Some characteristics of mafic dykes in Gondwanan land from South of Gorgan, Northeastern Iran: Implication to Petrogenesis and Paleotectonic

Aziz Rahimi–Chakdel[1*], Mostafa Raghimi[1]

1- Department of Geology, Faculty of Science, Golestan University, 49138–15739 Gorgan, Iran

* Corresponding Author: rahimiaz@yahoo.co.uk

Received: 26 January 2014 / Accepted: 08 May 2014 / Published online: 10 May 2014

Abstract

The igneous dykes are a small mafic rock unit exposed in the South Gorgan of Eastern Alborz, North Iran. These mafic dykes are intruded in the Middle–Upper Paleozoic sedimentary and metamorphic rocks units representing a part of the north Gondwana province. The studied samples were collected from various locations along the exposed bodies. Thin sections of these rocks show medium to coarse grained sizes and the texture varies from ophitic to intergranular under polarized microscope. The mineralogical composition of mafic dykes is dominated by large crystals of clinopyroxene, orthopyroxene, plagioclase and hornblende. These rocks can be classified as gabbroic rock. Geochemical studies show that these rocks have low to medium K_2O contents. The trace element data shows low La/Nb ratios (1.2–3.2) and LREE enrichment (La/Yb 10–21.4). The high LREE/HREE ratios and low Y content corresponding high Ti/Y ratios of the gabbros suggest that they could be derived from melt fractions of a garnet stable source. According to present data, it could be suggested that these rocks have been formed in a rift setting from partial melting of an asthenospheric mantle. This tectonic setting could be explained by the initiation of the opening of the Paleothetys in the northern part of Gondwana during the Late Ordovician.

Keywords: Gondwana, Mafic dykes, Gorgan, Eastern Alborz, Iran.

1–Introduction

The studied area is located in the Eastern Alborz (Fig. 1), which was the northern margin of the Gondwana (Fig. 2) during Palaeozoic (e.g. Stocklin, 1974; Salehie Rad, 1979; Berberian and King; 1981, Davoudzadeh *et al*., 1986; Davoudzadeh and Weber–Diefenbach, 1987; Sengor, 1990; Alavi, 1991, 1996; Stampfli and Borel, 2002; Allen, *et al*., 2003;Horton *et al*., 2008; Sinha, 2012, 2013). Mid Paleozoic mafic intrusions, sills, dykes, volcanic tuffs and lava flows are widespread in Iran (e.g. Jenny, 1977a; Delaloye *et al*., 1981; Alavi, 1996; Wendt *et al*., 2005). The most prominent volcanic activity is expressed by the up to 600 m– thick andesitic lavas and tuffs in the Soltan Maidan Formation in the eastern Alborz, which are ascribed to the breakup of the northern margin of Gondwana (Jenny, 1977b; Alavi, 1996). The Soltan Maidan volcanics are unconformably overlain by conglomerate and sandstones of Lower Devonian age (Wendt *et al*., 2005). However, in some places Lower to Middle Ordovician age deposits (Lashkarak Formation) underlie these volcanic rocks. Thus, the Soltan Maidan volcanic rocks are generally considered as Silurian in age (e.g. Sharabi, 1990; Zamani Pedram and Hossieni, 2003; Rahimi–Chakdel, 2007; Raghimi, 2010).

Jenny (1977a) has reported a 398 Ma age for the mafic dykes using K/Ar methods. The precise age of these sub–volcanic rocks is not known because K/Ar dating has yielded contradictory results ranging from 398 to 175 Ma. Nonetheless, the most recent ones are certainly rejuvenated (Delaloye *et al*., 1981). The early Devonian age (398 Ma) is consistent with field observation, as some dykes intrude Devonian deposits. Horton *et al*. (2008) have measured U–Pb of detrital zircon grains from Paleozoic sandstones of the Alborz Mountains. They have indicated detrital zircon ages in Late Devonian–Early Permian and Cambrian–Ordovician zircon crystallization. These ages could reflect magmatic activity related to subduction of Paleotethys or related oceanic lithosphere.

