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MAGMATIC EVALUATION OF THE KOH E SULTAN VOLCANO CHAGAI DISTRIC, BALOCHISTAN, PAKISTAN

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Abstract:
The Koh-e-Sultan volcano occurs in the western part of Chagai magmatic arc, situated in north-western part of Balochistan, Pakistan. The Koh-e-Sultan volcano stretches in a 770 km^2 area and is mainly represented by andesitic to dacitic lava flows and volcanoclastic sediments including agglomerate, tuffs, pumice, volcanic conglomerate, breccia and pyroclastic flows. The last explosive activity of this volcano is represented by pumice deposits of 0.09 million years old, mostly found towards west and southwest of Koh-e-Sultan volcano. The petrological study of various samples collected reveals that the lava flows are mainly represented by three main types of porphyritic andesites including; (a) hypersthene-andesite, (b) hypersthene-hornblende-andesite and (c) hornblende-andesite. The dacitic lava flows are also porphyritic and represented by only one variety of hornblende dacite. The pumice has rhyolitic composition and contains fragments of plagioclase, quartz, volcanic glass and minor biotite. The petrographic studies show a systematic decrease of anorthite contents as being younger, in hypersthene andesite range decreasing from An_{28-50} to An_{27-49}, in hornblende-hypersthene andesite from An_{26-47} to An_{21-40} in hornblende andesite from An_{20-38} to An_{17-35} and in dacite the range is An_{12-30}. The mafic mineral exhibits change from hypersthene through hornblende to biotite in rhyolitic pumice. The composition and proportion of mafic minerals in younger lava flows also changes. The concentration of opaque minerals generally decreases towards younger lava flows. The phenocryst and groundmass ratios increase towards younger volcanics from 30:70 to 60:40. These studies clearly indicate the progressive magmatic evolution of Koh-e-Sultan volcano from older to younger volcanics during Pliocene to Late Pleistocene.

Keywords: *Magmatic evolution; Koh-e-Sultan Volcano; Chagai magmatic arc.*

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INTRODUCTION:

The Koh-e-Sultan volcano is situated in the Chagai District of western Balochistan, Pakistan. The volcano occurs in an EW trending subduction related magmatic belt, known as Chagai Magmatic arc. The exposure of Koh-e-Sultan volcano stretches over an area of 770 km^2. There are three distinct series of volcanos in Koh-e-Sultan volcanic group having separate calderas known as, Kansuri, Abu and Miri [1]. Koh-e-Sultan volcano is multifaceted and characterized by several episodes of volcanic eruptions along a major NW-SE structure. Regionally Koh-e-Sultan is situated in the Tethyan belt which extends from Turkey through Iran into Pakistan. The Tethyan belt having important mineral deposits in the Chagai magmatic Arc includes the Saindak, Reko-Diq, Dasht-e-kain and Koh e Sultan etc, which have Iron, Sulphur, copper, gold and minor barite deposits.

In this paper detailed and systematic field and laboratory studies are presented and magmatic evolution of Koh-e-Sultan volcano arc described by separating volcanic episodes for the first time.

Previous Work

[1] Carried out pioneer geological studies in the Chagai Arc. Many foreigner geologists, [2-6] conducted research on Chagai Arc, they considered that the Chagai Arc is a continental margin type calc-alkaline magmatic arc, developed on the southern margin of the Afghan Block, and [7-10] conducted petrological studies and documented tholeiitic affinities and oceanic island arc character for the Late Cretaceous to Paleocene volcanic, calc-alkaline and transitional behavior of the Eocene lava flows and continental margin or Andean type calc-alkaline parentage of the Oligocene to Pleistocene volcanic rocks of the Chagai Arc. [11] carried out detailed and comprehensive field and laboratory studies on Chagai-Raskoh Magmatic arc and described crustal evolution of this arc.

