Journal of Sciences, Islamic Republic of Iran 17(2): 147-152 (2006) http://jsciences.ut.ac.ir
University of Tehran, ISSN 1016-1104

The Spatial Distribution of Some Chromite Deposits in Iran, Using Fry Analysis

A. Yaghubpur[1,*] and A.A. Hassannejad[2]

[1]*Department of Geology, Tarbiat Moalem University, 49 Mofateh, Tehran 15614, Islamic Republic of Iran*
[2]*Department of Geology, Damghan University, Damghan, Islamic Republic of Iran*

Abstract

The spatial distribution of mineralization is the foremost concern in regional exploration and it could be considered as a very important tool in the investigation of mineral deposits. There are several data manipulation methods by which the data can be evaluated. Fry analysis is a good method to determine the direction(s) of maximum continuity of the deposits and could be used in different types of deposits. Chromite deposits in Iran are postulated to be related to Alpine orogen. They are mostly podiform types and irregular in their settings. The deposits are located in the ophiolite complexes of Iran. The spatial distribution of five chromite deposits using Fry analysis has been recorded and it appears that the preferred orientation of each deposit coincides with the general trend of faults in each region.

Keywords: Fry analysis; Ophiolites; Chromite deposits; Iran

Introduction

Prospecting for mineral deposits includes all methods of mineral exploration based on certain properties of the rocks. With known spatial distribution of mineral deposits and their preferred orientation in a region, exploration would be more promising. For this purpose the spatial distribution of some of the chromite deposits of Iran were analyzed using Fry analysis [6] based on the method suggested by Vearncombe and Vearncombe [30]. Although “Fry plot” were originally developed for the analysis of strain and strain partitioning in rocks, similar methods, using Fourier series method for determination of the components of inter-atomic distances in crystals have been applied to model intra-atomic distances in different crystals [21,22]. Allison *et al.* [3] using “Patterson diagram” constructed cryptic structural trend in basement for the Scottish and Irish Caledonian orogen. Lagarde *et al.* [14], have also applied Fry analysis to late Carboniferous granitic plutons emplaced during regional deformation and found out that the plutons are distributed along reactivated deep faults and display elliptical shapes which are consistently oriented with respect to the regional strain field. Analytical methods of Fry [6], and Allison *et al.* [3] were developed by Vearncombe and Vearncombe [30] applying them to the spatial distribution of mineralization and as an alternative to directional variography, to the distribution of mineralization as recognized in drilling. Five examples of spatially distributed mineralization along with derived rose diagrams of the faults were recorded by Vearncombe and Vearncombe [30].

*E-mail: yaghubpur1002000@yahoo.com

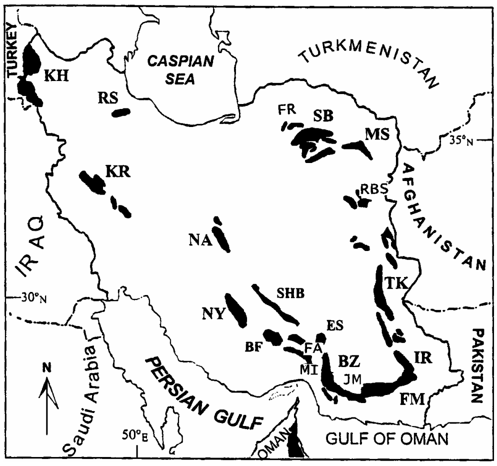

Figure 1. Index map showing the locations of major Iranian ophiolites and the localities of the five chromite deposits studied in this investigation. BF: Baft, BZ: Band-e-Ziarat, ES: Esfandagheh, FA: Fariab, FM: Fanuj-Maskutan, FR: Forumad, IR: Iranshahr, JZ: Jaz Murian, KH: Khoy, KR: Kermanshah, MI: Minab, MS: Mashad, NA: Nain, NY: Neyriz, RBS: Robat-Sefid, RS: Rasht, SB: Sabzevar, SHB: Shahr-e-Babak, TK: Tchehel-Kureh (after Ghazi and Hassanipak, 2000 [10], modified by the authors).

