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CENOZOIC MAGMATISM OF THE SURK AREA (CENTRAL IRAN) STRATIGRAPHY, PETROGRAPHY, GEOCHEMISTRY AND THEIR GEODYNAMIC IMPLICATIONS

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ABSTRACT. - Rifting and the resulting separation of the middle part of the Central and East Iranian Zones from the other parts of these zones occurred in pre-Turonian time. This is recorded by the presence of Ophiolites. Accretion of Ophiolitic Melange, of Ophiolites and of Turonian-Maestrichtian sedimentary cover took place during post-Maestrichtian tectonic events. Accumulation of thick Lutetian-early Oligocene volcanics is represented by alternations of subaqueous and subaerian volcanic rocks. In time, there is an alternation of alkaline, calc-alkaline, and transitional rocks. Late Oligocene-early Miocene intrusives of dominantly granodiorite-syenite-granite types show the same chemical characters. The late Pliocene magmatic event lies between alkaline and calc-alkaline trends, and the youngest volcanics distinctly show alkaline affinities. The rocks, both alkaline and alkaline feldspathoid-bearing, appear throughout the Cenozoic magmatic sequences, regardless of time and space . Neither magmatic zonation nor K_2O enrichment have been recorded from various distances above an hypothetical underlying Zagros Benioff zone. Therefore many of the geochemical and geological features, in the Surk area (Central Iran), do not allow to ascribe the Cenozoic magmatism to a subduction zone model and island arc system. A rift model is conceived and applied to the interpretation of the origin of the Cenozoic magmatic rocks and their tectonic setting. The emissions of alkaline magma resulting from the partial melting of the upper mantle are linked with the rhythmic opening of rift zones during Cenozoic times. A mutual contamination phenomenom between a basaltic magma and a bulky palingenetic acidic magma is responsible for the calc-alkaline and transitional rocks.

RESUME. - On observe dans la région de Surk (zone de l'Iran Central), pendant le Lutétien et le début de l'Oligocène, de puissantes accumulations de volcanites où alternent les émissions subaquatiques et subaériennes. Il s'agit de trachyandésites, andésites, rhyodacites et de shoshonites, avec des alternances de produits alcalins, calco-alcalins et intermédiaires. Les plutonites intrusives de l'Oligocène supérieur et du Miocène inférieur, principalement granodioritiques, syénitiques et granitiques, révèlent les mêmes caractères géochimiques. Les manifestations volcaniques du Pliocène se situent entre les tendances alcaline et calco-alcaline, tandis que les volcanites plus récentes montrent une tendance alcaline nette. Ainsi, des roches alcalines, éventuellement à feldspathoïde, ont-elles été produites dans des secteurs variés et à des époques diverses du Tertiaire. En outre, comme dans de nombreuses autres régions de la zone de l'Iran Central, on n'observe ni zonation magmatique, ni enrichissement en K_2O à des distances variables au-dessus d'une hypothétique zone de Benioff sous le Zagros.

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L'ensemble des données géochimiques et géologiques ne permet donc pas d'expliquer ce magmatisme tertiaire par l'existence d'une zone de subduction. En revanche, un modèle de rift peut être appliqué pour l'interprétation de la genèse et du cadre structural de ces roches éruptives. Les émissions de magma alcalin résulteraient de la fusion partielle du manteau supérieur, en liaison avec l'ouverture périodique, pendant le Tertiaire, d'une zone de rift. Quant aux roches calco-alcalines et intermédiaires, elles s'expliquent par une contamination mutuelle entre un magma basaltique et un volumineux magma acide palingénétique.

I - INTRODUCTION

In spite of the detailed investigations which have been carried out on the Cenozoic magmatic rocks of Iran, many recent papers still consider these rocks as plain calc-alkaline suites. In this paper the authors once again endeavour to describe in detail the stratigraphic, petrographic, and geochemical characters of these Cenozoic igneous rocks and their tectonic setting (cf. also AMIDI et al., 1984) in the Surk area.

This region is named after a local village (fig. 1). It covers an area of 11,125 km^2 between : 53°05, 53°30 , and 32°00, 32°20. About half of it has a mountain-desert morphology, typical of arid areas within the large central Iranian endoreic system, and it is very thinly populated. Low topographic features are also present, in roughly equal proportion.

From a structural point of view, the area studied belongs to the Central Iran Zone (STOCKLIN, 1968) constituted by a patchwork of horsts and grabens. This block-faulting tectonics has been accompanied by numerous, bulky volcanic emissions particularly during the Paleocene time, but also during Neogene- and Quaternary time. The volcanic range thus formed, called the Urumieh-Dokhtar Zone (SCHROEDER, 1944) is oriented NW-SE and forms the southwestern fringe of the Central Iran Zone ; it spreads over nearly 2,000 km and continues to the NW by the Little Caucasus and the Anatolian mountain ranges.

This sector was mapped chiefly on the 1:250,000 scale as part of a systematic quadrangle mapping for the Geological Survey of Iran (NABAVI and AMIDI, 1978). Later, the area was again subjected to detailed investigations and mapping on the 1:100,000 scale (AMIDI, 1975, 1984). The present paper is based on data gathered during an extensive regional mapping which was accompanied by petrographic and geochemical studies ; it is an attempt at a synthesis of the geology, genesis, and tectonic setting of the Cenozoic igneous rocks in this part of the Central Iran Zone.

II - STRATIGRAPHY-PETROGRAPHY-GEOCHEMISTRY

The oldest suite of rocks of the area includes ophiolites which are bounded by faulted zone. These ophiolites, which are the continuation of the Esfandagheh ophiolites (SABZEHEI, 1974), outcrop as far as the Nain-Anarak area ; they may then continue underground along the Great Kavir-Fault, connecting with the ophiolitic melange of the Sabzevar area. This ophiolitic belt probably originated during the pre-Turonian rifting and was overlain by Turonian-Maestrichtian deepwater sediments. The post-Maestrichtian or younger tectonic activities resulted in the accretion of ophiolitic melange with relatively undisturbed slabs of ophiolites. This belt can be divided into two parts :

a) The western, least tectonized zone or intact part, shows a nearly normal stratigraphical order. Strongly serpentinized harzburgite is by far the most common ultrabasic rock ; dunites or lherzolites are rarely found. The ultrabasic rocks are overlain in turn by plagioclase-bearing pyroxenite, followed by gabbro and diabase. Hornblende is widespread as a result of the alteration of primary clinopyroxene : in parts, those rocks can be defined as amphibolites . The above-mentioned basic rocks are overlain by radiolarian cherts and pelagic limestones which have yielded a microfauna spanning the age range from Turonian to Maestrichtian (AMIDI, 1975).