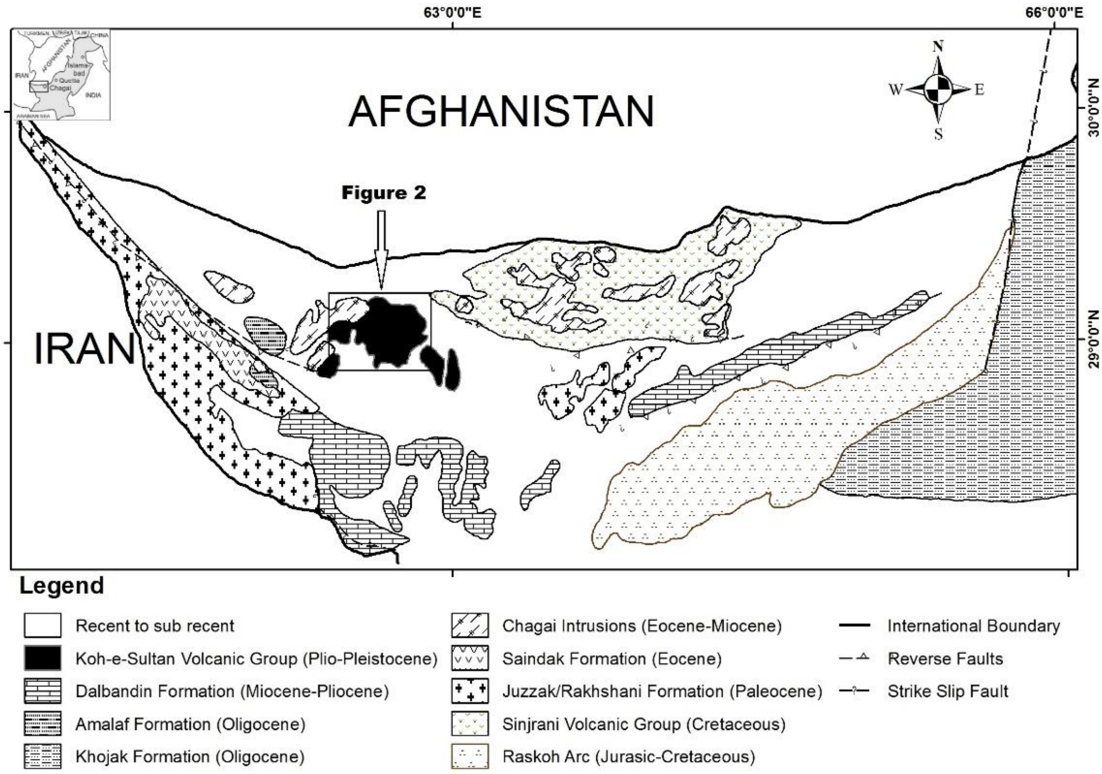


Figure 1

Fig 1: Regional Tectonic and geological map of Chagai Raskoh arc, Balochistan, Western Pakistan, showing Koh-e-Sultan volcano with black color (slightly modified after Siddiqui et al. 2015).

