Journal of Himalayan Earth Sciences Volume 47, No. 2, 2014, pp. 115-124

Facies and distribution of metamorphic rocks beneath the Muslim Bagh ophiolite, (NW Pakistan): tectonic implications

M. Ishaq Kakar[1], Mehrab Khan[2], Khalid Mahmood[3] and Andrew C. Kerr[4]
[1]Centre of Excellence in Mineralogy, University of Balochistan, Quetta, Pakistan
[2]Department of Geology, University of Balochistan, Quetta, Pakistan
[3]Department of Earth Sciences, University of Sargodha, Sargodha, Pakistan
[4]School of Earth and Ocean Sciences, Cardiff University, Cardiff, Wales, UK

Abstract

The Muslim Bagh ophiolite Complex comprises two massifs; Jang Tor Ghar Massif (JTGM) and Saplai Tor Ghar Massif (STGM) and shows a nearly complete ophiolite sequence that is structurally underlain by metamorphic sole rocks. The metamorphic rocks are found around both the massifs of Muslim Bagh ophiolite but, the best exposures are on the northwest side of JTGM and west of STGM. The sole rocks consist of mylonitic peridotite and sub-ophiolitic metamorphic rock series grading from (garnet-bearing) amphibolite facies to greenschist facies. A mylonitic texture in basal peridotite is the result of ductile lithospheric deformation while the sub-ophiolitic metamorphic rocks were formed during intra-oceanic subduction, i.e., the first stage of the emplacement of Muslim Bagh ophiolite. The foliation plane of the metamorphic sole rocks on the northwestern base of the JTGM strikes northeast–southwest with a dip ranging from 20º –75º to the east, while on the western side of STGM, it trends north–south and dips steeply towards east. Most of the lineations display northeast–east orientations which suggest that the ophiolite was obducted from west to east in the frame of today's geographic co-ordinates. During intra-oceanic subduction various parts of the subducted plate were accreted to the base of the overriding slab and subjected to a temperature between about 900–1,000 °C, forming mylonitic peridotite and then continued downwards to form the sub-ophiolitic metamorphic rocks.

Keywords: Intra-oceanic subduction; Metamorphic sole rocks; Mylonitic peridotites; Garnet amphibolites; Greenschists.

1. Introduction

The basal contact of many allochthonous ophiolite complexes are characterized by the presence of thin subjacent sheets of relatively high grade of metamorphic rocks. (e.g., Williams and Smith, 1973; Coleman, 1977; Searle and Malpas, 1980) that lie a structural position below the ophiolite and above the underlying sedimentary and volcanic rocks (Gnos and Peter, 1993). Metamorphic rocks are exposed around the Muslim Bagh ophiolite, with the best exposures found NW of Jang Tor Ghar Massif and west of Saplai Tor Ghar Massif. These rocks comprise mylonitic peridotite and sub-ophiolitic metamorphic rocks that range from garnetiferous amphibolites facies, to amphibolite facies to greenschist facies and un-metamorphosed sediments. Hunting Survey Corporation (1960), Bilgrami (1964) and Van Vloten (1967) described the ophiolite as extrusive and intrusive complex and the metamorphic rocks as thermal aureole. Ahmad and Abbas (1979) described these metamorphic rocks as tectonic slivers. Munir and Ahmed (1985) were the first to report the petrology of the metamorphic rocks of Jang Tor Ghar Massif. The purpose of this study is to document the facies and distribution of metamorphic rocks beneath the Muslim Bagh ophiolite and discuss their origin and significance for the emplacement of ophiolite.

2. Regional geological setting

The rocks in the Muslim Bagh area are divided into three geo-tectonic terranes (Fig. 1). In the south, the tectonically lowermost is the zone of the Indian passive continental margin. This zone consists mainly of limestone, sandstone and mudstone ranging in age from Early Jurassic to Paleocene (Warraich et al., 1995). The Calcareous Zone is thrusted over by the Suture Zone; lying between the Indian plate and Afghan Block (Gansser, 1964) and consists of the Muslim Bagh ophiolite (see next section) and the Bagh Complex. The Bagh Complex is an accretionary wedge complex, comprising Triassic to Jurassic sedimentary rocks (Naka et al., 1996), Cretaceous igneous rocks (Sawada et al., 1992), Cretaceous pelagic to hemi-pelagic sediments and a small amount of mélange (Mengal et al., 1994; Kojima et al., 1994). The Flysch Belt lies to the north of the Suture Zone and is composed of the Nisai Formation (Eocene; Allemann, 1979) at its base that unconformably overlies the ophiolite. These are succeeded by immature Oligocene turbidites of Khojak Formation (Qayyum et al., 1996), Miocene–Pliocene arenites and conglomerates of the Multana Formation and the Pleistocene lacustrine deposits of Bostan Formation (Fig. 1).