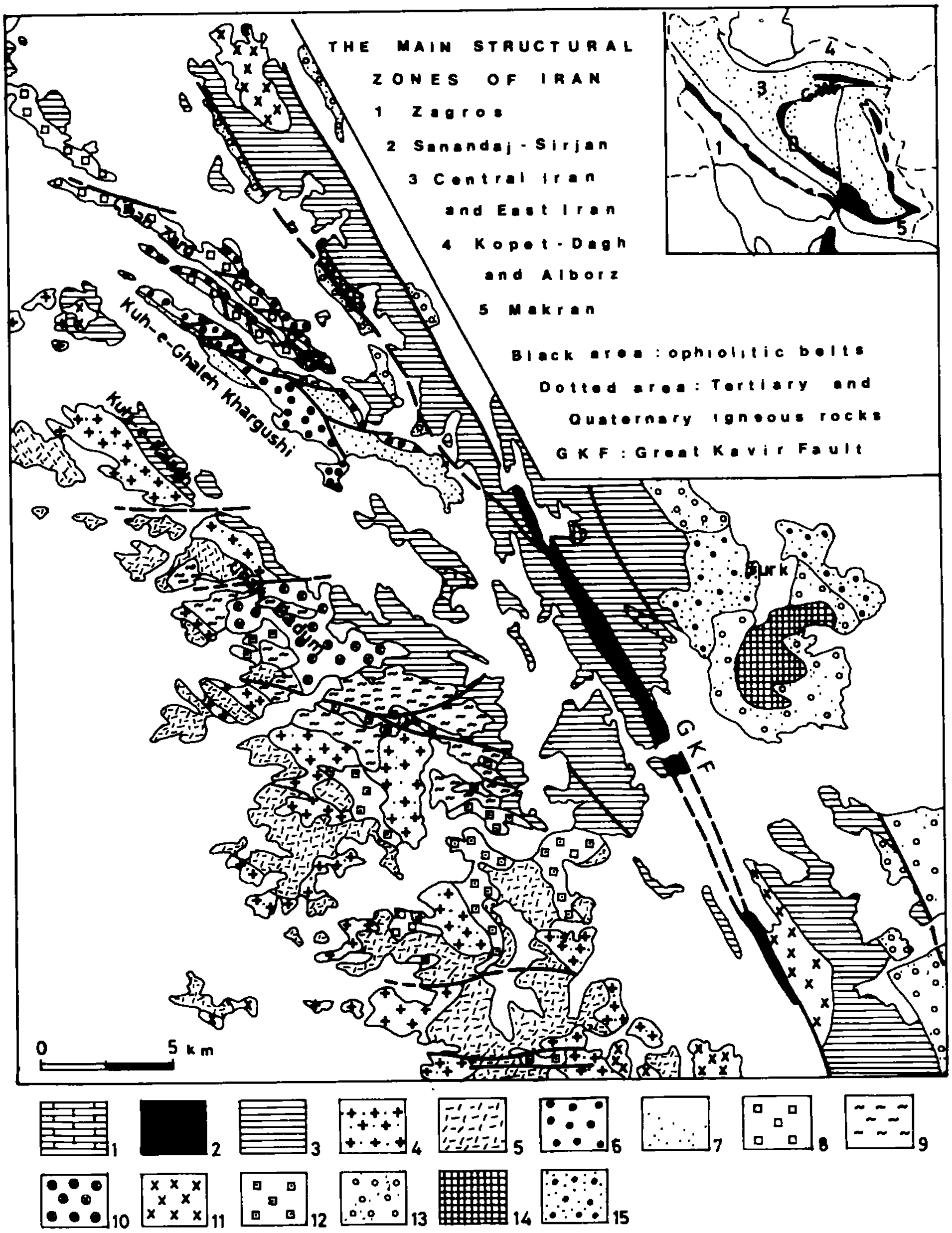

Fig. 1 - Geological sketch-map of the Surk area
1 : pre-Eocene rocks - 2 : ophiolitic belt - 3 : trachyandesites and andesites (E_1) - 4 : rhyodacites (E_2) - 5 : andesites (E_3)- 6 : shoshonites, absarokites (E_4) - 7 : banakites (E_4) - 8 : high-K dacites (E_4) - 9 : Oligocene rhyolites - 10 : monzonites and syenites - 11 : diorites and granodiorites - 12 : granites and aplites - 13 : Middle-Upper Miocene sediments - 14 : Late Miocene- Pliocene domes - 15 : Mio-Pliocene sediments.

b) Owing to the post-Maestrichtian movements, the primary contacts of the ophiolitic rock types in the eastern zone are not preserved and they form chaotic mixtures of various kinds of rocks. This zone is a "Coloured Melange" in the sense of GANSSER (1955). The ophiolites in this zone have the same petrographic characters, but they are intensely tectonized and altered. Alteration of pyroxene to serpentine and to amphibole (hornblende, actinolite), together with presence of albite, pumpellyite, and prehnite, all indicate a low grade static metamorphism (AMIDI, 1975).

During the Late Maestrichtian (in the ophiolitic belt) and after the Lower Cretaceous (in other parts of the area), the Surk region underwent a period of uplift and erosion. During the Late Lutetian, a shallow sea transgressed over the area ; at the same time, volcanic activity started. The Late Lutetian deposits unconformably overlie the deformed Cretaceous rocks.

During the Lutetian-early Oligocene, surimposition of several subaquatic and subaerian volcanic sequences indicates an active tectonic environment. Accumulation of about 2,200 meters of volcano-sedimentary rocks, pyroclastics, and lava flows over a period of about 20 M.y. is evidence of a rapidly-subsiding basin. The Paleogene volcanics in this area are composed of rocks of alternately acidic and intermediate, to basic composition. They are intruded by various phases of plutonic activity, or cut by younger extrusive rocks. They are further differentiated on the basis of their tectonic setting, and of their petrography and chemistry. From oldest to youngest, they include Eocene volcanics (E_1 , E_2 , E_3 , E_4) , Oligocene volcanics, Oligo-Miocene plutonites, late Miocene-Pliocene volcanics, and late Cenozoic-to-recent volcanics.

III - EOCENE VOLCANICS

The lowermost part of the Eocene rocks (E_1 = Lutetian ; based on paleontologic data ; 60 + 6 M.y. by radiometric dating), with a basal conglomerate, unconformably overlies the folded Rheto-Liassic shales and sandstones, and the Lower Cretaceous Orbitolina limestones. Trachyandesitic to rhyolitic, fine- to medium-grained ejecta are the products of bulky explosive eruptions. They are accumulated as several hundred meters of sediments in a shallow depositional environment. These volcanics are interbedded both with Nummulitic limestones and with immature volcanoclastics. The pyroclastics are lithic and crystal tuffs (containing variable amount of quartz, biotite, plagioclase, and K-feldspar), tuff-breccias, and breccias ; the grain size is quite heterogeneous.