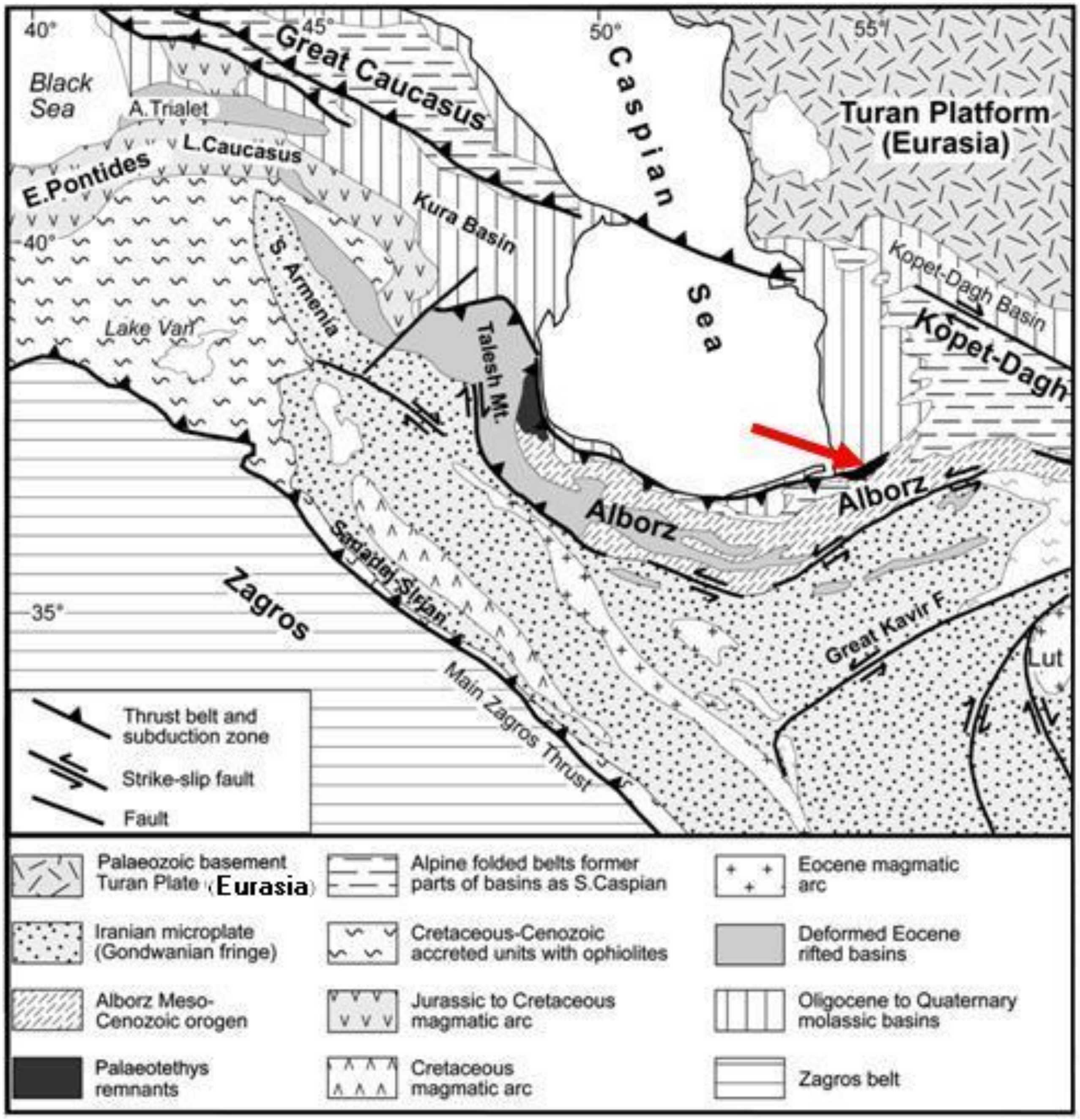

Figure 1) General tectonic map of North Iran and of the South Caspian region with slightly modified from Brunet (2003).The arrow shows the studied area.

Alternatively, these zircons may be the product of rift–related magmatism during opening of Paleotethys (Horton *et al*., 2008). These zircon data suggest that Iran was affiliated with Gondwana magmatic arcs or that rift–related magmatic activity during opening of Paleotethys. The poorly dated igneous rocks may include a record of Paleozoic zircon crystallization in the eastern Alborz. This could be consistent with Paleozoic paleobotanical evidence and basement ages including a Gondwanian affinity for the Alborz (Horton *et* *al*., 2008). Although poorly understood, middle to late Paleozoic magmatism may be the product of intra–arc or back–arc spreading related to opening of Paleotethys (Stampfli *et al*., 1991).

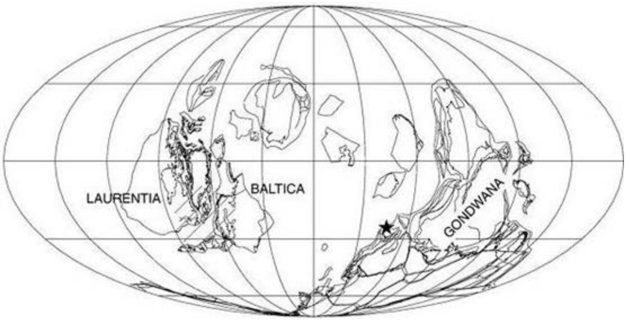

Figure 2) Palaeogeographical model of continental mass distributions during Late Ordovician (Hirnantian) times based on BugPlates Software (courtesy of Center for Geodynamics, Geological Survey of Norway). Star indicates the palaeoposition of the study area, assigned to the North Gondwanan Province.

Petrogenetic studies can provide important information for understanding the mantle source of the magmas and the tectonic evolution of the orogenic belt and adjacent regions (Gorring *et al*., 2001, 2003). In this paper, we report major and trace element geochemistry of mafic dykes from the southern Gorgan in northeastern of Iran in order to: (1) document the geochemical characteristics of these rocks; (2) investigate their mantle sources and petrogenesis; and (3) evaluate the paleotectonic implications for the southern Gorgan during the Paleozoic.