3. Muslim Bagh Ophiolite

The Muslim Bagh ophiolite comprises two main blocks; Jang Tor Ghar Massif (JTGM) and Saplai Tor Ghar Massif (STGM) (Bilgrami, 1964; Fig. 1). The two blocks are structurally related and belong to the same ophiolite nappe, and overlie a zone of subophiolitic mélange and sediments of the Bagh Complex (Mahmood et al., 1995; Naka et al., 1996; Fig. 1). The JTGM is mainly composed of foliated peridotite (harzburgite and dunite) and covers an area of about 150 km^2. The STGM shows a nearly complete ophiolitic sequence ranging from foliated peridotite at the base through the Mantle-Crust Transition Zone to crustal rocks at the top. Many outcrops of dunite both in STGM and JTGM have a large concentration of chromite, which are mined locally in the areas. The mantle rocks of Muslim Bagh ophiolite are intruded by a swarm of mafic dykes. These dykes vary from about 3-15 metres thick and trend NW-SE (Fig. 1). The crustal section of the Muslim Bagh ophiolite consists of bands of dunite, wehrlite, pyroxenite at the base overlain by the layered and foliated gabbro. The gabbroic section is followed by a less-developed sheeted dyke complex which is intruded at the base and in the middle part by plagiogranite. The zircon found in the plagiogranite yield a U-Pb crystallization age of 80.2 ± 1.5 Ma (Kakar et al., 2012).

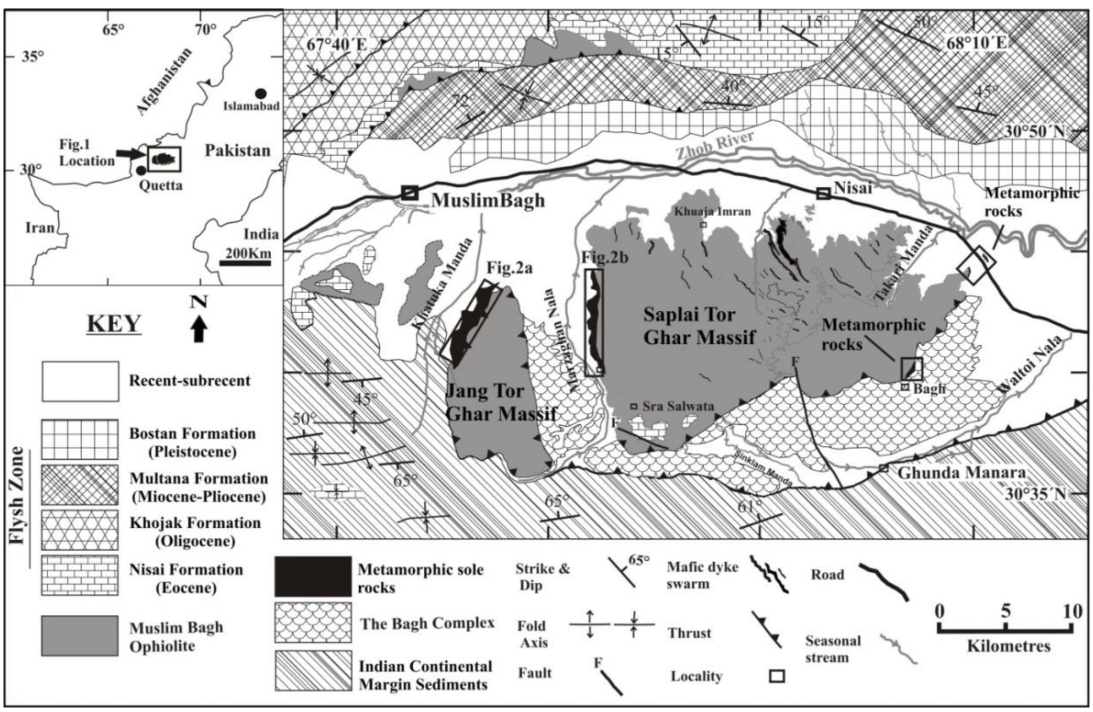

Fig. 1. Geological map of the Muslim Bagh area showing the Muslim Bagh ophiolite, the Bagh Complex, the sediments; of the Flysch zone, and the zone of Indian Passive continent margin. (After HSC, 1960; Van Vloten 1967; Mengal et al., 1994; Siddiqui et al., 1996; and Kakar et al., 2012).

4. Metamorphic sole

The metamorphic rocks (also known as the Metamorphic Sole Rocks) are distributed around the Muslim Bagh ophiolite; in the northwestern part of JTGM, west of STGM, east of Nisai town and in the mélange unit near the Bagh village (Fig. 1). These rocks are mainly amphibolites and greenschist facies metamorphic rocks. Thin slices of metamorphic rocks are found near the Nisai town and Bagh village both of them are not mapable on a reasonable scale (Fig. 1). They are thin blocks of amphibolite and greenschist facies rocks embedded in a mélange unit. The metamorphic rocks on the northwestern part of JTGM are mapped on a scale of 1:12500 (Fig. 2). The sole rocks of JTGM consist of a basal part of the foliated peridotite and the sub-ophiolitic metamorphic rocks; garnet amphibolite facies grades downwards into amphibolite facies and greenschist facies with calcite–marble inter-layers which exhibits decreasing metamorphic grade and decreasing intensity of deformation downward from the stratigraphic base of the ultramafic rocks. The basal part of the peridotite is mylonitic and banded. The metamorphic sole rocks beneath the STGM are not well exposed, with the exception of the mylonitic peridotite. In the sub-ophiolitic metamorphic rocks; amphibolite and greenschist facies are thin and poorly exposed.