Outpourings of magma as thin, thick, or massive andesitic and trachyandesitic lava flows, are recorded at different levels of the sequence, but generally in the uppermost part. The trachyandesitic and andesitic lavas are generally finely porphyritic and, on the basis of phenocrysts assemblages, they may be conveniently divided into the following three types :

a) Pyroxene andesites containing two generations of plagioclase phenocrysts: (1) unzoned crystals (An 67-70), and (2) zoned crystals (from An 45-55 to An 60-64), and augite. They are embedded in a groundmass with the same mineralogical composition, associated with abundant secondary minerals (uralite, chlorite, albite, quartz, prehnite, and pumpellyite).

b) Amphibole and pyroxene tranchyandesites with plagioclase (An 59-60), hornblende, and augite phenocrysts. The groundmass includes plagioclase, hornblende, augite, and alkali-feldspar.

c) Pyroxene and biotite trachandesites (Kuh-e-Kalagh area) containing phenocrysts of plagioclase (An 45-50), of biotite, and of augite (partly replaced by calcite), surrounded by a microlitic groundmass of plagioclase, K-feldspar, and secondary minerals.

As illustrated in figures 2,3, and 4, the trachyandesites are not strongly aklalic, although most lie in the alkali fields of MIYASHIRO (1978) and KUNO (1959), and in the shoshonitic domain of PECCERILLO and TAYLOR (1976) ; only two of them straddle the alkalic and calc-alkalic fields' boundary.

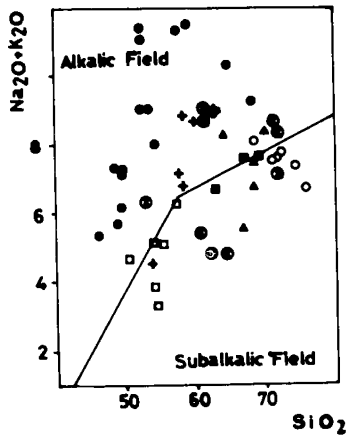

Fig. 2 - Diagram showing total alkalies vs. silica (Miyashiro, 1978)

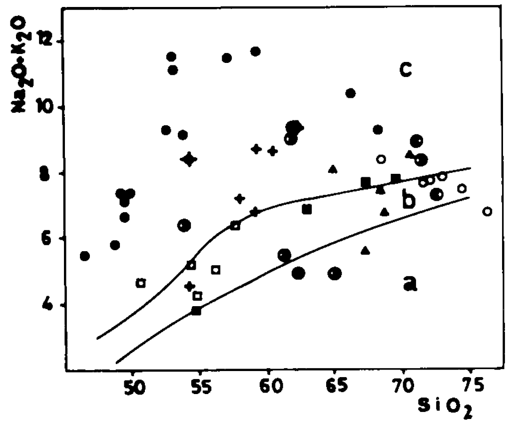

Fig. 3 - Diagram showing total alkalies vs. silica (Kuno, 1959)

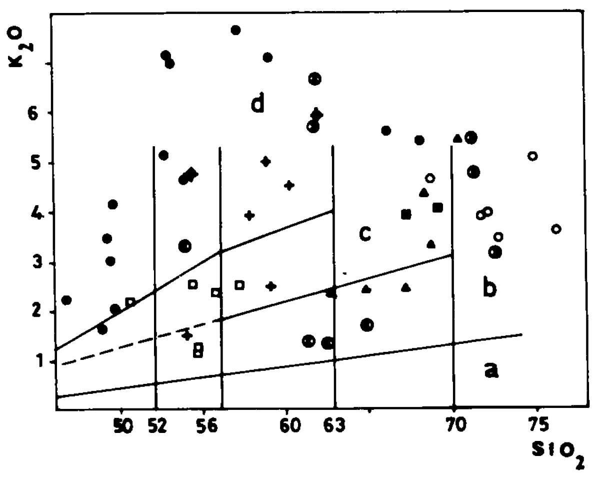

Fig. 4 - Diagram showing K_2O variation vs. silica (Peccerillo and Taylor, 1976)

Eocene volcanics

- \+ trachyandesites and andesites (E1)
- △ rhyodacites (E2)
- □ andesites (E3)
- ● shoshonitic rocks (E4)

- ○ Oligocene rhyolites
- ⊗ Oligo-Miocene intrusives
- ■ Pliocene volcanics
- ✦ Late Cenozoic-Recent volcanics

After the first volcanic episode, the emergence caused the area to become a center of subaerial volcanism (E_2). The lava flows generally range in compositon from dacitic to predominantly rhyodacitic ; they are partly autobrecciated, and have a hyalocrystalline texture. The glassy groundmass shows significant alignment ; it is sometimes devitrified into quartzo-feldspathic spherulites. Most phenocrysts are less than 3 mm long and consist of plagioclase (An 29-37), with quartz. The commoner mafic minerals are basaltic hornblende, and biotite (both extensively replaced by chlorite, calcite, and iron oxides) ; clinopyroxene is less common. Chemically the rhyodacites are transitionally situated either between the alkaline and subaklaline fields (fig. 2) or between the alkaline and calc-alkaline fields (fig. 3), or range between the calc-alkaline and high-K calc-alkaline domaines (fig. 4).

After the emplacement of the rhyodacites, the area was once again transgressed upon by a shallow sea (E_3). The explosive eruptions yielded the lower andesitic tuffs, lapilli tuffs, pumice tuffs, and breccias, which are interbedded with limestones and immature volcanoclastics. The pyroclastics are composed of various proportions of lithic and vitric fragments, crushed crystals of plagioclase, and rarely quartz, associated with epidote, chlorite, calcite, and iron oxides. Two rhyolitic spherulitic tuff horizons are present in this part of E_3. Andesitic or andesitic-basaltic lava flows form extensive, predominant layers at the top of the sequence. They are finally porphyritic and three distinct types with different composition are recognized :

a) Hypersthene-augite andesites consist essentially of zoned plagioclase (An 42-66), augite, and hypersthene phenocrysts, in a groundmass of augite and of laths or microliths of plagioclase.

b) Augite andesites, with plagioclase as the dominant phase (labradorite, sharply zoned to andesine at the rim), and augite. The groundmass has the same mineralogical composition, plus apatite, sphene, and secondary minerals.

c) Amphibole-augite andesites are rarely found. As phenocrysts, they contain plagioclase (An 60, replaced by albite and calcite), hornblende, and a minor amount of augite ; the hyalocrystalline groundmass is made up of plagioclase and amphibole.