2–Geological Setting

The Iranian plateau is divided into nine geological–structural zones (Stocklin, 1968). Based on this division, the Alborz zone lies with EW–trending in the north of Iran. This zone is sub–divided into three parts: east, central and west. The study area is located in the eastern part of the Alborz zone and belongs to the east Alborz subdivision (Fig. 1). The study area is situated approximately 5 Km south of the Gorgan city, in northeastern Iran. In this area, Paleozoic rock units comprise Upper Ordovician, Silurian and Upper Carboniferous deposits (Fig. 3). The main outcrops consist of the Gorgan metamorphic greenschists (Allen *et al*., 2003) intruded by Paleozoic mafic dykes (Gansser and Huber, 1962; Stöcklin, 1974). The Gorgan schists are known to the south, preventing a direct correlation with the Paleozoic units of the Iranian margin (Zanchi *et al*., 2009). The Gorgan schist has been suggested to be time equivalent of the Ghelli Formation, which is late Ordovician (late Katian–Hirnantian) in age, based on stratigraphic relationship (Ghavidel–Syooki *et al*., 2011). The field observations show no contact metamorphism at the boundary of mafic dyke and schists (Fig. 4). Then, it could be suggested that mafic dyke have been intruded in this area before Gorgan schist.

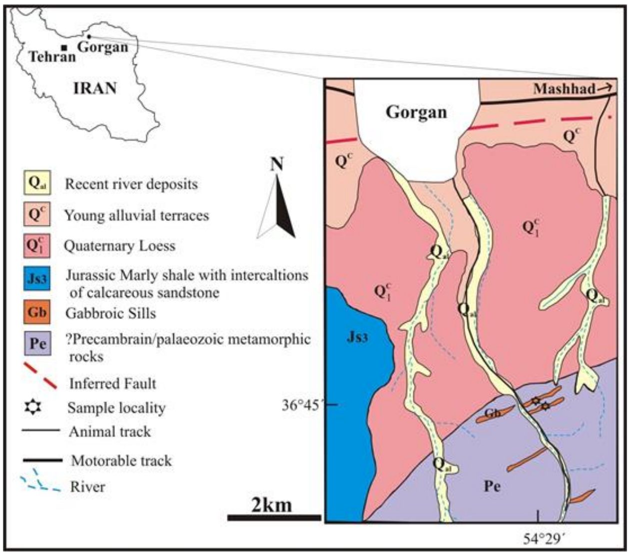

Figure 3) Geological map of the studied area (after Sharabi, 1990, and Zamani Pedram and Hossieni 2003).

3–Petrography

The mafic dykes are 1 to 5 meter in width and several hundred meters in length. They are surrounded by greenschists and show weak metamorphism (Fig. 4). The samples have mesocratic to melanocratic color index (Fig. 4).

Figure 4) Field photographs of samples in southern Gorgan (Rahimi-Chakdel 2007). a) Boundary of gabbro and foliated Schist are clearly visible with red and yellow lines (b). Close up photos show mesocratic (c) and melanocrati (d) colors. White mineral is plagioclase in c photo.

They have a basaltic composition, with medium to large–grained size. They show ophitic to intergranular textures under polarized microscope (Fig. 5). These rocks show some mineralogy variation, but are typically plagioclase–clinopyroxene–phyric with a groundmass of plagioclase microphenocrysts and Fe–Ti oxides.

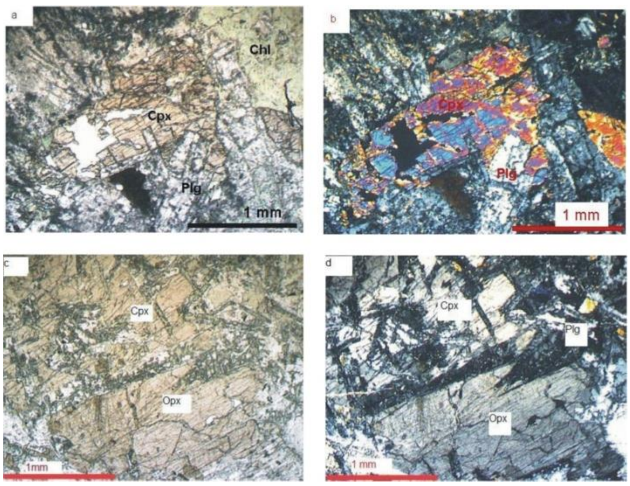

Figure 5) Images are showing intergranular, b) and ophitic, d) textures of gabbroic rocks in Southern Gorgan under PPL(a, c) and XPL(b, d). Cpx= Clinopyroxene, Opx= Orthopyroxene, Chl= Chlorite and Plg= Plagioclase (after Kretz, 1983).

The main minerals are plagioclase (40–45%), clinopyroxene (40–47%), hornblende (~5%), K–feldspar (~3%), orthopyroxene (~2%), and minor olivine, quartz and biotite. Accessory minerals include sphene, zircon, apatite, ilmenite and magnetite. The detailed mineralogy of all samples is listed in Table 1.

Clinopyroxene is the main phenocryst phase and often is up to 3–4 mm in diameter. It occurs in all samples, but it is rarely fresh being typically replaced along cracks by brown or blue chlorite and green hornblende.The plagioclsephenocrysts have euhedral shape. They are occasionally ophitically enclosed by pyroxene. Plagioclase laths are a major groundmass phase. They are typically sericitized. Olivine is also present as a phenocryst phase. Olivine is typically <0.5 mm in diameter.

The smaller olivine grains tend to be more altered and are often enclosed by clinopyroxene.

After the petrographic examination, the 7 freshest samples were selected from a total of 12 samples taken from the southern Gorgan (Table 2).

Table 1) Petrography and mineral assemblages of the South Gorgan mafic dykes, North Iran.

