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ON THE MAGMATISM OF THE SAVALAN VOLCANO (NORTH-WEST IRAN) ****

ABSTRACT. — The Savalan Plio-Quaternary volcanic structure is characterized by a two-stage development. A succession of ignimbritic and lava flows is ascribed to the first stage; in in the second stage extrusion of conspicuous volcanic domes and the formation of minor pyroclastic and lava cones has taken place. Petrographic and major-oxide chemical data suggest that a continuous variation from quartz-latiandesites to rhyodacites (RITTMANN classification; andesites to rhyodacites according to the differentiation index) has occurred. The differentiation trend may be considered typical of the calc-alkaline suites, in spite of a somewhat high Na content throughout the sequence.

The geotectonic setting of the broad magmatic province, to which the Savalan volcano belongs, cannot simply be related to subduction of the Afro-Arabian plate under the Euro-Asiatic (Turkish and Iranian) plate. Adequate attempts at explanation of volcanism within the Savalan area should not only take into account chemical constraints on magma generation, time relationships of past and recent volcanic activity and continental-collision theory, but also closeness of two oceanic-crust basins, namely the Black Sea and especially the (South) Caspian Sea.

RIASSUNTO. — Nel complesso vulcanico Plio-Quaternario del Savalan si riconoscono due fasi principali: nella prima ha avuto luogo una successione di coltri ignimbritiche e lave; nella seconda si è verificata l'estrusione di grandi duomi sommitali e la formazione di piccoli edifici lavici e piroclastici. I dati petrochimici suggeriscono una variazione continua da quarzo-latitandesiti a riodaciti (secondo la classificazione di RITTMANN). Il trend evolutivo può essere considerato tipico delle serie calc-alcaline con però un costante alto tenore in sodio.

La situazione geotettonica della provincia magmatica cui il Savalan appartiene, non si può mettere in semplice relazione con la subduzione della placca Afro-Araba sotto la placca Euro-Asiatica. Una adeguata interpretazione del vulcanesimo dell'area del Savalan deve tener conto, oltre che delle caratteristiche composizionali, delle relazioni temporali e dei processi legati alle collisioni continentali, anche della presenza di due vicini bacini con crosta oceanica, il Mar Nero e soprattutto il Mar Caspio meridionale.

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Introduction

The Savalan volcano is one of the most conspicuous Quaternary stratovolcanoes occurring within a young (early Tertiary to Quaternary) volcanic province, spread over an area exceeding 200,000 sq. km. (International Geological Map of Europe and the Mediterranean Region, 1 : 5 000 000, 1971) across the political borders of Turkey, Iran and the Soviet Union, and possibly extending to the east and to the South-East into two volcanic belts of the same age, the South Caspian Alborz volcanic province and the Central Iran volcanic belt (« Urmia-Dokhtar » zone of Schröder, 1944; Stöcklin, 1968) respectively. From the Van region of eastern Turkey, which roughly marks the southern part of the above mentioned province, a young volcanic belt can also be traced westward, throughout the entire Anatolian peninsula (Blumenthal et al., 1964).

If considered within more restricted limits, the volcanic province including the Savalan massif is roughly confined between two inland seas, the Black Sea and the (South) Caspian Sea, underlined by an oceanic crust (Neprochnov et al., 1970) and thought by some authors to represent the only true remnants of the most ancient Tethys ocean (« Tethys 1 » Dewey et al., 1973). The Savalan volcano itself is located in East Azerbaijan (Iran; see map fig. 1), close to the South Caspian depression which is characterized by an aseismic two-layered crust, i.e. by a 20-25 km thick « basalt » layer and a 15-25 km thick folded sedimentary pile (Neprochnov et al., op. cit.). Unusually thick Plio-Quaternary deposits belong to the sedimentary layer, and show evidence of strong subsidence and sedimentation during the latest Alpine tectogenesis; Fedynsky et al. (1972) believe that this fact is unique at least in the western part of the Tethys belt.

Some rather puzzling features have been recently brought to light by geophysical investigations in the crustal segment underlying the above mentioned volcanic province: earthquake epicenters appear to be scattered over a very broad area, and shocks occur both within and below a continental crust; their fault-plane solutions do not seem to follow a consistent pattern (McKenzie, 1972; Nowroozi, 1972). Thus, plate motion interpretations — owing also to the lack of paleomagnetic data — have resulted in widely different reconstructions, and the possibility has even been mentioned that volcanicity here might be related to a hot-spot type of activity leading to the accretion of continental crust in much the same way as oceanic crust is generated along mid-oceanic ridges (Nowroozi, 1972). An understanding of the recent evolution of this part of the Alpidic belt, based on factual data about time relationships and the nature of volcanism, such as has recently been attempted with success elsewhere (for the Mediterranean area see for example Barberi et al., 1974), could therefore be critical not only for a sound interpretation of the regional geology of the Middle East, but also for the type of volcanism not obviously related to plate convergence.