Ophiolite Complexes of Iran

Ophiolite complexes of Iran are part of Tethyan ophiolite belts of the Middle East which link to other Asian ophiolites such as Pakistan in the east as well as to ophiolites in the Mediterranean region such as Turkish, Troodos Greek, and east Europe in the west. These ophiolites, rest as giant thrust sheets upon a continental substrate, according to Nicolas [20].

On the basis of their age and abundance, the Iranian ophiolites have been divided into Paleozoic age groups [31] and Mesozoic age groups [4]. The Mesozoic age groups are by far the most abundant ophiolites in Iran and have been subdivided by Stocklin [27] into two subgroups: a) southern or outer sub-belt located in the west and south of the main Zagros reverse fault and b) northern or inner sub-belt located in the north and east of the main Zagros reverse fault (Fig. 1). The part of the northern sub-belt surrounding the Lut block is known as central Iranian ophiolitic mélange belt.

Iranian ophiolites have geographically been divided into four groups [18,19,26,29]: 1) ophiolites of northern Iran along the Alborz mountain range including Rasht ophiolites; 2) ophiolites of Zagros suture zone including the Neyriz and Kermanshah ophiolites which are apparently the extension of the Oman ophiolites; 3) ophiolites and color mélanges of the Makran region, located to the south of the Sanandej-Sirjan microcontinental block including Sorkhband and Rudan; and 4) ophiolites and color mélanges that mark the boundaries of the internal Iranian microcontinental block such as Minab, Baft, Sabzevar, Robat Sephid and Jaz Murian.

Based on the ages of emplacement derived from field relationships, Alavi [1], classified the Iranian ophiolites into three groups: a) Protrozoic ophiolites that crop out on the western edge of the Lut block in central Iran; b) pre-Jurassic ophiolites that are located within the Alborz range in the north; and c) post-Jurassic ophiolites that are the most abundant ophiolite terrains in Iran. Lippard *et al.* (1986) suggested that emplacement of all of the proposed Mesozoic ophiolites in Iran are pre-Paleocene [17]. Table 1 shows a summary of distribution, ages, chemical affinity and major structural and tectonic characteristics of the ophiolite complexes of Iran.

The ophiolite rocks in Iran which are located at eastern part of the Tethyan ophiolites deserve special attention, because they are found in various structural zones which surround a presumed microcontinent (Lut block). Different ophiolites surrounding the Lut block were studied by several geologists. Ophiolites of Neyriz [15,23,25], Nain [5], Sabzevar [2,11,16], Esphandagheh [24] Baft [4], Kermanshah [8], Khoy [7,8,12], Band Ziarat [13] Minab [18] have been investigated in more detail. The location of different ophiolite suits is shown in Figure 1.

The chromite deposits and chromite indices that were studied in this investigation are located in the east of Sabzevar (SB) (Fig. 2), Forumad Area (FR), northwest of Sabzevar (Fig. 3), Jaz Murian (JM), in the state of Sistan and Baluchistan (Fig. 4), Minab (MI) in the state of Hormozgan (Fig. 5) and Robat Sefid (RBS) in the state of Khorasan (Fig. 6). The location of these indices is shown in Figure 1.

The rocks of ophiolite complexes of Iran have some common characteristics in almost all localities. They include large Alpine-type ultramafic bodies represented mostly by harzburgite and dunite with subordinate lherzolite and pyroxenite [23]. The peridotites are usually invaded by smaller gabbro masses and in some places as in the areas of Neyriz and Esfandagheh they are associated with comparatively small masses of high grade amphibolites and eclogites [24]. The peridotites with their gabbro and eclogite-amphibolites assemblage also occur in the imbricated zones of the Zagros range. These ophiolitic rocks underwent extensive tectonic disruption, leading to tectonic contacts and steeply inclined and imbricated sheets. Many ophiolite complexes in Iran are only preserved in a strongly disturbed and often chaotic states [16]. In some regions as Nain area, the fragmentation and mixing have progressed to the degree that the relationships between different ophiolite units are no longer recognizable [5].