These rocks generally show subalkaline or calc-alkaline affinities ; but few of them straddle the alkaline and subalkaline fields' boundary (MIYASHIRO, 1978 ; fig. 2) and are situated in the high-K calc-alkaline field of PECCERILLO and TAYLOR (1976 ; fig. 4).

The fourth Eocene volcanic episode (E_4 ; 48 + 11 M.y. by radiometric dating) shows an exceptionally wide range of compositions from silica undersaturated types such as tephrites, phonolitic tephrites, and tephritic phonolites, to less undersaturated and silica-saturated types such as trachytes, quartz-trachytes, and peralkaline rhyolites. The lavas usually contain nepheline, and sometimes normative quartz. They show marked enrichment in alkalies, particularly K_2O. Most analysed rocks have K_2O/Na_2O ratios greater than 0,5 , with some greater than 1. These values are typical of certain rocks found in a wide range of tectonic settings, especially rocks of the "Shoshonitic association" (JOPLIN, 1968) which are believed to be characteristic of island arcs and stabilized orogenic areas (JAKES and WHITE, 1972 ; MACKENZIE and CHAPPELL, 1972 ; JOHNSON, 1973). In Iran, the feldspathoid-bearing rocks are widely found, both in time and space, and are closely related to deep-seated strike-slip faults (AMIDI, 1975 ; LESCUYER and RIOU, 1976 ; DIDON and GEMAIN, 1976 ; EMAMI, 1981 ; AMIDI et al., 1984).

They are characterized by high alumina contents (Al_2O_3 = 17,13 - 20,60) and high Ba, Rb and Sr contents. The high Fe_2O_3 values and correspondingly low FeO contents are mainly the result of secondary oxidation and alteration. TiO_2 and total Fe (as FeO) contents are comparatively low ($TiO_2 < 0,8$). Chemical analyses show that the rocks of this sequence in fact range from absarokites, shoshonites, banakites, to high-K dacites (chemical nomenclature of PECCERILLO and TAYLOR, 1976). The following subdivisions are based on petrographic and geochemical characters :

a) Silica-undersaturated analcite-bearing rocks. These rocks, with high normative nepheline (up to 10 %), range from absarokites to shoshonites. Absarokites are commonly porphyritic, with plagioclase as the dominant phenocryst phase (An 63-69, replaced by albite, calcite, and epidote), with minor diopsidic augite, olivine (largely replaced by chlorite and opaque minerals), and analcite. The groundmass includes the same mineralogical composition together with K-feldspar, accessory minerals, and secondary minerals. Shoshonites are commonly strongly porphyritic, with megacrysts of analcite (up to 3 cm). These lavas are typically characterized by analcite (replaced by pumpellyite, albite and zeolite), plagioclase, diopsidic augite, and a minor amount of olivine phenocrysts. The plagioclase crystals are rimmed by narrow owergrowths of alkali feldspar. Analcite phenocrysts, with many concentric trails of plagioclase laths, show evidence of syncrystallization with the potassic rim of the plagioclase. Sanidine, closely associated with plagioclase, is the essential component of the groundmass, together with abundant analcite, rare pyroxene, and high contents of secondary minerals (calcite, pumpellyite, chlorite, albite, zeolite, prehnite and iron oxides).

b) Silica-saturated or slightly undersaturated, non analcite-bearing rocks. Normative nepheline contents is less than 1 %. Pyroclastics as tuffs and breccias are dominant, but banatitic lava flows are present in the upper part of the sequence. Two distinct types are recognized : (1) sanidine-plagioclase-biotitebanakites , with both sanidine and plagioclase as common phenocrysts, biotite being seldom present ; quartz has been found with the above-mentioned minerals in the groundmass ; and (2) sanidine-plagioclase-augitebanakites , with phenocrysts of sanidine, plagioclase, and augite ; the groundmass consists of sanidine, plagioclase, augite, barkevikite, apatite, and secondary minerals.

c) Silica oversaturated alkaline rocks, with high-K dacitic composition. Tuffs and agglomerates form prominent layers at the base of the sequence. They contain fragments of older analcite-bearing rocks. The pyroclastics conformably overlie the absarokites and are overlain by oversaturated high-K dacitic lava flows. The lavas are commonly autobrecciated and have hyalocrystalline to microcrystalline textures. The groundmass is devitrified glass, with lithophysae and a spherulitic quartzo-feldspathic texture. Plagioclase (An 31-34), corroded quartz, and biotite are part of the phenocryst phase.

Because of the considerable volume of the high-K dacites, the fact that these rocks constitute a shoshonitic suite cannot be explained by regarding them as the end-product of a continuous crystal fractionation process. Anyhow, figures 2, 3, and 4 show that the absarokites, shoshonites, and banakites are all parts of the postulated crystal fractionation scheme, as usually supposed. But, if these rocks do not show a continuous fractionation trend with respect to the total alkalies and K_2O variations, this is not considered to be important (EWART et al., 1976). All the rocks of this episode are typically alkaline, both mineralogically and chemically. They lie within the alkaline definition of MIYASHIRO (1978) and KUNO (1959), and they definitively fall within the shoshonitic field of PECCERILLO and TAYLOR (1976).

IV - OLIGOCENE VOLCANICS

By Late Eocene-Early Oligocene time, the area underwent a period of uplifting and faulting, hence of erosion. A significant phase of eruption, composed of explosive and effusive activities, resulted in the emplacement of subaerial rhyolitic rocks, which unconformably covered much of the older rocks. These rhyolitic rocks are mainly flat-lying or gently dipping and show little deformation.

An explosive breccia is exposed in the lowermost part of the sequence with varying amounts of fragments of older rocks. The matrix is composed of vitroclasts, lithoclasts, and crystalloclasts, which are secondarily welded and devitrified into a spherulitic, quartzo-feldspathic texture. The crystal fragments are corroded quartz, plagioclase and K-feldspar ; biotite is rare.

The breccia is overlain by a brown spherulitic rhyolitic lava (pyromeride). The groundmass is vitrophyric with a typical fluidal texture ; it encloses phenocrysts of plagioclase (An 30-34), amphibole (largely replaced by iron oxides and sericite) and biotite. These rocks are characterized by large spherulites with fibres of quartz and of alkali feldspar (argilized). Extensively tourmalinized plagioclase, and the appearance of apatite, tourmaline, allanite and calcite, all indicate a post-magmatic pneumatolytic phase.

