome spinel lineations in the harzburgite tectonite.

In agreement with these authors, it is concluded that the most reliable indicator of the ridge direction is the strike of the dyke swarm. Using this criterion and dyke-chilling statistics, S. J. Lippard (pers. comm.) has shown that the Oman ophiolite represents oceanic crust from the SW flank of the ridge axis with a mean orientation of NW–SE.

In summary therefore, the structural measurements are referred to the following geometrical reference frame:

(i) Palaeohorizontal plane: either (a) a plane perpendicular to the mean orientation of the dyke swarm parallel to strike, or (b) the contact between the layered sequence and the harzburgite tectonite: the petrological 'Moho';
(ii) Ridge direction: strike of the dyke swarm (NW–SE); and
(iii) SW flank of the ridge axis.

Use and interpretation of olivine petrofabric diagrams in ophiolite studies

Data from forty-eight olivine petrofabric analyses are presented later in this paper. A full appreciation of these data requires some knowledge of the response of the olivine crystal to deformation at elevated temperatures and pressures . This topic, reviewed in detail in Nicolas & Poirier (1976), is dealt with only briefly in this section.

Olivine belongs to the orthorhombic crystal system (Fig. 2a). Any orientation of olivine which involves passive body rotation alone, e.g. by magmatic convection currents, will tend to orient [010] perpendicular to the flow plane and [100] and [001] within the flow plane, leading to an olivine petrofabric diagram with a clustering of [010] perpendicular to the flow plane and girdles of [100] and [001] within it (Fig. 2b).

Nicolas *et al.* (1972) have shown that the dominant mechanism of deformation of olivine in the oceanic upper mantle and lower crust is simple shear that induces gliding within the olivine lattice in one direction on a series of activated planes. For typical oceanic upper-mantle/lower-crust-confining pressures of 5–10 kb and strain rates in the region of $10^{-4}\ s^{-1}$, the system (0kl) [100] (i.e. slip in a [100] direction on (0kl) planes) is activated at temperatures between 950 and 1300°C and (010) [100] above 1300°C (Carter & Ave Lallemant, 1970).

The olivine deformation path proposed by Nicolas *et al.* (1973) for the oceanic upper mantle and lower crust is illustrated in Fig. 2c & d, with the type of olivine petrofabric diagrams anticipated from such a scheme. The starting point is a crystalline aggregate with randomly oriented olivine crystals. If this crystalline aggregate is subjected to simple shear, the olivine crystals will tend to line up with their short [010] axes perpendicular to the shear plane. This process continues until, in the mid-temperature range, an (0kl) plane is aligned parallel to the shear couple, or in the high-temperature range, the (010) plane. In both cases, gliding will then take place in the

