Review of age, Rb-Sr geochemistry and petrogenesis of Jurassic to Quaternary igneous rocks in Lut Block, Eastern Iran

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Abstract

The Lut Block (Eastern Iran) extends over 900 km in a north-south direction and is only 200 km wide in an east-west direction. It is confined by the Nayband fault and Shotori Range on the west. The eastern edge is bordered by the Sistan suture zone and Nehbandan Fault. The northern termination of Lut Block is the depression of Kavir-e-Namak and the Great Kavir Fault. The Makran arc, including the Bazman volcanic complex and the Jaz-Murian-Depression, define the southern edge. Sixty-five percent of the exposed rocks within the Lut Block are volcanic and plutonic rocks. Klateh Ahani, Shah Kuh and Surkh Kuh granitoids (Middle Jurassic,165-162 Ma) are among the oldest rocks exposed within the Lut Block. Based on mineralogy, low values of magnetic susceptibility [(1 to 50) × 10^{-5} SI], and high initial $^{87}Sr/^{86}Sr$ = 0.7073-0.709, Klateh Ahani, Shah Kuh and Surkh Kuh granitoids are classified as belonging to the ilmenite-series of reduced S-type granitoids. They formed in a continental collision tectonic setting and the magma originated from with the continental crust. The next episode of magmatism was in the Late Cretaceous. Granitoids are reported at three localities with ages within the short time interval between 76.6 to 74 Ma. Based on mineralogy, low values of magnetic susceptibility [(1 to 50) × 10^{-5} SI], and high initial $^{87}Sr/^{86}Sr$ = 0.712, the Bajestan granitoid (76.6 Ma) is classified as belonging to the ilmenite-series and the magma was formed in continental collision setting. Gazu granodiorite (75.2 Ma), located near the Nayband fault and within Tabas Block, is calc-alkaline with initial $^{87}Sr/^{86}Sr$ = 0.7045 that was formed above a subduction zone. Bazman granodiorite (74.2 Ma) is part of the southern Cretaceous volcanic-plutonic belt which was also formed due to subduction. During the Late Paleocene (61-56 Ma) ignimbrites are erupted in Vaghi and Junchi. Based on their $(^{87}Sr/^{86}Sr)i$ = 0.7073-0.7068 these magma originated within the continental crust. The episode of Middle Eocene to Early Oligocene (39-30 Ma.) was very important in term of magmatism and mineralization. Diorite, monzonite, quartz monzonite, and granodiorite are reported in different part of the Lut Block. Based on mineralogy, high values of magnetic susceptibility [(400 to 1600) × 10^{-5} SI], and low initial $^{87}Sr/^{86}Sr$ < 0.7057, they are classified as belonging to the magnetite-series of oxidant I-type granitoids. These magmas originated above a subduction zone. Basaltic rocks within the Lut Block near Ferdows (42 Ma) and Mud (31.4 Ma) have signatures of island arc basalts. Younger Neogene basaltic rocks (15.5 to 1.74 Ma) from East Neh along the eastern margin of Lut Block and Nayband area along the western margin of Lut Block have the characteristic of ocean island basalts.

Keywords: *Lut block, Isotope composition, source of magma, Iran*

Introduction

The area reviewed and studied in this paper is located within the Lut block in eastern Iran between 30°00′ and 34°00′ north latitude and 57°00′ and 60°00′ east longitude (Figs. 1 and 2). According to Stocklin and Nabavi (1973), the Lut block extends over some 900 km in a NS direction from Doruneh fault in the north to the Juz-Morian basin in south, but is only 200 km wide in an EW direction from Nayband fault and Shotori range in the west to East-Iranian range and Nehbandan fault in the east. From N to S the most important towns are in the Lut block are Gonabad, Bajestan, Ferdows, Tabas, Deyhuk, Khur, Birjand, Sarbisheh and Mud.

The paleotectonic setting of Lut block is not well understood. Some generalized works were done on tectonic and magmatism of Lut, but these are imperfect and even contradictory (Soffel &Forster, 1980; Davoudzadeh *et al.,* (1980); Berberian & King, 1981; Camp & Griffis, 1982; Tarkian *et al.* (1983); Tirrul *et al*., (1983) and Jung *et al*., (1983). The Lut region evinces a platform character in its sedimentation during the whole Paleozoic period. Due to intensive orogenic movements during Mesozoic and Tertiary, a breaking and splitting of this platform has occurred, which led to a reactivation of different lineaments that separated Central Iran into mosaic-like blocks (Tarkian *et al.,* 1983). The Central Lut is separated from Tabas block to the west by the marked NS structure of the Shotori Range. Compared to its present position, the Lut Block underwent an anti-clockwise rotation of 30–90°, possibly during the Tertiary, relative to Eurasia (Westphal *et al*., 1986) due to the collision of India (and Afghanistan) with Eurasia.

The magmatic activity in the Lut block began in the middle Jurassic 165-162 Ma and reached its peak in the Tertiary. Volcanic and subvolcanic rocks of Tertiary age cover over half of Lut block with up to 2000 m thickness and formed due to subduction prior to the collision of the Arabian and Asian plates (Camp & Griffis, 1982; Tirrul *et al.*, 1983); Berberian *et al.,* 1999). Eastern Iran, and particularly the Lut block, has a great potential for different types of mineralization as a result of its past subduction zone tectonic setting, which lead to extensive magmatic activity.

The main purpose of this paper to better understand the tectonic-magmatic setting of the Lut block based on a review of the previously published geochemical characteristics, Sr isotopes and age dating of all of the igneous rocks presented by Lotfi (1982), Tarkian *et al.,* (1983), Jung *et al.*, (1983), Esmaeily (2001), Saadat *et al.,* (2008 , 2009), Walker *et al.*, (2009), Malekzadeh, 2009, Malekzadeh *et al.,* 2010; Karimpour & Moradi 2010, Moradi *et al.,* 2011, and Arjmandzadeh *et al.,* 2010a-b.

Geology, Chronology and Petrography

The oldest igneous rocks dated within the Lut block are Klateh Ahani, Shah Kuh and Surkh Kuh (165-162 Ma) Middle Jurassic granitoid rocks (Fig. 1). Bajestan batholith and Bazman granodiorite are dated at 77 and 74.2 Ma (Upper Cretaceous (Fig. 1). Gazu granodiorite, which located within Tabas Block, was also emplaced at 75.2 Ma (Fig. 1). In Early Paleocene time Vaghi ignimbrite (61.6 Ma) and Late Paleocene Junchi ignimbrite (56.7 Ma) were erupted (Fig. 1). Granitoid rocks of Middle to Late Eocene time (43.2-38.2 Ma) are found at several locations with the Lut Block (Fig. 1). Granitoids younger than 38 Ma are not reported from the Lut Block, but basalts are common (Fig. 2).

The oldest basalts are exposed in Ferdows (42 Ma), Mud (31.4 Ma) (June *et al*., 1983) and Qal-e-Gonbad (39.6 (Ma) (Fig. 2) (Tarkian *et al.*, (1982)). Neogene alkali basalts with age of 4.81 to 1.74 Ma are erupted along the Eat Neh fault on the eastern margin of the Lut Block and with ages of 2.2 to 15.5 along the Nayband fault on the western margin of Lut Block (Walker *et al.,* 2009). Based on their age, from older to younger, the magmatic rocks in the area are described below:

The oldest magmatic activity in the Central Lut is the Surkh-Kuh intrusion, located 20 km SSW of Talekheshtak. This granite to granodiorite intrusive body occurs at a marked crushed zone between the strongly folded Coloured Mélange and Flysch complex. Sr isotope determinations in the whole-rock and biotites of two samples yielded a Middle Jurassic age (171-165 Ma) (Tarkian *et al.,* 1983).

Klateh Ahani biotite granodiorite batholith, located 25 km south of Gonabad. It is made up of three unites: biotite granodiorite, hornblende biotite granite and biotite granite. This exposed part of the batholith is 8 × 2 km. The age of this batholith is 162.4 Ma (Moradi *et al.,* 2011). This batholith intruded regional metamorphosed Shemshake formation. Biotite granodiorite has the biggest exposure.

Jurassic

The Shah-Kuh granitic pluton, which is one of the biggest batholite of Iran with approximately 50 km lengthen, was emplaced ~162 Ma ago. It is made of two main units: granodioritic and syenogranitic (Esmaeily, 2001; Esmaeily *et al.,* 2005). The granodioritic unit crops out in the northern and central parts of the pluton and affords the largest exposure. Granodiorite and monzogranites composed mainly of quartz, plagioclase, microperthitic alkali feldspar, biotite and green amphibole. Ferro-magnesian silicates amount to 15–20% of the modal composition. Textural relationships indicate that plagioclase was the first felsic mineral to crystallize, whereas K-feldspar was a late insterstitial phase. Quartz sometimes displays recrystallized features indicative of incipient solid-state deformation. Zircon, apatite, zoned allanite, rutile, titanite and opaques are common accessory minerals. Fine-grained mafic enclaves are abundant in the central part of the pluton. They are dioritic to tonalitic in composition and contain plagioclase, amphibole, biotite, subordinate quartz and scarce relict pyroxene (partly replaced by amphibole). Their grain size is about 2 mm on average. The size of the enclaves is variable, with minimum, maximum and average lengths of respectively, 0.5, 30 and 12 cm. Enclave shapes are globular, with fine-grained quenched or reaction margins. All these features indicate a co-magmatic nature of the enclaves and their hosts (Esmaeily, 2001; Esmaeily *et al.,* 2005). The southern and eastern parts of the pluton are mainly composed of syenogranites with subordinate alkali-feldspar granites. These rocks are generally coarse grained and display a porphyritic texture with pink K-feldspar megacrysts up to 3 cm long (average and minimum lengths: 1 and 0.5 cm, respectively). Although, the contact with the granodioritic unit is generally transitional over 50–100 m, it is possible to observe syenogranites locally cutting monzogranites, as well as monzogranitic enclaves included in the syenogranites, indicating that the syenogranites are slightly younger than the granodioritic unit. The mineral assemblages include perthitic alkali feldspar, plagioclase, quartz, biotite, and muscovite. Biotite amounts to 10–15% of the modal composition.