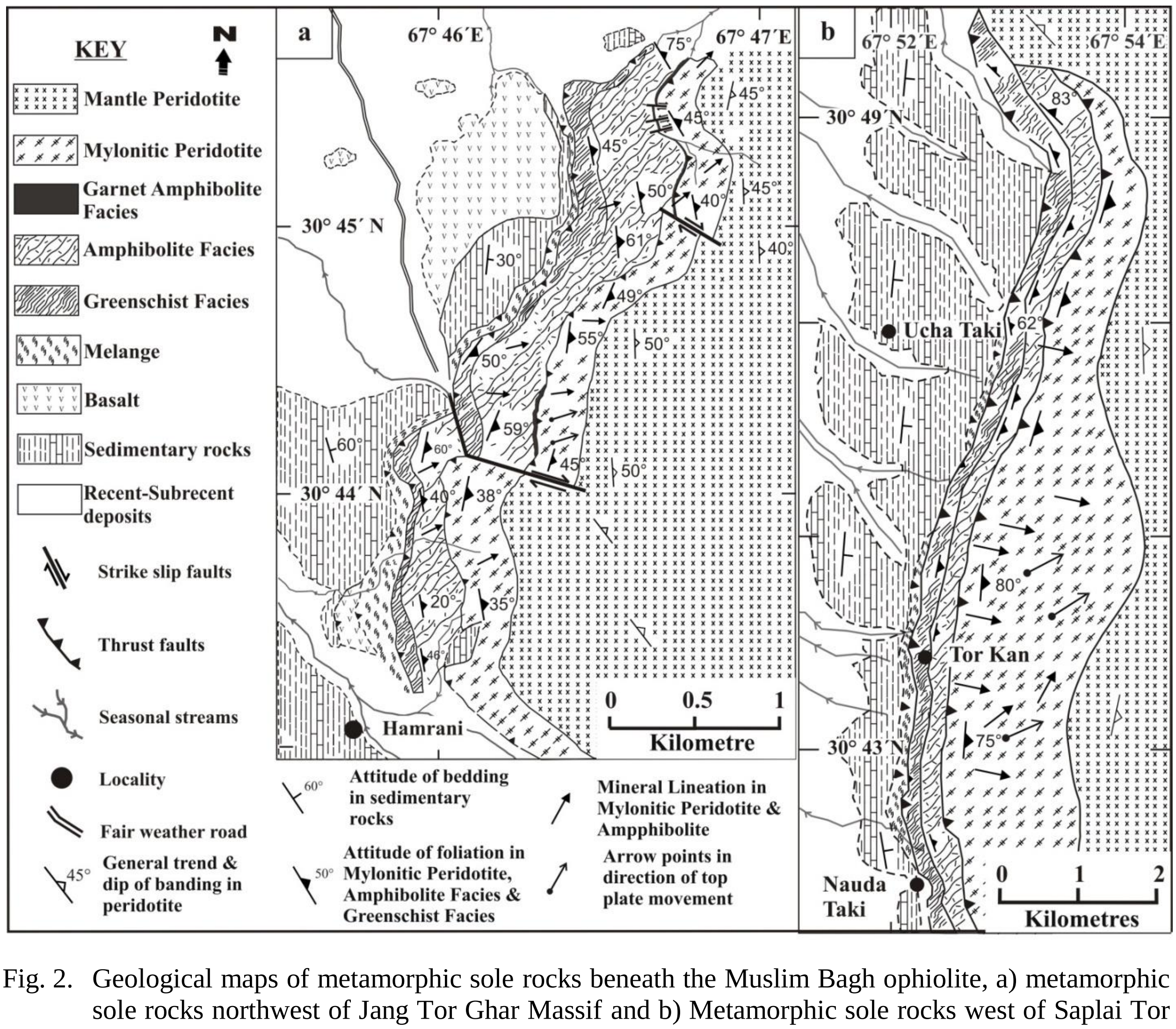

Fig. 2. Geological maps of metamorphic sole rocks beneath the Muslim Bagh ophiolite, a) metamorphic sole rocks northwest of Jang Tor Ghar Massif and b) Metamorphic sole rocks west of Saplai Tor Ghar Massif.

All the sub-units of metamorphic sole rocks i.e., basal peridotite and the sub-ophiolitic metamorphic rocks like garnet amphibolite facies, amphibolite facies to greenschist facies are separated by the thrust faults and indicating decreasing intensity of deformation downward from the stratigraphic base of the ophiolitic rocks. A number of measurements of the penetrative structures (foliation and lineation) are made at both the exposures of metamorphic sole rocks of Muslim Bagh ophiolite. These structures are shown on Figure 2. The foliation plane in the metamorphic sole rocks on the northwestern base of the JTGM strikes northeast with a dip ranging from 20º –75º to the east (Fig. 2). While the sole rocks on the western side of the STGM trend north to south and dip steeply towards the east. The majority of the lineations display NE-E orientations.

In Muslim Bagh, the metamorphic rocks can be divided into sub-units as mylonitic peridotite, garnet amphibolites facies, amphibolites facies, and green schist facies.

4.1. Mylonitic peridotite

The base of both the JTGM and STGM of Muslim Bagh ophiolite is marked by mylonitic peridotite. These rocks are banded (Fig. 3a), sheared and about 500 metres thick (Fig. 2). The banding is concentrated along the base of the peridotite sequence becoming less intense upwards and is readily distinguishable from earlier planer and linear fabrics recognized at higher levels in the sequence that are formed under mantle conditions (Nicolas,1989). This is because this banding is due primarily to ophiolite emplacement (Boudier and Coleman, 1981).