Sample No	**Latitude, Longitude**	**Texture**	**Mineral assemblage**
06GAR001	N36º45´00˝, E54º29´00˝	Medium-grained, Intergranular texture	Cpx+ Plg+ Kf+Ol+ Fe-Ti+ Ap+Sph
06GAR002	N36º45´00˝, E54º29´00˝	Fine- to medium-grained Intergranular- texture	Cpx+ Plg+ Kf+ Fe-Ti+ Hbl+Ap+Zr+ Qtz
06GAR003	N36º45´00˝, E54º29´00˝	Medium-grained, Ophitic texture	Cpx+ Plg+ Kf+ Fe-Ti+ Hbl+Ap+ Sph +Zr
06GAR004	N36º45´00˝, E54º29´00˝	Medium-grained, Intergranular	Cpx+ Plg+ Kf+ Fe-Ti+Ap+Zr+ Sph+ Qtz
06GAR005	N36º45´00˝, E54º29´00˝	Medium-grained,Ophitic texture	Cpx+ Plg+ Kf+Ol+ Fe-Ti+Ap+Zr+ Sph+ Qtz
06GAR006	N36º45´00˝, E54º29´00˝	Medium-grained, Granular texture	Cpx+ Plg+ Kf+ Fe-Ti+ Ap+Zr+ Chl+ Sph+ Qtz
06GAR007	N36º45´00˝, E54º29´00˝	Medium-grained, Ophitic texture	Cpx+ Plg+ Kf+ Fe-Ti+Ap+Zr+ Sph +Qtz

Ap,apatite; Cpx, clinopyroxene; Fe-Ti, Fe-Ti oxides; Kf, K-feldspare; Ol, olivine; Plg, plagieoclase; Qtz, quartz; Hbl, hornblende; Zr, zircon; Sph, sphene (Kretz, 1969)

4–Geochemistry

The selected samples were crushed and powdered in an agate mill for geochemical analysis. Major elements were determined by X–ray fluorescence (XRF). Selected trace elements (Sc, Rb, Cs, Sr, Y, Zr, Hf, Nb, Ba) were determined by WD–XRF on pressed powder pellets. Other trace elements, including rare earth elements (REE), were analyzed by inductively coupled plasma mass spectrometry. All chemical analyses were performed in the laboratories of the Geological Survey of Iran.

Full major and trace element analyses of the mafic dykes are presented in Table 2. The samples exhibit no significant variations in major and trace element. The mafic dykes are basaltic (Fig. 6a) in composition (SiO_2 49.75–51.67 wt %) and in the tholeiitic field on standard AFM plot (Fig. 6b). All the gabbro samples show typical E–type MORB Basalt affinity (Fig. 6c). They have high abundances of total Fe_2O_3 (15.13–16.97 wt %), CaO (7.11–9.51 wt %) and relatively low concentrations of Al_2O_3 (11.27–12.65 wt %), MgO (6.66–8.48 wt %) and K_2O (0.95–1.24 wt %).

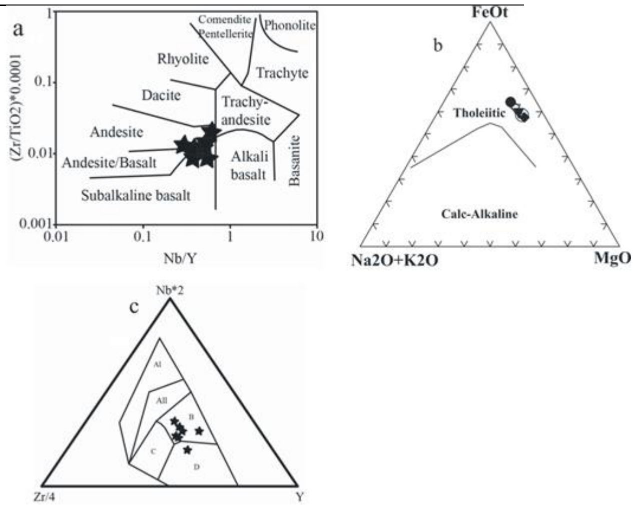

*Figure 6a) Zr/TiO_2–Nb/Y diagram after Winchester and Floyd (1977) b) AFM diagram showing geochemical variations. The tholeiitic and calc-alkaline trend are after Wilson (1989), c) Nb*2–Zr/4–Y variation diagram (Meschede 1986) for the mafic dykes of Southern Gorgan, North Iran. AI, within-plate alkali basalts; AII, within-plate alkali basalts and within-plate tholeiites; B, E-type MORB; C, within-plate tholeiites and volcanic-arc basalts; D, N-MORB and volcanic-arc basalts.*

The trace elements Sc, Rb, Ce, Sr, Y, Zr, Hf, Nb, Ba show little absolute variation, ranging from 24 to 29 ppm, 32 to 43 ppm, 1.1 to 1.9 ppm, 301 to 371 ppm, 31 to 41 ppm, 157 to 241 ppm, 7.4 to 9.2 ppm, 12 to 21 ppm, 309 to 439 ppm, respectively. All sample REEs are normalized to Chondrite (Sun and McDonough, 1989). All the samples are enriched in light REE (LREE) relative to heavy REE (HREE) and show in Chondrite normalized REE pattern (Fig. 7).