Table 1: Major, trace and REE elements analysis of basalt of Lut block (1= Jung et al. (1983); 2 = Walker *et al.* 2009)

Location	Tabas[1]	Nayband fault[2]			East Neh[2]			Ferdows[1]	Mud[1]	
Sample No	Lu 58	1	2	3	AvNeh	BvNeh	CvNeh	Lu 39	Lu 340	Lu 343
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalts	
Age (Ma)	15.5	2.6	2.2	2.25	1.6	1.74	4.81	42	31.4	31.4
SiO_2	54.09	52.11	50.65	50.93	48.80	53.06	52.77	50.22	49.08	48.85
TiO_2	2.25	2.02	2.43	2.43	2.40	1.87	1.89	1.58	0.86	1.15
Al_2O_3	14.60	15.46	15.24	15.37	14.83	14.84	14.84	17.22	13.49	13.12
Fe_2O_3	1.85	8.08	3.93	9.35	3.9	8.30	3.39	4.27	2.84	6.08
FeO	7.64	0.112	5.4	0.123	5.77	0.126	4.45	4.01	5.25	2.32
MnO	0.13	4.68	0.12	5.33	0.13	5.00	0.11	0.13	0.14	0.13
MgO	4.99	8.32	5.26	8.55	5.06	9.16	4.97	6.19	11.56	10.24
CaO	6.64	5.29	8.62	5.05	10.42	4.90	8.82	6.88	8.38	9.31
Na_2O	3.74	1.409	4.98	1.413	4.80	1.535	4.86	3.80	3.90	2.84
K_2O	1.54	1.138	1.32	1.142	1.5	1.081	1.48	1.91	1.58	1.87
P_2O_5	0.48	1.08	1.13	0.54	1.28	0.69	1	0.64	0.29	0.82
Total	98.84	99.70	100.43	100.23	100.50	100.55	99.94	99.33	99.43	99.20
Rb	25	21.7	22.7	20.5	28.2	27.3	33	36	27	39
Sr	743	1513.9	1340.9	1389.0	1462.1	1479.8	6192.3	862	870	1440
Ba	283	517.4	403.9	398.2	396.9	425.3	444.8	294	500	725
Nb	17	34.9	39.7	39.3	41.6	32.7	32	9	2	2
Zr	196	266.9	279.8	270.8	276.1	234.7	260.2	249	106	169
Ga		21.0	21.7	21.8	20.9	20.0	21.3			
La	23	47.31	40.48	43.01	39.8	45.86	45.69	28	39	82
Ce	72	92.79	84.52	92.66	83.82	100.09	90.76	107	75	137
Pr		24.1	21.8	21.72	21.8	22.88	23.23			
Nd	28	43.45	46.09	49.33	41.93	50.98	43.81	34	22	58
Sm		8.76	9.8	10.67	8.54	10.74	8.96			
Eu		2.1	2.43	2.71	2.2	2.68	2.18			
Gd		5.25	6.37	6.99	5.83	7.01	5.77			
Dy		3.36	4.12	4.56	3.84	4.56	3.67			
Er		1.39	1.71	1.96	1.69	1.95	1.66			
Y	11	21.4	25.4	24.7	26.1	23.4	18.9	19	6	
Yb		1	1.22	1.5	1.14	1.45	1.26			

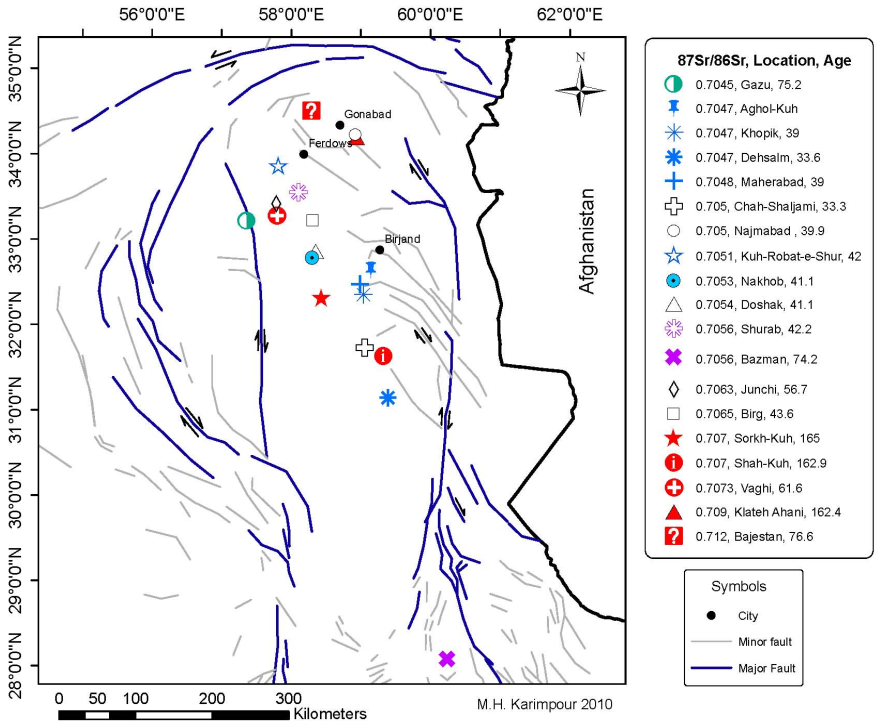


Figure 1: Map showing Location and age of granitoid rocks within Lut Block (References see Table 4) .

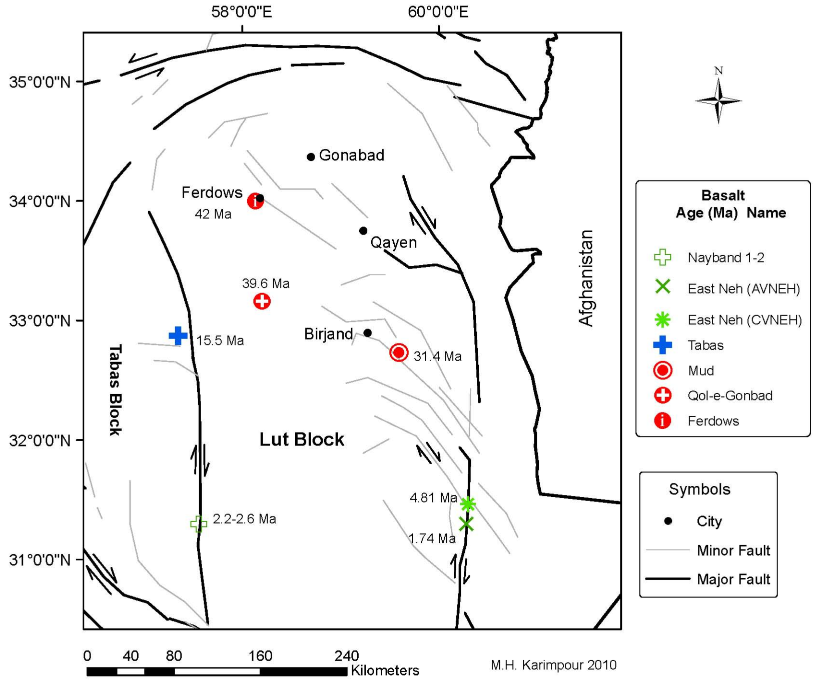


Figure 2: Map showing Location and age of basalts within Lut Block.

Cretaceous

The Bajestan granite-granodiorite (north of Ferdows) was emplaced within clastic and calcareous Jurassic sediments and andesitic volcanics. The country rocks were thermally metamorphosed. The hornblende-hornfels facies was reached within the calcareous sections. All over the outcrop, the intrusive rocks are uniformly medium to course-grained and dark greenish-grey to light reddish-grey. The marginal parts are porphyritic. The modal mineral contents quartz-microdiorite in the east, granodiorite and granite to a porphyritic marginal granite in the northwest. Fresh sample are rare, almost all of them show an imprint of hydrothermal alterations and reactions. This is indicated by tourmaline patches of some cm in diameter at the southern part of the intrusion. Relics allowed to deduce that ortho and clinopyroxene occur in the dioritic samples, whereas hornblende and biotite were the prevailing mafic minerals in the granitic samples. Two Rb/Sr dates yielded ages around 77 Ma. This implies that the magmatic activity must have commenced in the uppermost Cretaceous (Jung *et al.*, 1983).

The Gazu granodiorite occurs within Tabas Block near the Nayband fault zone, 15 km southwest of Deyhuk. The intrusive body penetrated partly limestone of the Shotori Formation, partly sandstone and shales of the Lower Jurassic Shemshak Formation. Texture of granodiorite is porphyry. The intrusive and the limestone close to the contact zone are mineralized. All the characteristic features of a copper dissemination of porphyry type can be found. Distinct hydrothermal alteration occurs mainly in the central part of the intrusion. Rb and Sr isotope determinations in the whole rock and biotite of one sample yielded an age of 75 Ma (Late Cretaceous).

Tertiary

Ignimbrites were erupted repeatedly during the entire early Tertiary period of activity of the Lut volcanism. The oldest unit is Vaghi (southwest of Khur) with K/Ar age 61 Ma (lower Paleocene). The ignimbrite of Junchi (southwest of Khur) has an age of some 56 Ma (upper Paleocene) and the ignimbrite of Doshak and Nakhob (southwest of Khur) of some 41 Ma (middle Eocene) (Jung *et al.,* 1983). The youngest unit is the ignimbrite of Mud, which is younger than the underlying basalts which have ages of 31 Ma. The vast ignimbrite sheets show a reddish main facies and vitreous black basal sections in most cases. The vitreous matrix is only preserved in these vitrophyric sections. Elsewhere the phenocrysts are embedded in a groundmass of fine fibrous microlites. Only the youngest ignimbrite unit near Mud contains pumice fragments and shards in glassy condition. Andesitic to rhyodacitic ignimbrites can be distinguished on the ground on the basis of their chemical compositions. Amphibole only occurs in a few units. It is a brown-greenish edenitic hornblende. Clinopyroxene is a minor constituent almost in all units. Biotite is a minor constituent everywhere. It is represented by lepidomelane in the ignimbrites between Ferdows and Deyhuk. Higher Mg- contents are remarkable between Khur and She Changi. Apatite and zircon are ubiquitous accessories; tridymite and natrolite fill the vesicles. All ignimbrites show imprints of differentiation and alteration which took place during and after their eruption and deposition (Jung *et al.,* 1983).