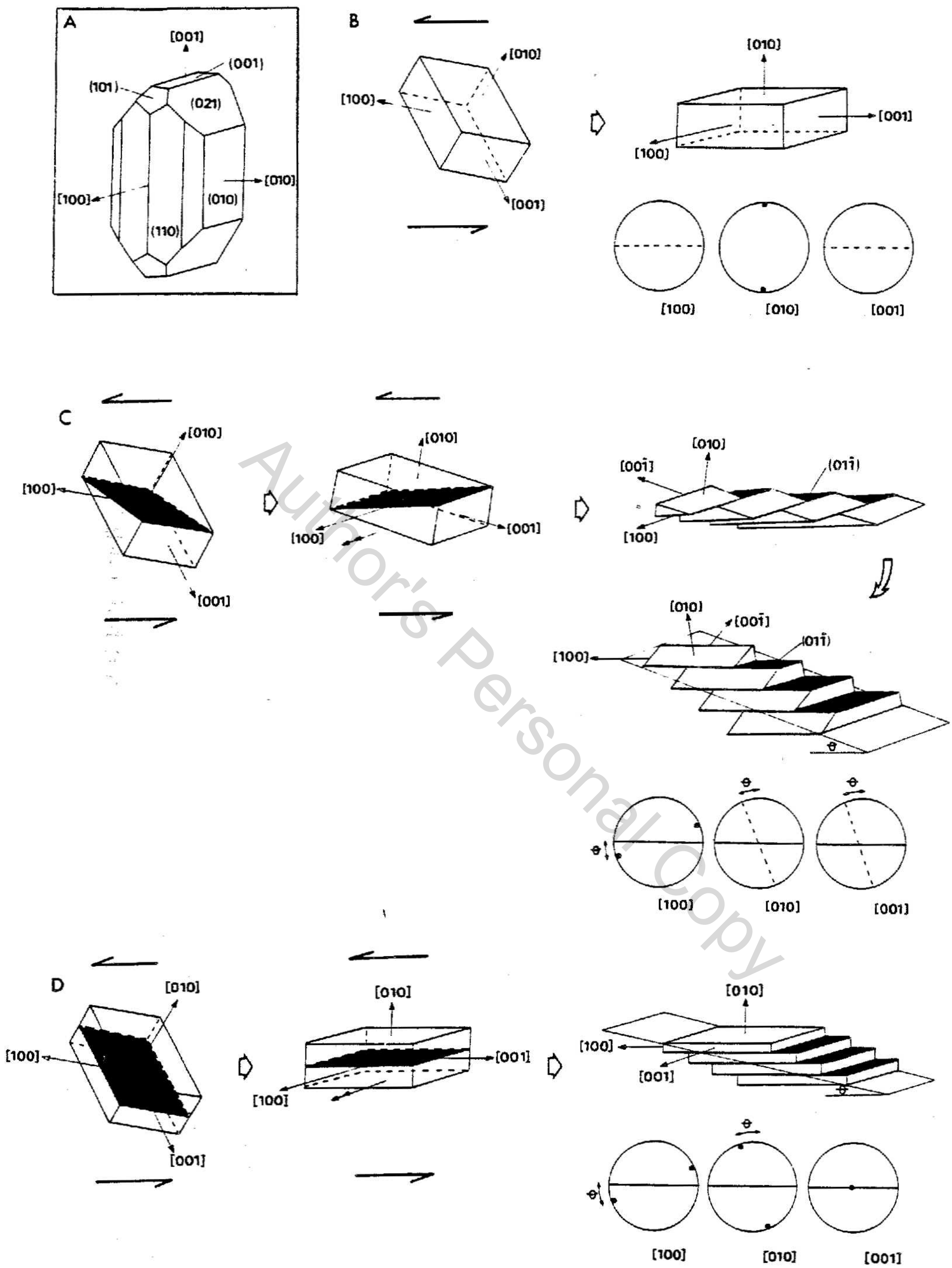

FIG. 2. (a) The olivine crystal. (b) Passive body rotation of olivine into an alignment of minimum resistance to flow. (c) Deformation of olivine by simple shear at moderate temperatures (950–1300°C). Gliding on (0kl) planes is portrayed by (0$\bar{1}\bar{1}$). Gliding in the direction of [100] shown by the double-headed arrow. Two views of the deformed crystal are shown, the lower one depicting the plane of the tectonite foliation defined by mineral elongation making an angle θ with the slip plane. (d) Deformation of olivine by simple shear at high temperatures (>1300°C).

[100] direction and will produce the petrofabric diagrams shown in Fig. 2c & d. In the first case (Fig. 2c) the olivine petrofabric diagram is typified by clustering of [100] and girdles of [010] and [001]. In the second case, all crystallographic axes form clusters. In both the medium- and high-temperature ranges, the tectonite foliation, defined by mineral elongation, makes an angle θ with the slip planes. The smaller the angle θ the higher the amount of shear. The sense of asymmetry of the slip planes with respect to the tectonite foliation reveals the sense of shear. With increasing strain, recrystallization becomes more and more important.

In summary, therefore, olivine petrofabric diagrams have the potential of revealing:

(i) whether an olivine-bearing crystalline aggregate consists of randomly oriented olivine crystals (rare), olivine crystals that have undergone passive body rotation only in a viscous medium (e.g. layered gabbros and peridotites) or olivine crystals that have undergone both passive body rotation and intercrystalline gliding (tectonites). This is useful in distinguishing tectonized from non-tectonized rocks of the layered sequence;

(ii) the slip system, and hence estimates of the temperature of deformation in the tectonites;

(iii) the sense of shear in tectonites; and

(iv) in favourable conditions, the relative amount of shear in tectonites.