The mylonitic and banded harzburgite and dunite at the base of the ophiolite record plastic deformation developed possibly within the granulite facies (Boudier and Coleman, 1981; Nicolas, 1989). The porphyroclastic texture becomes increasingly developed close to the basal thrust plane of the ophiolite. A 900-1,000ºC temperature range is ascribed to this kind of texture (Mercier and Nicolas, 1975). Mylonitic texture with complete recrystallization of olivine is common within a few metres from the contact of amphibolites.

Petrographically, the harzburgite from the mylonitic peridotite are darker in colour and less altered than associated dunite. They are porphyroclastic and mylonitic in texture. The original grains are fine grained and stretched into long thin streaks with large amounts of strain and recrystallization (Fig. 3b). These flow structures are observed almost in every thin section. The mineral composition of mylonitic peridotite is olivine, pyroxene, serpentine and opaque.

4.2. Garnet amphibolite facies

The garnet amphibolite facies rocks are only exposed below the JTGM and are about a metre thick. It is hard, well foliated and has alternate bands of dark colour and light colour minerals that vary in thickness from 2-5 millimetres. Foliation and lineation in garnet amphibolite are parallel to sub-parallel to those found in the mylonitic peridotite. No relict igneous textures have been observed. Large garnet grains are present in garnet amphibolite facies rocks and range in size from about 2 to 3 millimetres (Fig. 3c).

The garnetiferous amphibolite consists of hornblende, plagioclase and garnet with minor minerals like epidote, quartz, apatite and magnetite. The hornblende is poikiloblastic and crystals are lineated parallel to the rock foliation. In some thin sections foliation is well marked due to segregation into dark and light colour bands. The dark colour bands consist of hornblende while the light bands consist of plagioclase and quartz. The core of the garnet grains has numerous inclusions of quartz and probably magnetite, which align to the rock foliation (Fig. 3d).

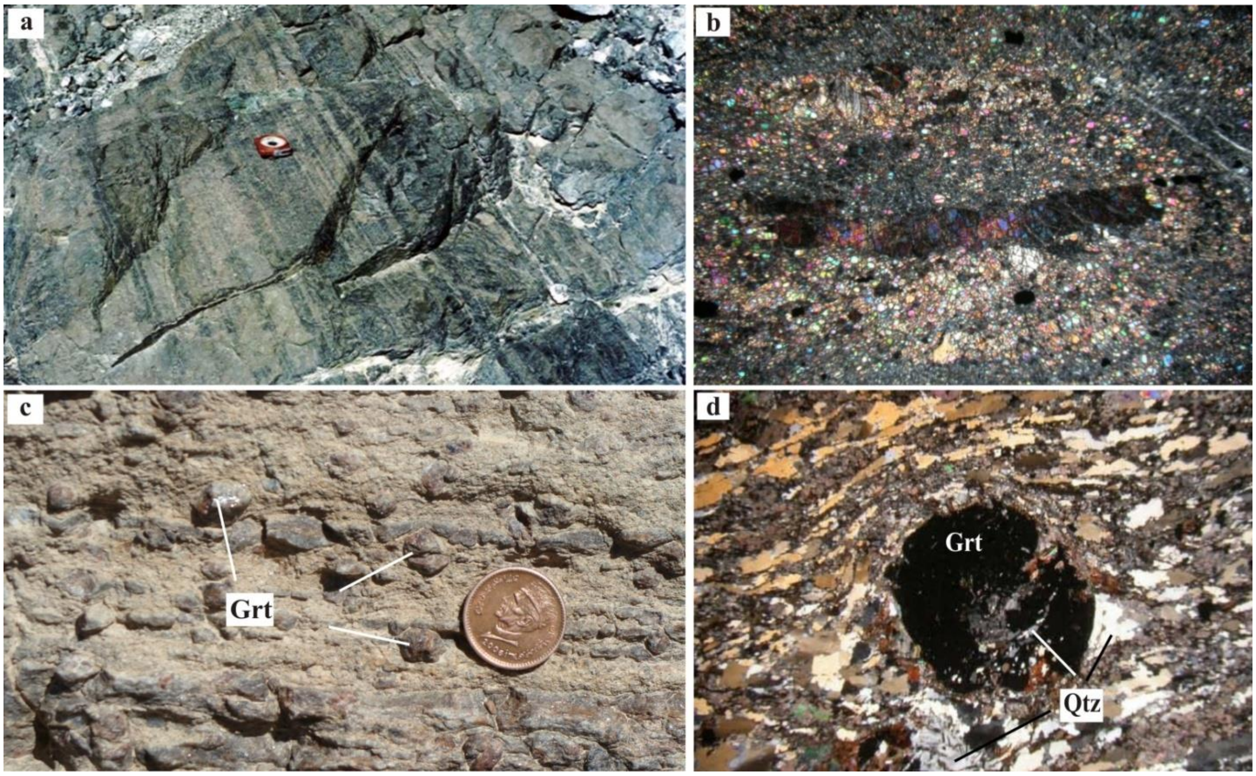

Fig. 3a) Banding in mylonitic peridotite from the metamorphic sole rocks of Jang Tor Ghar Massif of Muslim Bagh ophiolite; b) Stretched and aligned (left to right) the grains of olivine in mylonitic peridotite, XPL x 5; c) large garnet grains in garnet amphibolite, Jang Tor Ghar Massif of Muslim Bagh Ophiolite; d) the garnet grains (Grt) showing inclusions of quartz (Qtz), XPL x 1.5. Mineral abbreviations are taken from Kretz (1983).