In all papers which discuss the geotectonics of the area, no specific reference is made to the nature and time relationships of volcanism, and quite understandably so, since — at least to the writers' knowledge — little reliable information is available from the area at large, and none at all from the Iranian sector, except for a brief report by ALBERTI & STOLFA (1973). Following one of the most fundamental tenets of plate tectonics, DEWEY & SMITH (1971), CRAWFORD (1972) and DEWEY et al. (1973) related the young calc-alkaline volcanism at the northern

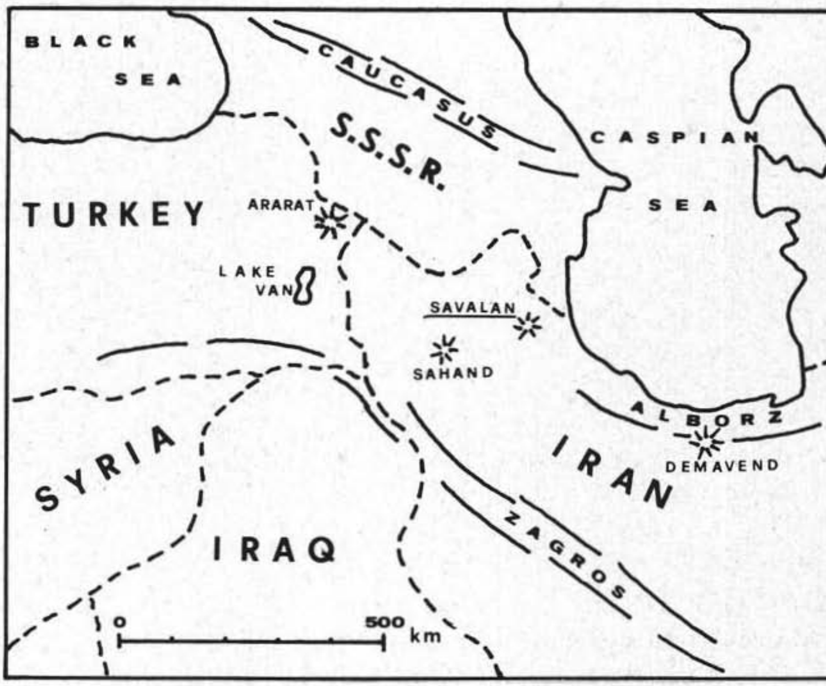

Fig. 1. — Sketch-map showing the location of the Savalan volcano in the Middle-Eeast area.

margin of the Afro-Arabian plate to subduction of the same plate underneath the Eurasiatic (Anatolian) plate. More recently INNOCENTI et al. (1975) postulated a diachronous collision between the above mentioned continental plates to explain the geographic discontinuity of the recent calc-alkaline volcanic activity in the belt running from the western to central Taurus and to the Van region of Eastern Turkey. LAMBERT et al. (1974) however, primarily on the basis of minor and trace element data obtained from a suite of calc-alkaline lavas from Mount Ararat, which is a volcano lying almost at the center of the previously mentioned province, discount the origin of Ararat volcanism by plate consumption, and accept the MCKENZIE (1972) hypothesis of the geotectonic evolution of the entire zone between the Black Sea and the Caspian Sea. Generalized overthrusting and crustal thickening are the basis of this hypothesis. The same authors seem to prefer an indirect control on the Ararat magmatism by a former subduction zone, which would have induced water migration and accumulation. Water in its turn would trigger magma generation in the upper mantle.

Within the Iranian sector, which includes the two provinces of West and East Azerbaijan, volcanic activity, seemingly occurring in 4 cycles, spans the whole Tertiary and Quaternary periods (Explanatory Notes of the N.I.O.C., Geological Map of Iran, 1959; and P. Bordet, 1973, oral communication) and, possibly within the last period, has brought about the construction of two imposing structures, the Sahand and the Savalan. The impressive development of pyroclastic deposits, which though largely reworked in places, blanket the countryside to an unusual thickness and the predominantly light-coloured appearance of lava flows and volcanic bodies clearly point to a highly explosive, silica-saturated calc-alkaline volcanism. The type of recent calc-alkaline volcanism, and what its relation is to the volcanic activity both to the west (Armenia and Anatolia) and to the east (Alborz and Central Iran) is, however, not yet known.

In a previous report (Alberti & Stolfa, 1973) some basic data were given on the Savalan volcano, which has physiographic traits typical of shield-volcanoes topped by a cap of more viscous, steeply rising lava domes. Two main stages in the development of the volcanic structure can be distinguished:

a) a pre-caldera stage, leading to a succession of ignimbritic and lava flows, and

b) a post-caldera stage, during which several volcanic domes (« the Upper Series ») were emplaced.