Structural measurements

The locations of the three traverses described in this study are shown in Fig. 3. The complete ophiolite stratigraphy is well exposed in each of these traverses with the exception of Wadi Bani Kharus where the pillowed volcanics are largely covered by recent deposits. The following structural measurements were recorded from the harzburgite tectonite and layered sequence of the three traverses:

S_{0t} : mineral layering in harzburgite tectonite;

S_{1t} : tectonite foliation in harzburgite tectonite;

L_{1t} : chrome spinel lineation in harzburgite tectonite;

S_{0c} : mineral layering in layered sequence;

S_{1c} : tectonite foliation in layered sequence; and

L_{1c} : tectonite lineation in layered sequence.

This notation is taken for the most part from Juteau *et al.* (1977). Several other structural measurements were recorded, notably dyke orientations in the harzburgite tectonite and mineral lineations in undeformed rocks of the layered sequence. However, these were never found in sufficient numbers to be quantitatively significant.

In each traverse, the structural measurements were related to the geometrical reference frame described above by rotating the petrological 'Moho' to horizontal and recording the strike of the dyke swarm (now sub-vertical after rotation). The results of this rotation on the means of the structural measurements for the three traverses are shown in Figs 4 & 5 and Table 1.

Mineral layering in the layered sequence in all three traverses is shallow dipping (<20°) and dips into the ridge axis in Wadi Ragmi and Ath Thuqbah and along the ridge in Wadi Bani Kharus. Mantle flow planes approximated by S_{1t} and S_{1c} are shallow dipping for Wadi Ath Thuqbah and Bani Kharus but moderately inclined (~45°) in Wadi Ragmi, and mantle flow directions given by L_{1c} and L_{1t} lie within or close to mantle flow planes. All mantle flow directions are oriented at moderate to high angles (>30°) to the palaeo-ridge.

In summary, the results of the structural measurements for the three traverses show that although there is an overall tendency for planar fabrics to be shallow dipping (<20°) and mantle flow direction to be oriented at high angles to the palaeo-ridge axis, the contrasting geometrical disposition of the various structural elements with respect to the palaeo-ridge direction in each traverse shows that no unique kinematic model can be formulated for the Oman ophiolite based on this data set.

Olivine petrofabric analysis

Forty-eight oriented specimens from the harzburgite tectonite and layered sequence of the three traverses were collected for olivine petrofabric analysis. Equal-area, lower-hemisphere projections of [100], [010] and [001] axes for most of these specimens are shown in Fig. 6.

The following points are significant:

(i) Olivine in undeformed layered gabbros and peridotites away from the base of the layered sequence shows an orientation due to passive body rotation alone (Specimens 36, 84). Some preferred orientation of olivine [100] and [001] within the layering plane is shown (specimen 84). This is consistent with the orientation of olivine by magmatic convection currents.

