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Serpentinized Peridotites of Bi'r Tuluhah Ophiolite Complex, Saudi Arabia- Some geological aspects and Economic perspective

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ABSTRACT

This paper presents an account of various observations encompassing field geological, petrographic, genetic aspects and economic significance of serpentinized peridotites of ophiolite complex of Bi'r Tuluhah area of Saudi Arabia. The Bi'r Tuluhah ophiolites were emplaced during sinistral transpression of the Hulayfah-Ad Dafinah-Ruwah suture. The complex comprises a suite of layered gabbro, diorite, serpentinized peridotite and amphibolite. The ophiolites are strongly deformed, metamorphosed, and altered by listwaenitization (silicification and carbonatization) in the shear zones with predominantly low-grade greenschist facies metamorphism and in some places amphibolite grade. Petrography of serpentinized peridotite revealed enriched serpentinization and calcitization. Field evidences and laboratory studies indicate that the area may have a good potential for gold, chromium and allied mineralization.

Keywords: Serpentinised peridotites, Ophiolites, Economic significance, Bi'r Tuluhah, Pre-Cambrian Arabian Shield.

INTRODUCTION

Ophiolites are widespread in the Arabian Pre-Cambrian shield along shear zones as discontinuous patches of small areal extent. Country regional geological map shows five types of distinct chrono-litho zones (Fig 1). Mafic-ultramafic ophiolite complexes of the Arabian shield make up less than 1% of the surface area and are very valuable in delineating the origin of the shield because of their possible tectonic significance as remnants of oceanic crust and indicators of arc-arc suturing [1, 2]. They provide stratigraphic, geochronologic and structural evidences along with evidence of active ocean-floor magmatism along with development of tectono-stratigraphic terranes in the shield and suturing during terrain amalgamation [3-5].

The mineralogy, chemistry, and tectonic settings of Arabian and Nubian shield ophiolites are well studied by Stern et al., [4] Among the mafic-ultramafic complexes reported in the region, not all are ophiolites. Some of the complexes are non-diagnostic lenses of sheared serpentinites, some are intrusions in the base of volcanic arcs and some are layered intrusions. Hence utmost care is required while identifying, interpreting and correlating with other complexes [7, 8] However, majority of the complexes are characterized by properties of an ophiolite complex. Major ophiolite complexes are distributed at Jabal Ess, Jabal Wask, Bi'r Tuluhah, Darb Zubaydah, Jabal Tarwah and Jabal al Uwayjah in the Kingdom. Common rock suite includes layered and massive gabbro, diorite, serpentinized peridotite, amphibolite, bronzite peridotite, metavolcanics, tuffs, plagiogranites, pillow basalts, harzburgite etc. By virtue of the structural disturbances, one or more of these lithologies are absent. An account of some field geological and petrographic studies of one such ophiolite complex exposed at Bi'r Tuluhah in the north central Arabian Shield is presented in this paper.

Fig. 1. Simplified Geological Map of Saudi Arabia (Source: Saudi Geological Survey)

The Bi'r Tuluhah ophiolites are at the northern end of the Hulayfah-Ad Dafinah-Ruwah suture joining the Hijaz-Jiddah-Asir terranes and the Afif terrane. The Bi'r Tuluhah ophiolites are believed to be rooted in the shear zones with which they are associated, marking the sites of consumption of oceanic crust. The purpose of this report is to describe the lithology, structure, and field relations of Bi'r Tuluhah ophiolites with emphasis on the serpentinized peridotites which occupy major portion of the ophiolitic complex in Bi'r Tuluhah. More over serpentinized peridotites are important by virtue of being hosts for chromitite and/or ferrochrome ore in the study area.

STUDY AREA

The area falls to the west of Bi'r Tuluhah where ophiolites are exposed. A simplified geological map and sub-divisions of different geological terrains shows a variety of Pre-Cambrian rock types in the Arabian Shield (Fig.2). The area has a greenish tone on the Google Earth image indicating the intense serpentinization parts of this area (Fig. 2).