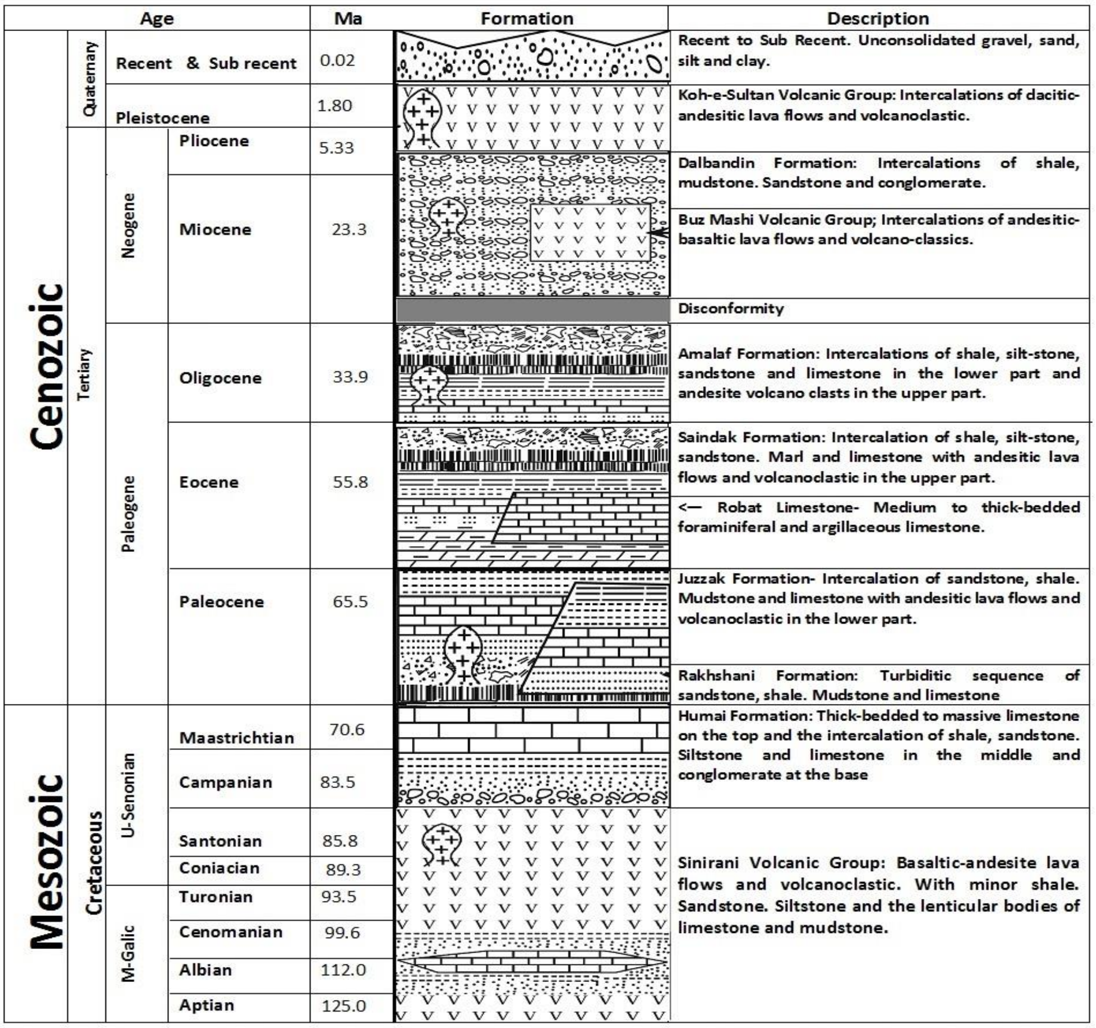


Fig 2: Generalized Stratigraphic Sequence in Chagai Magmatic Arc, Slightly Modified After Siddiqui 2015

Geological Setting

The Chagai arc is an EW trending subduction related magmatic arc it is 500 km long 150 km wide. The major part of the Chagai arc occurs in Pakistan but it also extends westward in Iran and towards north in Afghanistan [10-13].The Plio-Pleistocene volcanic rocks occur about 30 km N and NE of Nokkundi (Fig. 1). This arc belongs to an ancient Tethyan convergence zone [14], which was initiated during Early Cretaceous, due to an intra-oceanic convergence in Ceno Tethys [11 & 15],

The oldest rock sequence in the Chagai arc is Late Cretaceous Sinjrani Volcanic Group followed by Late Cretaceous (Maestritchian) Humai formation, Paleocene Juzzak Formation, Eocene Saindak Formation, Oligocene Amalaf Formation/Robat Limestone, Miocene to Pliocene Dalbandine Formation, Middle to late Miocene Buze Mashi Koh Volcanics, Plio-Pliestocene Koh-e-Sultan Volcanic Group and Quaternary gravel alluvium and sand dunes [10]. The Late Cretaceous and Paleocene volcanism is dominated by basalts and andesite, whereas Eocene volcanism is generally dominated by andesite and minor dacites. (Figure. 2).

The Koh-e-Sultan Volcano

The Koh-e-Sultan Volcano comprise of stratified intercalations of volcanoclastic including pyroclastic flows, agglomerate, tuffs, pumice, volcanic conglomerate breccia and minor andesitic to dacitic lava flows. The last explosive activity of this volcano is represented by pumice deposits of 0.09 Ma, which is found towards west and southwest of Koh-e-Sultan.The volcano is considered Pliocene to Pleistocene in age [11]. The details of Koh-e-Sultan Volcano as follows.