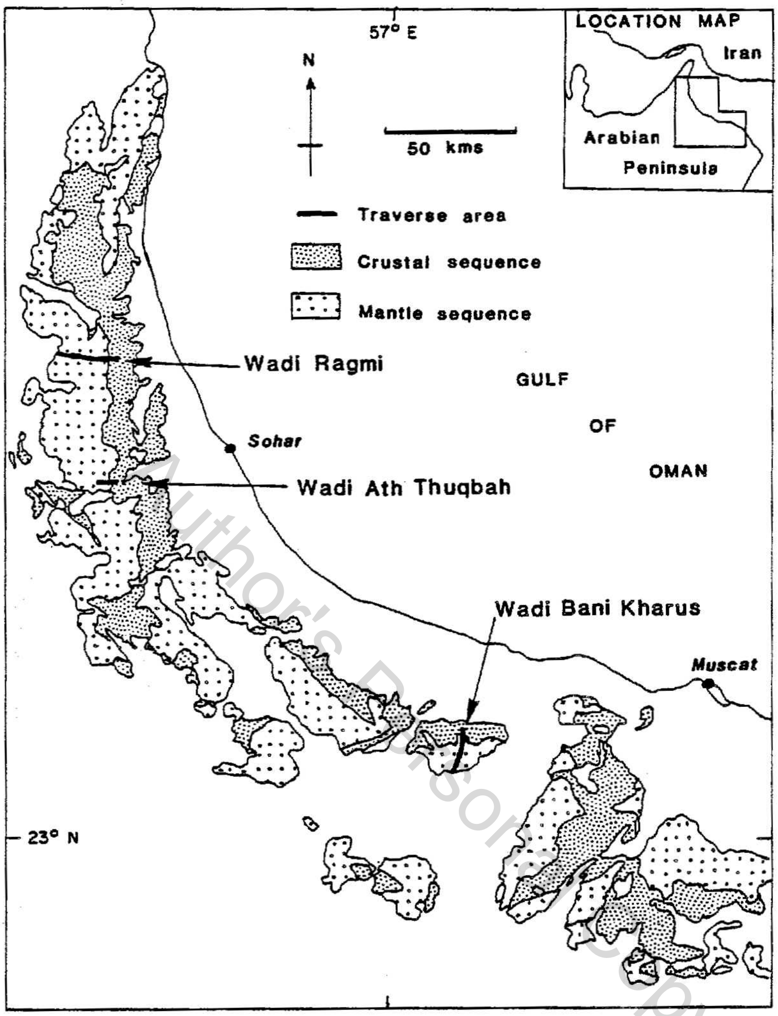

FIG. 3. Location map of the three traverses and outcrop area of the most northerly ophiolite blocks in the Sultanate of Oman.

(ii) The tectonized layered gabbros and peridotites at the base of the layered sequence have an olivine orientation consistent with deformation at both moderate (950–1300°C) and high (>1300°C) temperatures (specimens 33, 193, 2419).

(iii) Harzburgites immediately underlying the petrological 'Moho' have a fabric which is identical in terms of intensity, shear sense and the type of slip plane activated with the layered gabbros and peridotites immediately above the petrological 'Moho'.

(iv) All harzburgites show a tectonite olivine fabric.

(v) There is no obvious correlation between depth in the harzburgite tectonite and the olivine slip system activated. The [100] (0kl), moderate-temperature slip system is the most prevalent. Similarly shear senses are highly variable down section.

(vi) In a number of cases (specimens 60, 71, 2297) a [100] (001) slip system has been identified. This has not previously been described from either experimental or natural studies and cannot, at present, be explained.

Conclusions

Kinematic models of ocean-crust formation (Langseth *et al.* 1966; Sleep 1975; Lachenbruch 1976; Tapponnier & Francheteau 1978) portray mantle material upwelling beneath oceanic