The caldera rim itself is mostly deeply eroded, and is preserved only to the east, and, to a lesser extent, to the north-west and the south-west of the central depression. Minor central-type eruptive centers have built small, sometimes well preserved volcanic cones roughly along the caldera rim, mostly in a later, sub-recent time. Alberti & Stolfa (1973) have already commented upon the remarkable homogeneity of the rocks of the Upper Series, which belong to different eruption centers within the caldera and cover almost 100 sq. km with thicknesses of up to 1000 m. Rocks of the Upper Series carry no quartz (except for some corroded, occasional xenocrysts) and according to the Rittmann (1973) classification should be termed leuco-quartz-latiandesites. A calc-alkaline nature, with a somewhat high Na content, was noted.

In this report more general information is given, based on 13 new chemical analyses of samples collected from different parts of the massif. The data refer to rocks of either the pre-caldera stage, which will be here called « the Lower Series », or of the late minor centers located high in the volcanic structure. The time relationships of some of the latter samples are, however, uncertain. The analyzed samples were selected from 300 samples, on account of their freshness (confirmed microscopically), their location in the structure, and their position in the volcanic pile.

Petrography

The petrography of rocks of the Upper Series has been described in the previous report by ALBERTI & STOLFA (1973). Volcanics of the Lower Series are not sensibly different. They are generally massive, dark grey to brownish, weakly or non-vesicular rocks. At the microscope they are classified as macro- to micro-porphyritic andesites, with zoned plagioclase (andesine to oligoclase, mostly with a complicated zoning pattern and rich in inclusions, sometimes thoroughly fritted), brown hornblende and biotite phenocrysts, the latter two minerals being subordinate to plagioclase. Augite may also occur as macrophenocrysts, but more commonly is restricted to microporphyritic size; it generally tends to form glomeroporphyritic aggregates. Orthopyroxene is occasionally seen as small, stout prisms. It seems to be more abundant in volcanic units low in the succession and in some lava flows which build the eastern, better-preserved caldera walls. Characteristically, all phenocrysts in the Savalan volcanics are euhedral, plagioclase and biotite showing only occasionally some evidence of resorption. Hornblende rarely mantles augite, and may have a strongly corroded pyroxene core.

The large size (up to 1-2 mm) of euhedral sphene, apatite and magnetite (titanomagnetite) noticed in the Upper Series rocks (ALBERTI & STOLFA, 1973), can also be found in the Lower Series volcanics, but these minerals are not ubiquitous, nor are they as abundant, and the grain size is reduced. This could be related to the fact that in rocks of the Lower Series groundmass percentage is as a rule somewhat higher, and the size of the phenocrysts is commonly smaller than in the Upper Series. Plagioclase microlites, pyroxene granules and small opaque specks, together with clear to brownish glass, sometimes markedly devitrified, are the main groundmass components.

The texture is massive to trachytic, pilotaxitic or hyalopilitic, remarkably devoid of vesiculation features and with little evidence of fragmentation, flattening and cataclastic or flow structures. Distinction between ignimbrites and lavas rests basically on field evidence.

The more silicic rock-types differ from the above mentioned volcanics merely by a higher percentage of glass, which is generally fresh and may show good perlitic fracturing, by a lower An-content of plagioclase, by a lesser amount of the hydrous mafic minerals and by an almost complete lack of pyroxene.

Petrochemistry

19 chemical analyses (major elements only) of rocks of the Savalan volcano are reported in table 1. They are arranged from left to right on the basis of ascertained or inferred position upward in the volcanic sequence.

Table 1

Chemical analyses of the Savalan volcanics
The location of the samples is shown in fig. 2