Most of magmatic activity in the Lut block formed in middle Eocene. In Khur area, three different volcanic rock types were dated. The whole-rock biotite ages indicated the formation of the volcanics in the middle Eocene: dacite of Kuh-e-Birg (43 Ma), shoshonitic andesite of Qol-e-Gonbad (39 Ma) and andesite of Cheshmeh-Khuri (39 Ma) (Tarkian *et al.*, 1983). The age of basalt of southwestern Ferdows and Hows-Mola Rahim are between 42 and 43 Ma. Also, the age of syenite porphyry of the Kuh-e-Robat-e-Shur (35 km southwest of Ferdows) is 42 Ma (Jung et al. (1983)). Dacitic rocks of Shurab-Galeh Chah are around 42 Ma. In addition, monzonitic porphyries of Maherabad and Khopik area (70 km of southwest of Birjand) are middle Eocene (39 Ma).

Middle to late Tertiary basalts are volumetrically subordinate. They are represented mainly as lavas and in some cases as dykes and vents in near surface sections. They are porphyritic with fine-grained or even dense groundmass. The phenocrysts of olivine and plagioclase which can reach 2mm in diameter constitute 30%-60% vol. Groundmass includes olivine, clinopyroxene, Fe-Ti oxides and apatite. Secondary minerals include fine biotite, chlorite patches and carbonate veins (Jung *et al.,* 1983).

The andesitic volcanics were erupted together with the dacites and rhyodacites during a time interval of some 50 Ma from the youngest Cretaceous to the early Neogene. It can be assumed that the intensity of the volcanic activity was varying significantly during this time span. It may even have ceased temporarily. Local angular unconformities might have been formed during such pauses. The texture is nearly exclusively porphyritic, however, contain varying phenocrysts. A classification can be based on the mafic phenocryst contents: 1) olivine andesite, 2) olivine pyroxene andesite, 3) pyroxene andesite, 4) pyroxene biotite andesite, 5) pyroxene hornblende andesite, 6) hornblende biotite andesite and 7) hornblende biotite pyroxene andesite. The groundmass includes plagioclase, clinopyroxene, hornblende, accessories (magnetite, ilmenite, apatite, and rare zircon) and secondary minerals (carbonate, chlorite and epidote) (Jung *et al.*, 1983).

Shoshonitic andesitic rocks around Khur have porphyry texture. Their phenocrysts predominantly zoned with plagioclase and clinopyroxene near the triple junction diopside-salite-augite. Olivine is the most basic representatives, orthopyroxene, hornblende and biotite only occurs in the less basic rocks sporadically. Quartz phenocrysts have not been encountered. The groundmass consists mainly of plagioclase laths and clinopyroxene. Less abundant, are biotite, apatite and rarely hornblende. Quartz and alkali feldspar could not be detected microscopically (Jung *et al.*,1983).

Dacitic rocks have coarse porphyritic texture contain phenocrysts up to several mm in size. The following verities can be found on the grounds in accordance to their petrographical criteria: 1) pyroxene dacite, 2) pyroxene hornblende dacite, 3) pyroxene hornblende biotite dacite, 4) pyroxene biotite dacite, 5) hornblende dacite, and 6) hornblende biotite dacite. The groundmass includes plagioclase, quartz, orthopyroxene, clinopyroxene, hornblende and biotite. Accessory minerals contain apatite, magnetite, ilmenite, hematite and rare zircon (Jung *et al.,* 1983). Dacitic rocks of Shurab-Galeh Chah have porphyry texture including phenocrysts of quartz, feldspar and mafic materials in a groundmass of fine grained quartz + feldspar. The plagioclase phenocrysts constitute 25-30% of the rock volume and up to 4 mm in diameter. Quartz makes up 7-10% of the rock volume with 0.5-2 mm length. Amphibole generally comprises 10-15% with maximum 1.5 mm length. The amount of biotite in the central part of the intrusion is higher than at other places, 5-8% of the rock volume. The length of it is up to 2.5 mm. Hematite, magnetite and apatite are common accessory minerals (Lotfi, 1982).

The dome of the Kuh-e-Robat-e-Shur is classified as quartz keratophyre in the Geological Quadrangle Map “Boshruyeh”. Its rocks are holocrystalline-porphyritic. The phenocryst phases clinopyroxene, hornblende, biotite and plagioclase constitute glomerophyric aggregates of up to 5 mm diameter. Within such an aggregate the grain boundaries show anhedral “plutonic” configurations. The hornblendes contain cores of pyroxene. The glomerophyric aggregates are magmatically corroded at their outer rims and mantled by coatings of alkali feldspar, especially in sections where plagioclase makes up the rim. They are euhedral Na-rich potassium feldspar which grade continually into groundmass sizes. Other phenocrysts are apatite and zircon. The groundmass consists exclusively of euhedral alkali feldspar and interstitial quartz (Jung *et al.*, 1983).

The oldest rocks in the Maherabad and Khopik area are volcanic rocks, including tuffit and dacitic to rhyodacitic tuff. The subvolcanic porphyries are of Eocene age, and intruded into volcanic rocks. More than fifteen intrusive stocks have been recognized which host porphyry Cu-Au mineralization. The composition of mineralization-related intrusive rocks varies from gabbro to monzonite. They were subjected to hydrothermal alteration spatially within and adjacent to monzonitic intrusions. Monzonitic porphyry rocks with irregular contacts are the main stocks in both Maherabad and Khopik areas. Petrographically, five monzonitic intrusive phases can be distinguished based on presence and abundance of phenocrysts of quartz and ferromagnesian minerals such as biotite and hornblende: 1) monzonite porphyry, 2) hornblende monzonite porphyry, 3) biotite monzonite porphyry, 4) hornblende quartz monzonite porphyry and 5) biotite hornblende monzonite porphyry (Fig. 3). These subvolcanic rocks were extensively altered and the highest density of veinlets was seen in them (up to 50 veinlets in 1 m^2). Color of these rocks is dominantly yellow to creamy duo to quartz-sericite-pyrite alteration. Monzonitic rocks appear to be main source of mineralization. The monzonitic porphyries have porphyry to glomeroporphyry texture and contain phenocrysts of andesine, K-feldspar, hornblende, biotite and minor quartz in a fine-grained matrix. The groundmass consists mainly of quartz and feldspar. Plagioclase phenocrysts (up to 4^{mm}) are euhedral and normally zoned. They also have sericitized. K-feldspar and hornblende phenocrysts are up to 1^{mm} and 3^{mm}, respectively and were altered. Accessory minerals include zircon, apatite and magnetite. Sericite and quartz are common secondary minerals (Malekzadeh, 2009).

Najmabad Tertiary intrusive rocks are located 25 km south of Gonabad. Hornblende monzonite porphyry, hornblende biotite monzonite porphyry and biotite monzonite porphyry are identified in Najmabad (Karimpour & Moradi 2010). Based on mineralogy and high values of magnetic susceptibility [(>500) × 10-5 SI], therefore it is classified as belonging to the magnetite-series of oxidant type granitoids (I-type granitoids). Monzonite porphyries are characterized by medium light rare earth element (LREE) enrichment and high low heavy REE (HREE). Based on REE content and (La/Yb)N= 9-64 magma did not originated from continental crust.

Chah Shaljami prospecting area is located 190 Km south of Birjand and 15 km southwest of Qaleh Zari mine. Tertiary volcanic rocks are intruded by a series of Subvolcanic intermediate intrusive rocks Karimpour *et al.,* 2009). Subvolcanic rocks have quartz monzonite to granodiorite composition. The results of U-Pb zircon age dating of the Chah Shaljami Subvolcanic rock is 33.3 Ma (Arjmandzadeh *et al*., 2010a-b). Three broad zones of altered rocks are exposed in Chah Shalghami (3× 1 Km) (Karimpour, 2006). Aster satellite data are processed by using special method and important minerals such as: alunite, quartz, jarosite, montmorillonite, kaolinite, chlorite, dickite, and epidote are identified. Some of these minerals cannot be identified at the surface, so by processing Aster satellite data it is possible to recognize the alteration minerals and the zoning more accurate in comparison with field work. Based on Aster satellite data processing, field and Lab-working several alteration zones such as: vugy quartz, quartz-alunite, quartz-montmorillonite, and quartz-chlorite are identified. Based on vugy quartz, quartz-alunite, and shape and extend of alteration zones and sub-volcanic dikes Chah Shalghami is lithocap of porphyry copper deposit (Karimpour, 2006). Areas near the surface has potential for gold (high sulfidation epithermal) and at depth it has potential for porphyry copper deposit

Dehsalm intrusive complex is located about 55 km west of Nehbandan; South Khorasan. Dehsalm are mainly pyroxene hornblende monzodiorite, pyroxene biotite monzodiorite, pyroxene biotite quartz monzonite, hornblende monzonite, pyroxene hornblende monzonite, pyroxene monzonite, pyroxene hornblende diorite, biotite granite and porphyry granite (Arjmandzadeh *et al*., 2010a-b). Hornblende monzonite and pyroxene hornblende monzodiorite are mainly porphyritic in texture, and exposed to the North West and the center of the area. These units intruded before the other subvolcanics and host the majority of the ore. Granite units distributed throughout the map and intruded hornblende monzonite and pyroxene hornblende Monzodiorite. Pyroxene hornblende monzonite intrusive body differs texturally from hornblende monzonite and is very coarse grained and has Poikilitic texture. This unit exposed to the North West and North South of the map and is less altered than other intrusive bodies. Major alterations include secondary biotite, propylitic, sericite-argillic, epidote, sericite-calcite-silica (Arjmandzadeh et al., 2010a-b). The results of U-Pb zircon age dating of the Dehsalm subvolcanic rock is 33.6 Ma (Arjmandzadeh *et al*., 2010a-b).