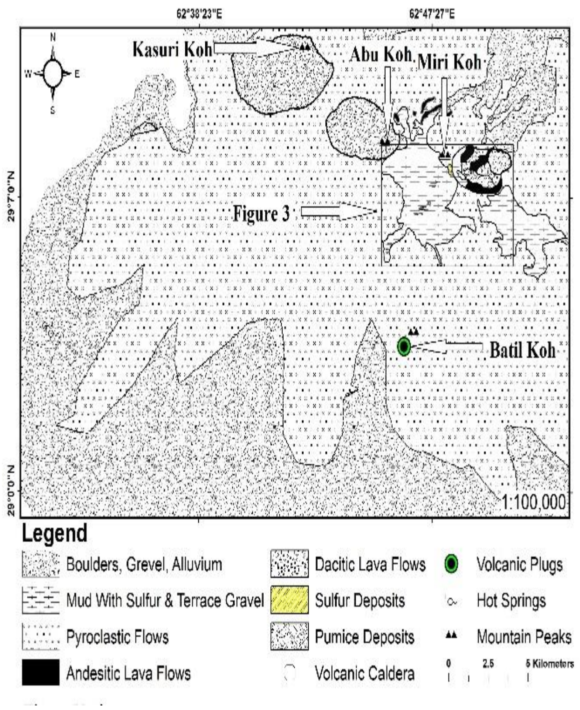


Fig 3: Complete Geological Map of Koh-e-Sultan

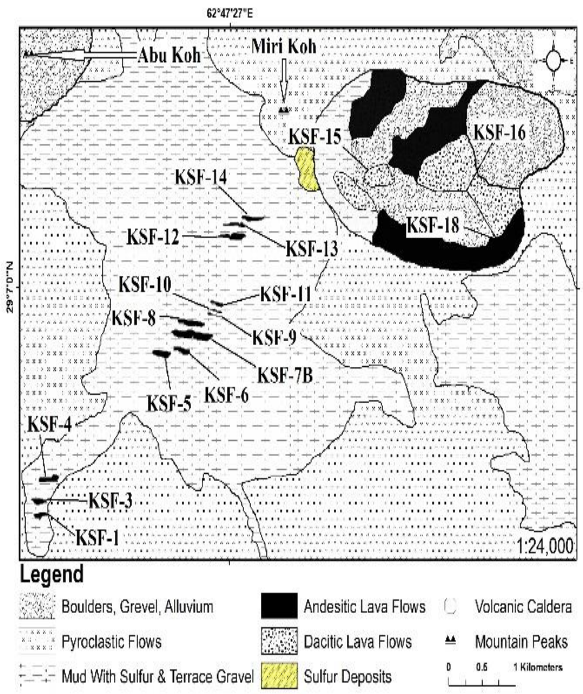


Fig 4: Focused part of Geological Map Showing Volcanic flows

Pyroclastic Flows

Pyroclastic flows cover the major part of Koh-e-Sultan volcano and are light grey to dark grey in color, weathers to light reddish grey. The thickness of pyroclastic flows ranges from 50m to 1000m. A total number of 14 of pyroclasts flows are encountered, which are intercalated with volcanic, conglomerate, agglomerate and lava flows (Fig-3).

Agglomerates

The agglomerates are light grey, maroon and black in color and forms 3 to 15 m thick strata. It is mainly comprised of sub-angular to sub rounded fragments of andesite and dacite, which are 15 to 60 cm in diameter. Occasionally small volcanic bombs and spindles are also observed which exhibit glassy vesiculated margins with extensional cracks on the outer surfaces. These fragments and volcanic bombs are embedded in a medium to fine-grained tuffaceous matrix. The tuff and lapilli tuff are grey, greenish grey, maroon, reddish brown and light brownish in color. They generally formed 3 to 5 m thick beds consisting of less than 1 mm to 3 mm size fragments of dacitic and andesitic lava flows and volcanoclastic entrenched by fine and well compact volcanic ash of the same material.

Volcanic Conglomerate and Breccia

These rocks are generally light grey and light brownish in color and mainly composed of angular to sub angular (breccia) or sub rounded to rounded conglomerate fragments of andesitic to dacitic volcanic rocks, tuffs, intrusive rocks and sandstone, entrenched by tuffaceous sandy matrix of the same color.

Andesitic Lava Flows

On the southern side of Mirri crater thirteen cycles of andesitic flows are found and one occurs inside the Mirri Crater. The thicknesses of flows vary from 1 to 2 m having color grey to greenish grey. Andesitic lavas are commonly intercalated with tuff and agglomerate. They are porphyritic and have phenocrysts of pyroxene, plagioclase and hornblende which found in the matrix of same minerals Fig-4).

Dacitic Lava Flows

Inside the Miri crater there are two cycles of dacitic eruptions having color grey to pinkish grey. The lava flow is 3 to 8 m thick. The dacitic lava flows generally occur as small volcano inside the crater of Koh-e-Sultan Volcano (Fig-5D). The Dacitic flows are porphyritic and have phenocrysts of hornblende, quartz, plagioclase and biotite in a fine-grained ground mass of same composition (Fig-5E).