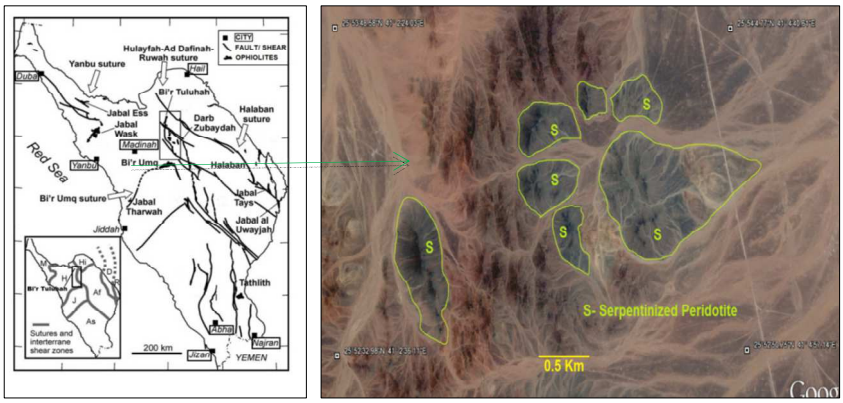

Fig.2 A. Distribution of Ophiolite Complexes and major Fault/ Shear Zones Af= Afif; As = Asir; D = Ad Dawadimi; H:Hijaz, Hi:Hail, J:Jiddah, M:Midyan, R:Ar Rayn. (Modified from [3, 4& 5]B. Google Earth image of part of study area

MATERIALS AND METHODS

During the field visit by the author in 2007-2008 to this province, geological traverses were made in the study area to observe various rock types. Four samples each of serpentinized peridotite and ferrochrome ore were collected. The rock samples were finished into thin sections by adopting manual conventional method of grinding, at the Geological Survey of India, Hyderabad and were petrographically studied using petrological stereo microscope. Polished rock sample is studied using Veho VMS-004 USB Microscope at 200x magnification. The chromitite ore samples were geochemically assayed at a local laboratory by portable XRF method.

DISCUSSION

General geological setting

The Bi'r Tuluhah ophiolite out-crops are present in the northern part of the Hulayfah- Ad Dafinah fault zone (HDFZ) in the north-central part of the Arabian shield (Fig.3 A & B). The HDFZ is overlain and intruded by post-amalgamation basins and granites and displaced by Neoproterozoic NW trending Najd faults. The ophiolite belt extends for a length of 30 km trending NS direction crops out in subtle hills in the study area, raising 15 to 40 m above the wadi (valley)plains [9].

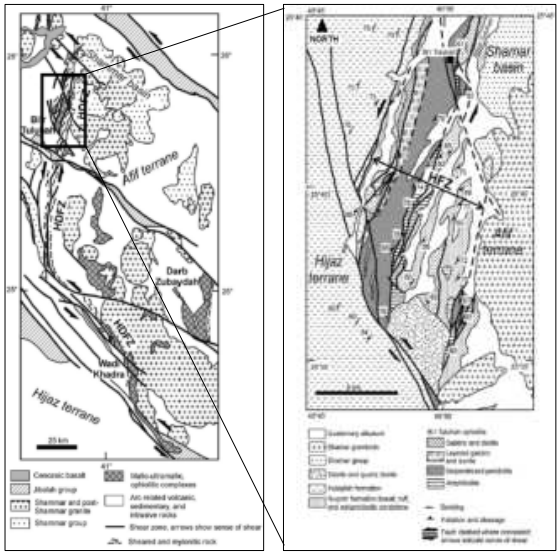

Fig. 3 A. Regional and B. Simplified geologic map showing the location of the Bi'r Tuluhah.[11- 13]

Delfour (1977) described an ophiolitic assemblage along the northern Nabitah suture and mapped ophiolitic rocks as part of newly defined Urd group ophiolites in his Nuqrah quadrangle map of 1:250K scale These ophiolitic rocks are best exposed near Bi'r Tuluhah, the spring for which the complex is named [10].