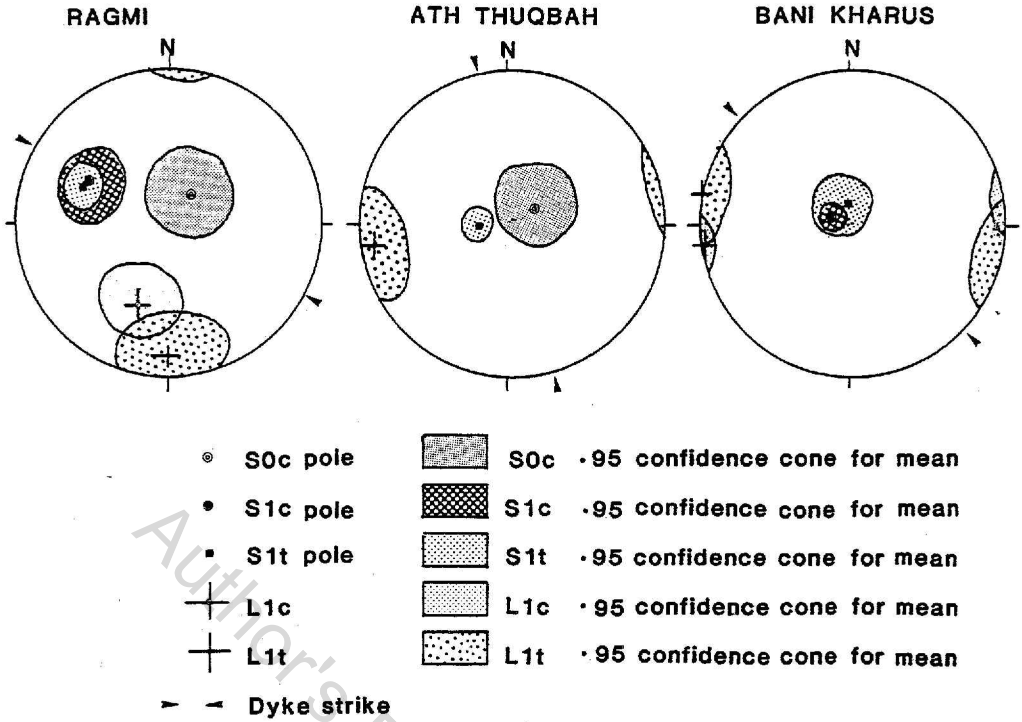

FIG. 4. Plotted mean structural measurements for each traverse rotated to a horizontal petrological 'Moho'. All projections are equal area, lower hemisphere. Each mean and confidence cone is the result of at least 100 measurements.

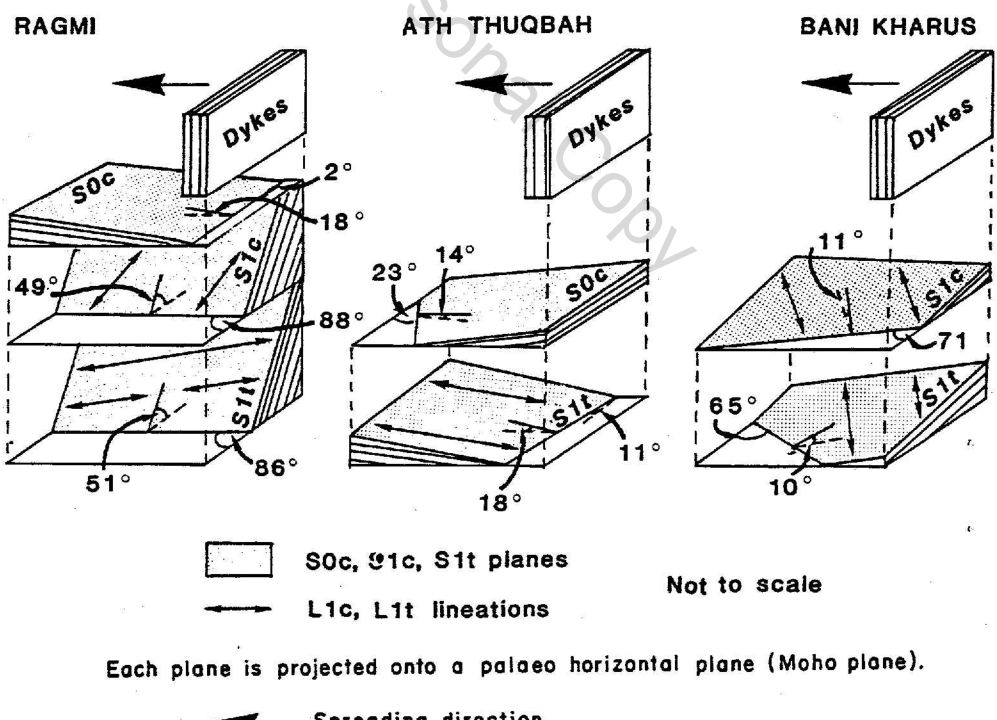

FIG. 5. Perspective views of the structural elements of the three traverses following rotation of the petrological 'Moho' to the horizontal.