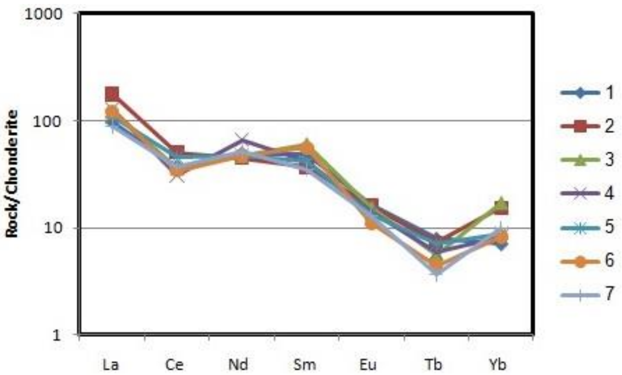

Figure 7) Chondrite-normalized REE patterns after Sun and McDonough (1989) of mafic dykes, South Gorgan, North Iran.

5–Discussion

All mafic dykes show a decrease in total Fe_2O_3, K_2O, P_2O_5 and TiO_2 concentrations with increasing MgO abundances (Fig. 8) whereas an increase Al_2O_3 and CaO concentration with decreasing MgO. It may be the result of accumulation of Fe–Ti oxides. Therefore, the parent magmas of dykes should have low SiO_2 abundances and high total Fe_2O_3, TiO_2 and CaO contents (Table 1). All these characteristics preclude a simple, common evolution by closed–system fractionation process. They can be suggested the operation of combined processes of partial melting of enriched, refractory lithospheric mantle that experienced some fractional crystallization(e.g. Yang *et al.*, 2007a, b).All samples have little variable SiO_2 (49.75–51.67 wt%), MgO (6.46–8.48 wt%), Al_2O_3 (11.27–12.65wt%) values. These dyke samples represent low to medium K (Fig. 9) tholeiitic type, with high TiO_2, total Fe_2O_3, low MgO (>6.0 wt%) and SiO_2 (49.75–51.67 wt%) abundances.

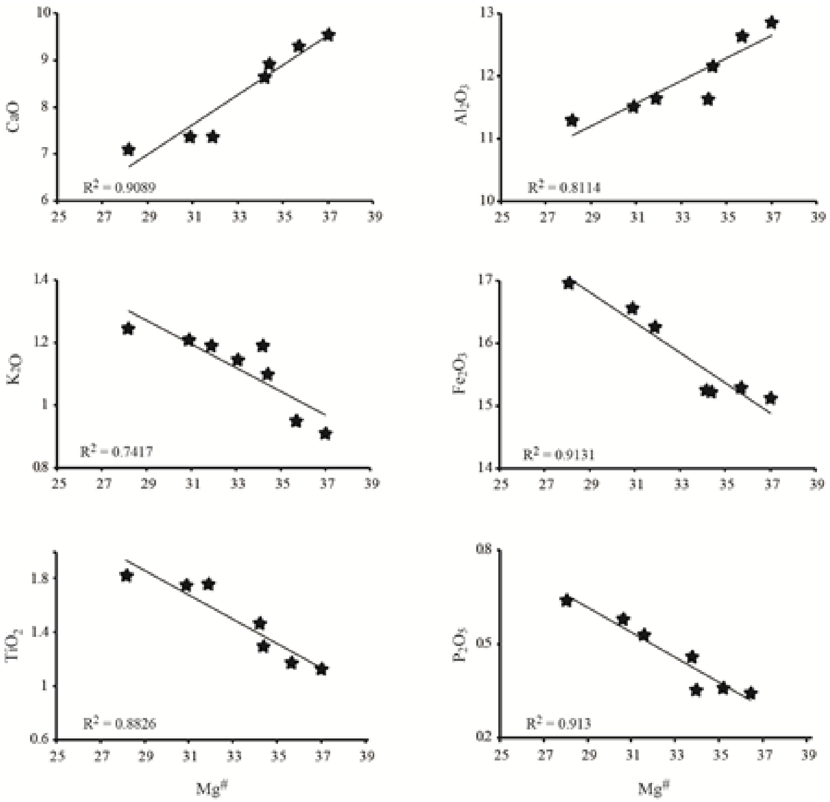

Figure 8) Major and trace elements vs Mg# for mafic dykes, South Gorgan, North Iran.

La/Yb ratios are high (10–21.4) in all samples (Table 2). The low La/Yb ratios reflect a melting regime dominated by relatively large melt fractions and/or spinel as the predominant residual phase (e.g. Yang*et al.*, 2007b; Riley *et al.*, 2005; Falloon *et al.*, 1988) whereas high

La/Yb ratios are indicative of smaller melt fractions and/or garnet control. The high LREE/HREE ratios and low Y content corresponding high Ti/Y ratios of the gabbros suggest that they could be derived from small melt fractions of a garnet stable source. Zr and Y do not fractionate significantly during partial melting (e.g. Yang*et al.*, 2007a).

Table 2) Major (wt%) and trace element (ppm) data of mafic dykes from Gorgan, NE Iran.