4.3. Amphibolite facies

The amphibolite facies rocks are present at both the exposures of metamorphic sole rocks, but they are well developed in the JTGM and range in thickness from 300–600 metres (Fig. 2), forming high mountain peaks while in STGM it is not well exposed. The amphibolites are dark grey to black, foliated rocks, composed of hornblende, altered plagioclase, epidote, biotite and opaque. The amphibolites have a sharp upper contact with garnet amphibolite facies and grade downwards into greenschist facies rocks. In the transitional zone between amphibolite and greenschist facies there are various layers of variable thickness comprising different types of schist, bands of quartzite and marble. The thickness of the quartzite/marble bands ranges from about 1 centimetre to 20 centimetres (Fig. 4a). The amphibolite facies is gradational over several tens of metres into greenschist facies by decrease in grain size and variation in colour. It grades from prismatic hornblende into actinolite in the transitional zone to chlorite in the underlying green schist facies (Miyashiro, 1994).

The major constituent minerals of the amphibolite facies rocks are; black to bluish green hornblende, plagioclase, epidote, quartz, biotite, muscovite and other accessory minerals like garnet, opaque, chlorite. The amphibolite is porphyroblastic and contains porphyroblasts of hornblende. In some thin sections the hornblende is poikilitic and contains inclusions of quartz. In amphibolites, the hornblendes are interlayered with plagioclase defining clear schistosity (Fig. 4b).

4.4. Greenschist facies

The greenschist facies rocks are about 100–250 metres thick (Fig. 2). In the sole rocks of JTGM, the greenschist facies have a gradational upper contact with amphibolite facies while the lower part is in thrust contact with the mélange unit (Fig. 4c). The greenschist facies rocks show strong polyphase deformation. Banded quartzite comprises the bulk of greenschist facies. The other lithologies present include muscovite-sericite schist, banded quartzite, marble and garnetiferous phyllite. The marble and quartzite bands are common at various horizons.

The greenschist consists predominately of chlorite, muscovite, plagioclase and quartz with minor epidote, garnet, biotite and opaque (Fig. 4d). Chlorite is bright green to pale green in colour and pleochroic and occurs in composite crystals. The maximum interference colours are of low first order with abnormal shades of blue. The chlorite ranges in colour from green to olive green and are slightly pleochroic. Multiple twinning is common. Muscovite occurs as elongate flakes and makes the foliation.

5. Discussion

The major occurrences of metamorphic sole rocks found beneath both the massifs of Muslim Bagh ophiolite i.e., JTGM and STGM, are typical of those found beneath other ophiolites such as Semail Oman (e.g., Searle and Malpas 1980; Gnos and Peter, 1993), Bay of Islands, Newfoundland, Canada (e.g. Williams and Smith 1973), ophiolites in Turkey (e.g. Lytwyn and Casey, 1995; Collins and Robertson 1998; Celik and Delaloye, 2006; Parlak, et al., 2006; Celik, 2007), ophiolites in Tibet (e.g. Wang et al., 2008, Guilmette, et al., 2009). The Muslim Bagh sole rocks comprise mylonitic peridotite and sub-ophiolitic metamorphic rocks which display an inverted metamorphic sequence grading from garnet amphibolite facies directly beneath the mylonitic peridotite, amphibolite facies to lower greenschist facies near the mélange contact (Munir and Ahmed, 1985; Mahmood et al., 1995; Fig. 2). The metamorphic sole is possibly a composite of rocks developed at different pressures and temperatures, and at different times along a thrust plane, which were subsequently amalgamated into a single column beneath the advancing oceanic slab (Lytwyn and Casey, 1995).