	127	160	49	125	37/72	38/72	240	S32°	S29°	S6°	S39°	S8°	S46°	46	301	19	54	58A	2
SiO_2	59.14	59.35	59.35	59.60	60.30	61.86	62.02	62.35	62.80	62.85	62.89	62.93	62.95	62.99	63.66	63.85	64.15	66.25	68.15
TiO_2	0.79	0.88	1.09	0.83	0.86	0.77	0.77	0.57	0.60	0.55	0.55	0.60	0.60	0.67	0.63	0.63	0.61	0.49	0.36
Al_2O_3	17.64	17.28	17.11	17.60	16.77	17.59	17.15	16.75	16.80	16.90	16.83	16.84	16.73	16.21	16.64	16.30	16.29	15.71	15.06
Fe_2O_3	3.11	3.89	3.92	3.55	3.85	3.02	3.16	3.38	3.22	3.08	3.34	3.20	3.70	2.89	2.47	1.91	1.39	1.34	1.31
FeO	1.85	1.37	1.55	1.51	1.22	1.39	1.45	0.66	0.57	0.73	0.36	0.57	0.27	0.82	1.34	1.59	1.78	1.38	0.79
MnO	0.05	0.06	0.05	0.05	0.06	0.04	0.06	0.06	0.06	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.04	0.04
MgO	2.87	2.63	2.13	2.87	2.51	1.86	1.97	1.86	2.09	2.00	1.99	1.82	1.72	2.01	1.60	1.64	1.58	1.36	0.90
CaO	5.69	5.49	4.78	5.51	5.32	4.36	4.74	4.36	4.28	4.22	4.20	4.15	4.28	4.10	3.99	3.78	3.59	3.24	2.39
Na_2O	5.16	4.95	4.94	5.18	4.98	4.85	4.87	5.20	5.02	5.14	4.98	5.14	5.38	5.11	5.02	4.94	5.09	4.97	4.69
K_2O	2.47	2.75	3.21	2.40	2.89	2.83	2.70	2.75	2.45	2.35	2.62	2.65	3.17	3.25	3.23	2.83	3.06	3.20	3.61
P_2O_5	0.52	0.56	0.55	0.48	0.56	0.39	0.41	0.40	0.37	0.38	0.45	0.37	0.42	0.42	0.35	0.33	0.36	0.31	0.20
L.O.I.	0.39	0.32	0.90	0.37	0.41	0.44	0.54	1.27	1.20	1.23	1.20	1.18	0.40	0.97	0.50	1.69	1.46	1.21	2.28
	99.68	99.53	99.58	99.95	99.73	99.40	99.84	99.61	99.46	99.48	99.47	99.50	99.68	99.49	99.48	99.54	99.41	99.50	99.78
C.I.P.W. Norm																			
or	14.61	16.27	18.99	14.20	17.09	16.74	15.97	16.12	14.46	13.90	15.57	15.57	18.35	19.22	19.11	16.74	18.10	18.93	21.35
ab	43.61	41.84	41.75	43.78	42.09	40.99	41.16	44.01	42.44	43.49	41.92	43.49	45.59	43.19	42.43	41.75	43.02	42.00	39.64
an	17.64	16.77	14.99	17.64	14.83	17.83	16.92	14.18	16.12	16.12	15.85	15.01	12.23	11.66	13.29	13.91	12.53	11.07	9.34
di	5.61	5.31	4.00	5.11	6.16	0.99	3.06	3.67	1.73	1.51	1.51	2.16	4.10	4.63	3.29	2.13	2.36	2.37	0.95
hy	4.58	4.12	3.47	4.81	3.42	4.19	3.51	-	-	-	-	-	-	2.88	2.48	3.50	4.03	2.97	1.81
en	-	-	-	-	-	-	-	2.90	4.30	4.20	4.20	3.50	2.40	-	-	-	-	-	-
ap	1.21	1.31	1.28	1.12	1.31	0.91	0.96	1.01	1.01	1.01	1.01	1.01	1.01	0.98	0.82	0.77	0.84	0.72	0.47
il	1.50	1.67	2.07	1.58	1.63	1.46	1.46	1.06	1.06	1.06	0.91	1.06	0.61	1.27	1.20	1.20	1.16	0.93	0.68
mt	3.83	2.06	2.00	2.62	1.63	2.38	2.64	0.70	0.46	0.93	-	0.46	-	0.86	2.65	2.77	2.02	1.94	1.63
tn	-	-	-	-	-	-	-	-	-	-	0.20	-	0.59	-	-	-	-	-	-
hm	0.47	2.47	2.54	1.74	2.72	1.38	1.34	2.88	2.88	2.40	3.36	2.88	3.68	2.30	0.64	-	-	-	0.18
Q	6.24	7.42	7.59	6.99	8.44	12.10	12.29	11.76	13.74	13.62	13.74	13.20	10.56	11.54	13.09	15.10	13.82	17.36	21.45
τ	15.79	14.01	11.16	14.96	13.71	16.54	15.94	20.26	19.63	21.38	21.54	19.50	18.91	16.57	18.44	18.03	18.36	21.92	28.81
σ	3.61	3.63	4.06	3.46	3.58	3.13	3.01	3.27	2.81	2.82	2.90	2.82	3.66	3.50	3.29	2.89	3.14	2.87	2.74
D.I.	64.46	65.53	68.33	64.97	67.62	69.83	69.42	71.89	70.64	71.01	71.23	72.30	74.50	73.95	74.63	73.59	75.04	78.29	82.44

° From Alberti & Stolfa (1973).