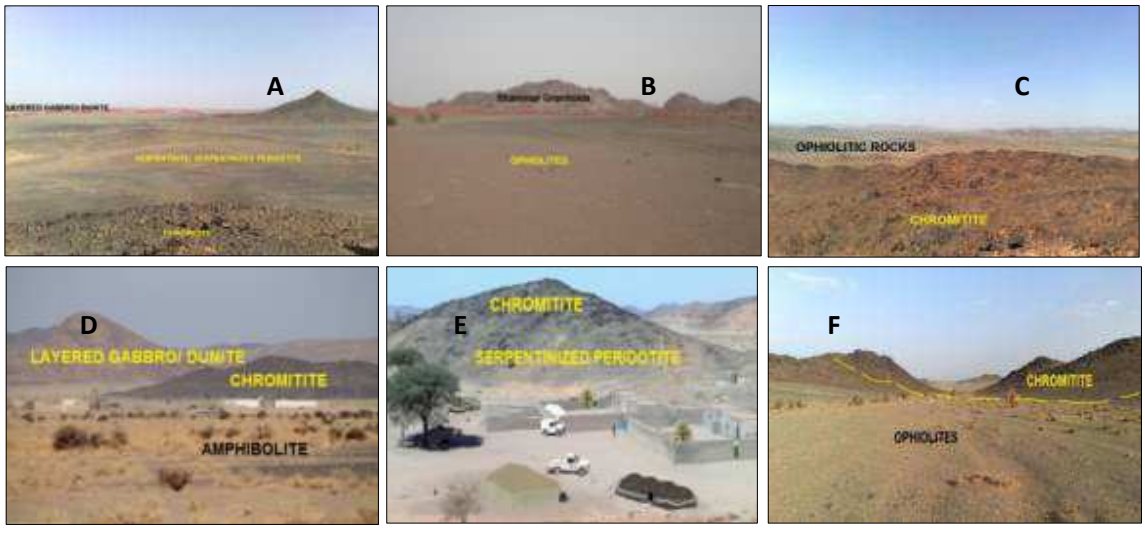

Fig.4 A. Field disposition of ophiolitic rocks (Photo facing North). B. Shammar granitoids on the East with broadly demarcated lithological contact (Photo facing East). C. Chromitite on the hill top amidst ophiolitic rocks (Photo facing South. D, E and F. Chromitite rich rocks (dark colored) in the backdrop of ophiolite complex (Photo facing West).(Source: Google Earth)

Field Relations

The ophiolite rocks in the study area, trend in more or less NNE-SSW direction in linear fashion with a steep easterly to south-easterly dip of 70^{o}. It is a common feature that these rocks are strongly weathered and thick coating of desert varnish is observed on the out crop surface. The study area comprises various rock types like layered gabbro, dunite, amphibolite, thin bands of bronzite peridotite, diorite and serpentinized peridotite. Out of these rocks, serpentinized peridotite occupies major portion. Chromitite forms as an entity within serpentinized peridotites. According to Delfour the ophiolitic rocks are faulted against steeply dipping andesitic and rhyolitic rocks on the east and on the west; they are apparently uncomfortably overlain by a basal conglomerate of the Hulayfah group [10] (Fig 4 A-F).