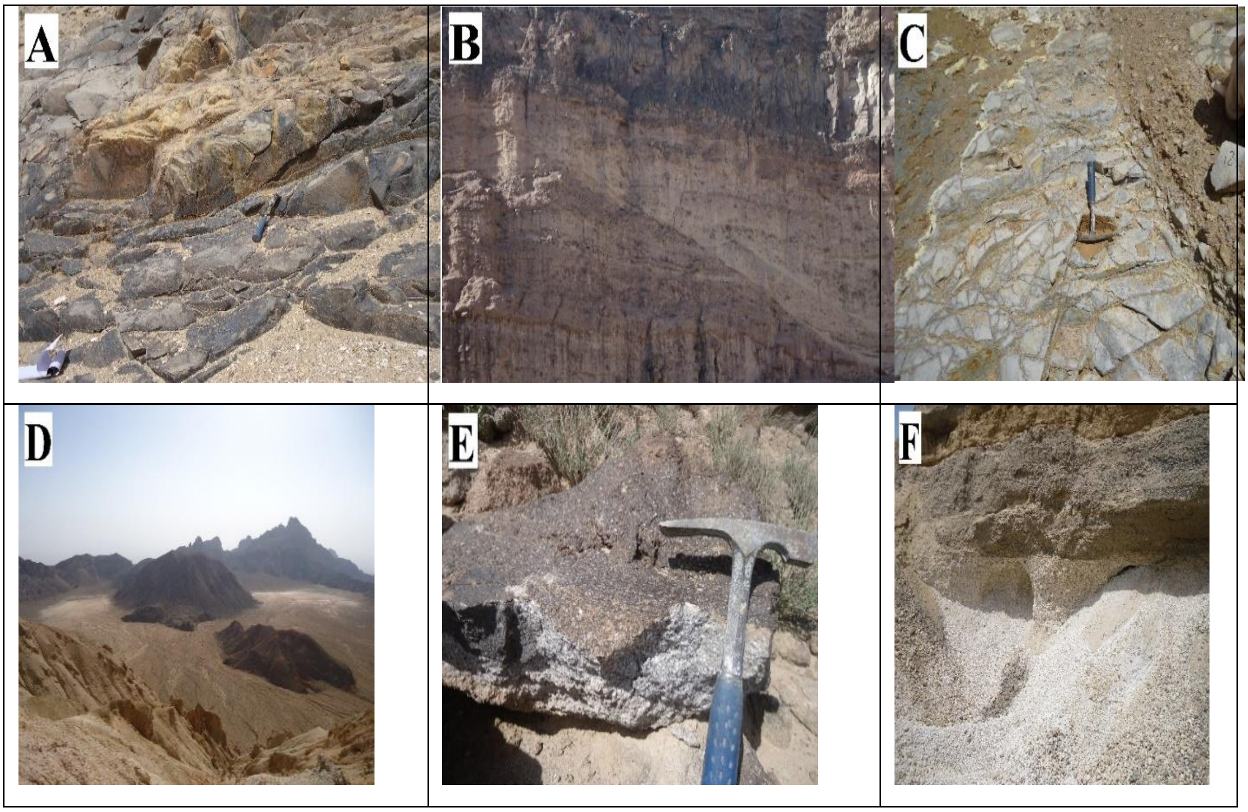


Fig-5: A view of Andesitic flows, Miri Crater, Dacitic flows, pyroclastic flows and Rhyolitic Pumice deposits.

Rhyolitic Pumice

Lenticular bodies of rhyolitic pumice and beds up to 3 m thick with small lateral extension, occur within the Quaternary alluvium towards the south and west of the Koh-e-Sultan volcano. These bodies are white when fresh, but weather yellowish brown. The pumice is mainly composed of loosely packed less than 1 mm size fragments of plagioclase, quartz, volcanic glass and minor biotite cemented by volcanic glass. To the south and southeast of Miri Peak the volcanic rocks are partially to completely argillic due to hydrothermal activity. (Fig-5F).

Petrography

Petrographic studies of 16 different samples carried out, each selected sample represent the separate lava flow 14 flows are Andesitic and all are hypo crystalline porphyritic and sub-intersertal in texture. Phenocrysts of plagioclase, Amphibole and pyroxene are entrenched in a micro-crystalline to glassy matrix of same minerals. (Fig-3)

Up to 1mm large Plagioclase crystals are columnar, lathlike, euhedral to sub-hedral which display oscillatory zoning and poly synthetic twining fluid inclusions are found on outer zones of some plagioclase crystals. In Andesitic flows Amphibole typically characterized by hornblende, this is found in Considerable quantity, grains are small, euhedral, prismatic with multilateral basal sections and rarely exhibits poly-synthetic twinning and displays green to yellow green pleochroism. Both ortho-pyroxene and clino-pyroxene are found as small sub-hedral to euhedral prismatic crystals. Green to pale brown Pleochroism shows by ortho-pyroxene and twinning is polysynthetic.

Table-1 The Salient Petrographic Features of Various Lava Flows from the Koh-e-Sultan Volcano.