Outflowings of vast quantities of rhyolitic lavas are the last magmatic manifestations of the Paleogene. A typical fluidity sometimes imparts a fine stratification. The rocks have a finely porphyric texture, with phenocrysts of plagioclase (An 20-23), orthoclase, amphibole and biotite, embedded in devitrified, vitrophyric, and quartzo-feldspathic groundmass.

One sample only is alkaline ; all the other analyses show subalkaline or calc-alkaline affinities (MIYASHIRO, 1978 ; KUNO, 1959), but they plot in the high-K calc-alkaline field of PECCERILLO and TAYLOR (1976) (fig. 2, 3 and 4).

Secondary alteration, mainly as a result of low-grade burial metamorphism, but also partly due to weathering and hydrothermal processes, has affected all the Paleogene volcanic rocks, with varying intensity from place to place (AMIDI et al., 1982). The following minerals are scattered throughout the rocks, but in some parts, they occur either as veinlets or as filling of vesicles : chlorite, calcite, actinolite, quartz, albite, zeolite, calcium garnet, hematite, epidote, clinozoisite, pumpellyite, and prehnite.

V - OLIGO-MIOCENE INTRUSIONS

All the Paleogene rocks are intruded by moderate- to shallow-depth intrusions, but the metamorphic aureols are not well developed in the volcanic rocks. Individual intrusive bodies and complexes vary in size from batholiths down to small bodies and dikes. In the field, they are intermediate to felsic in composition. The earliest intrusive phases are relatively more mafic, whereas the younger ones are progressively more felsic. Their petrography and petrochemistry show a three-phase complex : diorite-granodiorite, monzonite-syenite and granite-aplite. The most felsic and youngest unit is often found as intrusions of very shallow depth, such as small aplitic bodies and dykes. One of the features common to virtually all of the intrusives of the area, is the presence of numerous, generally East-West-trending dykes. They have an aplitic-granodioritic composition and are traceables over several kilometers. Field relations and correlation with other dated intrusions of Iran (AMIDI, 1975 ; CAMP and GRIFFIS, 1982), indicate a late Oligocene-early Miocene solidification age for the major intrusions.

The diorite-granodiorite intrusions have medium-grained, granular textures ; the two following types are distinguished : (a) plagioclase (zoned, An 60-65 to An 42-48) + augite + quartz (small amount), and (b) plagioclase (labradorite to andesine) + augite + hornblende + quartz (medium amount). Chemically these rocks are typically calc-alkaline.

The monzonite and syenite intrusions also have a medium-grained, granular texture, with two petrographic subdivisions : (a) abundant plagioclase (labradorite) + augite + K-feldspar, and (b) plagioclase (labradorite) + alkali feldspar + hornblende. Quartz and K-feldspar myrmekitic intergrowths are one of the main features of these rocks. Chemically they are significantly alkaline ; they lie within the alkaline field of MIYASHIRO (1978) and KUNO (1959), and in the shoshonitic field of PECCERILLO and TAYLOR (1978) (fig. 2, 3, 4).

True granites are not commonly observed. They have porphyritic texture and consist of alkali felsdpar (32 %), plagioclase An 33-43 (25 %), quartz (35 %) and biotite (5 %).

Dikes and small intrusive bodies cross-cutting the country rocks are the youngest, most felsic products of a long line of magmatic activity. They are generally very fine-grained, with a porphyric and spherulitic texture. Their mineralogical composition includes abundant K-feldspar (kaolinitized), acidic plagioclase, and quartzo-feldspathic spherulites with common myrmekitic intergrowths of feldspar with quartz. Late pneumatolytic phases are indicated by the appearance of tourmaline, apatite, sphene, clinozoisite, allanite, muscovite, jarosite, and barite.

Chemically, both granites and aplites range from subalkaline or calc-alkaline into the alkaline fields of MIYASHIRO (1978) and KUNO (1959). In the PECCERILLO and TAYLOR K_2O-variation diagram (1976), they form a transitional zone between calc-alkaline and high-K calc-alkaline domaines (fig. 2, 3, 4).

VI - LATE MIOCENE - PLIOCENE VOLCANICS

A probable magmatic gap occurred during the Middle-Upper Miocene and in this interval the area behaved as a Basin-and-Range tectonic environment. Parts of the area emerged as ranges and parts were covered by continental and lagoonal basins which were filled by clastic and detritic materials, punctuated by conglomerates, sandstones and siltstones, of Middle-Upper Miocene age. These were later folded and uplifted in the well-known Late Miocene-Pliocene phase (STOCKLIN, 1977). Post-tectonic magmatism is marked by significant extrusions in the form of domean volcanoes (EMAMI and MICHEL, 1982).

The exogene dome of Kuh-e-Surk is composed of thick rhyodacitic lavas which are finely porphyric. Their basal part, which is composed of dark-grey, semi-opaque, devitrified glass, has been rapidly cooled by flowing upon the pre-existing topography. Most of the groundmass of the lavas, with vitrophyric and slightly fluidal texture, consists of laths or microliths of plagioclase with quartz, amphibole, biotite and K-feldspar. Most phenocrysts are composed of zoned plagioclase (core An 52-54 to An 43-45 in the rim part), basaltic hornblende, and biotite. The phenocrysts rarely show flow alignment.

The Kuh-e-Mill extrusion (12 M.y. by radiometric dating) is an elongated NW-SE endogene dome which has been emplaced at the faulted contact between the Neogene and Paleogene sequences. It is clearly porphyric , with plagioclase zoned from An 45-50 (core) to An 38-40 (rim), and green hornblende phenocrysts. The hyalocrystalline groundmass includes laths and granules of plagioclase, also quartz, and abundant apatite.

Chemical analyses show that these rocks are situated close to the subalkaline-alkaline limit (fig. 2, 3), but in figure 4, they lie in the high-K calc-alkaline domain.

Very slightly tilted Plio-Pleistocene gravels, conglomerates and fan-conglomerates, unconformably overlie the older rocks sequences. They contain fragments of Mio-Pliocene volcanics rocks.

Alkali basaltic rocks ranging from basalts to andesites are the dominant types amongst the analysed Late Cenozoic to Recent lavas. They represent the latest magmatic activities of the country. These volcanics can be found near the area studied as isolated pyroclastic cones or flat-lying lava flows, which are finely porphyritic. The flows usually have a hyalomicrolitic groundmass, with plagioclase and sanidine microliths showing flow alignments. The phenocrysts are either basaltic hornblende or biotite, and plagioclase (An 40-44).