Location:	N36°45´00˝, E54°29´00˝						
Sample:	1	2	3	4	5	6	7
wt%							
SiO_2	50.34	51.59	49.75	51.67	50.81	51.23	51.09
Al_2O_3	12.65	11.51	12.87	11.27	12.17	11.64	11.63
$Fe_2O_3^t$	15.27	16.57	15.13	16.97	15.23	16.24	15.25
MgO	8.48	7.41	8.89	6.66	7.98	7.61	7.93
CaO	9.31	7.37	9.51	7.11	8.91	7.38	8.65
Na_2O	1.23	1.28	1.15	1.35	1.18	1.34	1.16
K_2O	0.95	1.21	0.91	1.24	1.1	1.19	1.19
MnO	0.21	0.16	0.31	0.12	0.21	0.19	0.22
TiO_2	1.17	1.74	1.12	1.81	1.29	1.75	1.46
P_2O_5	0.36	0.58	0.34	0.64	0.35	0.53	0.46
Total	99.97	99.42	99.98	98.84	99.23	99.1	99.04
Mg#	35.7	30.9	37.01	28.18	34.4	31.9	34.2
ppm							
Rb	33	33	32	43	33	42	34
Sr	334	301	307	368	346	371	345
Y	31	34	33	38	35	41	37
Zr	241	157	164	167	185	233	176
Hf	9.2	7.4	7.6	7.7	8.2	8.7	7.9
Nb	19	13	17	21	17	12	14
Ba	439	377	366	318	354	309	324
La	23	42	29	30	26	29	21
Ce	23	31	22	19	28	21	23
Nd	23	21	22	31	22	22	24
Sm	7.5	5.6	9.3	6.3	6.3	8.5	5.4
Tb	0.69	0.63	0.49	0.51	0.61	0.38	0.32
Yb	1.2	2.6	2.9	1.4	1.5	1.4	1.7
Ta	1.4	1.3	1.2	1.4	1.3	1.2	1.4
Eu	0.94	0.93	0.89	0.83	0.78	0.64	0.76
Sc	25	28	24	29	25	27	26

However, the dykes display low Rb/Sr (<0.1) and high Ba/Rb (>10). All of the dykes are enriched in LILE and LREE and depleted in Nb and Ta anomalies which are suggesting that metasomatism of source were triggered by subduction–related fluids or melts. Thus, the geochemical data indicate that all of the dykes may have formed by relatively low–percentage melting of an amphibole–bearing (e.g. Dai *et al*., 2011), refractory lithospheric mantle source in the garnet stability field. It may be metasomatized by recycled crustal materials prior to generation.

6–Paleotectonic implications

The major part of the study area belongs to the stable northern margin of Gondwana at least until middle Paleozoic (e.g. Allen *et al*., 2003). During the Paleozoic, the Iran and Arabian plates formed a coherent terrain and were separated from the Turan Plate by the Paleo – Tethys (e.g. Stampfli, 1996). As a consequence of the Late Ordovician glaciations and a lowstand of sea level, large areas of northern Gondwana including Azerbaijan, the western and central Alborz, parts of the Sanandaj–Sirjan Belt, the Zagros Mountains and eastern Iran were emergent since the Late Cambrian/Early Ordovician (Wendt *et al*. 2005). Stampfli, (1996), and Stampfli and Pillevuit (1993) have presented evidence from Alborz and elsewhere that the PaleoTethys opened in Silurian time.

A palaeogeographic reconstruction of Iran during the Silurian/Lower Devonian was presented by Davoudzadeh *et al*. (1986). In the Late Paleozoic, or Early Triassic, the Iranian Plate drifted away from the Arabian Plate by the opening of the Neo–Tethys. At this time, the Iranian Plate collided with the Turan Plate. Stampfli *et al*. (1991) suggested that the Alborz block separated from Gondwanaland in Ordovician–Silurian times (Fig. 6c). It collided with Eurasia in the late Triassic with subduction of Paleotethys (Şengor *et al*., 1988).

In Iran, Turkey, and Greece the closure of PaleoTethys did not take place before Carnian, late Triassic, 231 m.y. ago, (Davoudzadeh and Schmidt 1984; Stampfli, 1996). By the late Carnian, about 225 m.y. ago, there was no Paleotethys left on an Iranian transect. Then, subduction of PaleoTethys oceanic crust under Turan plate started in Late Devonian and continued into Triassic and led to the formation of a volcanic arc (Baud and Stampfli, 1989). The obducted remnants of the PaleoTethys Ocean were included in several rock assemblages including ophiolite complexes, meta–flysch and some submarine pyroclastics in the Binaloud range, northeastern Iran (Alavi, 1992). Clark *et al*. (1975) have noted Upper Devonian equivalents might be present in the schists and phyllites in the mountain ranges of the Talesh Range from the western Alborz. Such metamorphic rocks are preserved in the studied area as Gorgan schists of the eastern Alborz.

Based on the above explanations, the Gorgan schists of the studied area could be remnants of the PaleoTethyan collision occurring as discontinuous outcrops along the northern Gondwana margin of the present range. However, the Gorgan schists have surrounded the mafic intrusions which are rift–related magmatic activity during opening of Paleotethys (Figs. 2, 6c). Some diabase sills erupted in other parts of Iran such as Mighan, Khoshyeilagh and Shirooyeh of eastern Alborz during Early Devonian (Wendt *et al*. 2005).

As mentioned above, it can be ascribed that the emplacement of the mafic gabbroic dykes was a part of the north Gondwana at late Ordovician–Silurian by Middle–Late Devonian time.