Lava Flows	Rock Suites	Field Occurrences	Common Textures	(Anorthite Content)	Phenocrysts Groundmass Ratios	Accessory Minerals	Secondary Minerals
KSF-16	Dacite	thin massive lava flows & volcanic clasts	holo-crystalline porphyritic and cumulophyric	(An_{12-30})	60:40 to 55:45	Ap, Py, Mag, and Ccp	Chl, Bt, Ser, Cal, Hem, Lm.
KSF-15	Dacite	thin massive lava flows & volcanic clasts	holo-crystalline porphyritic and cumulophyric	(An_{12-30})	60:40 to 55:45	Ap, Py, Mag, and Ccp	Chl, Bt, Ser, Cal, Hem, Lm.
KSF-18	Hornblende -andesite	massive lava flows & volcanic clasts	Euhedral and hypo crystalline in texture	(An_{17-35}),	55 : 45 to 50 : 50	Ap, Py, Hbl Mag and Ccp.	Chl, Ser, Cal, Hem.
KSF-14	Hornblende -andesite	massive lava flows & volcanic clasts	Euhedral and hypo crystalline in texture	(An_{18-36}),	55 : 45 to 50 : 50	Ap, Py, Hbl Mag and Ccp.	Chl, Ser, Cal, Hem.
KSF-13	Hornblende -andesite	massive lava flows & volcanic clasts	Euhedral and hypo crystalline in texture	(An_{19-37}),	55 : 45 to 50 : 50	Ap, Py, Hbl Mag and Ccp.	Chl, Ser, Cal, Hem.
KSF-12	Hornblende -andesite	massive lava flows & volcanic clasts	Euhedral and hypo crystalline in texture	(An_{20-38}),	55 : 45 to 50 : 50	Ap, Py, Hbl Mag and Ccp.	Chl, Ser, Cal, Hem.
KSF-11	Hypersthen e-hornblende -andesite	massive lava flows & volcanic clasts	hypo-crystalline, porphyritic, sub-intersertal and cumulophyric	(An_{21-40}),	40 : 60 to 35: 65	Ap, Hbl,Mag, Mg, Py and Ccp,.	Chl, Ser, Cal, Hem.
KSF-10	Hypersthen e-hornblende -andesite	massive lava flows & volcanic clasts	hypo-crystalline, porphyritic, sub-intersertal and cumulophyric	(An_{22-42}),	40 : 60 to 35: 65	Ap, Hbl,Mag, Mg, Py and Ccp,.	Chl, Ser, Cal, Hem.
KSF-9	Hypersthen e-hornblende -andesite	massive lava flows & volcanic clasts	hypo-crystalline, porphyritic, sub-intersertal and cumulophyric	(An_{22-42}),	40 : 60 to 35: 65	Ap, Hbl,Mag, Mg, Py and Ccp,.	Chl, Ser, Cal, Hem.
KSF-8	Hypersthen e-hornblende -andesite	massive lava flows & volcanic clasts	hypo-crystalline, porphyritic, sub-intersertal and cumulophyric	(An_{23-43})	40 : 60 35: 65	Ap, Hbl,Mag, Mg, Py and Ccp,.	Chl, Ser, Cal, Hem.

KSF-7	**Hypersthene-hornblende-andesite**	**massive lava flows & volcanic clasts**	**hypo-crystalline, porphyritic, sub-intersertal and cumulophyric**	**(An_{24-44})**	**40 : 60 35: 65**	**Ap, Hbl,Mag, Mg, Py and Ccp,.**	**Chl, Ser, Cal, Hem.**
KSF-6	**Hypersthene-hornblende-andesite**	**massive lava flows & volcanic clasts**	**hypo-crystalline, porphyritic, sub-intersertal and cumulophyric**	**(An_{26-47})**	**40 : 60 to 35: 65**	**Ap, Hbl,Mag, Mg, Py and Ccp,.**	**Chl, Ser, Cal, Hem.**
KSF-5	**Hypersthene-hornblende-andesite**	**massive lava flows & volcanic clasts**	**hypo-crystalline, porphyritic, sub-intersertal and cumulophyric**	**(An_{26-47})**	**40 : 60 to 35: 65**	**Ap, Hbl,Mag, Mg, Py and Ccp,.**	**Chl, Ser, Cal, Hem.**
KSF-4	**Hypersthene-andesite**	**massive lava flows & volcanic clasts**	**hypo crystalline porphyritic and sub-intersertal in texture**	**(An_{27-49})**	**35 : 65 to 30: 70**	**Ap, Mag, Mg, Py and Ccp,.**	**Chl, Ser, Cal, Hem.**
KSF-3	**Hypersthene-andesite**	**massive lava flows & volcanic clasts**	**hypo crystalline porphyritic and sub-intersertal in texture**	**(An_{28-50})**	**35 : 65 to 30: 70**	**Ap, Mag, Mg, Py and Ccp,.**	**Chl, Ser, Cal, Hem.**
KSF-1	**Hypersthene-andesite**	**massive lava flows & volcanic clasts**	**hypo crystalline porphyritic and sub-intersertal in texture**	**(An_{28-50})**	**35 : 65 to 30: 70**	**Ap, Mag, Mg, Py and Ccp,.**	**Chl, Ser, Cal, Hem.**

Abbreviations for rock-forming minerals are after Kretz (1983).

The sample No KSF-1 to KSF-4 contain Small prismatic and polygonal inclusions of hypersthene on larger phenocrysts of plagioclase and flows fall in hypersthene andesite and from KSF-5 to KSF-11 the Large phenocrysts of hornblende contain inclusions of plagioclase and hypersthene. Which fall in hornblende hypersthene andesite and KSF-12 to KSF 14 and KSF-18 have small polygonal and prismatic inclusion of hornblende also found on some big sized phenocrysts of plagioclase are fall in Hornbland Andesite.