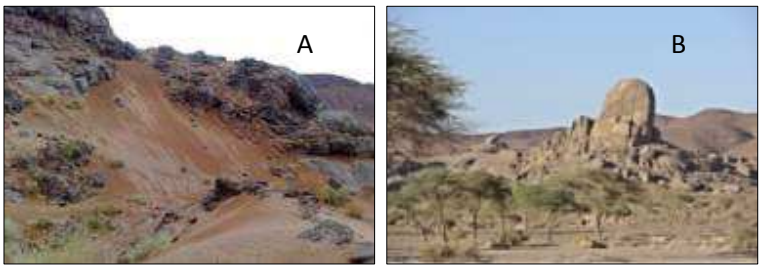

Fig.5 A. Pillow basalts on the western boundary (Photo facing North-east) and B. Shammar granitoid outcrops on the eastern boundary (Photo facing East). (Source: Google Earth)

Structure and Tectonics

The ophiolitic rocks of Bi'r Tuluhah are strongly folded and sheared and together with rocks of the Nuqrah formation constitute a sub-vertical brittle-ductile shear zone that resulted from sinistral transpression during suturing between the Afif and Hijaz terranes [12, 13] The Hulayfah-Ad Dafinah-Ruwah suture zone extends more than 500 km to the south and southeast continues as an ophiolite-decorated shear zone and is one of the longer sutures identified in the Arabian shield. Lithologic contacts in the fault zone are mostly faults so that original stratigraphic and structural relations are obscure, but an ophiolite is identified at Bi'r Tuluhah on the basis of the presence of amphibolite, serpentinized peridotite, layered gabbro, and non-cumulus gabbro [10]. The fault zone on the west is flanked by volcanic and volcanoclastic rocks of the Hulayfah formation (Fig. 5A). Epiclastic and bimodal basalt and rhyolite of the Shammar granites of Shammar group overlie and intrude the fault zone on the east (Fig. 5B). The ophioloites have undergone dislocation on the north and south flanks, by the effect of Post-Shammar northwest trending sinistral Najd faults.

The rocks are strongly serpentinized but harzburgite and dunite protoliths are recognized. Petrographic sections reveal that the rocks are mylonitized and have a strong cataclastic texture although ghost equant grains and a relict granoblastic texture are recognized in thin sections [9]. Serpentinized harzburgite comprises about 15% orthopyroxene, 80% serpentinized olivine presudomorphs, and minor chromite and magnetite.

Structurally, the Bi'r Tuluhah ophiolite is a set of discontinuous fault-bounded lenses. Bi'r Tuluhah ophiolites are ubiquitously exhibit cleavage, shearing, deformed along the entire length of Hulayfah fault zone, although at places ultramylonite, schist and carbonate-altered serpentine record discrete shears within the fault zone, together with the flanking Nuqrah formation indicating listwaenitisation. All shear surfaces are subvertical, and any low-angle thrusts that may have been originally present have been obliterated or steepened by subsequent deformation. Plagiogranite dikes occur in the center of the ophiolites where serpentinized harzburgite prevails, as intrusions which have been interpreted as forming late during ophiolite magmatism and presence of rodingite margins indicated intrusion prior to complete serpentinization [3].

It is considered that the Bi'r Tuluhah complex as a typical alpine-type ophiolitic complex exposed in an overturned, north-trending anticline. The complex as consisting of a 2-km-wide zone of alternating serpentinized dunite and harzburgite, a transition zone with alternating serpentinized peridotite, anorthosite, and chromitite, a 200-m-wide zone of alternating serpentinite and metagabbro, a zone of listwaenite, and a 3-km-wide zone of interlayered pillow and amygdaloidal metabasalt and meta-andesite, mafic tuff, and jasper from the core of the structure outwards [10]Predominantly low-grade greenschist facies metamorphism occurs, but in some places the rocks reach

amphibolite grade. In shear zones, alteration results in list waenitization and locally the only evidence that mafic-ultramafic rocks underlie a given area is the presence of upstanding ridges of listwaenite that are resistant to erosion.

A detailed mapping near the Bi'r Tuluhah complex revealed that the ultramafic rocks occur as steeply dipping, fault-bounded slab within a metavolcanic and metasedimentary sequence constituting pillowed basalt, andesite, breccia, tuff, conglomerate, greywacke and rhyodacite[11]In addition, a garnet-clinopyroxene amphibolite unit bordering the harzburgite and dunite was mapped They pointed out that that the Bi'r Tuluhah complex represents a fragment of mantle and basal crustal rocks emplaced diapirically in an "epicontinental" setting.