7–Summary and Conclusions

A suite of mafic gabbro dykes are intruded in the Middle–Upper Paleozoic rock units representing a part of the north Gondwana province. These rocks are characterized by altered olivine, plagioclase and pyroxenes under optical microscopy. Pyroxenes are typically replaced along cracks by brown or blue chlorite and green hornblende during later regional metamorphism. These rocks are basaltic, andesite and andesite/basalt rocks in composition. Based on present geochemical data, mafic dykes are originated from partial melting of an ancient, refractory lithospheric mantle source at depth of garnet stability. The tectonic environment of mafic dyke can be assigned to the initiation of the opening of Paleotethys in northern part of Gondwana province in late Ordovician time.

Acknowledgments:

The authors would like to thank Dr. E. Saccani and Dr. A. K. Sinha for their appreciate comments which help us to improve manuscript. The authors acknowledge the financial support of the Research Deputy of Golestan University. We appreciate Dr. Damavandi for providing assistance during field work over the past several years.

References:

Alavi, M. 1991. Sedimentary and structural characteristics of the Paleo–Tethys remnants in northeastern Iran. Geological Society of America Bulletin: 103, 983–992.

Alavi, M. 1992. Thrust tectonics of the Binaloud region; NE Iran. Tectonics: 11, 360–370.

Alavi, M. 1996. Tectonostratigraphic synthesis and structural style of the Alborz mountain system in northern Iran. Journal of Geodynamics: 21, 1–33.

Allen, M. B., Ghassemi, M.R., Shahrabi, M., Qorashi, M. 2003. Accommodation of late Cenozoic oblique shortening in the Alborz range, northern Iran: Journal of Structural Geology: 25, 659–672.

Berberian and King, 1981. Towards a palegeography and tectonic evolution of Iran. Cannadian Journal of Earth Sciences: 18, 240–265.

Baud, A., Stampfli, G.M. 1989. Tectonogenesis and evolution of the Cimmerides: the volcanic–sedimentaryTriassic of Aghdarband (Kopet–Dagh, North–East Iran). In: Şengor A.M.C. (Ed.), Tectonic Evolution of the Tethyan Region. 265–275 pp.

Clark, G. C., Davies, R. ., Hamzepour, B., Jones, C.R. 1975. Explanatory text of the Bandar–e–Pahlavi quadrangle map (with contributions by M. Ghorashi, B. Hamdi and N. Nabvai). Geological Survey of Iran, Geological Quadrangle No.D3, 1–198. Tehran.

Dai, J. Wang, C, Hébert, R., Li, Y., Zhong, H., Guillaume, R., Bezard, R., Wei, Y. 2011. Late Devonian OIB alkaline gabbro in the Yarlung Zangbo Suture Zone: Remnants of the Paleo–Tethys? Gondwana Research: 19, 232–243.

Davoudzadeh, M., Schmidt, K. 1984. Plate tectonics, orogeny, and mineralization in the Iranian fold belts; report of a German–Iranian research program 1977–19. Neues Jahrbuch fuer Geologie und Palaeontologie Abhandlungen: 168, 182–207.

Davoudzadeh, M., Lensch, G., Weber–Diefenbach, K.1986. Contribution to the paleogeography, stratigraphy and tectonics of the Infracambrian and Lower Paleozoic of Iran.Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen: 172, 245–269.

Davoudzadeh, M., Weber–Diefenbach, K. 1987. Contribution to the paleogeography, stratigraphy and tectonics of the Upper Paleozoic of Iran. Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen: 175, 121–146.

Delaloye, M., Jenny, J. and Stampli, G. 1981. K–Ar dating in the eastern Elburz (Iran). Tectonophysics: 79, 27–36.

Falloon, T. J., Green, D. H., Hatton, C. J., Harris, K. L. 1988. Anhydrous partial melting of a fertile and depleted peridotite from 2 to 30 kbar and application to basalt petrogenesis. Journal of Petrology: 29, 1257–1282.

Jenny, J.G. 1977a. Geologie et stratigraphie de l'Elbourz oriental entre Aliabad et Shahrud, Iran. These presentee la Faculte des Sciences de l'Universite de Genve, 1–238.

Jenny, J.G. 1977b. Precambrien et Paleozoique inferieur de l'Elbourz oriental entre Aliabad et Shahrud, Iran du nord–est. Eclogae Geologicae Helvetiae: 70, 761–770.

Horton B.K., Hassanzadeh, J., Stockli, D.F., Axen, G.J., Gillis, R.J., Guest, B., Amini, A.H., Fakhari, M., Zamanzadeh S. M., Grove, M. 2008. Detrital zircon provenance of Neoproterozoic to Cenozoic deposits in Iran: Implications for chronostratigraphy and collisional tectonics. Tectonophysics: 451, 97–122.

Gansser, A., Huber, H. 1962. Geological observations in the Central Elburz, Iran. Schweizerische mineralogische und petrographische Mitteilungen: 42, 583–630.

Ghavidel–Sivaki, M., Hassanzadeh, H., Vecoli M. 2011. Palynology and isotope geochronology of the upper Ordovician–Silurian successions(Ghelli and Soltan Maidan Formation) in the Khoshyeilagh area, eastern Alborz Range, northern Iran; stratigraphic and palaeogeographic implications. Rewiew of Plalaeobotany and Palynology: 164, 251–271.

Gorring M. L., Kay, S. M. 2001. Mantle sources and processes of Neogene slab window magmas from southern Patagonia, Argentina. Journal of Petrology: 42, 1067–1094.