A sequence of thick basalt flows rests on conglomeratic sediments and red beds around the town of Mud some 40 km southeast of Birjand. The K/Ar age is 31.4 Ma. It is thus somewhat younger than in the Ferdows-Khur region where the youngest dating reach down to not less than 40 Ma. The basalts at the edge of the basin north of Mud are tectonically tilted and in upright position, thus indicating an age of the basin tectonics younger than that of the volcanic events. The Mud basalts are overlain by andesitic- dacitic brecciated tuffs, lahar breccias and thick andesitic-dacitic lava flows. These rocks are distinctly porphyritic with some 30% vol. of olivine and augite phenocrysts. The groundmass is distinctly trachytoid due to fluidly aligned plagioclase laths. Grains of clinopyroxene and rare biotite flakes occur scattered in this rock type. Weathered occurrences become white mottled and cruble away due to analcite growth in the glass matrix (Jung *et al.*, 1983).

Neogene/Quaternary

Based on the exposed rocks, magmatism in Quaternary time was mainly basalt type. Basalts are found mainly along the Nayband and Nehbandan faults on eastern and western margin of the Lut Block. These basalts have porphyritic texture. Phenocrysts are olivine, clinopyroxene, and plagioclase. They are within-plate alkali basalts (Saadat *et al.* 2009). Basalts are also exposed to the southern part of Lut Block within the Makran arc. These basalts are calc-alkaline type. Small lherzolitic inclusions are interpreted as mantle fragments (Jung *et al.,* 1983). To the southern part of Nayband fault, there are several craters which lamproites magma type was erupted.

WHOLE-ROCK GEOCHEMISTRY

Major and some trace and REE elements analysis of the least altered or fresh of igneous rocks of Lut block are presented in Table 1, 2, and 3. Geochemical signatures of basaltic and granitoid rocks described below separately.

Basaltic rocks

The SiO_2 content of basaltic rocks vary from 48.8 wt% to 54.09 wt% (average SiO_2 of 50.35 wt%) (Table1). A plot of (K_2O + Na_2O) vs. SiO_2 (Le Bas *et al.,* 1986) shows that basaltic rocks plot in the field of basalt, basaltic andesite, trachy basalt, basaltic trachy andesite. They are mainly alkaline-type basalt (Fig. 3). Based on Fe^t, Ti, Al and Mg contents, these rocks mostly plot in the field of basalt in Jensen diagram (1976). However, basalt of Mud plots in komatiitic basalt to high-Mg tholeiite basalt (Fig. 4).

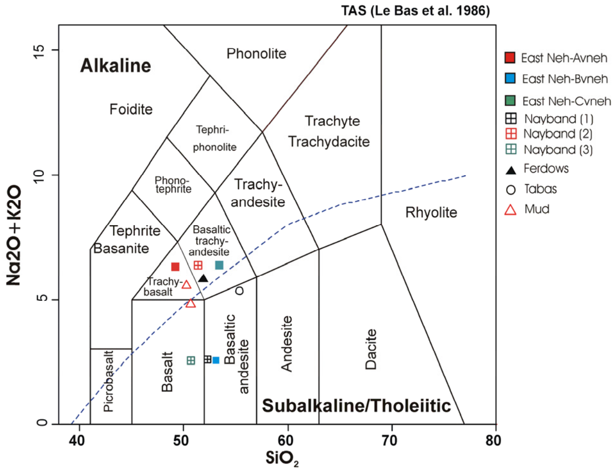


Figure 3: Classification of basaltic rocks by %Na_2O + %K_2O versus %SiO_2 (Le Bas *et al.*, 1986).

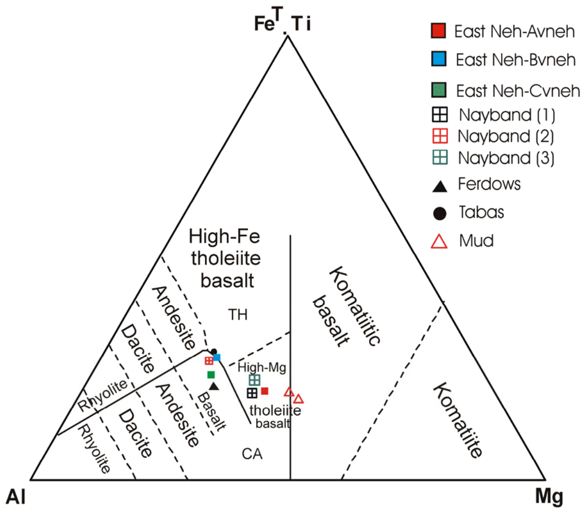


Figure 4: Classification of basaltic rocks by Fe^t, Ti, Al and Mg contents (Jensen, 1976).

Rock/MORB normalized spider diagram of Tertiary (Late Eocene to Mid Oligocene) basaltic rocks within Lut Block from Ferdows (42 Ma) and Mud (31.4 Ma) are plotted in Fig. (5a). The compositions of these older basalts are similar to the signatures seen in island arc basalts, with negative Nb, with elevated abundances of the large ion lithophile elements (LILE; e.g. Sr, Ba and Rb) compared with high-field strength elements (HFSE; e.g. Zr, Y and Ti) (Fig. 5a). Negative Nb is an important signature of island arc basalts. This mainly related to type and composition of garnet. The partition coefficient of Nb for garnet within eclogite is higher than garnet in garnet peridotite, therefore during partial melting the Nb content of basaltic magma generated in subduction is lower (Westrene *et al*., 1999- 2001).

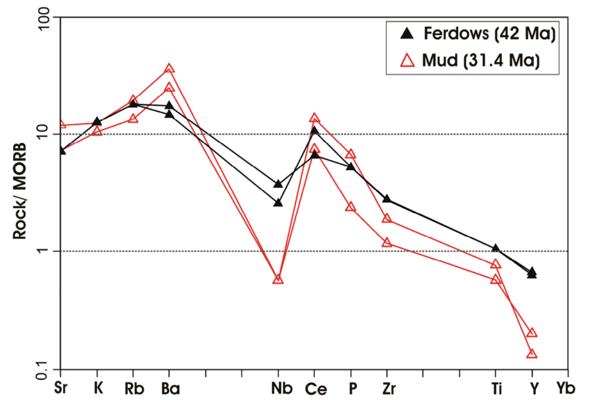


Figure 5a: MORB-normalized spider diagrams for basaltic rocks from Ferdows, Tabas and Mud areas (within Lut Block). Data from Jung *et al.*, 1983.

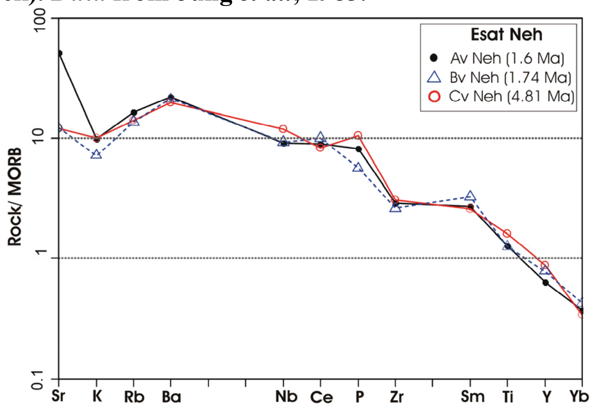
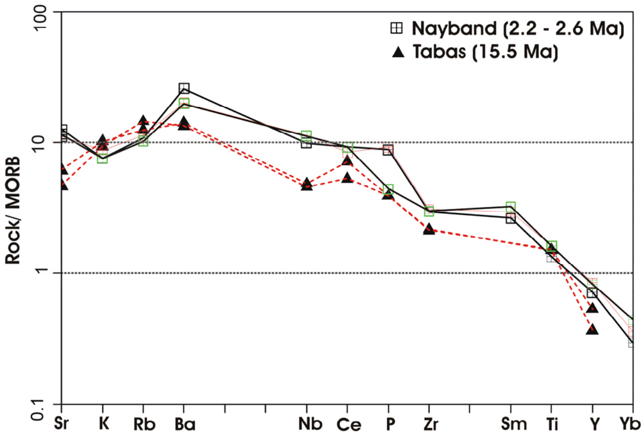


Figure 5b: MORB-normalized spider diagrams for basaltic rocks from East Neh (east margin of Lut Block). Data from Walker *et al.*, 2009.

Rock/Morb normalized spider diagram of Neogene basaltic rocks (15.5 to 1.74 Ma) from East Neh (east margin of Lut Block) and Nayband – Tabas area (west margin of Lut Block). (Walker *et al.,* 2009); (Sadaat *et al.,* 2009) are plotted in Figs. (5b-c). The compositions are similar to the signatures seen in ocean island basalts (OIB), with elevated abundances of the large ion lithophile elements (LILE; e.g. Sr, Ba , Rb) compared with high-field strength elements (HFSE; e.g. Zr, Y, Ti)



.Figure 5c: MORB-normalized spider diagrams for basaltic rocks from Nayband and Tabas area (west margin of Lut Block). Data from Walker *et al.*, 2009 and Jung *et al.*, 1983.

Granitoid rocks

The SiO_2 content of granitoid rocks vary from 57.89 wt% to 73.2wt% (average SiO_2 of 65.37 wt %) (Table 2). A plot of (K_2O + Na_2O) vs. SiO_2 (Cox *et al.* 1979) shows that granitoid rocks plot in the field of granite, granodiorite, syenite and diorite. They are mainly sub- alkaline type (Fig. 6).

A plot of (K_2O + Na_2O-CaO) vs. SiO_2 shows that Granitoid rocks mainly plot in the field of calc-alkalic. Granodiorite of Surkh-Kuh and syenite of Kuh-e-Robat-e-Shur are alkali-calcic and alkalic respectively (Fig. 7). The K_2O contents of rocks are between 2.03 wt% to 6.51 wt% (Table 2). Most of rocks plot in the high-K calc-alkaline field on the K_2O versus SiO_2 diagram. Kuh-e-Robat-e-Shur and Aghol-Kuh are shoshonitic and calc-alkaline respectively (Fig. 8) of (Peccerillo & Taylor, 1976).