Table 1. Summary of characteristics of the Iranian ophiolites

Region	Ophiolite complex	Formation age (Ma)	Emplacement age (Ma)	Remarks
North-Northwest	Khoy	98-103 (Ar/Ar)	95-96 (Ar/Ar)	Complete sequence exposed, harzburgite E-MORB, T-MORB
Zagros	Rasht	Pre-Jurassic	(?)	Paleo tethys remnant
	Kermanshah	(?)	Post-Campanian Pre-Maastrichtian	Highly dismembered harzburgite, IAT, OIB
	Sahneh	86.3 Ma	(?)	Highly dismembered harzburgite
	Neyriz	93-95 Ma (Ar/Ar) 96-98 Ma (Ar/Ar)	89 Ma (Ar/Ar) Post-Campanian Pre-Maastrichtian	Harzburgite, MORB, IAT
South Central Iran	Nain	Cretaceous (?)	Pre-Paleocene	Harzburgite-lherzolite, small ocean basin around Lut block
	Shahr-Babak	Cretaceous	Pre-Paleocene	Harzburgite-lherzolite, small ocean basin around Lut block, IAT
	Baft Esphandagheh	Upper Cretaceous	Pre-Paleocene	Harzburgite, small ocean basin around Lut block, MORB, IAT
Makran	Band-e-Zeyarat	144-166 (Ar/Ar)	Early-Paleocene	Harzburgite, back-arc marginal basin around Lut block, E-MORB and IAT
	Ganj	135 (K/Ar)		
	Dar-Anar (?)	170 (Ar/Ar)		
	lranshahr	Upper Cretaceous	Pre-Paleocene	Backarc marginal basin
	Fanuj-Maskutan	Upper Cretaceous	Pre-Paleocene	Backarc marginal basin
East Northeast	Tchehel-Kureh	Upper Cretaceous	Pre-Paleocene	Mainly harzburgite, small ocean basin around Lut block MORB-IAT
	Sabzevar	Upper Cretaceous	Pre-Paleocene	Harzburgite, small ocean basin between Lut and Asian blocks, IAT chemis-try
	Mashad	Pre-Jurassic	(?)	

After Ghazi A.M. and Hassanipak A.A., 2000 [10].

Chromite Deposits of Iran

More than 74 chromite potentials have found in different ophiolite terrains of Iran, 18 of them are currently mining and four of them are in different stages of exploration [32]. Most of the minable deposits have been discovered and have been mined in last decade, but due to tectonic disturbance, their distribution patterns and their extents always remained as puzzle for the prospectors. The mode of occurrence of almost all Iranian chromite deposits is podiform and the shape on the ore bodies is like a pod, a lens or a rod and they are highly discontinuous in structure [32].

Based on the morphology, age of the host rocks and available age dating on some of the ophiolite hosted chromite deposits (Table 1), it seems that the chromite deposits of Iran could be categorized as late Proterozoic to recent (800-0 Ma) chromite type of Stowe [28]. According to Stowe [28], in these types of deposits, ophiolite-hosted podiform chromite deposits predominate, indicating plate tectonic settings similar to those of present times. The deposits are hosted by ophiolites that were tectonically re-emplaced along extinct convergent plate sutures. High degree of serpentinization is a major characteristics feature of ophiolite-hosted Iranian chromite deposits. The host of chromium ore in these deposits is mainly serpentinite, dunite and harzburgite. Several magnesite veins are usually seen within all of the chromite deposits.

The texture of the chromium ore of the deposits in Iran is usually orbicular or nodular, and the ore consists of spherical chromite in a serpentine or olivine matrix. The nodules range in diameter from less than 2 mm to more than 2 cm. The type of chromite in almost all deposits is moderately refractory and Cr/(Cr+Al) atomic ratio ranges from 0.4 to 0.8. The highest Cr/Fe ratio in Faryab chromite mine (Fig. 1) is reported to be 3.5 [28].

In the present study five ophiolite complexes were chosen for application of Fry analysis to their chromite indices distribution and their structural trends. These deposits are situated in east Sabzevar, Forumad, Jaz Murian, Minab, and Robat-Sefid ophiolite complexes. They are distributed in northeast, east, southeast and south central parts of the country. The deposits occur in distinct clusters and along with their ophiolite hosts were obducted over central Iran during late Cretaceous time. Since then Tertiary and Quaternary tectonic events caused deformation in the structural features of Iran and developed superimposed microstructures. These changes often cause problems for the prospectors, and they are always interested in finding a way to realize the structural trends of the deposits.