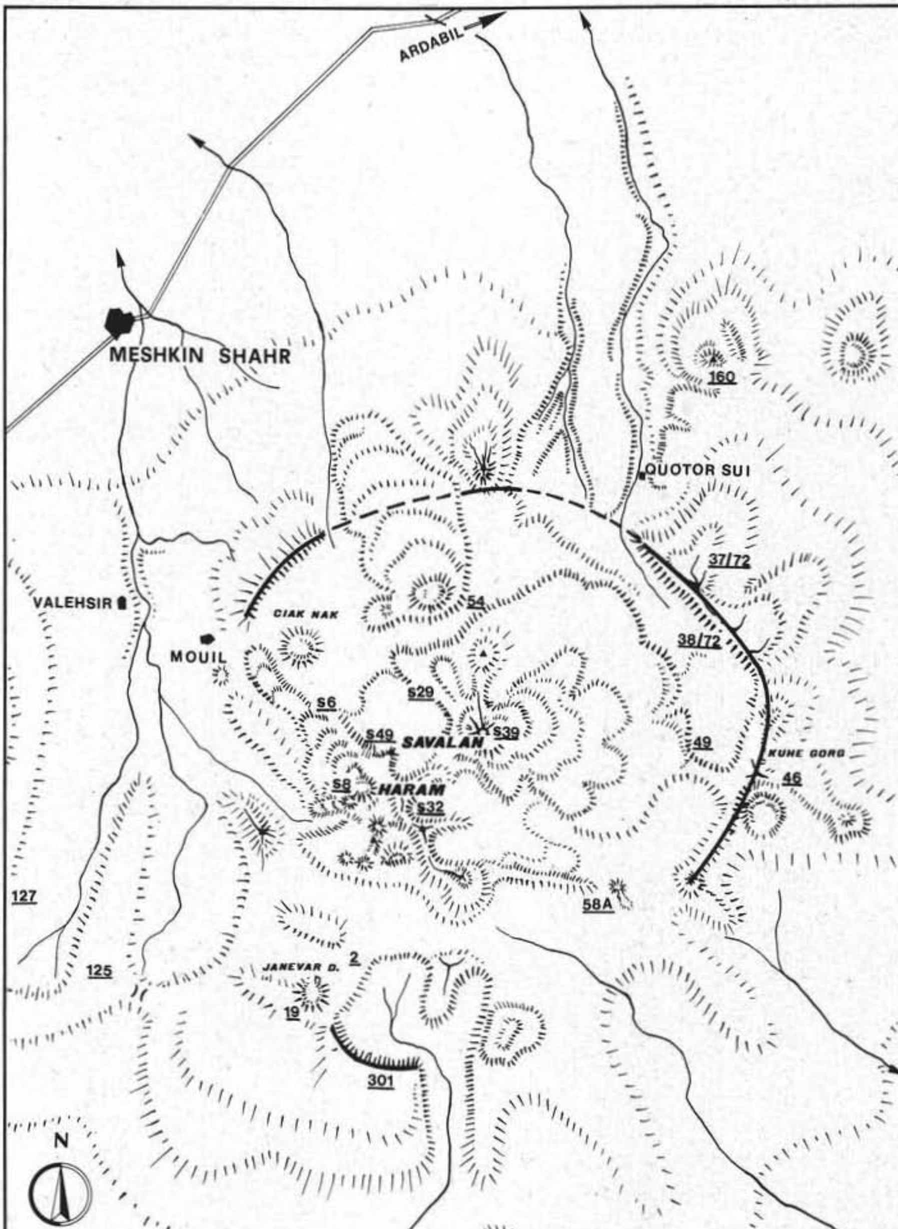

Fig. 2. — The location of analyzed samples (see Table 1) in the Savalan massif. Sample S39 marks the top of the highest peak (4811 m.). Sample 49, though located in the central depression, belongs to the Lower Series; it occurs in the basement of the Upper Series domes.

Following the Rittmann (1973) classification, the Savalan volcanics vary from quartz-latiandesite to rhyodacite (fig. 3), with a prevalence of quartz-latiandesites in the Lower Series and of leuco-quartz-latiandesites in the Upper Series.

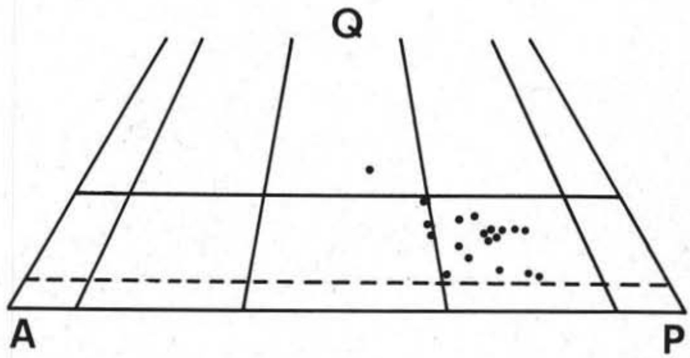

Fig. 3. — Plot of normative Q: A: P ratios of the analyzed Savalan volcanic rocks on the Streckeisen (1967) triangle.

According to the Irvine & Baragar (1971) classification, the samples vary from andesite to dacite, whilst following the Middlemost (1973) scheme they are andesites and high-lime dacites. The Rittmann classification is preferable because it provides a better discrimination between otherwise rather similar rock-types.

The plot of the major elements against the Differentiation Index (fig. 4), shows that a continuous variation trend exists from the quartz-latiandesites to the rhyodacites, except possibly for the K_2O values to be commented upon below. Also a remarkable constancy of rather high Na_2O values is displayed. The continuous trend suggests that the more silicic rock types are normal differentiates with no selective enrichment of any major element.