Petrographic aspects

The macroscopic examination of polished surface of the serpentinite shows profuse serpentinization of the groundmass and calcitization is a common feature. In hand specimen, serpentinized dunite is fine grained and dark gray to green, and in thin section is an aggregate of serpentine minerals that locally have a well-developed box work texture derived from the original olivine [9]. It contains anhedral grains of chromite and magnetite, and small lenses of massive chromite. The euhedral to subhedral olivine macrocrystic grainsappear to be fresh.

The serpentinized peridotitic rock exhibits fine grained porphyritic texture comprising phenocrysts of olivine (500 microns) set in very fine grained pale green ground mass (mostly 40 microns size) of subhedral to euhedral diopside (clinopyroxene). Olivine is subhedral to euhedral and is profusely serpentinized (Fig. 5 A& B).

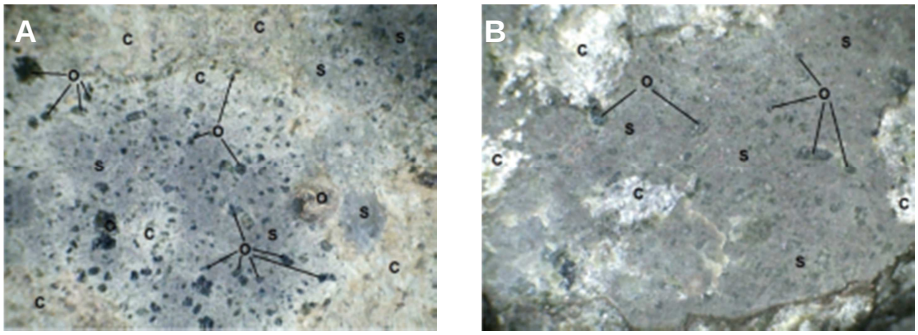

Fig. 5 A & B. Macro-petrography of polished sections of serpentinite, O- Olivine, S- Serpentine, C- Calcitization

Few laths of plagioclase are also noticed in ground mass. Reddish brown iron oxides (goethite) are disseminated throughout the rock. Examination of polished sections of serpentinite samples revealed that the rock predominantly contains serpentine with accessory grains of magnetite and chromite.(Fig. 6 A-F).

In the area west of the serpentinized peridotite, various lithologies viz., layered gabbro and dunite with minor wehrlite, lherzolite, websterite, and olivine clinopyroxenite, occur in the form of narrow bands ranging in centimeters to meters [11]. Primary structures are intensely obscured by serpentinization, it is difficult to state whether these banded rocks are mantle tectonites or ultramafic cumulates [12] (Fig. 6 A, B). A narrow linear zone of mafic plutonic rocks exists towards west, consisting gabbro and diorite in the north exists close to Bi'r Tuluhah, and fault slivers of layered gabbro in the southern part. The gabbro and diorite unit in the northern part either occur as intrusions or are faulted against the ophiolitic rocks delaying the process of ophiolite magmatism [11]. The southern layered gabbro has a cumulus texture in pyroxene- and hornblende rich phases and may be a cumulate part of the ophiolite succession. To east of the peridotite, as a part of the ophiolite, out-crops of amphibolite are found [10] (Fig.4D). Fine-grained amphibolite is strongly schistose and lacks clear textural or relict mineralogic indications of its protoliths. Coarse-grained amphibolite appears to be the result of epidote-amphibolite facies metamorphism of gabbro and diabase [12] Massive, locally pillowed metabasalt and chert together with fine-grained sandstone, keratophyre, and interbedded felsic tuff and minor basalt make up the volcanoclastic rocks of the Nuqrah formation located on either side of the mafic-ultramafic units along the fault zone [11, 12] (Fig. 4E) Top of ophiolites succession are marked by the presence of basalt and chert which represent pelagic environment but their association with felsic tuffs and sandstone suggest that they are part of a supra-subduction volcanic arc system. The metabasalt is a fine-grained, light gray to gray-green rock, the original structure and texture of which are virtually obliterated by metamorphism. The rock is identified as basalt in the field by its mafic composition, generally massive appearance,