KSF15 and KSF-16 are dacitic in composition both are Hornblende Dacite, found inside the Mirri Crater, the texture is holo-crystalline and porphyritic. The Plagioclase and Amphibole having size 0.1 to 7.0 mm are entrenched by microcrystalline matrix of same minerals. Euhedral to sub-hedral, equant, lathlike and columnar shape. Crystals of Plagioclase are found in dacitic flow which displays polysynthetic twinning. The anorthite content of this flow is An_{12-30}. And zoned plagioclase crystals at places parallel to zoning planes have rich fluid inclusions towards their margins. Earlier generated small tabular and lathlike plagioclase inclusions are found on large plagioclase phenocrysts. Tiny, columnar, small an-hedral and equant crystals of plagioclase occur as groundmass. The sub-hedral to an-hedral, microcrystalline and equant shaped Quartz found in Matrix. Brownish green hornblende represents the amphibole. Large hornblende crystal usually found as a prismatic and euhedral in shape on polygonal basal section and rarely display polysynthetic twinning. Few crystals of hornblende display an edge of rich inclusions of fluids towards the margin. Throughout the ground mass aggregates of small prismatic lamellae the dacitic lava flows are also porphyritic and represented by only one variety of hornblende dacite. (Table-1)

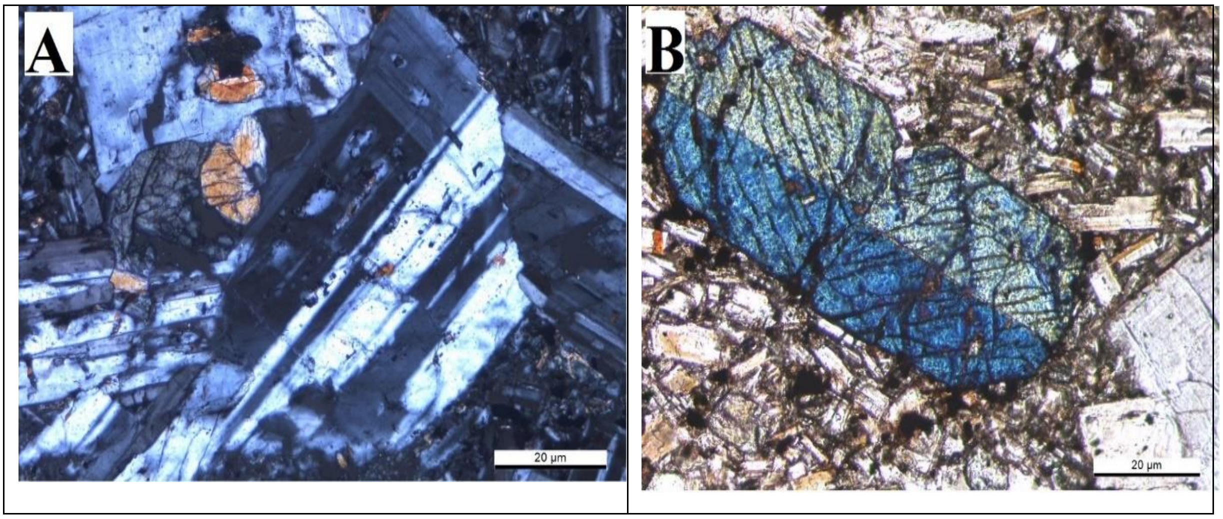
KSF-15 & 16
Both are thin massive dacitic lava flow which contain volcanic clasts, The texture of this flow is holo-crystalline, porphyritic and cumulophyric, Apatite, Magnetite, Pyrite and Chalcopyrite occurs as an accessory minerals and Chlorite, Biotite, Calcite, Sericite, Hematite and Limonite occurs as a secondary minerals, The Anorthite content range is An_{12-30} and Phenocrysts groundmass ratio is from 60:40 to 55:45. (Fig-6D)

KSF-18, 14, 13 & 12
These all flows are massive with volcanic clasts, euhedral and hypo crystalline in texture, In this flows Apatite, Magnetite, Pyrite, Chalcopyrite and Hornblende found as an accessory minerals and Chlorite, Calcite, Sericite and Hematite are found as a secondary minerals. The phenocrysts groundmass ratio is 55:45 to 50:50, but the range of Anorthite content is increasing from KSF-18 toward KSF-12 as being older in KSF-18 $An_{17-35,}$ KSF-14 $An_{18-36,}$ KSF-13 An_{19-37} and in KSF-12 is $An_{20-38,}$. The flows are fall in hornblende Andesite. (Fig-6C)