It must be emphasized that even if reference is made to the 2-stage development of the volcanic structure, no evidence of any major compositional break is present, except for two seemingly unrelated trends of the K_2O values, which correspond exactly to the Lower and Upper Series rocks. Such trends, actually based on few points, are obviously reflected in the (Na_2O+K_2O) value as well. Unpublished data (Bruni, personal communication) does however demonstrate that such differing trends are only apparent, and are simply due to a sampling gap. The idea is thereby strengthened that magma evolution throughout the Savalan volcanic history has been continuous or at last devoid of any major break.

A plot of weight percent SiO_2 v. (Na_2O+K_2O) is shown in fig. 5. It can be readily seen that despite the somewhat high Na-content the Savalan volcanics lie below the σ (Rittmann serial index, 1957) = 4 line, and hence do not belong to the alkaline suite. Furthermore, in the $(Al_2O_3\text{-}Na_2O)$ versus TiO_2 diagram (fig. 6) these rocks fall close to the $\tau = 15$ line, which represents the frequency maximum

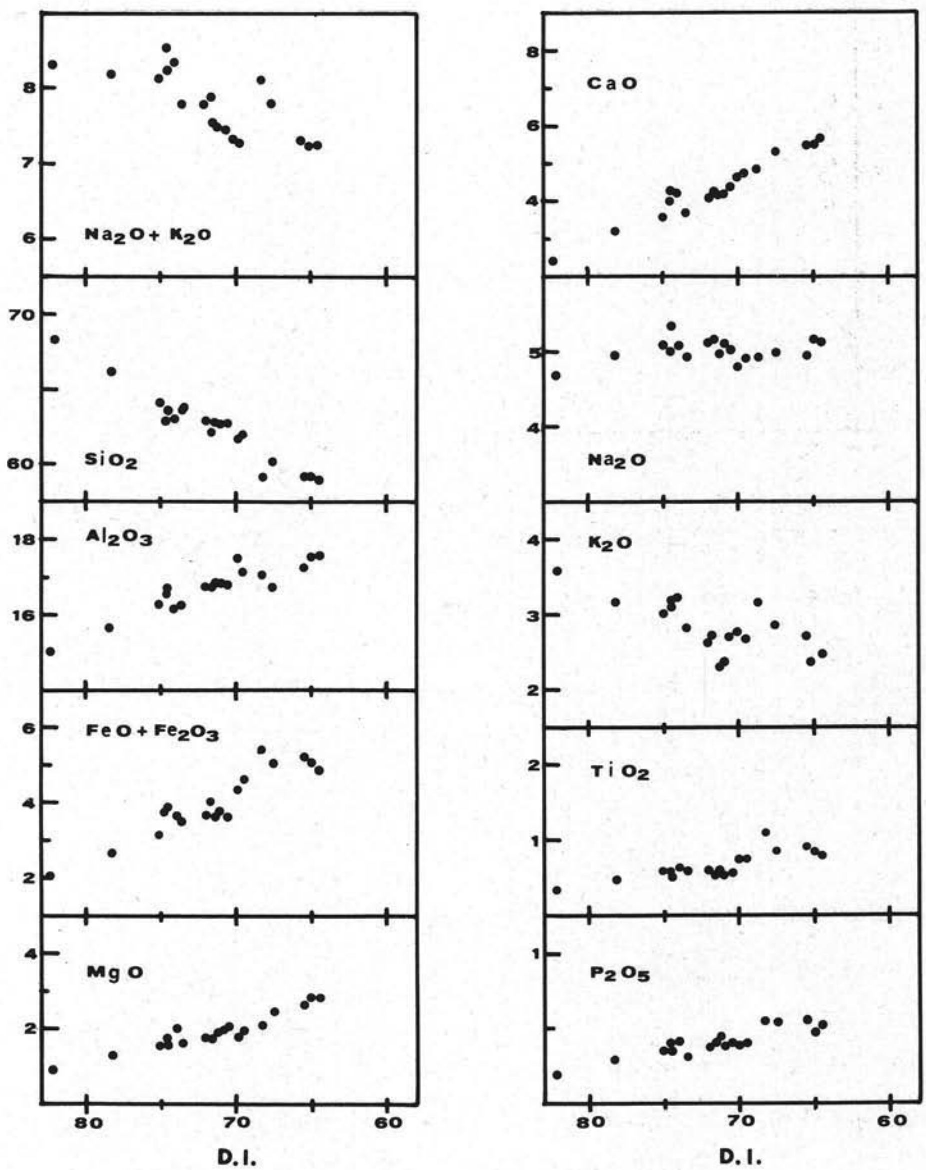

Fig. 4. — Major-oxide variation diagrams against the differentiation index (after THORNTON & TUTTLE, 1960).