As indicated in figures 2, 3, and 4, the latest magmatic activities of the area show distinctly alkaline affinities and their chemical analyses plot within the alkaline field of MIYASHIRO (1978) and KUNO (1959) or within the shoshonitic field of PECCERILLO and TAYLOR (1976).

VII - CONCLUSION AND DISCUSSION

The Cenozoic volcanic and plutonic rocks described in this paper began to be formed during the Lutetian after a lapse of time of about 20 M.y., following the emergence of the Late Cretaceous ophiolitic belt.

The Surk area was the site of five significant phases of volcanic activities during the Lutetian to Early Oligocene interval. These included alternations of subaquatic and subaerian volcanism. Late Eocene folding episodes have affected the

Eocene volcanic rocks. In addition, interference folds are unconformably overlain by gently-dipping rhyolitic volcanics of Oligocene age. These evidences indicate an active environment and various epeirogenic and orogenic phases of uplifting. Paleogene magmatism with trachyandesitic (E1) and shoshonitic (E4) rocks shows a well-defined alkaline trend (fig. 2, 3, 4). Paleogene andesitic volcanics (E3) are generally calc-alkaline. Rhyodacites (E2) and Oligocene rhyolites range from subalkaline through alkaline (fig. 2) or from calc-alkaline through alkaline (fig. 3) and finally from calc-alkaline to the high-K calc-alkaline trends (fig. 4). On the basis of petrographic, geochemical and tectonic setting of the Paleogene volcanism, the following conclusions can be drawn : (1) this volcanic activity alternates between subaquatic and subaerian environments ; (2) the rocks are formed of alternating sequences of basic-intermediate to felsic composition ; (3) chemically, the Paleogene volcanics are composed of alternations of alkaline and calc-alkaline affinities with transitional rocks. Volcanism probably ceased in Late Oligocene times.

Intermediate to felsic Oligo-Miocene intrusions are widespread in the folded Paleogene volcanics. They are actually a complex of several phases which lie close to the triple-point between diorite-granodiorite (calc-alkaline), monzonite-syenite (alkaline), and granite (close to alkali granite). All those rocks range from subalkaline to alkaline (fig. 2), or from calc-alkaline to alkaline fields (fig. 3), and finally from high-K calc-alkaline to shoshonitic fields (fig. 4). The petrography, geochemical characters, and alternating nature of the intrusive rocks sequences, all indicate close similarities with Paleogene volcanism, but they are in no way linked to any volcanic activities of the area.

In Middle-Upper Miocene time, the area behaved as a Basin-and-Range tectonic environment and the lagoonal and continental basins are both marked by detrital materials. The Middle-Upper Miocene red beds were deformed during a phase which can be correlated with Late Pliocene-Early Pliocene folding throughout Iran. The post-tectonic magmatism is recorded by extrusions in the form of domean volcanoes. Chemically, they straddle the alkaline and calc-alkaline domains' boundary.

The latest volcanic activity occurred in Late Cenozoic or in recent times. It is distinctly alkaline.

Changes in magmatic characters closely depend upon changes in regional tectonics. The exact nature of the relationships between igneous and tectonic activities and the way in which they both change with time throughout Iran, is not properly understood as yet.

The Cenozoic igneous rocks which are found throughout much of Iran have hitherto been ascribded to the calc-alkaline series. They were also linked with different ophiolitic belts and, consequently, to the subduction theory (VIALON et al., 1972 ; TAKIN, 1972 ; DEWEY et al., 1973 ; FOERSTER, 1978 ; JUNG et al., 1975 ; ALBERTI et al., 1980 ; BERBERIAN and BERBERIAN, 1981). Many complications arise when an attempt is made at arguing that the Cenozoic igneous rocks of the area are the products of continued northward subduction and of deep-seated partial melting of oceanic lithosphere along the Zagros main suture. On the basis of the following evidences, we believed that Tertiary magmatism is not related to subduction.

In recent years, a large body of data indicates that alkalies and the K_2O contents of rocks with the same SiO_2 contents increase regularly with increase in depth of the underlying Benioff zone and with lateral distance away from trench axis. Other geochemical variations in this process are increase of the K_2O/Na_2O ratio, and decrease in iron enrichment (KUNO, 1966 ; DICKINSON and HATHERTON, 1967 ; HATHERTON and DICKINSON, 1969 ; NINKOVICH and HAYS, 1972 ; JAKES and WHITE, 1972 ; NIELSON and STOIBER, 1973 ; MIYASHIRO, 1975 ; etc.). Another peculiarity of island arc magmatism is the magmatic zonation which can be recognized in the volcanics of active continental margins (KUNO, 1959 ; JAKES and WHITE, 1969, 1972 ; GILL, 1970 ; MACKENZIE and CHAPPELL, 1972 ; MIYASHIRO, 1974 ; LEFEVRE, 1979 ; SUGIMURA, 1981 ; etc.). In these orogenic provinces, the earliest volcanic manifestations are tholeiitic, and they occur on the oceanic side of island arcs. The tholeiitic rocks are stratigraphically and/or laterally followed by calc-alkaline rocks, then finally by the shoshonitic or alkaline rocks. In addition, TiO_2 contents appear to increase across island arcs towards the continent, and reach their maximum in the shoshonitic or alkaline associations (JAKES and WHITE, 1972 ; LEFEVRE, 1979).

Many detailed studies which have recently been carried out on the Cenozoic magmatic rocks of Iran (AMIDI, 1975 ; LESCUYER and RIOU, 1976 ; DIDON and GEMAIN, 1976; CAILLAT et al., 1978 ; EMAMI, 1981 ; CAMP and GRIFFIS, 1982 ; AMIDI et al., 1984) all fail to agree with the subduction-generated magmatism hypothesis. There is no progressive alkalies, K_2O, and TiO_2 enrichment occuring either in time or in space for the area's Cenozoic igneous rocks. From the chemical point of view, alternations of alkaline and calc-alkaline or of immature calc-alkaline and alkaline magmatic activities during Cenozoic time do not agree with the characters of island arc magmatism. No magmatic zonation can be found, either stratigraphically or laterally, in the igneous rocks of the area. This paper argues that alkaline or shoshonitic series do alternate both in time and space. More especially, chemical alternations in Cenozoic magmatism have already been reported in other parts of Iran (AMIDI, 1975 ; DIDON and GEMAIN, 1976 ; LESCUYER and RIOU, 1976 ; EMAMI, 1981 ; AMIDI et al., 1984). In parts of Iranian Azerbaijan, volcanic rocks show nearly wholly alkaline affinity (DIDON and GEMAIN, 1976 ; RIOU, 1979).