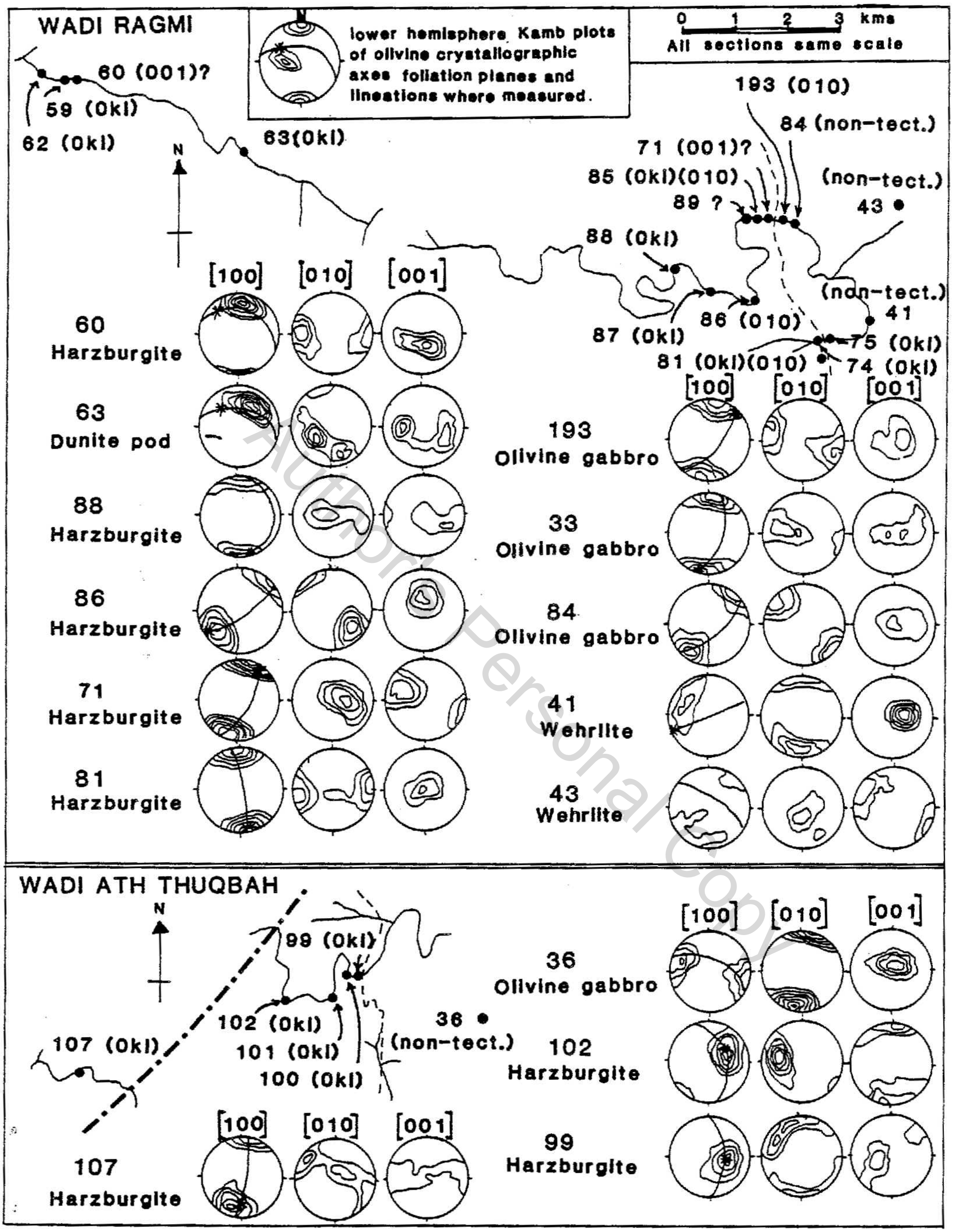

FIG. 6. Sketch map of each traverse showing the locations of specimens that were selected for olivine petrofabric analysis. Equal-area lower hemisphere projections of [100], [010] and [001] axes of at least sixty-five olivine grains, plotted as Kamb diagrams are shown for most of the specimens. The projections are contoured in 2σ intervals with the lowest contour equal to 4σ. Layering (S_0) or foliation (S_1) planes and lineation (L_1) are shown where discernible in outcrop. The slip direction is always [100] irrespective of which slip system is activated; the slip plane and the shear sense are discussed in the text.