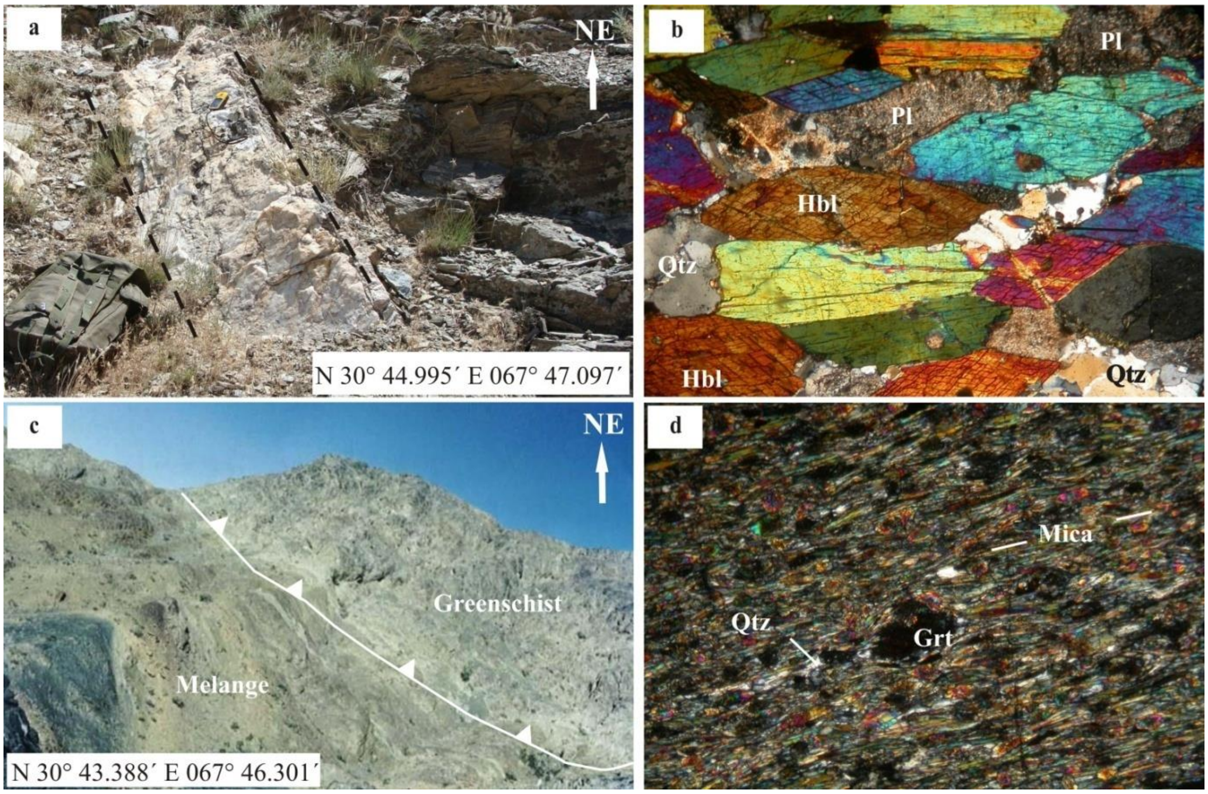

Fig. 4a) Quartzite band in amphibolite facies rocks from the metamorphic sole rocks, Jang Tor Ghar Massif of Muslim Bagh Ophiolite. b) the alignment of plagioclase (Pl) and hornblende (Hbl) in amphibolite from left to right, XPL x 5; c) Field photograph showing lower contact of greenschist facies with mélange, Jang Tor Ghar Massif of Muslim Bagh ophiolite; d) Photomicrograph of greenschist showing the constituent minerals like chlorite, muscovite and quartz with opaque XPL x 1.5.

The Muslim Bagh Ophiolite yields zircon U-Pb crystallization age on plagiogranite as 80.2 ± 1.5 Ma (Kakar et al., 2012). This age is the formation age of Muslim Bagh ophiolite. Hornblende was also dated from the amphibolites in subophiolitic metamorphic rocks that yielded a good K Ar age of 80.5 ± 5.3 (Sawada et al., 1995) and an Ar-Ar age of 65.7 ± 1.5 Ma (Mahmood et al., 1995). These ages are interpreted as the age of ophiolite emplacement. If the emplacement age (80.5 ± 5.3) of the K-Ar dating is correct then we conclude that the Muslim Bagh ophiolite had formed at 80.2 ± 1.5 Ma and emplaced during or immediately after their formation.

Mylonitic texture is observed in the basal peridotite whereas going upward asthenospheric microstructures predominate. The mylonitic textures are formed in response to ductile lithospheric deformation during the initiation of intra-oceanic subduction, at temperatures from 900 –1000 °C (Boudier and Coleman, 1981; Nicolas, 1989; Mahmood et al., 1995; Elitok and Druppel, 2008). The highest-grade rocks (garnet amphibolite) directly beneath the basal ophiolitic thrust were the first to accrete to the base of the ophiolite (e.g., Searle and Malpas, 1980; Ghent and Stout, 1981; Lytwyn and Casey, 1995). The heat necessary to produce the first stage high-grade metamorphic event was probably supplied from the residual heat of hot peridotite of the obduction slab; presumably 900–1000 °C (e.g. Nicolas, 1989; Mahmood et al., 1995), or 1100–1200 °C (e.g., Elitok and Druppel, 2008).

In short, during intra-oceanic subduction various parts of the subducted plate are accreted to the base of the future Muslim Bagh Ophiolite and subjected to a range of metamorphic conditions at about 900–1,000 °C (Nicolas, 1989), forming mylonitic peridotite and continuing eventually downwards to high grade amphibolite conditions to form garnet amphibolite facies and amphibolite facies, at a later stage of emplacement (overthrust) processes, medium to lower grade metamorphic conditions produced greenschist facies (e.g., Mahmood et al., 1995; Fig. 5a). Finally, the Muslim Bagh Ophiolite was obducted over the Indian Platform along with underlying Bagh Complex (e.g., Naka et al., 1996; Fig. 5b).