and the local presence of pillow structure. The basalt has a strongly developed, fine-grained metamorphic foliation composed of saussuritized plagioclase, epidote, carbonate, chlorite, clinozoisite, and iron oxides [9]. Dikes of diabase, gabbro, plagiogranite, and diorite cut all the serpentinized ultramafic rocks, and plutons of diorite and quartz diorite intrude the southern part of the ophiolite.

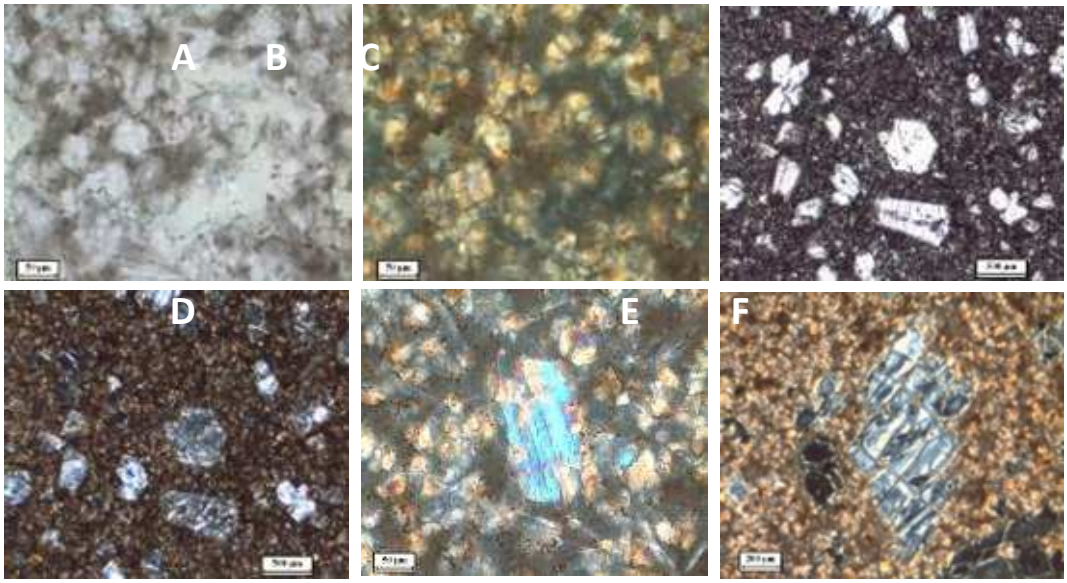

Fig. 6.Photomicrographs of serpentine peridotites of Bi'r Tuluhah A. Olivine in pyroxene groundmass. B. Olivine in pyroxene groundmass in cross-polars C. Euhedral olivine grains in pyroxene groundmass in plain polarized light. D. Euhedral olivine grains in pyroxene groundmass in cross-polars. E. Subhedral to euhedral serpentinised olivine grains in cross-polars. F. Highly serpentinized olivine with polygonal cracks in plain polarized light

Structurally, the Bi'r Tuluhah ophiolite is a set of discontinuous fault-bounded lenses. Bi'r Tuluhah ophiolites are ubiquitously exhibit cleavage, shearing, deformed along the entire length of Hulayfah fault zone, although at places ultramylonite, schist and carbonate-altered serpentine record discrete shears within the fault zone, together with the flanking Nuqrah formation. All shear surfaces are subvertical, and any low-angle thrusts that may have been originally present have been obliterated or steepened by subsequent deformation. Plagiogranite dikes occur in the center of the ophiolites where serpentinized harzburgite prevails, as intrusions which have been interpreted as forming late during ophiolite magmatism and presence of rodingite margins indicated intrusion prior to complete serpentinization [3].