Fry Analysis

Mapping at scales relevant to a geological problem, with an emphasis on structural geology is very useful in understanding the directional controls on mineralization. There are several methods, one of which is Fry analysis that could be used as a complement to mapping. Using Fry analysis in mine and prospect scale could help determine the location of successful drilling for mineral potentials. This reduces the spatial bias inherent in the distribution of drilling to determine the direction of the ore-rich zones.

Fry analysis [6] can easily be used by placing a sheet of tracing paper on which a series of parallel reference lines in a north pointing have been drawn and location of each data points recorded. The reference lines are typically north pointing on the map. On the second sheet of tracing paper with the center point (or origin), a set of marked parallel lines are kept parallel to those on the first sheet. The origin of the second sheet is placed on the data points in the first sheet and the second sheet marked with all the positions of points of the first sheet. Then the origin of the second sheet is placed on a different data point on the first sheet and the positions again recorded on the second sheet for all the data points. The work continues, maintaining the same orientation until all points on the first sheet have been used as the origin on the second sheet. For n data points there will be $n^2 - n$ translations. The resulting Fry plot could further be analyzed by construction of a rose diagram recording joint frequency *vs.* directional sector. Fry analysis was used by Vearncombe and Vearncombe [30] for finding a spatial distribution of five different types of prospects in different localities with different geologic ages.

Fry analysis and derivative rose diagrams of the structural terrains were applied for all of the indices of chromite bearing zones of Iran based on the method suggested by Vearncombe and Vearncombe [30]. Therefore the spatial relationships of the indices and the rose diagrams of the major faults were prepared for all of the indices of deposits. The deposits and their respective indices are: east Sabzevar (northeast of Iran), with 25 indices (Fig. 2); Forumad (northeast of Iran), with 15 indices (Fig. 3); Jaz Murian (southeast of Iran), with 27 indices (Fig. 4); Minab (south central of Iran), with 28 indices (Fig. 5) and Robat-Sefid (east of Iran), with 19 indices (Fig. 6).

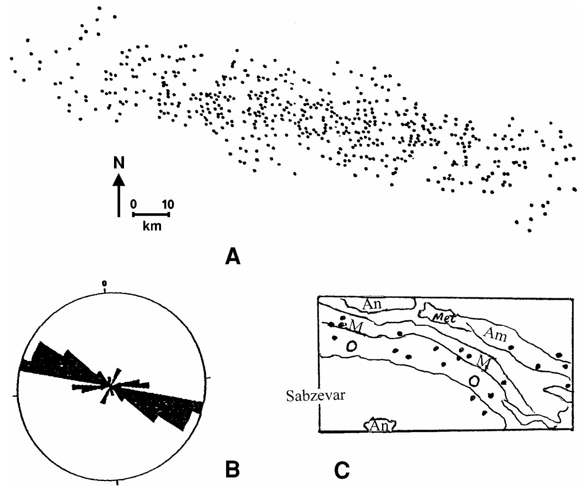

Figure 2. Translations of the spatial distribution of *25* chromite indices (A); derivative rose diagram of the faults (B); and sketch of geological map of the area (C) in East Sabzevar ophiolite. O: ophiolite; Am: amphibolite; M: Mesozoic rocks; Met: metamorphic rocks; An: Andesite.

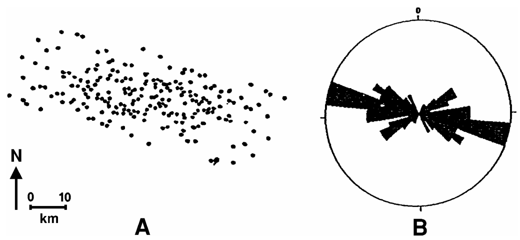

Figure 3. Translations of the spatial distribution of 15 chromite indices (A) and derivative rose diagram of the faults (B) in Forumad ophiolite.