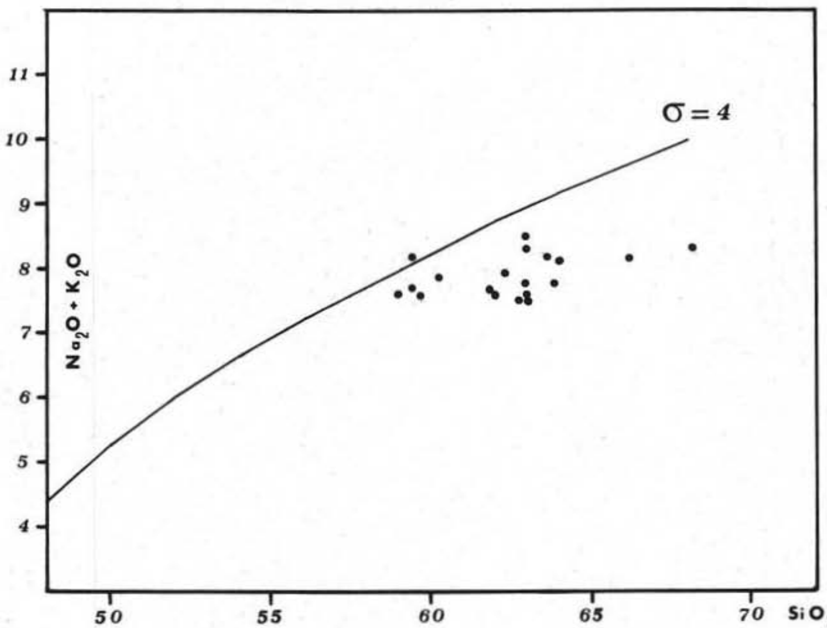

Fig. 5. — SiO_2-alkali diagram for the Savalan rocks. The curve σ (Rittmann serial index, 1957) = 4 separates the calc-alkaline from alkaline associations.

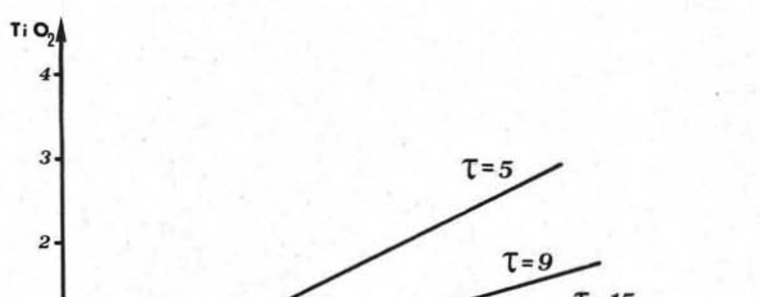

Fig. 6. — $TiO_2/(Al_2O_3\text{-}Na_2O)$ diagram, showing the cluster of Savalan volcanics at the $\tau = 15$ line (frequency maximum of orogenic associations: Gottini-Grasso, 1968).

of orogenic volcanics (Gottini-Grasso, 1968), and hence truly represent an orogenic suite.

Use of the AFM diagram (fig. 7), where a very weak Fe enrichment can be seen, underlines a calc-alkaline trend to the exclusion of any tholeiitic type of magma differentiation. In the same diagram, besides the line dividing the tholeiitic from the calc-alkaline field, two other lines are drawn, representing the main trends of the so-called « Central Iran » and « Alborz » magmatism, both of Tertiary to Quaternary age (JUNG et al., 1975). The Savalan trend is seen to fall very close to the « Alborz » trend. It will be noted in passing that the projection of points representing analyses of the Ararat suite, studied by LAMBERT et al. (1974), rather tends to outline a « Central Iran » trend.

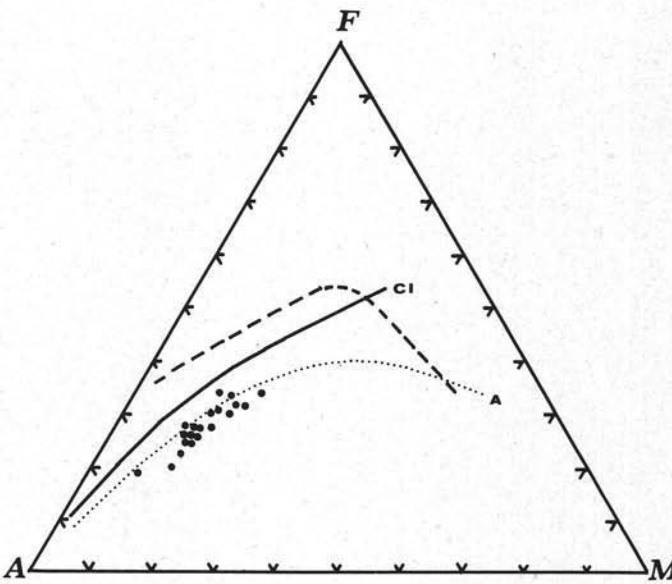

Fig. 7. — A F M diagram for the Savalan volcanics. The dashed line separates tholetiitic from calc-alcaline associations (after IRVINE & BARAGAR, 1971). Curve « A »: Alborz trend; curve « C.I. »: Central Iran trend (after JUNG et al., 1975).

Discussion

Owing to the lack of systematic trace element and isotope data, little can be safely said at present on the origin of the Savalan magma. The present report merely aims at a definition of the main trends of the Savalan magmatism, seen in the regional geotectonic context.