Le Bas, M. J., Le Maitre, R. W., Streckeisen,A., Zanettin, B. 1986. A chemical classification of volcanic rocks based on the total Alkali–silica Diagram. Journal of Perology: 27, 745–750.

Meschede, M. A. 1986. Method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb–Zr–Y diagram". Chemical Geology 56, 207–218

Rahimi–Chakdel, A. 2007. Geochemistry and petrogenesis investigations of igneous veins in Ziarat village of Gorgan, Gorgan University of Agricultural sciences and Natural Resources. Technical report. 47p (non publ.).

Raghimi, M. 2010. Tectono–magmatic setting of deformed plutonic rocks of Gorgan Schists in Naharkhoran, Gorgan–Iran. Gorgan University of Agricultural sciences and Natural Resources. Technical report. 56p (non publ).

Rickwood, P. C. 1989. Boundary lines within petrologic diagrams which use oxides of major and minor elements. Lithos: 22, 247–267.

Riley, T. R., Leat, P. T., Curtis, M. L., Millar, I. L., Dunca, R. A., Fazel, A. 2005. early–Middle Jurassic dolerite dykes from western Dronning maud land (Antarctia): Identifying mantle sources in the Karoo large igneous province. Journal of Petrology: 46, 1489–1524.

Salehi-Rad, M. R. 1979. Etude géologique de la region de Gorgan (Alborz oriental, Iran) These de docteur 3em cycle.

Şengor, A. M. C. 1990. A new model for the late Palaeozoic–Mesozoic tectonic evolution of Iran and implications for Oman. In: Robertson, A.H.F., Searle, M. P. and Ries, A.C. (Eds), The geology and tectonics of the Oman region, 797–831, Geological Society, London.

Sharabi, M., 1990. Geological map of Gorgan 1:250000, Geological survey of Iran, Tehran.

Sinha A. K., 2012. Petrological characterization of Proterozoic mafic dykes from the Singhbhum craton, eastern India, 34th International Geological Congress, Brisbane, Australia.

Sinha, A. K., 2013. Geochemistry of distinct mafic dykes from the damodar valley gondwana basins and chhotanagpur gneissic terrain, eastern india: implications for their petrogenesis and tectonic setting, Geological Society of America Abstracts with Programs.

Stampfli, G.M. 1996. The Intra–Alpine terrain: a Paleo–Tethyan remnant in the Alpine Variscides. Eclogae Geologicae Helvetiae: 89, 13–42.

Stampli, G. M., Borel, G. D. 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones. Earth and Planetary sciences letters: 196, 17–33.

Stampfli, G. M., Marcoux, J., Baud,A. 1991. Tethyan margin in space and time. Palaeogeography, Palaeoclimatology, Palaeoecology: 87: 374–409.

Stampfli, G.M., Pillevuit, A. 1993. An alternative Permo–Triassic reconstruction of the kinematics of the Tethyan realm. In: Dercourt J., Ricou L.–E., and Vrielinck B. (Eds.), Atlas Tethys Palaeoenvironmental Maps,Explanatory Notes. Gauthier–Villars, Paris, 55–62 pp.

Stöcklin, J. 1968. Structural history and tectonics of Iran: A review. The American Association of Petroleum Geologists Bulletin: 52, 1229–1258.

Stöcklin, J. 1974. Possible ancient continental margins in Iran. In: Burk, C.A. and Drake, C.L. (Eds), The geology of continental margins, 873–887, Springer–Verlag; Berlin, Heidelberg, New York.

Sun, S. S., McDonough, W. F. 1989. Chemical and isotopic systematics of oceanic basalts: implication for mantle composition and processes. In: Saunders, a. D. and Norry, M.J. (eds) Magmatism in the ocean basins. Geological society, London, Speacial publications: 42, 313–345.

Wendt, J., Kaufmann, B., Belka, Z., Farsan, N., Karimi Bavandpur, A. 2005. Devonian /lower and palaeogeography of Iran, Part II. Northern and central Iran. Acta geologica polonica: 55, 31–97.

Wilson, M. 1989. Igneous Petrology. London. Unwin Hyman, 494pp.

Winchester J, Floyd P. 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology 20, 325–343

Yang, J. H, Sun, J.F, Chen, F., Wilde, S.A., Wu, F. Y. 2007a. Sources and Petrogenesis of Late Triassic Dolerite Dikes in the Liaodong Peninsula: Implications for Post–collisional Lithosphere Thinning of the Eastern North China Craton. Journal of Petrology: 48, 1973–1997.

Yang, J. H, Wu, F. Y, Wilde, S. A, Xie, L.W, Yang, Y. H, Liu, X. M. 2007b Trace magma mixing in granite genesis: in–situ U–Pb dating and Hf–isotope analysis of zircons. Contributions to Mineralogy and Petrology: 153, 177–190.

Zamani Pedram, M., Hossieni, H. 2003. Geological map of Gorgan 1:100000, No. 6862, Geological survey of Iran, Tehran.

Zanchi A, Zanchetta S, Berra F, Mattei M, Garzanti E, Molyneux S, Nawab A, Sabouri J 2009. The Eo–Cimmerian(Late? Triassic) orogeny in North Iran, In; Brunet MF, Wilmsen M, Granath JW (Eds), South Caspian to central Iran Basins, Special Publications, Geological Society of London: 312, 31–55.