Plot of Al-(K+Na+2Ca) versus Fe+Mg+Ti indicate that Maherabad, Khopik, Aghol-Kuh and Kuh-e-Robat-e-Shur rocks are metaluminous with Al-(K+Na+2Ca)<0 whereas Surkh-Kuh, Shah-Kuh and Bajestan granitoid rocks plot in the field of peraluminous (Fig. 9).

Table 2: Major, some trace and REE elements analysis of granitoid rocks of Lut block (1= Jung *et al.*, 1983); 2= Esmaeily, 2001; 3 = Tarkian *at al.*, 1982).

Location	Bajestan[1]		Shah-Kuh[2]		Sorkh-Kuh[3]		Kuh-e-Robat-e-Shur[1]	Aghol-Kuh[1]
Sample No	Lu 1080	1079	S-1	M-1	208D	R20	Lu 32	Lu 262
Rock type	Granite-porphyry	Granite	Synogranite	Monzogranite	Granodiorite		Syenite-porphyry	Monzonite porphyry
Age (Ma)	76.6	N.A	161.6	162.9	170.0	162.8	42	N.A
SiO_2	72.18	68.85	73.20	66.82	60.11	62.98	65.34	58.57
TiO_2	0.28	0.40	0.23	0.23	0.74	0.59	0.46	0.61
Al_2O_3	12.89	14.96	14.04	15.33	16.21	15.81	15.81	17.52
Fe_2O_3	0.50	0.35	2.19	3.46	0.95	3.54	2.42	4.02
FeO	1.46	2.08	0.60	1.91	5.52	0.22	1.39	2.20
MnO	0.03	0.03	0.04	0.10	0.13	0.03	0.09	0.16
MgO	0.65	1.03	0.45	1.79	2.79	0.42	0.52	2.73
CaO	1.29	2.23	1.86	3.95	4.80	3.50	1.77	5.84
Na_2O	2.73	2.62	2.81	2.61	2.32	0.69	4.44	3.92
K_2O	4.82	4.76	4.51	3.63	2.62	6.51	4.93	2.03
P_2O_5	0.07	0.15	0.08	0.16	0.13	0.10	0.13	0.31
Rb	262	294	182	143	100	246	181	45
Sr	189	247	186	320	210	39	147	606
Ba	320	426	306	535	382	556	719	514
Nb	16	21	14.0	11			67	
Zr	162	145	49	17	130	105	457	102
Rb/Sr	1.38	1.19	0.98	0.4	0.48	2.30	1.23	0.074
Rb/Ba			0.6	0.3				
La	58	13	38.60	41.35	39	52	58	
Ce	79	37	75.20	84.72	82	291	118	
Pr								
Nd	12	24	31.08	37.32	27		34	
Sm			5.46	6.76				
Eu			0.79	1.34				
Gd			4.51	6.05				
Dy			3.26	5.35				
Er			1.65	2.82				
Y	29	25			-	-	52	
Yb			1.43	2.82				

Table 2 continues. Major, some trace and REE elements analysis of granitoid rocks of Lut block (4-5= Malekzadeh, 2009, Malekzadeh *et al.*, 2010a & b; 6-Karimpour & Moradi, 2010; 7- Moradi *et al.*, 2011; and 8- Arjmandzadeh *et al.*, 2010a-b).

Location	**Maherabad[4]**	**Khopik[4]**	**Najmabad[5]**		**Klateh Ahani[7]**		**Chah Shaljami[8]**	
Sample No	MA-126	KH-88	KP-2	KP-3	KC-118	KC-114	CH-18	AC-2
Rock type	Hornblende monzonite	Diorite-monzonite	Hornblende Monzonite	Hornblende Monzonite	Biotite granodiorite	Biotite granodiorite	Hlb Bt granodiorite	monzodiorite
Age (Ma)	39	38.2	33.9		163.5		33.6	
SiO_2	57.89	64.76	65.1	65.37	62.25	65.68	62.96	55.05
TiO_2	0.58	0.39	0.42	0.32	0.61	0.32	0.53	0.67
Al_2O_3	15.11	14.65	15.38	14.24	13.35	13.29	14.27	14.09
Fe_2O_3	2.08	1.89	1.92	1.82	2.11	1.82	3.11	4.9
FeO	5.03	3.95	3.23	2.89	6.3	4.7	2.1	2.5
MnO	0.18	0.08	0.02	0.02	0.11	0.03	0.1	0.1
MgO	1.93	1.54	1.5	2.59	3.25	2.38	2.95	3.83
CaO	7.32	4.30	3.84	3.93	3.36	2.1	4.51	8.3
Na_2O	3.30	3.20	5.69	5.29	2.92	3.44	3.36	1.96
K_2O	2.59	3.03	1.37	2.07	3.65	3.51	3.4	4.57
P_2O_5	0.38	0.18	0.18	0.13	0.16	0.1	0.33	0.32
Rb	57	84	27	19	176	121	101.8	117.8
Sr	905	541	504	400	201	351	717.6	767.5
Ba	1109	1153	198	151	256	953	867	714
Nb	4	4	5.2	3.4	12	4.5	13	10.9
Zr	98	84	167	147	124	89	156.7	159.9
Rb/Sr	0.062	0.144	0.053	0.047	0.87	0.34	0.140	0.15
Rb/Ba	0.05	0.07	0.139	0.125	0.687	0.12	0.11	0.16
La	20.2	13.6	16.5	13.6	29	7.4	38.8	37.8
Ce	42.7	26	37.8	28.7	62.4	14.3	69.7	73.2
Pr	5.26	3.02	4.57	3.61	7.07	1.52	7.44	8.63
Nd	22.6	12.2	18.1	13.9	26.6	6.4	26.2	33.8
Sm	4.52	2.54	2.98	2.63	5.13	1.33	4.31	6.28
Eu	1.28	0.69	0.85	0.86	0.98	0.27	1.11	1.7
Gd	3.88	2.11	2.2	2.1	4.65	1.17	3.09	5.19
Dy	0.60	1.89	1.33	1.34	4.56	0.94	2.68	3.9
Er	1.96	1.14	0.56	0.6	2.66	0.49	1.35	1.94
Y	16	10	6.2	6.9	27	4.6	14	20.9
Yb	1.91	1.18	0.5	0.55	2.61	0.42	1.24	1.76
(La/Yb)N	7.13	7.77	22.25	16.67	7.49	11.87		
Eu/Eu*	0.93	0.91	1.01	1.12	0.614	0.66		

Table 3: Major, some trace and REE elements analysis of acid-intermediate volcanic rocks of Lut block (1= Lotfi, 1982; 2= Jung *et al.*, 1983); 3= Walker *et al.*, 2009))

Location	**Shurab- Galehchah[1]**		**Vaghi[2]**	**Nakhob[2]**	**Doshak[2]**	**Kuh-e-Birg[2]**	**Junchi[2]**	**Qol-e-Gondad-Jang[2]**	**Nehbandan Fault[3]**
Sample No	449	170R	Lu 335	Lu 248	Lu 114	Lu 118	K.II.16	338	4
Rock type	Dacite	Dacite	Ignimbrites	Ignimbrites	Ignimbrites	Dacite	Ignimbrites	Andesite	Andesite
Age (Ma)	N.A	42.2	61.6	41.1	4.1	43.6	56.7	39	27.5
SiO_2	62.61	63.27	69.13	57.38	69.52	62.40	73.3	52.16	60.99
TiO_2	0.48	0.57	0.35	0.73	0.34	0.55	0.21	0.90	1.30
Al_2O_3	14.51	15.70	13.76	17.18	13.88	16.30	13.05	15.41	17.21
Fe_2O_3	1.73	2.17	1.43	3.96	2.33	2.41	0.88	6.54	2.8
FeO	1.41	1.46	0.54	1.41	0.23	1.35	0.45	0.78	2.86
MnO	0.06	0.08	0.07	0.11	0.06	0.08	0.07	0.11	0.089
MgO	1.87	2.15	0.73	2.30	0.66	1.60	0.33	5.87	1.71
CaO	3.38	3.31	1.58	5.27	2.29	3.50	1.38	8.73	4.93
Na_2O	4.31	4.39	4.63	4.64	3.66	5.54	3.89	3.18	4.54
K_2O	3.03	2.63	3.00	1.92	4.18	2.40	3.28	2.87	2.55
P_2O_5	0.18	0.14	0.07	0.23	0.10	0.16	0.05	0.46	0.43
$H_2O^{(+)}$	1.30	2.23				0.90	3.25		
Total	98.83	99.69							100.81
Rb	89	80	261	81	150		133		95.6
Sr	660	590	143	559	183		163		759.6
Ba	1179	842	197	742	530		814		514.5
Nb									18.7
Zr	160	150	194	202	164		111		232.5
Ga									18.7
Rb/Sr			1.82	0.14	0.82		0.816		0.12
La	18	32							29.08
Ce	52	29							55.61
Pr									14.09
Nd	5	10							23.66
Sm									5.54
Eu									1.39
Gd									4.36
Dy									3.96
Er									2.31
Y	5	4							26.1
Yb									2.2

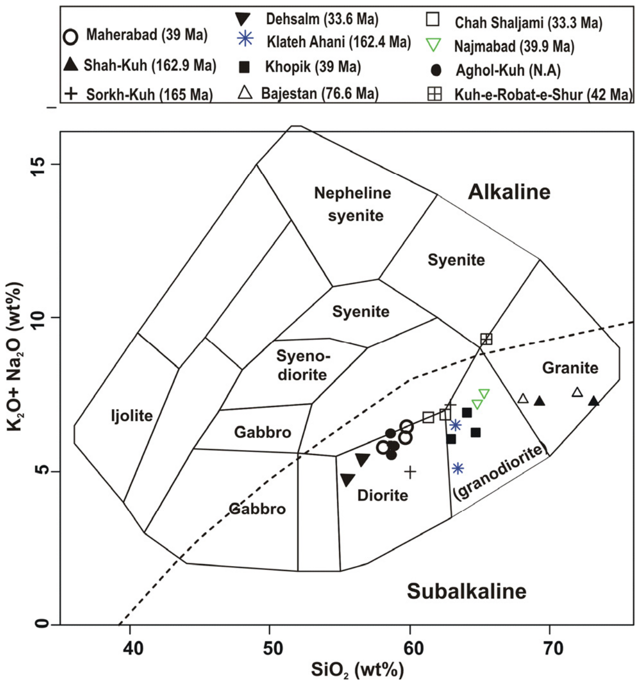


Figure 6: Classification of granitoid rocks by %Na_2O + %K_2O versus %SiO_2 (Cox *et al.*, 1979).