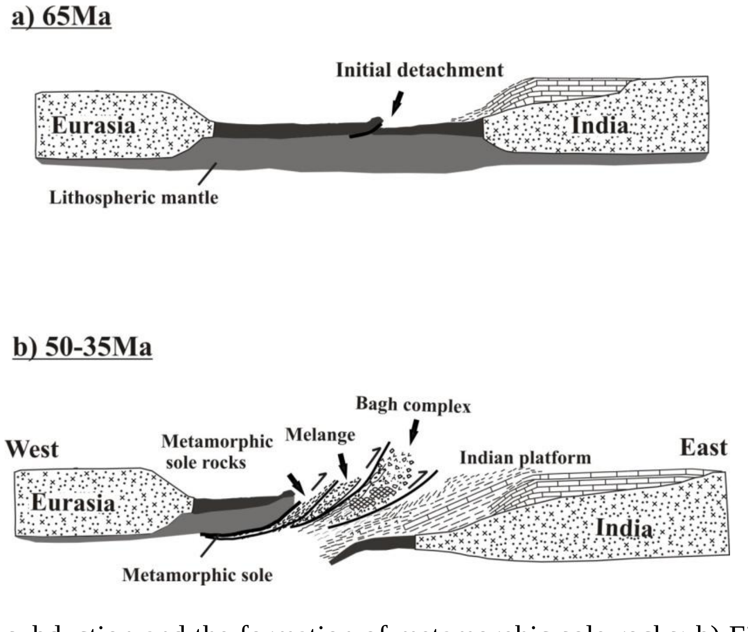

Fig. 5a) Intra-oceanic subduction and the formation of metamorphic sole rocks; b) Final emplacement of Muslim Bagh ophiolite along with Bagh Complex on to the Indian continent passive margin. See the text for discussion.

6. Conclusions

The above discussion leads to the following conclusions:

1. The Muslim Bagh ophiolite has typical metamorphic sole rocks beneath both the massifs. The sole rocks consist of a basal mylonitic peridotite and sub-ophiolitic metamorphic series displaying an inverted metamorphic sequence grading from garnet amphibolite facies to amphibolite facies to lower greenschist facies.
2. Mylonitic texture is observed in the basal peridotite which is formed in response to ductile lithospheric deformation during the initiation of intra-oceanic subduction at temperatures possibly ranging from 900 –1000 °C.
3. The sub-ophiolitic metamorphic rock series were formed during intra-oceanic subduction, where various parts of the subducted plate are accreted to the base of the overriding plate and subjected to variable metamorphic conditions.
4. The kinematic analyses of the sole rocks suggest that the Muslim Bagh ophiolite emplaced from west to east in the present geographic frame of reference.

Acknowledgments

This work is part of the PhD study of the first author. Director Centre of Excellence in Mineralogy, University of Balochistan is thanked for providing the field work facility. We are thankful to the reviewers for their constructive comments and suggestions.

References

Ahmad, Z., Abbas, S.G., 1979. The Muslim Bagh Ophiolite. In: Farah, A., Dejong, K.A. (Eds.), Geodynamics of Pakistan. Geological Survey of Pakistan, Quetta, 243–249.

Allemann, F., 1979. Time of emplacement of the Zhob Valley Ophiolite and Bela Ophiolite, Balochistan, (Preliminary report). In: Farah, A., Dejong, K.A. (Eds.), Geodynamics of Pakistan. Geological Survey of Pakistan, Quetta, 213–242.

Bilgrami, S.A., 1964. Mineralogy and petrology of the central part of the Hindu Bagh Igneous complex, Hindu Bagh Mining District, Zhob Valley. West Pakistan Geological Survey Records, 10, 28.

Boudier, F., Coleman, R.G., 1981. Cross section through the peridotites in the Semail ophiolite, Southeastern Oman. Journal of the Geophysical Research, 86, 2573-2592.

Celik, O.M., 2007. Metamorphic sole rocks and their mafic dykes in the eastern Tauride belt ophiolites (southern Turkey): implications for OIB-type magma generation following slab break-off. Geological Magazine, 144 (5), 849–866.

Celik, O.M., Delaloye, M.F., 2006. Characteristics of ophiolite-related metamorphic rocks in the Beysehir ophiolitic mélange (Central Taurides, Turkey), deduced from whole rock and mineral chemistry. Journal of Asian Earth Sciences, 26, 461–476.

Coleman, R.G., 1977. Ophiolite-Ancient oceanic lithosphere? Minerals and rocks. Springer-Verlag, New York.

Collins, A.S., Robertson, A.H. 1998. Processes of Late Cretaceous to Late Miocene episodic thrust-sheet translation in the Lycian Taurides, SW Turkey. Journal of the Geological Society, 155(5), 759-772.

Elitok, O., Druppel, K., 2008. Geochemistry and tectonic significance of metamorphic sole rocks beneath the Beysehir-Hoyran ophiolite (SW Turkey). Lithos, 100, 322-353.

Gansser, A., 1964. Geology of the Himalayas. Wiley Inter Science London.

Ghent, E.D., Stout, M.Z., 1981. Metamorphism at the base of the Semail ophiolite, southeastern Oman Mountains. Journal of Geophysical Research, 86, 2557–2571.

Gnos, E., Peters, T., 1993. K–Ar ages of the metamorphic sole of the Semail Ophiolite: implications for ophiolite cooling history. Contributions to Mineralogy and Petrology, 113, 325–332.

Guilmette, C., Hébert, R., Wang, C.C., Villeneuve, M., 2009. Geochemistry and geochronology of the metamorphic sole underlying the Xigaze Ophiolite, Yarlung Zangbo Suture Zone, South Tibet. Lithos, 112, 149–162.

Hunting Survey Corporation, 1960. Reconnaissance Geology of Part of West Pakistan. A Colombo Plan cooperative project, Government of Canada, Toronto.

Kakar, M.I., Collins, A.S., Mahmood, K., Foden, J.D., Khan, M., 2012. U-Pb zircon crystallization age of the Muslim Bagh ophiolite: Enigmatic remains of an extensive pre-Himalayan arc. Geology, 40 (12), 1099-1102.