ECONOMIC PERSPECTIVE

In the 20th century most of the known metallic-ore districts of Arabia were "rediscovered" with relative ease with ancient workings as exploration guides.In addition to the importance of terrane mapping to mineral exploration, the ophiolitic rocks themselves are targets for certain types of mineralization.The Bi'r Tuluhah ophiolites host a linear belt of discontinuous high- Cr podi-form ferrochrome or more precisely chromitite ore that runs for a length of ~20km. The ferruginous signature is clearly evident from the Google Earth image. Four samples of the ferrochrome ore collected show the following grades (Table 1). The ferrochrome ore in hand specimen shows dark brown color exhibiting coarse granular texture with high specific gravity.

Table. 1. Geochemical assay of ferrochrome ore in the study area

Sample#	SiO_2	Al_2O_3	TiO_2	Cr_2O_3	FeO	Fe_2O_3	MnO
SU2	0.14	8.94	0.08	**60.72**	9.90	4.04	0.83
SU5	0.11	7.00	0.04	**62.58**	10.26	4.18	1.78
SU9	0.11	8.59	0.05	**65.14**	10.84	1.16	0.97
SU11	0.12	8.38	0.19	**64.47**	13.49	1.82	1.33

Mineralizationsin ophiolitic complexes which include disseminated Cu, Ni and Cr in the ultramafic part of oceanic rocks or in their serpentinite equivalent localized in suture zones which are classified as ophiolitic type[14].Field reconnaissance of ophiolite rocks envisaged by few earlier workers revealed possibility of cobalt and gold mineralization [3, 15]. Ancient gold mines are also located along the contact of a quartz diorite pluton that intruded serpentinite of the Jabal al Wask complex [16]. Gold mineralization has been found along the length of the Nabitah mobile belt in the Arabian Shield and tends to be concentrated in quartz veins related toplutons that intrude serpentinized peridotites and carbonated serpentinite [17].In view of these findings, the study area, Bi'r Tuluhahalso deserves further detailed multidisciplinary exploration to ascertain the feasibility of winning the ore deposit.

CONCLUSION

Ophiolites are widespread in the Arabian shield and available information varies in quality and quantity. Unfortunately, none are known in sufficient detail to fully determine their tectonic setting. In the region of Bi'r Tuluhah the ophiolites are represented by rock types, viz., serpentinized peridotite, gabbro, dike complex, basalt, and pelagic rocks wherever they are complete. However, as is evident from this review, ophiolites are ubiquitously deformed, with the consequence that typical ophiolite successions are not preserved at every occurrence. Nevertheless, sufficient diagnostic lithologic criteriaare present to confidently conclude that numbers of the mafic-ultramafic complexes of theshield are indeed ophiolites. The Bi'r Tuluhah ophiolite is preserved ina subvertical shear zone that forms the northern part of the Hulayfah-Ad Dafinah-Ruwahshear zone created during sinistral transpression. The ophiolites have a small surface area, but are criticalfor understanding of the tectonic history of the Arabian shield, and warrant ongoing studyand exploration. Petrographic examination revealed predominance of serpentine with the presence of heavies like magnetite and chromitesuggesting a suprasubduction origin for the ophiolites; chemistry of these heavies can very well be used to decipher the petrogenesis. Presence of siliceous list waenite in the alteration zones standing out as resistant ridges adds importance in terms of precious metal exploration in the study area. The area is also endowed with vast resources of ferrochrome ore (Cr_2O_3 ~60%) that deserves further detailed scientific studies.Efforts must be concentrated on the exploration for new mineral deposits in the serpentinized segments of the ophiolitic complex of Bi'r Tuluhah and similar complexes elsewhere in the Kingdom.

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