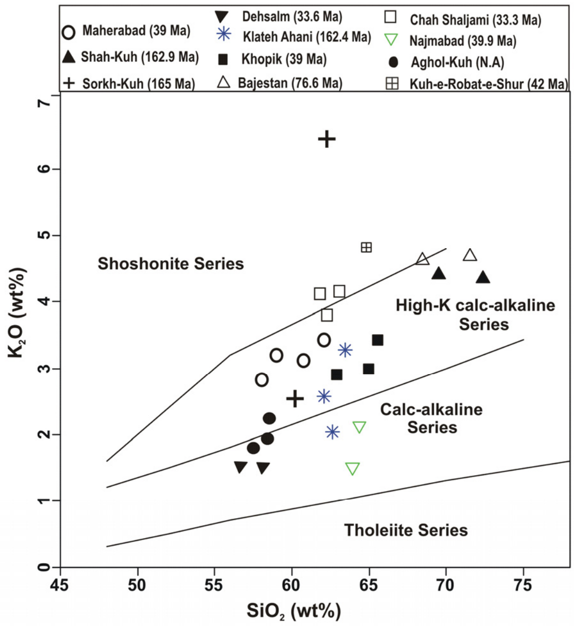


Figure 8: Granitoid rocks are mainly high-K calc-alkaline based on %K_2O versus %SiO_2 diagram (Peccerillo and Taylor, 1976).

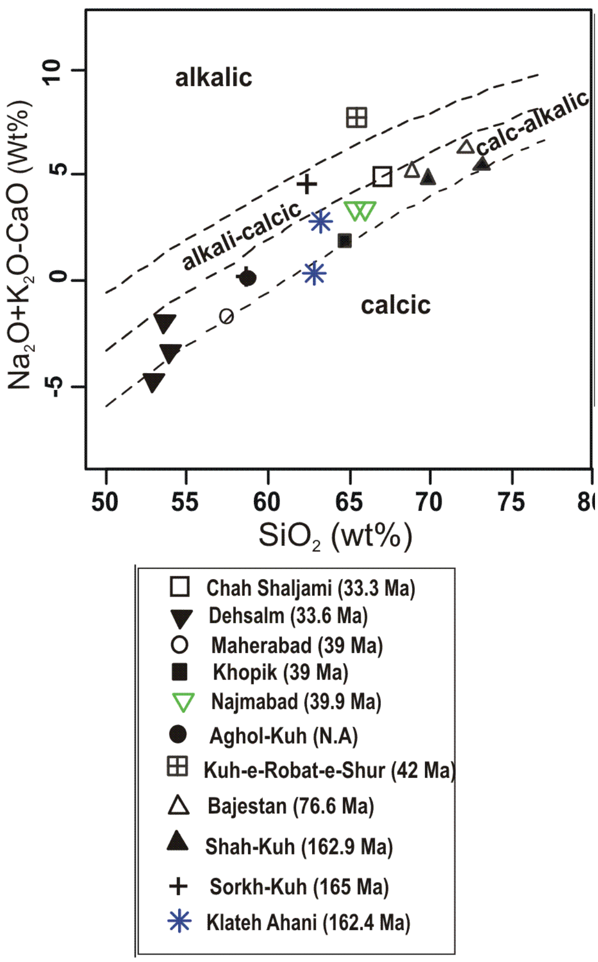


Figure 7: The rocks mainly plot in the field of calc-alkalic based on Na_2O+K_2O-CaO versus SiO_2 diagram.

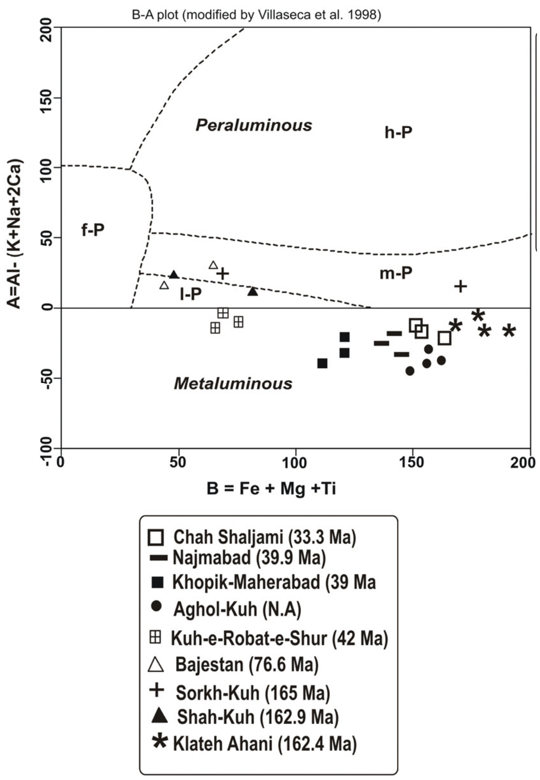


Figure 9: Maherabad, Khopik, Aghol-Kuh and Kuh-e-Robat-e-Shur rocks are metaluminous and other granitoid rocks plot in the field of peraluminous based on Al-(K+Na+2Ca) versus Fe+Mg+Ti diagram (Villaseca *et al.*, 1998).

Based on Rb, Yb, Nb and Ta concentrations, Maherabad, Khopik, Najmabad, Dehsalm and Chah

Shaljami intrusive rocks plot in volcanic arc granite (VAG) field whereas Shah-Kuh and Bajestan granitic rocks are affinity to syn-collision granite (syn-CLOG). Kuh-e-Robat-e-Shur syenite plot in within plate granite (WPG) (Fig. 10).

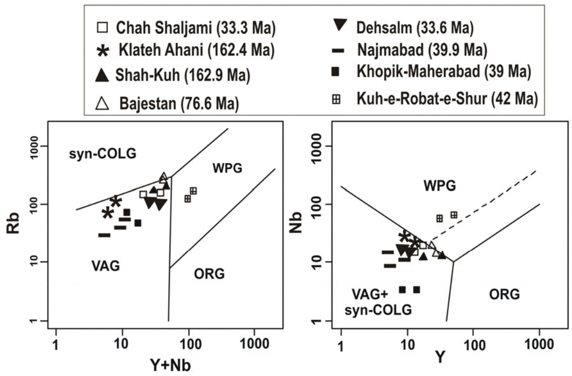


Figure 10: Plot of granitoid rocks in Pearce *et al.*, (1984) diagram. VAG = volcanic arc granite, syn-COLG = syn-collision granite, WPG = within plate granite, ORG = orogenic granite.

Rock/bulk continental crust normalized spider diagram of Jurassic and Bajestan granitoid rocks are plotted in Fig. (11) and for Tertiary granitoids plotted in Fig. (12.). The The spider pattern of Tertiary granitoids rocks are similar to the signatures seen in island arc intrusive rocks, with negative Nb, with elevated abundances of the large ion lithophile elements (LILE; e.g. Sr, Ba and Rb) (Fig. 12). Negative Nb is an important signature of island arc magma. This mainly related to type and composition of garnet which goes under partial melting. The spider patterns of Jurassic and Bajestan granitoids rocks are do not show any negative Nb and them quite different from Tertiary granitoids (Fig. 11). This indicate that the Jurassic and Bajestan granitoids originated from the continental ctust.

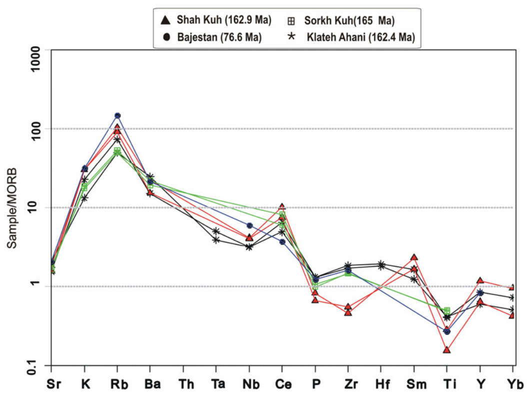


Figure 11: MORB normalized some REE and trace elements diagram for Jurassic and Bajestan granitoid samples (Pearce, 1983).

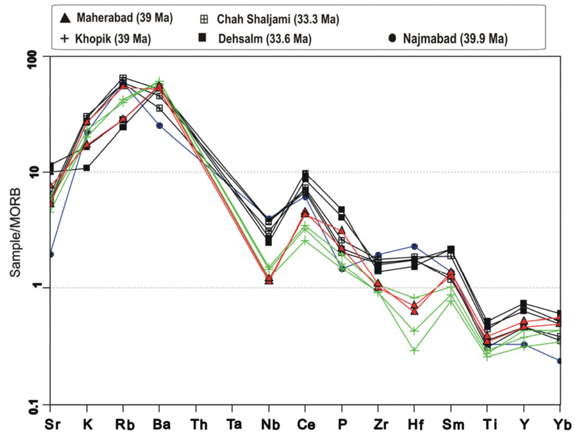


Figure 12: MORB normalized some REE and trace elements diagram for Tertiary granitoid samples (Pearce, 1983).

MAGNETIC SUSCEPTIBILITY

Granitic rocks were classified into the magnetite series and the ilmenite series by Ishihara (1977). Ishihara recognized that in Japan there is a distinct spatial distribution of granitic rocks that contain magnetite coexisting with ilmenite and those that contain ilmenite as the only Fe-Ti oxide. He recognized that the magnetite-series granitoids are relatively oxidized, whereas the ilmenite-series granitoids are relatively reduced. Granites showing a magnetic susceptibility value of >3.0 × 10^{-3} (SI units) are classified as belonging to the magnetite series (Ishihara, 1981).