Kojima, S., Naka, T., Kimura, K., Mengal, J.M., Siddiqui, R.H., Bakht, M.S., 1994. Mesozoic radiolarians from the Bagh Complex in the Muslim Bagh area, Pakistan: their significance in reconstructing the geological history of ophiolites along the Neo-Tethys suture zone. Bulletin of Geological Survey of Japan, 45, 63–97.

Kretz, A., 1983. Symbols for rock forming minerals. American Mineralogist, 68, 277-279.

Lytwyn, J.N., Casey, J.F., 1995. The geochemistry of post-kinematic mafic dike swarms and subophiolitic metabasites, Pozanti-Karsanti ophiolite, Turkey: evidence for ridge subduction. Geological Society of America Bulletin, 107, 830–850.

Mahmood, K., Boudier, F., Gnos, E., Monié, P., Nicolas, A. 1995. ^{40}Ar / ^{39}Ar dating of the emplacement of the Muslim Bagh ophiolite, Pakistan. Tectonophysics, 250, 169-181.

Mengal, J.M., Kimura, K., Siddiqui, M.R.H., Kojima, S., Naka, T., Bakht, M.S., Kamada, K., 1994. The lithology and structure of a Mesozoic Sedimentary-igneous assemblage beneath the Muslim Bagh ophiolite, Northern Balochistan, Pakistan. Bulletin of the Geological Survey of Japan, 45, 51-61.

Mercier, J.C., Nicolas, A., 1975. Textures and fabrics of upper mantle peridotites as illustrated by basalt xenoliths. Journal of Petrology, 16, 454-487.

Miyashiro, A., 1994. Metamorphic petrology. Oxford University Press, New York.

Munir, M., Ahmed, Z., 1985. Petro-chemistry of the contact rocks from northwestern Jang Tor Ghar segment of the Zhob Valley ophiolite, Pakistan. Acta Mineralogica Pakistanica 1, 38-48.

Naka, T., Kimura, K, Mengal, J.M., Siddiqui, R.H., Kojima, S., Sawada, Y., 1996. Mesozoic sedimentary-igneous Complex, Bagh Complex, in the Muslim Bagh Area, Pakistan. Opening and Closing Ages of the Ceno-Tetheyan Branch. In: Yajima, J., Siddiqui, R.H. (Eds.), Proceedings of Geoscience Colloquium, Geoscience Laboratory, Geological Survey of Pakistan, Islamabad, 16, 47-94.

Nicolas, A., 1989. Structures of Ophiolites and Dynamics of Oceanic Lithosphere. Kluwer, Dordrecht.

Parlak, O., Yilmaz, H., Boztug, D., 2006. Origin and Tectonic Significance of the metamorphic Sole and Isolated Dykes of the Divrigi Ophiolite (Sivas, Turkey): Evidence for Slab Break-off prior to Ophiolite Emplacement. Turkish Journal of Earth Sciences, 15, 25-45.

Qayyum, M., Niem, M.R., Lawrence, R.D., 1996. Newly discovered Paleogene deltaic sequence in the Katwaz basin, Pakistan and its tectonic implications. Geology, 24, 835–838.

Sawada, Y., Nageo, K., Siddiqui, R.H., Khan, S.R., 1995. K-Ar ages of the Mesozoic Igneous and metamorphic rocks from the Muslim Bagh area, Pakistan. Proceedings of Geoscience Colloquium, Geoscience Laboratory, Geological Survey of Pakistan, Islamabad 12, 73-90.

Sawada, Y., Siddiqui, R.H., Khan, S.R., Aziz, A., 1992. Mesozoic igneous activity in the Muslim Bagh area, Pakistan, with special reference to hot spot magmatism related to the break-up of the Gondwanaland. Proceedings of Geoscience Colloquium, Geoscience Laboratory, Geological Survey of Pakistan, Islamabad 1, 21–70.

Searle, M.P., Malpas, J., 1980. The structure and metamorphism of rocks beneath the Semail ophiolite of Oman and their significance in ophiolite obduction. Transactions of the Royal Society of Edinburgh, Earth Science, 71, 247–262.

Siddiqui, R.H., Aziz, A., Mengal, J. M., Hoshino, K., Sawada, Y., 1996. Geology, Petrochemistry and Tectonic Evolution of Muslim Bagh Ophiolite Complex Balochistan, Pakistan. Geologica, Geoscience Laboratory, Geological Survey of Pakistan, Islamabad, 3, 11-46.

Van Vloten, R., 1967. Geology and chromite deposits of the Nisai area, Hindu Bagh mining district, West Pakistan. Geological Survey of Pakistan records, 2, 32.

Wang, W., Aitchison, J.C., Lo, C., Zeng, Q., 2008. Geochemistry and geochronology of the amphibolite blocks in ophiolitic melanges along Bangong-Nujiang suture, central Tibet. Journal of Asian Earth Sciences, 33, 122–138.

Warraich, M.Y., Ali, M., Ahmed, M.N., Siddiqui, M.R.H., 1995. Geology and structure of the Calcareous zone in the Muslim Bagh in the Qilla Saifullah Area, Balochistan. Geologica, 1, 61-75,

Williams, H., Smith, W.R., 1973. Metamorphic aureoles beneath ophiolite suites and alpine peridotites: tectonic implications with west Newfoundland examples. American Journal of Science, 273, 594–621.