KSF-11, 10, 09, 08, 07B, 06, 05
These all seven flows are massive flows which having volcanic clasts, hypo crystalline, porphyritic, sub-intersertal and cumulophyric in texture, In this flows Apatite, Magnetite, Pyrite, Chalcopyrite and Hornblende found as an accessory minerals and Hypersthene, Chlorite, Calcite, Sericite and Hematite are found as a secondary minerals. The phenocrysts groundmass ratio is 40:60 to 35:65, but the range of Anorthite content is increasing from KSF-11 toward KSF-05 as being older in KSF-11 $An_{21-40,}$ KSF-10 $An_{22-42,}$ KSF-09 $An_{22-42,}$ KSF-08 $An_{23-43,}$ KSF-07B $An_{24-44,}$ KSF-06 An_{26-47} and in KSF-05 is $An_{26-47,}$. The flows are fall in hornblende hypersthene Andesite. (Fig-6B)

KSF-04, 03, 01
All three flows are massive having volcanic clasts, hypo crystalline, porphyritic and sub-intersertal in texture, In this flows Apatite, Magnetite, Pyrite and Chalcopyrite found as an accessory minerals and Hypersthene, Chlorite, Calcite, Sericite and Hematite are found as a secondary minerals. The phenocrysts groundmass ratio is 35:65 to 30:70, but the range of Anorthite content is increasing from KSF-04 toward KSF-01 as being older in KSF-04 $An_{27-49,}$ KSF-03 $An_{28-50,}$ KSF-01 An_{28-50}. The flows are fall in hypersthene Andesite. (Fig-6A)

Magmatic Evaluation
The petrological studies of various lava flow shows three types of porphyritic andesite including; hypersthene-andesite, hypersthene-hornblende-andesite and hornblende-andesite, The dacitic lava flows which are also porphyritic and represented by only one variety of hornblende dacite. The mafic mineral exhibits change from hypersthene through hornblende to biotite in rhyolitic pumice. The composition and proportion of mafic minerals in younger lava flows also changes. The concentration of opaque minerals generally decreases towards younger lava flows. The studies show a systematic decrease of anorthite contents in each rock type as being younger (Table-1).



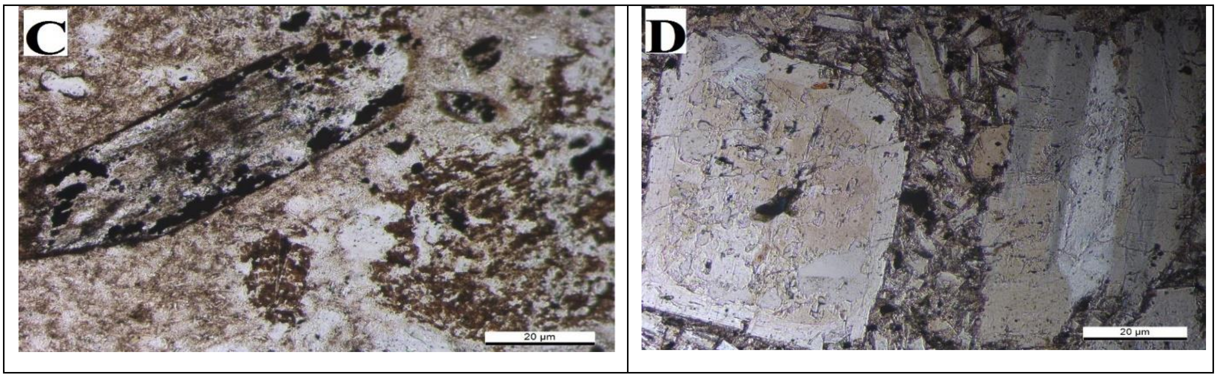


Fig-6: Microscopic view of Plagioclase, Hornblende, Apatite and hypersthene in thin section studies of volcanic episodes

CONCLUSION:

The field and laboratory studies revealed three varieties of andesite including, hypersthene-andesite, hypersthene-hornblende-andesite and hornblende-andesite and one variety of each; hornblende dacite and rhyolitic pumice in the Koh-e-Sultan volcano. The petrographic studies show a systematic decrease of anorthite contents in plagioclase from hypersthene andesite to hornblende andesites. The mafic mineral exhibits change from hypersthene through hornblende to biotite. The composition and proportion of mafic minerals in younger lava flows also exhibit changes. The concentration of opaque minerals generally decreases towards younger lava flows. The phenocryst groundmass ratios generally increase towards younger volcanic. The studies show progressive magmatic evolution of Koh-e-Sultan volcano represented by hypersthene-andesiti, hypersthene-hornblende-andesite, hornblende-andesite through dacite to rhyolitic pumice during Pliocene to Late Pliestocene.

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