Shah Kuh (161 Ma), Klateh Ahani (162.4Ma), Surkh Kuh (162 Ma), and Bajestan (76.6 Ma) plot in the field of ilmenite-series on the Rb/Sr versus Magnetic susceptibility diagram (Fig. 13). Their magnetic susceptibility is mostly less than 100 × 10^{-5} SI. However, magnetic susceptibility of Maherabad (39 Ma), Khopik (39 Ma), Chah Shaljami (33.3 Ma), Najmabad (39.9 Ma), Aghol Kuh and Dehsalm (33.6 Ma) granitoids rocks is between 140 × 10^{-5} to 5000 × 10^{-5} SI. These rocks plot in the magnetic-series filed (Fig. 13).

Sr ISOTOPES

Basalts

Basalts are found along the Nayband and Nehbandan faults on eastern and western margin of the Lut Block, central part of the Lut and also to the south north of Makran (Fig. 2). The $^{87}Sr/^{86}Sr$ of published basalts is as follow: Tabas (15.5 Ma) = 0.7047-0.7055; Ferdows (42 Ma) = 0.7045; and Mud (31.4 Ma) = 0.7042-0.7044 (Jung et al, 1983).

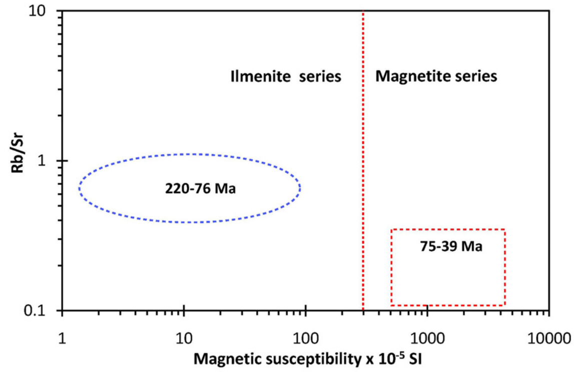


Figure 13: A plot of Rb/Sr vs. magnetic susceptibility shows that the older and younger igneous rocks belong to the ilmenite and magnetic series respectively.

Granitoids

Sr isotope and age (based on Rb-Sr, K-Ar and U-Pb) data for representative samples of Lut block felsic rocks are given in Table 4. All of the granitoid rock formed during Tertiary time have $(^{87}Sr/^{86}Sr)i$ <0.706, therefore the magma did not originated from the continental crust (Fig. 14, Table 4). Shah Kuh, Klateh Ahani and Surkh Kuh (Mid Jurassic) have $(^{87}Sr/^{86}Sr)i$ = 0.7081-0.7068. This means that the magma originated from continental crust.

Table 4: Rb-Sr isotopic and age data of igneous rocks of Lut block (1= Jung *et al.*, (1983); 2= Esmaeily, 2001; 3 = Berberian *et al.*, (1984); 4= Tarkian *et al*., (1983); 5= Lotfi, 1982; 6= Biabangard & Moradian, 2008 and 7= Malekzadeh, 2009, Malekzadeh *et al*., 2010a & b; 8-Karimpour & Moradi 2010; 9- Moradi *et al.*, 2011; 10- Arjmandzadeh *et al*., 2010a-b).

	Sample	K-Ar (Ma)	Zircon U-Pb	Rb-Sr (Ma)	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$(^{87}Sr/^{86}Sr)m$	$(^{87}Sr/^{86}Sr)i$
Sorkh Kuh[1]	Granodiorite208D	-	-	170.0	103	220	1.3549	0.71025 ±0.00008	0.7070
	Granodiorite 208A	-	-	164.8	104.3	213	1.417	0.71059	0.7073
	GranodioriteR 20	-	-	162.8	253	104	7.0622	0.72276 ±0.00008	0.7065
Shah Kuh[2]	Monzogranite (M-1)	162.9	-		129	310	1.20407	0.709597	0.7068
	Monzogranite (M-2)	162.9	-		142	317	1.21755	0.708965	0.7062
	Syenogranite (S-1)	161.6	-		226	175	3.7386	0.714688	0.7060
	Syenogranite (S-2)	161.6	-		199	165	3.49134	0.714250	0.7063
Bajestan[1]	Hornblende granite (LU-152)	77.0	-		223.6	274.4	2.3609	0.71280 ±0.00007	0.7120
	Granite (Ta 561)	76.6	-		232	233.4	2.8811	0.71570 ± 0.00008	0.7126
	Granite porphyry (LU 1080)	76.6	-		250.3	135.5	5.3521	0.71435 ±0.00008	0.7101
Bazman[3]	Granodiorite			74.2	91	514	0.516	0.70619	0.70565
Gazu[4]	Granodiorite	75.2	-	-	48	634	0.2256	0.7047±0.00010	0.7045
Vaghi[1]	Ignimbrite Lu 114	61.6	-		143.8	238	1.8271	0.70882 ±0.00008	0.7073
Junchi[1]	Ignimbrite Lu 118	56.7	-		147.7	178.3	2.3978	0.70859 ± 0.00001	0.7068
Kuh-e-Birg[1]	Dacite	43.6			126	274	1.3226	0.7078 ±0.00010	0.7063
Kuh Robat Shur[1]	Syenite porphyry Lu 32	42	-		170.7	159.4	3.1027	0.70690 ±0.00007	0.7051
Shurab Ghalehchah[5]	Dacite 170R	-	-	42.2	81	602	0.3928	0.70583±0.00008	0.7056
Shurab Ghalehchah[5]	Dacite 166	-	-	41.3	40	597	0.1951	0.70491 ±0.00007	0.7048
Nakhob[1]	Ignimbrite Lu 335	41.1	-		238.8	284.8	2.0487	0.70653±0.00001	0.7053
Doshak South[1]	Ignimbrite Lu 248	41.1	-		91.8	628.7	0.42307	0.70556 ±0.00001	0.7053
Qol-e-Gondad-Jang[1]	Andesite	39			80	2725	0.0855	0.70553 ±0.00006	0.7055
Aghol Kuh[1]	Monzonite porphyry Lu 262				52	657.7	0.097	0.70494 ±0.00016	0.7048
Taftan[6]	Andesite	6.95 to 0.71							0.70532 0.70592
Maherabad[7]	Hornblende monzonite MA-126		39.0		49.1	906	0.1565	0.704950±0.000009	0.7048
Khopik[7]	Hornblende monzonite KH-88		38.2		66.1	493	0.3873	0.704970±0.00001	0.7047
Najmabad[8]	Quartz monzonite KC-3	-	39.9	-	17.5	365	0.1385	0.705200±0.00006	0.705122
Klateh[9] Ahani	Granodiorite (KI-7)	-	162.4	-	117	154	2.195	0.714200±0.00007	0.709131
Chah[10] Shaljami	Quartz monzonite CH-33, 39	-	-	33.3	49-118	360-1210	0.117-0.489	0.7049-0.705251	0.704700
Dehsalm	Px Hlb diorite Qtz monzonite D6-227, D12-250	-	-	33.6	49-85	1210	0.117	0.704752-0.705179	0.704752

Table 5. Rb-Sr isotopic and age data of igneous rocks of Mashhad Paleo-Tethys (Karimpour 2010a , b)

	Sample	Zircon U-Pb	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr	(^{87}Sr/^{86}Sr)m (2σ)	(^{87}Sr/^{86}Sr)i
Dehnow Mashhad	Biotite granodiorite	215	100.1	438	0.6609	0.70997 (1)	0.70794
Kuhsangi Mashhad	Biotite granodiorite	217	95.2	382	0.7198	0.71081 (1)	0.70859
Khajeh Mourad	Aplite granite	205	210.5	108	5.6155	0.72622 (0)	0.709853
Mashhad	Biotite muscovite granite	205	235.4	149	4.5695	0.72148 (1)	0.708161

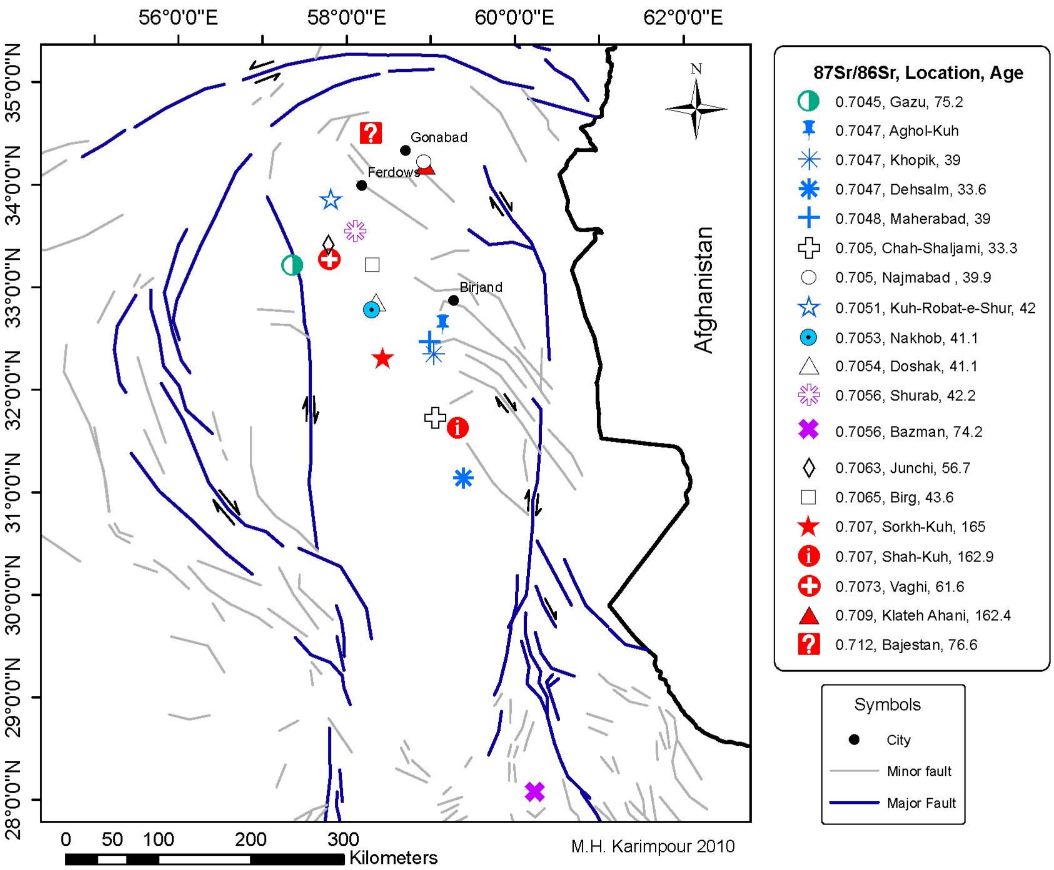


Figure 14: Map showing Location, Isotopes and age of granitoid and volcanic rocks within Lut Block (References Table 4).