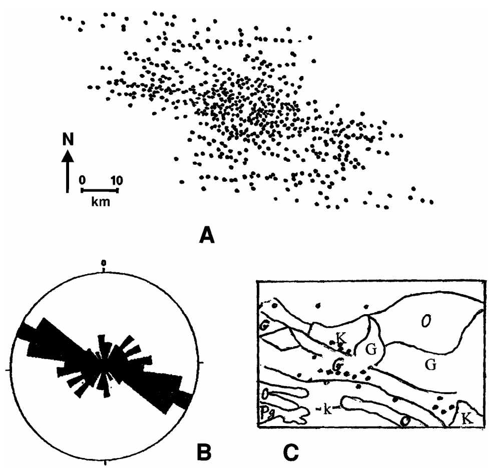

Figure 4. Translations of the spatial distribution of 27 chromite indices (A); derivative rose diagram of the faults (B); and sketch of geological map of the area (C) in Jaz Murian ophiolite. O: ophiolite; K: Cretaceous rocks; G: gabbro diorite; Pg: paleogene.

Discussion

There are many data manipulation methods, including contouring, drawing dialation maps and direction variography by which the data can be evaluated. Contouring and dialation maps are always used as major tools in evaluation of the deposits and provide maps as the final products. But for evaluating a deposit with each of these two methods, one should have quite large data sets, and small data sets are of little value in the evaluation of a prospect.

Fry analysis and variography both utilize pairs of data in data computation, but variography is an algebraic approach, while Fry analysis is a geometric approach. Fry analysis uses each and every spatial relationship and is not dependent on mathematical model. Fry analysis according to Vearncombe and Vearncombe [30], can produce interpretable result with modestly size data sets that include 14 or more samples. Typically the larger the number of sample data, the more reliable the end results.

Looking at the spatial distribution of the chromite indices and rose diagrams of the faults of each of the five chromite deposits (Figs. 2-6), one can see that most of the deposits' orientations are more or less similar to the fault directions, and the spatial distribution of the indices and rose diagrams of the faults in all of the deposits are remarkably similar. This indicates that structural controls on distribution of the chromite deposits in ophiolite complexes of Iran are highly important and understanding of major fault trends in each deposit could be of great help in further prospecting. It also seems that knowing the spatial distribution of the indices and rose diagrams of the faults, continuity of the chromite lenses or pods could be extrapolated.

Conclusion

The spatial distribution of mineralization in all of the studied indices of five chromite deposits in ophiolite complexes of Iran were prepared using Fry analysis, based on methods suggested by Vearncombe and Vearncombe [30]. The results were then compared with the rose diagrams of the structural trend prepared from the faults of each of the deposits. Apparent similarity in these figures indicates that the structural controls on the distribution of the chromite deposits in the ophiolite complexes of Iran are very important and by finding the main structural trends in each deposit, further prospecting could be more promising.

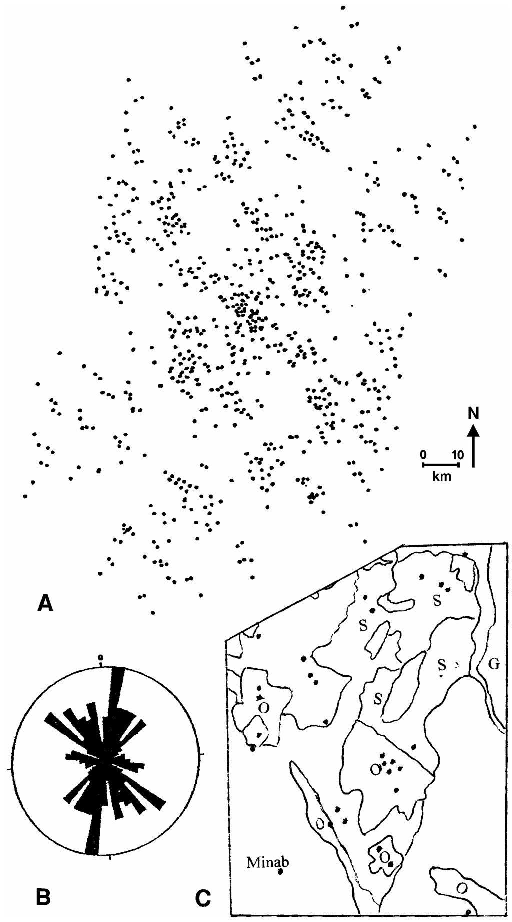

Figure 5. Translations of the spatial distribution of 28 chromite indices (A); derivative rose diagram of the faults (B) and sketch of geological map of the area (C) in Minab ophiolite. O: ophiolites; S: schist, phyllite, *etc.*; G: gabbro diorite.