Migration of magmatism is not even, and increasingly younger volcanic manifestations are not found at increasingly great distances from the Zagros suture zone. As to the geometry of subduction zones, the igneous rocks which should result from partial melting of the oceanic crust, could not have intruded the remaining oceanic crust as an ophiolitic belt (SABZEHEI, 1974 ; AMIDI, 1975 ; LENSCH et al., 1980; etc.).

The minimun depth of alkali magma generation along a subducting plate, based on earthquakes focal depths, is generally considered to be greater than 150 km (NINKOVICH and HAYS, 1972 ; KEITH, 1978), but may vary, depending on the rate of plate convergence and on the amount of water present (MIYASHIRO, 1974). Such depths have not been recognized for the descending slab underlying the Central Iranian zone. Hypocenters in the Zagros region seldom exceed 100 km (HAGHIPOUR et al., 1984). It is unlikely that northward subduction along the Zagros suture produced alkaline volcanism during the Cenozoic period.

Therefore, nearly all geochemical and geological features of our Cenozoic magmatic rocks are inconsistent with a volcanism related to a subduction zone model. This model is inadequate to explain the distribution and geochemistry of the Cenozoic magmatic rocks in the area. The volume of calc-alkaline rocks makes it unlikely that they were formed through fractional crystallization of basaltic magma. Another, quantitatively important group, includes those rocks whose chemical characters range from calc-alkaline to alkaline.

The Iranian volcanic provinces are arranged along cratonic fractures which, throughout geological times, have been active during various phases. Cenozoic magmatic activities are accompanied by the opening up of those basins which are related to the creation of new horst-and-graben system. After the beginning of the Early Tertiary, reactivation of widespread, deep-seated faults, resulted in the releasing of lithostatic pressure and in partial melting of the upper mantle at depth. After each episode of magma generation, successive melts rose to the surface along these faults. Both the rising and concentration of the basaltic magma were probably facilitated by the development of local zones of tension, and even within an overall compressional regime. This local tension has been convincingly demonstrated experimentally in clay model deformation (WILCOX et al., 1973). Presence of alkaline or felspathoidal igneous rocks during Cenozoic time (AMIDI, 1975 ; DIDON and GEMAIN, 1976 ; LESCUYER and RIOU, 1976 ; RIOU, 1979 ; STALDER, 1971 ; EMAMI, 1981 ; CAMP and GRIFFIS, 1982 ; AMIDI et al., 1984) can be ascribded to the tensional rift zone of a continental area such as the East African rift system (KING, 1970), the Rhine province of Western Germany (CARMICHAEL et al., 1974), the Jebel al Abyad province of Saudi Arabia (BAKER et al., 1973), and the Basin-and-Range province of the United States (LEEMAN and ROGERS, 1970). In these examples, stress is released, apparently allowing partial melting in depth. The strongly undersaturated lavas are especially located along zones of crustal weakness, characterized by high mobility during the Cenozoic period. The only tectonic condition which led to the development of feldspathoidal (generally analcite-bearing), potassic rocks, is the reactivation of isostatically-controlled fault zones (JOHNSON et al., 1976).

The MILANOVSKY model of rifting (1972) proposed by SABZEHEI (1974) was discussed in detail and applied by AMIDI (1975), LESCUYER and RIOU (1976), DIDON and GEMAIN (1976), CAILLAT et al. (1978), EMAMI (1981), AMIDI et al. (1984) to the interpretation of generation of Cenozoic magmatic rocks and of their geodynamic situation. The emissions of alkaline magmas are linked with rhythmic opening of the rift during the Cenozoic period, mostly occurring during the Paleogene, thus favouring the rise of basaltic magma. This was accompanied by melting of crustal materials giving birth to granitic, or rhyolitic, magmas. Both the intermediate calc-alkaline and transitional magmatisms result from the melange of those two basic and acidic magmas (EMAMI, 1981 ; EMAMI and MICHEL, in press).

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	54.00	57.69	58.68	58.80	60.09	64.80	67.24	68.30	68.77	70.32	50.52	54.30	54.63
Al_2O_3	17.50	17.71	16.57	19.00	18.80	17.40	15.48	13.00	16.14	15.70	18.20	14.30	18.00
Fe_2O_3	5.06	2.59	6.75	3.54	3.21	3.84	3.08	1.79	2.42	1.46	3.85	9.37	6.20
FeO	3.54	3.37	1.20	1.64	0.47	0.65	0.38	0.38	0.20	0.37	4.95	4.31	1.38
TiO_2	0.68	1.00	0.54	0.79	0.64	0.29	0.56	0.28	0.26	0.29	0.92	0.75	0.68
CaO	6.94	5.90	2.50	4.40	4.35	2.90	2.95	6.03	3.00	2.20	8.51	5.70	9.01
MgO	4.89	2.65	0.29	2.41	0.95	0.76	1.45	0.63	0.47	0.36	5.49	3.55	2.63
Na_2O	3.13	3.43	3.81	4.44	4.19	5.72	3.25	3.13	3.44	3.10	2.49	2.69	2.69
K_2O	1.50	3.89	5.02	2.47	4.49	2.54	2.45	4.38	3.38	5.47	2.19	2.58	1.19
MnO	0.25	0.12	0.14	0.14	0.13	0.02	0.14	0.05	0.04	0.05	0.07	0.06	0.10
P_2O_5	0.18	0.11	0.16	0.30	0.15		0.13	0.07	0.07		0.30	0.19	0.15
H_2O-	0.38		0.46	0.25		0.58	1.10	0.15	0.23	0.24	0.21	0.14	0.48
H_2O+	1.11	1.90	2.57	1.27	2.34	1.30	1.56	1.89	1.27	0.25	1.93	1.84	3.08
CO_2			0.53	0.03		0.12	0.31	0.38	0.80	0.52	0.25	0.15	0.26
SO_3								0.08	0.04				0.02
Total	99.16	100.36	99.22	99.48	99.81	100.92	100.08	100.54	100.53	100.33	99.88	99.93	100.50