In the previous section it has been shown that the Savalan volcanics, all attributable to a Pliocene-Quaternary age, display a calc-alkaline, orogenic character. A continuous variation, both on chemical and petrographic grounds, from weakly oversatured (more than 6 % Q, CIPW norm) to oversatured (more than 20 % Q) rocks (quartz-latiandesite to rhyodacite, RITTMANN classification) has been established. Serious difficulties arise in the assessment of such a type of magmatism in the wider regional framework. Thus, for instance, while the Savalan differentiation trend in the AFM diagram (fig. 7) has been shown to closely follow the Alborz trend, use of the K_2O-SiO_2 diagram (fig. 8), which JUNG et al. (1975) used to distinguish the « Alborz » and « Central Iran » trends, reveals a cluster of the Savalan rocks in an intermediate position between the above trends, with a slight shift towards that of the Central Iran.

The Ararat suite of LAMBERT et al. (1974) maintains a « Central Iran » type of trend. With reference to the relationships between the K_2O/SiO_2 ratios of

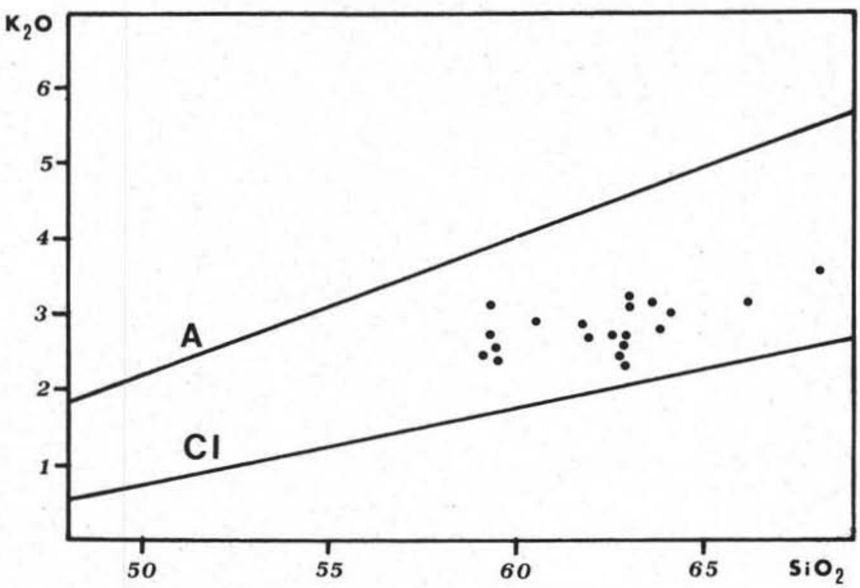

Fig. 8. — K_2O/SiO_2 diagram for the Savalan volcanic rocks. Lines « A » and « C.I. » show the trend of the Alborz and Central Iran volcanics respectively (after JUNG et al., 1975).

volcanic rocks and depth of related Benioff zones in active plate margins suggested by HATHERTON & DICKINSON (1969) and NINKOVICH & HAYS (1972), JUNG et al. (1975) have postulated magma generation for the Alborz and Central Iran volcanic zones at a depth of about 250 km and at 120 to 150 km respectively. Magmatic activity in both zones has been related by the same authors to a two-stage (early Tertiary and Pliocene-Quaternary) subduction of the Arabian plate underneath an Iranian plate, with a major interruption during the mid-Tertiary. Using the same criteria, magmatic sources for Savalan rocks turn out to be located at a depth of about 160 km. For Ararat rocks a shallower origin, at less than 120 km, would result; but a far lesser depth (between 40 and 50 km) is assumed by LAMBERT et al. (1974), who, on the basis of the melting relationships of andesite with variable H_2O content (GREEN, 1972), and on geochemical and textural evidence, outlines two sequences of crystallisation for the Ararat sequence.

It does not seem possible to make such inferences regarding the postulated subduction of the Arabian plate beneath the Anatolian plate, which is believed to have triggered the recent calc-alkaline volcanism of the Lake Van region (INNOCENTI et al., 1975).

Difficulties of interpretation are compounded by:

1) lack of agreement on plate boundaries and motion, as mentioned in the introduction;
2) the geographic trend of the Central Iran and Alborz volcanic zones, which at their north-western extremities tend to merge into a single province in Azerbaijan, thereby pointing to a possible « mixed » character of the local volcanism;
3) the lack in the Savalan volcanics of textural and/or mineralogical relics clearly referable to equilibria at depth;
4) the very basement over which the Savalan structure has been built, which is an early Tertiary (?) predominantly basic and alkaline (K-rich) sub-province, possibly attributable to a shoshonitic cycle (ALBERTI et al., 1974).

Intensified studies of volcanism in this area may well help to resolve a major geotectonic problem of the Alpidic belt straddling the Anatolian and Iranian plateaux.

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