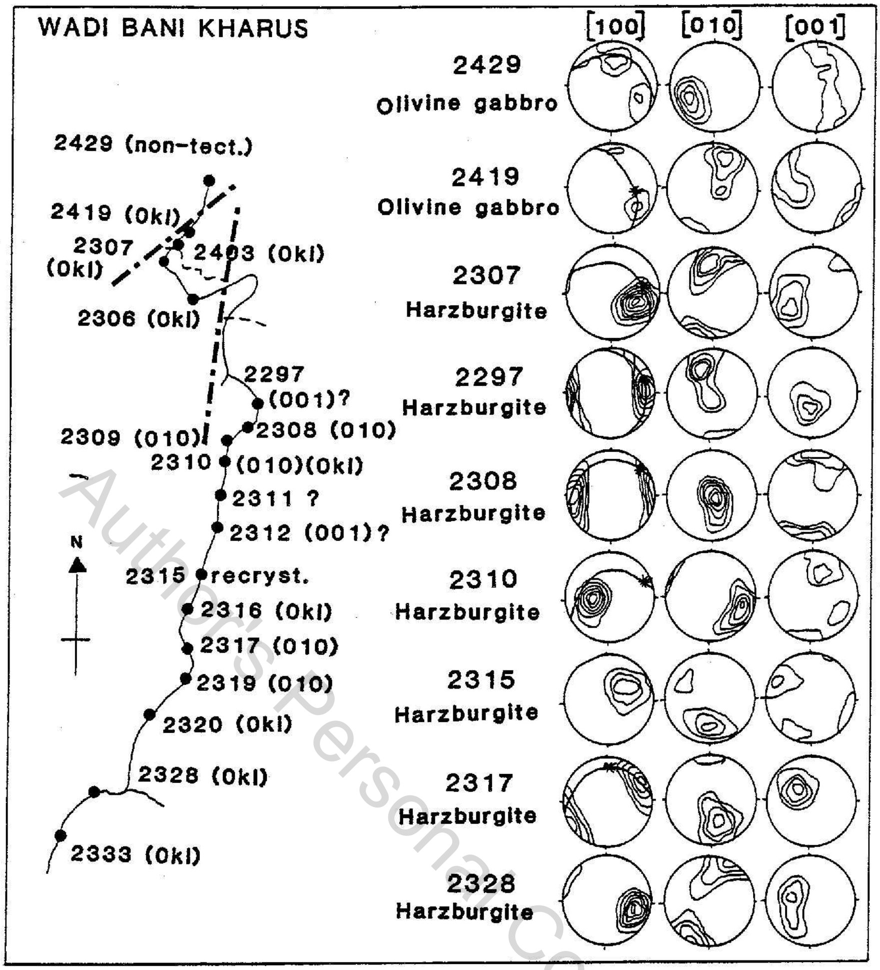

FIG. 6. (continued)

TABLE 1. *Mean structural measurements for each traverse following rotation of the petrological 'Moho' to the horizontal. Measurements shown as dip amount over dip direction; 95% confidence cones shown in brackets. Each mean is the result of at least 100 measurements.*

	Wadi Ragmi	Wadi Ath Thuqbah	Wadi Bani Kharus
Dyke strike	120°	165°	131°
S_{1t}	51/116° (10.2)°	18/086° (8.0)°	10/155° (16.4)°
L_{1t}	18/183° (24.5)°	09/260° (23.6)°	00/281° (20.6)°
S_{0c}	18/212° (24.0)°	14/232° (21.8)°	Sub-parallel to S_{1c}
S_{1c}	49/118° (19.0)°	Undeformed	11/112° (8.5)°
L_{1c}	46/213° (20.0)°	Undeformed	02/084° (14.0)°

*S_{0t} sub-parallel to S_{1t} in all cases.