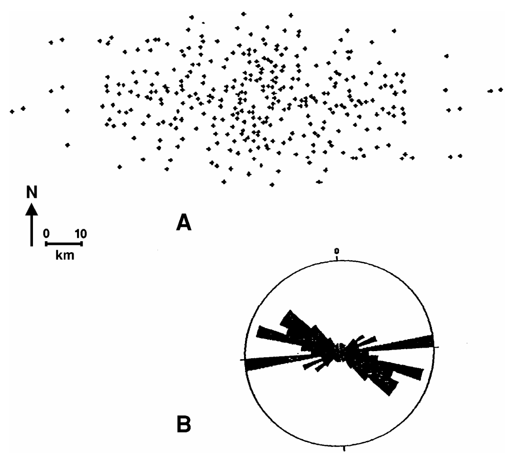

Figure 6. Translations of the spatial distribution of 19 chromite indices (A), and derivative rose diagram of the faults in Robat Sefid ophiolite.

References

1. Alavi M. Tectonic Map of the Middle East; Geological Survey of Iran, 1 sheet, Scale: 1:5,000,000 (1991).
2. Alavi-Tehrani N. Geology and Petrography in the Ophiolite Range NW Sabzevar (Khorassan, Iran), with Special Regard to Metamorphism and Genetic Relations in an Ophiolite Suite. *Unpub. Ph.D. Thesis*, University of Saarburcken, 147 p. (1976).
3. Allison I., de Paor D.G., Haszeldine S., Bowman A., and Maguire M. Cryptic Structural Trends in basement revealed by Patterson diagrams: Examples from the Scottish and Irish Caledonian Orogen. In: Sengupta S. (Ed.), *Evolution of Geological Structures in Micro to Macro-Scales*. London, Chapman and Hall, p. 487-495 (1997).
4. Arvin M. and Robinson P.T. The petrogenesis and tectonic setting of lavas from the Baft ophiolitic melange, southwest of Kerman, Iran. *Canadian Journal of Earth Sciences*, **31**: 824-834 (1994).
5. Davoudzadeh M. Geology and Petrography of the Area North of Nain, Central Iran. Geological Survey of Iran, Rept. No. 39, 83 pp. (1972).
6. Fry N., Random point distributions and strain measurement in rocks. *Tectonophysics*, **60**: 89-105 (1976).
7. Ghazi A.M., Chathamn B., Hassanipak A.A., Mahoney J.J., and Duncan R.A. A Petrographic investigation of the Khoy ophiolite, NW Iran: Implications for Tethyan magmatism and ophiolite genesis, ridgefield school: The Troodos ophiolite and mid-ocaean ridge processes. Larnaca, Cyprus, p. 13 [abstr.] (1999).
8. Ghazi A.M. and Hassanipak A.A. Geochemistry and Petrology of subalkaline and alkaline extrusives of Kermanshah ophiolite, Zagros suture zone, SW Iran. *Journal of Asian Earth Sciences*, **17**: 319-332 (1999).
9. Ghazi A.M., Hassanipak A.A., Duncan R.A., Hogen L.G., and Mahoney J.J. Geochemistry, 40Ar/39Ar ages and preliminary isotopic analyses of the Khoy ophiolite, Northwestern Iran [abstr.]. *Eos Transactions of the American Geophysical Union*, **79**: F654 (1997a).
10. Ghazi A.M. and Hassanipak A.A. Petrology and geochemistryof the Shahr-Babak ophiolite, Central Iran. *Geological Society of America*, Special paper, **349**: 485-497 (2000).
11. Ghazi A.A., Hassanipak A.A., and Wallace K. Geochemistry, petrology and geology of the Sabzevar ophiolite, Northeastern Iran: Implication on Tethyan tectonics. *Geological Society of America*, Abstracts and Programs, **29**: A-229 (1997b).
12. Hassanipak A.A. and Ghazi A.M. Petrology, geotectonic setting of the Khoy ophiolite, Northwest Iran. *Journal of Asian Earth Sciences*, **18**: 43-55 (1999).
13. Hassanipak A.A., Ghazi A.M., and Wampler J.M. REE characteristics and K/Ar ages of the Band-Ziarat ophiolite Complex, Southeastern Iran. *Canadian Journal of Earth Sciences*, **33**: 1534-1542 (1996).