To have an idea about the type of continental crust, the (^{87}Sr/^{86}Sr)i of granitoid rocks formed during collision of Iranian plate with Turan plate (continental collision during Pale-Tethys) are reported in Table 5. The initial (^{87}Sr/^{86}Sr) of Paleo-Tethys granitoids are between 0.7078-0.7089 (Karimpour *et al.,* 2010 a, b). This means that Shah Kuh, Klateh Ahani, Surkh Kuh granitoids, and Paleo-Tethys granitoid are have similar (^{87}Sr/^{86}Sr)i, therefore they originated from continental crust with similar chemical composition.

Bajestan granitoids have (^{87}Sr/^{86}Sr)i = 0.710-0.720 (Fig. 14, Table 4). This means that the magma originated from continental crust. The continental crust that Bajestan granitoid magma was originated was different from other part of the Lut Block (very high (^{87}Sr/^{86}Sr)i). This indicates that Bajestan joined the Lut Block after the collision (Upper Cretaceous time).

During Upper Cretaceous in short time interval between 74 to 76.6 Ma at three localities granitoids are reported. Bajestan (76.6 Ma), Bazman (74.2 Ma) and Gazu (75.2 Ma) (Fig. 14, Table 4). Gazu granodiorite is calc-alkaline with initial ^{87}Sr/^{86}Sr =0.7045 was formed due to subduction. Gazu is located near the Nayband fault and within Tabas Block (Fig. 14). Bajestan granitoid ((^{87}Sr/^{86}Sr)i > 0.710) formed during the continental collision and the magma originated in the continental crust. To the southern part of the Lut Block, Bazman and Taftan strato volcano are located. Tectonic setting which these volcanoes were formed was a subduction zone.

Conclusions

Regional metamorphism (Mid Jurassic orogeny) has turned shale and sandstone of Shemshak Fm. into slate and quartzite. Shah Kuh, Klateh Ahani and Surkh Kuh granitoid rocks were intruded slate and quartzite in Middle Jurassic (162-165 Ma) due to continental collision (Fig. 15). Based on mineralogy, low values of magnetic susceptibility [(5 to 11) × 10^{-5} SI], therefore it is classified as belonging to the ilmenite-series of reduced type granitoids (S-type granitoid). Chemically, they show enrichment in LILE = Rb, Ba, Zr, Th, Hf, K and REE = Ce, Sm and depletion in Sr, P and Ti. Based low $(La/Yb)_N$ = 7-11.5 and $(^{87}Sr/^{86}Sr)_i$ = 0.7081-0.7068 magma originated from continental crust during continental collision (Fig. 15). These intrusive have potential for Sn mineralization.

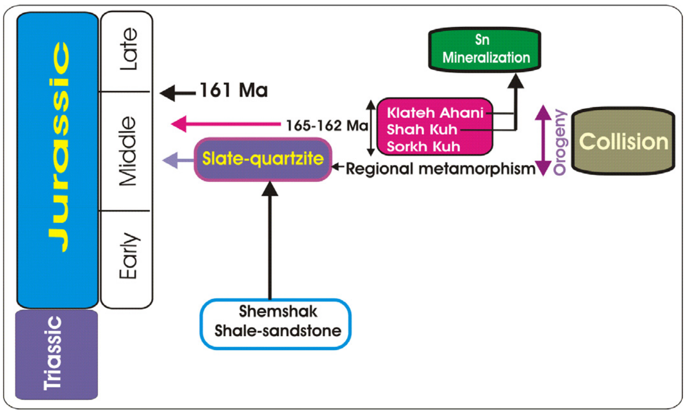


Figure 15: Diagram illustrates the timing and tectonic setting of Mid Jurassic magmatism in Lut Block.

In Late Cretaceous in short time interval between 74 to 76.6 Ma at three localities granitoids are reported (Fig. 16). Gazu is located near the Nayband fault and within Tabas Block. Gazu granodiorite (75.2 Ma) is calc-alkaline with Initial $^{87}Sr/^{86}Sr$ = 0.7045 was formed in subduction zone. Bajestan granitoid with $(^{87}Sr/^{86}Sr)_i$ = 0.710-0.720 formed during the continental collision (76.6 Ma) and magma originated from the continental crust. To the southern part of the Lut Block, Bazman (74.2 Ma) and Taftan volcanic plutonic belt are located. They were formed in subduction zone associated with the northward subduction of the Indian oceanic crust under the Makran plate.

Beginning in the Tertiary, in Late Paleocene (61-56 Ma), ignimbrite are erupted in Vaghi and Junchi. Based on the $(^{87}Sr/^{86}Sr)_i$ = 0.7073-0.7068 the magma originated within the continental crust.

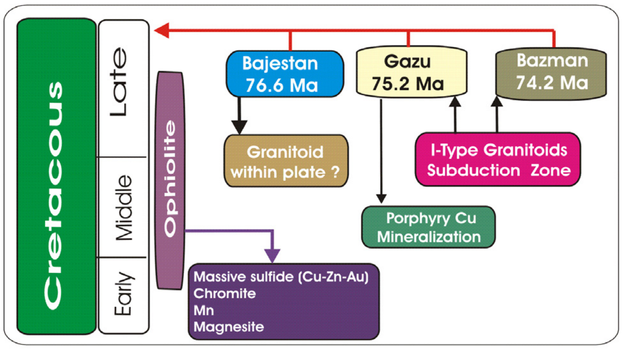


Figure 16: Diagram illustrates the timing and tectonic setting of Late Cretaceous magmatism in Lut Block.

The episode of Middle Eocene to Early Oligocene (39-30 Ma.) was very important in term of magmatism and mineralization (Fig. 16). Diorite, monzonite, quartz monzonite, and granodiorite are reported in different part of the Lut Block (Maherabad, Khopik, Hired, Aghol Kuh, Kajeh, Najmabad, Ferdows, Dehsalm, Chah Shaljami, and Qaleh Zari (Karimpour *et al*., 2009; Karimpour & Stern, 2009; Karimpour & Moradi, 2010; Malekzadeh *et al.,* 2010). Based on mineralogy, high values of magnetic susceptibility [(400 to 1600) × 10^{-5} SI], low initial $^{87}Sr/^{86}Sr$ < 0.7057 they are classified as belonging to the magnetite-series of oxidant I-type granitoids. Based on Rock/MORB normalized spider diagram, basaltic rocks formed during Late Eocene to Mid Oligocene within Lut Block from Ferdows (42 Ma) and Mud (31.4 Ma) have signatures of island arc basalts. Both granitoid rocks and basalts which formed between 30 to 43 Ma within the Lut Block magma originated in subduction zone (Fig. 17). Based on the present location of basalt, granitoids rocks and exposure of remnant of Neo-Tethys oceanic crust along the eastern margin of Lut Block, the oceanic crust was subducting south westward under the Lut Block (during 43-30 Ma.) (Fig. 18). Based on Maherabad, Khopik, Dehsalm and Chah Shaljami, the episodes of 40-38 Ma and 34-33 Ma. are very important with regard to porphyry Cu-Au mineralization (Fig. 17).

Rock/MORB normalized spider diagram of Neogene basaltic rocks from East Neh (east margin of Lut Block) and Nayband area (west margin of Lut Block) have the characteristic of ocean island basalts (OIB).

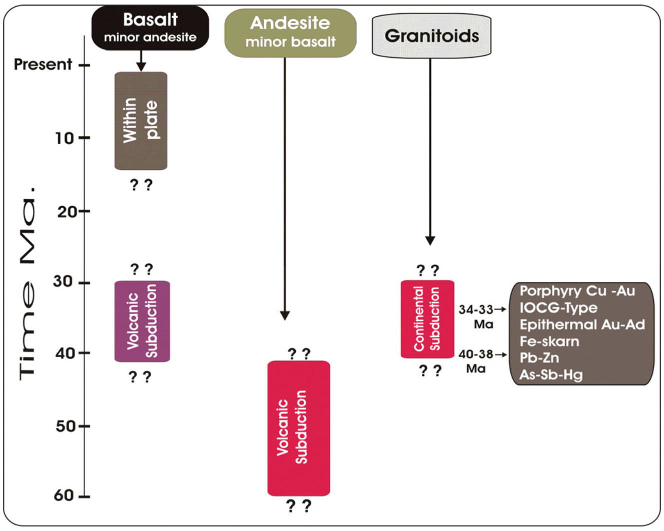


Figure 17: Diagram illustrates the timing and tectonic setting of Tertiary magmatism in Lut Block.

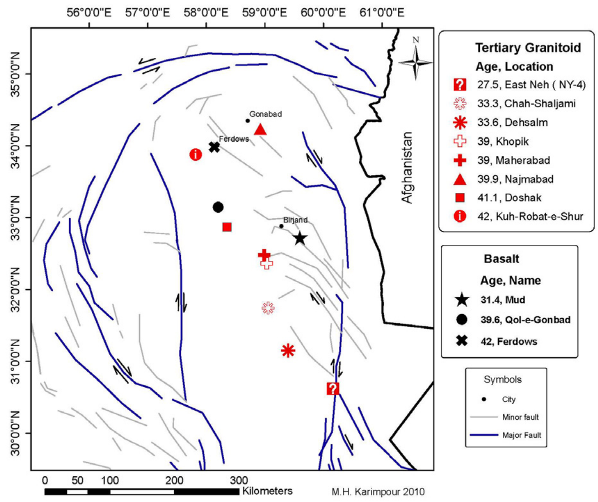


Figure 18: Map showing Location, Isotopes and age of Tertiary granitoid and basalts within Lut Block (References Table 1 and 4).

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