	14	15	16	17	18	19	20	21	22	23	24	25	26
SiO_2	54.68	55.94	57.07	46.54	48.83	49.47	49.00	49.30	49.33	52.46	52.80	52.97	53.88
Al_2O_3	16.68	16.01	18.82	17.45	20.73	20.11	20.60	20.08	20.60	21.50	19.88	19.88	19.49
Fe_2O_3	6.75	7.15	2.99	5.60	5.09	5.60	5.25	5.58	5.56	4.64	2.72	2.72	4.57
FeO	2.78	2.43	2.20	4.03	2.49	2.78	2.04	2.66	2.03	0.62	1.37	1.36	0.74
TiO_2	0.72	0.84	0.54	0.89	0.72	0.79	0.80	0.71	0.72	0.68	0.39	0.39	0.76
CaO	6.40	6.65	6.20	9.35	8.93	7.70	7.76	7.50	7.51	5.88	4.35	4.24	4.78
MgO	3.85	3.31	3.26	6.66	3.85	3.68	4.06	3.13	4.03	1.76	2.25	2.20	2.46
Na_2O	3.08	2.72	3.84	3.26	4.17	2.93	4.00	4.28	4.10	4.13	4.20	4.04	4.42
K_2O	1.28	2.38	2.52	2.19	1.66	4.17	3.40	3.08	2.07	5.13	7.31	7.09	4.65
MnO	0.20	0.15	0.18	0.21	0.19	0.16	0.15	0.15	0.18	0.10	0.16	0.14	0.10
P_2O_5	0.80	0.25	0.20	0.37	0.38	0.36	0.12	0.40	0.31	0.45	0.19	0.10	0.75
H_2O-	0.26	0.22	0.37	0.44	0.58	1.87	0.24		0.37	0.44	0.24	0.26	0.34
H_2O+	2.45	1.89	1.64	2.35	2.29	0.44	2.40	2.91	2.35	2.62	3.52	3.98	2.85
CO_2		0.32	0.31	0.55	0.41		0.44		0.63		0.44	0.41	0.35
SO_3				0.08						0.03	0.36		0.02
Total	99.93	100.26	100.16	99.97	100.32	100.06	100.26	99.78	99.79	100.44	100.18	99.78	100.16

	27	28	29	30	31	32	33	34	35	36	37	38	39
SiO_2	57.60	59.01	65.05	68.03	68.62	71.56	74.22	72.73	74.47	76.25	61.29	62.16	64.83
Al_2O_3	17.13	18.78	17.35	17.34	14.74	15.14	13.87	13.55	10.36	13.05	16.24	17.25	16.50
Fe_2O_3	2.88	3.68	2.45	1.85	2.14	1.49	1.35	1.46	1.07	1.19	2.46	2.11	1.87
FeO	0.60	0.54	0.25	0.24	0.49	0.63	0.17	0.23	0.31	0.16	2.72	2.64	1.96
TiO_2	0.41	0.45	0.30	0.27	0.35	0.21	0.15	0.22	0.10	0.11	0.65	0.52	0.39
CaO	3.62	3.16	2.50	1.10	1.80	1.50	1.20	2.02	3.44	1.23	6.42	5.37	5.28
MgO	1.03	0.92	0.80	0.51	1.14	0.66		0.64	1.82	0.22	3.22	2.70	2.23
Na_2O	3.81	4.56	4.73	3.88	3.59	3.76	3.78	4.31	2.38	3.19	4.05	3.69	3.25
K_2O	7.69	7.13	5.64	5.44	4.65	3.91	3.94	3.58	5.13	3.63	1.41	1.25	1.75
MnO	0.07	0.07	0.05	0.04	0.07	0.08	0.04	0.08	0.05	0.04	0.16	0.19	0.05
P_2O_5	0.18	0.21	0.07	0.04	0.03	0.04	0.02		0.05	0.04	0.07	0.11	0.09
H_2O-	0.27	0.35		0.29	0.37				0.19	0.17		0.50	0.28
H_2O+	1.57	0.99	1.22	0.79	1.11	1.06	0.74	1.61	0.77	0.77	1.34	1.67	1.32
CO_2		0.62			0.27								
SO_3	2.70			0.04					0.01	0.09			0.59
Total	99.56	100.47	100.41	99.86	99.37	100.04	99.48	100.43	100.15	100.14	100.03	100.16	100.39

	40	41	42	43	44	45	46	47	48	49	50
SiO_2	53.60	61.14	61.62	71.12	71.37	72.43	62.94	67.18	69.26	54.22	62.09
Al_2O_3	19.66	13.87	15.55	14.43	11.61	14.04	17.00	16.24	14.57	19.77	15.52
Fe_2O_3	4.85	2.56	3.28	0.20	0.56	1.59	2.49	2.12	1.91	4.50	3.80
FeO	3.62	2.99	2.34	0.40	0.23	0.34	1.14	0.26	0.28	5.95	0.30
TiO_2	0.77	0.25	0.57	0.26	0.28	0.25	0.47	0.35	0.39	0.32	0.47
CaO	7.72	1.95	3.55	1.55	3.13	1.72	4.55	3.65	3.13	2.05	5.19
MgO	1.45	5.50	2.08	0.54	0.75	0.72	2.12	1.30	1.35	4.51	0.63
Na_2O	3.10	2.35	3.66	3.48	3.63	4.19	4.50	3.89	3.76	3.59	3.44
K_2O	3.28	6.70	5.74	5.48	4.81	3.18	2.38	3.94	4.07	4.78	5.91
MnO	0.17	0.05	0.12	0.07		0.04	0.04	0.12	0.05	0.06	0.13
P_2O_5	0.24		0.15		0.02	0.04	0.22	0.05	0.19	0.03	0.09
H_2O-	0.23	0.22	0.12	0.42	0.28		0.68	0.47	0.35	0.26	0.18
H_2O+	1.54	1.92	0.98	0.67	1.42	1.48	1.18	0.49	0.33	0.49	0.68
CO_2	0.19	0.41	0.09					0.30	0.27		1.73
SO_3				0.77	2.18						
Total	100.42	99.91	99.85	99.39	100.27	100.02	99.71	100.36	99.91	100.53	100.16

Table 1 : Chemical analyses of Eocene volcanics (1-30), Oligocene volcanics (31-36), Oligo-Miocene intrusives (37-45), Late Miocene-Pliocene volcanics (46-48), and Late Cenozoic-Recent volcanics (49-50) from the studied area. All analyses taken from AMIDI (1975). Nomenclature after MIDDLEMOST (1980), except for E_4 (nomenclature after PECCERILLO and TAYLOR, 1976).

E_1 : 1, andesite ; 2-5, trachyandesites ; E_2 : 6-7, dacites ; 8-9, rhyodacites ; 10, rhyolite ; E_3 : 11-12, basalts ; 13-15, andesites ; 16, trachyandesite ; E_4 : 17-21, absarokites ; 22-26, shoshonites ; 27-28, banakites ; 29-30, high-K dacites .- 31, dacite ; 32-36, rhyolites .-37, diorite ; 38-39, granodiorites ; 40, monzonite ; 41-42, syenites ; 43-45, granites .-46, dacite ; 47-48, rhyodacites .-49, subalkalic basalt ; 50, andesite.

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