14. Lagarde J.L., Omar S.A., and Roddaz B. Structural characteristics of granitic plutons emplaced during weak regional deformation: Examples from Late Cretaceous plutons, Morocco. *Journal of Structural Geology,* **12**: 334-343 (1990).
15. Lanphere M.A. and Pamic T. 40Ar/39Ar ages and tectonic setting of ophiolites from Neyriz southeast Zagros range, Iran. *Tectonophysics*, **96**: 245-256 (1983).
16. Lensch G., Mihm A., and Alavi-Tehrani N. Petrography and geology of the ophiolite belt north of Sabzevar/ Khorasan (Iran). *Neues Jahrbuch fur Mineralogie, Abhanlungen*, **131**: 156-178 (1977).
17. Lippard S.J., Shelton A.W., and Gass I.G. The ophiolites of northern Oman. *Geological Society of London*, Memoir, 11, 178 p. (1986).
18. McCall G.J.H. Explanatory text of Minab quadrangle map, J 13. *Geological Survey of Iran*, 530 p. (1985).
19. McCall G.J.H. The geotectonic history of the Makran and adjacent areas of southern Iran. *Journal of Asian Earth Sciences*, **15**: 517-531 (1997).
20. Nicolas A. *Structure of Ophiolites and Dynamics of Oceanic Lithosphere*. Kluwer Academic Publishers, Dordrecht, the Netherlands, 367 p. (1989).
21. Patterson A.L. A Fourier series method for the determination of the component on intra-atomic distances in crystals. *Physics Review*, **46**: 372-376 (1934).
22. Patterson A.L. A direct method for the determination of componenets of inter-atomic distances in crystals. *Zeitschrift fur Kristallographie*, **90**: 517-554 (1935).
23. Ricou L.E. L'etude geologique de la region de Neyriz (Zagros Iranien) et l'evolution structurale des Zagrides. *These* Doct. Etat, Paris (1974).
24. Sabzehei M. Les ophiolitique de la region d'Esfandagheh (Iran meridional), etude petrologique et structurale, interpretation dans le carde Iranien. *These* Doct. Etat, Grenoble (1974).
25. Sarkarinejad K. Petrology and tectonic setting of the Neyriz ophiolite, southwest Iran. In: Ishiwatari, et al., (Eds.), *Ircum-Pacific Ophiolites*; Proceedings, 29th International Geological Congress, Part D, p. 221-234 (1994).
26. Stocklin J. Possible ancient continental margins in Iran. In: Burke C.A. and Drake C.L. (Eds.), *The Geology of Continental Margins*. New York, Springer Verlag, p. 873-887 (1974).
27. Stocklin J. Structural correlation of the Alpine ranges between Iran and Central Asia. *Societe Geologique de France*, Memoire Hors-Serie, No. 8, p. 333-353 (1977).
28. Stowe C.W. Compositions and tectonic settings of chromite deposits through time. *Economic Geology*, **89**: 528-546 (1994).
29. Takin M. Iranian geology and continental drift in the Middle East. *Nature*, **235**: 147-150 (1972).
30. Vearncombe J. and Vearncombe S. The spatial distribution of mineralization: Allpication of fry analysis. *Economic Geology*, **94**: 475-486 (1999).
31. Weber-Diefenbach K., Davoudzadeh M., Alavi-Tehrani N., and Linsch G. Paleozoic ophiolites in Iran, geology and geochemistry, and geodynamic implication. *Ofioliti*, **11**: 305-338 (1986).
32. Yaghubpur A. *Mineral Deposits of Iran: A Brief Review*. Mineral Resources and Development, Daya Publishing House, Delhi-110 035, p. 191-202 (2005).