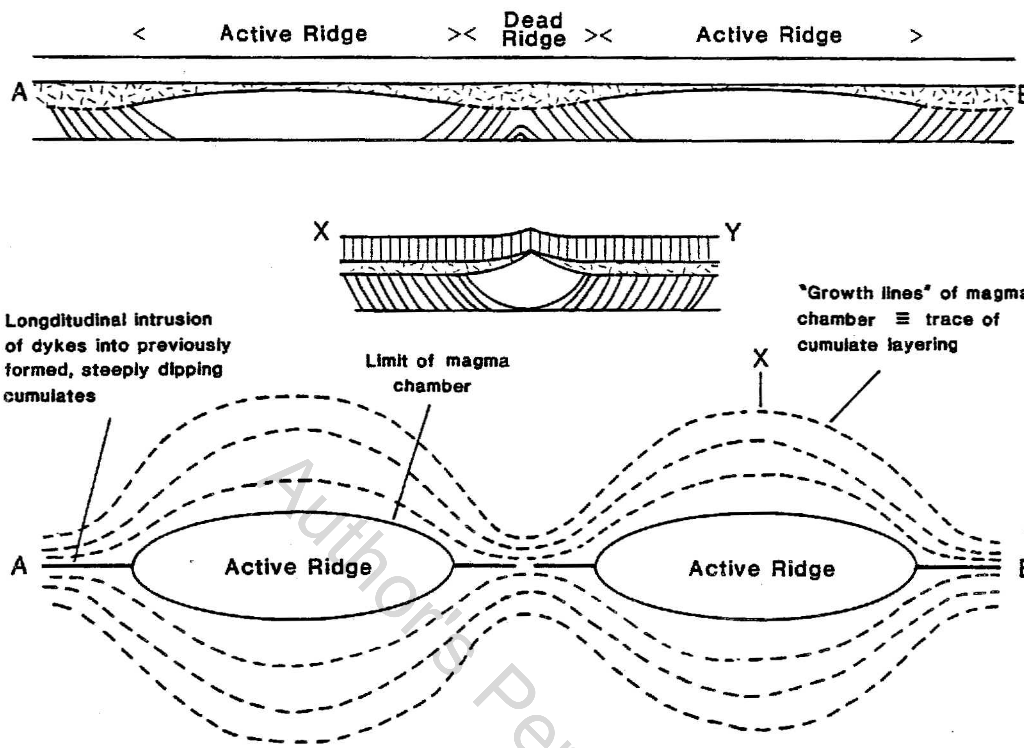

FIG. 7. Diagram illustrating hypothesis that oblique attitudes of structural elements with respect to orientation of palaeo-ridge may be due to discrete ellipsoidal magma chambers strung out along the ridge.

spreading centres and diverging along sub-horizontal flow planes beneath the newly created oceanic lithosphere. If ophiolites sample this oceanic lithosphere then they should show a small angle between mantle flow planes and the palaeohorizontal, a high angle between mantle flow directions, given by chrome spinel lineations and olivine [100] maxima, and the direction of the palaeo-spreading axis and a uniform shear sense. Nicolas & Violette (1982) have already shown that this idea may not be tenable based on a synthesis of structural measurements from eleven ophiolites. They recognize a 'Table Mountain type', approximating to the situation described above, and an 'Acoje type' which preserves vertical rather than horizontal fabrics in the harzburgite tectonite, deformed cumulates and large-scale folds which they ascribe to diapiric rather than laterally spreading asthenospheric flow.

Based on the structural measurements presented earlier, the Oman ophiolite would appear to be generally of the Table Mountain type. However the lack of correlation between the geometry of the structural elements in the three traverses suggests that no unique kinematic model for the Oman ophiolite can be formulated. Rather, a different kinematic interpretation for each traverse is valid based on their unique geometries. Furthermore, the lack of correlation with depth of shear sense and type of slip system activated suggests that the Oman harzburgite tectonite did not uniformly accrete against the base of the oceanic lithospheric plate. Petrologic data (Browning 1982) suggests rather that the Oman harzburgite tectonite results from the juxtaposition of various mantle areas just beneath the palaeo-spreading axis magma chamber during active spreading, these areas having equilibrated at different depths beneath the palaeo-spreading axis.

The angle between the strike of the mineral layering in the layered sequence and the strike of the dyke swarm varies from 0–70° in the three traverses studied. A spreading model with a continuous magma chamber beneath the ridge would predict that this angle should be zero. The data therefore suggest a model of discrete magma chambers beneath the ridge (Fig. 7); the closing of magma chambers parallel to the ridge axis occurring where the angles between the dyke swarm strike and the cumulate layering strike depart from parallelism. In this case the flow planes and flow directions in the mantle might be expected to reflect this geometry.

Magma-chamber models for oceanic ridges (e.g. Casey & Karson 1981) show layering dipping towards the ridge axis. This geometrical configuration has often been used to determine which flank of a spreading ridge an ophiolite represents (e.g. Hopson *et al.* 1981). The data presented here are not consistent and do not therefore resolve the argument of whether the Oman ophiolite represents the NE (Pallister 1981) or SW (S. J. Lippard pers. comm.) flank of a NW–SE spreading ridge.

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