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FIRST DATA ON THE SAVALAN VOLCANO (EASTERN AZERBAIDJAN, IRAN): THE UPPER SERIES

ABSTRACT. — Field observations gathered during an expedition in the summer of 1970 are reported. These observations together with petrographic and chemical data obtained from samples of the Savalan « Upper Series » constitute the first systematic contribution to the knowledge of the magmatism of this volcanic area. From the data it results that the Savalan is a volcanic group formed by several eruption centers, and that the « Upper Series » volcanics are quartz-bearing latite-andesites according to the Streckeisen classification.

RIASSUNTO. — Vengono riportate le osservazioni di campagna svolte durante una spedizione avvenuta nell'estate 1970. Queste osservazioni, assieme a dati petrografici e chimici ottenuti da campioni raccolti in questa prima fase della ricerca riguardante le vulcaniti della « serie superiore » del Savalan, costituiscono un primo contributo alla conoscenza ed alla definizione del magmatismo di questa zona vulcanica dell'Azerbaidjan orientale finora poco nota.

Dai dati ottenuti e dalle osservazioni svolte il Savalan risulta un gruppo vulcanico formato da diversi centri eruttivi in cui la « serie superiore » è costituita da rocce che cadono nel campo delle latitandesiti nella classificazione di Streckeisen.

Introduction.

The Savalan volcano is a huge extinct composite structure, located in eastern Azerbaidjan (north-western Iran) some 120 km East of Tabriz (fig. 1).

According to available maps it reaches 4,811 m (*), thereby constituting the third highest peak in Iran (after Damavand and Alamkuh). Considering that it rises above a 1,000 to 1,500 m-high plateau, this

(*) According to our estimates, this figure is 100 to 200 m too high. HEIM (1952) reported, from aneroid measurements, 4,680 m; BOBEK (1934) also records a figure around 4,500 m.

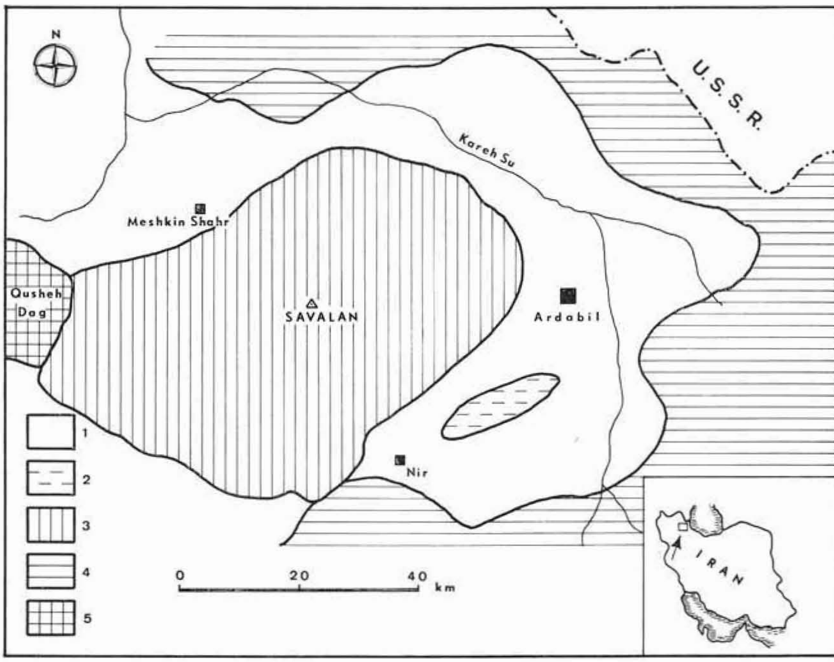
makes more than 3,000 m of volcanic sequences. But even more striking is its large area which, though difficult to estimate because of encroachment of satellitic and small independent volcanic bodies, and of not--clearly defined lower slopes where loose, unconsolidated volcanic debris irregularly covers reworked, mostly terraced, alluvial sediments, is more than 2,000 sqkm.

Keeping in mind such figures, it becomes evident that the Savalan volcano is the most conspicuous geographical hallmark of Azerbaidjan. It also represents one of the most conspicuous late-Tertiary to Quaternary volcanic centers studding the whole area from the Aegean Sea in the West to Baluchistan (Persian Gulf region) in the East: to name some of the most important, Erciyes, Bingol, Suphan, Buyuk Agri (Ararat) in Turkey, Sahand, Damavand, Bazman and Taftan in Iran, Kuh-i-Sultan in West Pakistan. Most of these volcanoes still await adequate attention from the petrological point of view. In some cases, this might be explained by their remoteness.

The Savalan volcano is characterized in particular by an uncommonly large quantity of erupted material: total volume can be estimated to be around 3,000 km^3.

Thus, it is surprising to see that so far no attention, other than cursory, has been paid to the Savalan volcano. A search of the literature has revealed only some early contributions, such as that of GREWINGK (1853) and of SJOEGREN (1888). All other works on regional aspects — foremost among these the study by RIEBEN (1934) — make brief mention of it. GANSSER (1966) refers to Savalan in a few paragraphs, linking it to the Armenian volcanic district, and attributing to it a Quaternary age. Here, too, as in pratically every work mentioning Savalan volcano, a predominant andesitic nature is reported. Except for some papers on geomorphic and glaciological aspects, the authors are not aware of any other contributions on the Savalan volcano.

The opportunity to gather additional data was created in the summer of 1970, when one of the writers (A.A.) took part in an expedition organized with the help of the « Sezione XXX Ottobre » of the Italian Alpine Club (C.A.I.) of Trieste, and with a financial contribution by the Faculty of Science, Trieste University. Reconnaissance work was done on the highest part of the volcano, while all major peaks were climbed. It might be mentioned here that two of these peaks reach almost the same height of Savalan s.s.: when viewed from a distance, especially from the South and from the North, the volcano appears as a 3-peaked mountain. Following the local use, we named the other two peaks Haram and Haram Buzurk respectively. HEIM



LEGENDA

1. Pliocene-Quaternary cover: mainly alluvial, unconsolidated sediments, and subordinate tuffs. - 2. Miocene (?) sandstones and flysch-type deposits. - 3. Savalan volcanics. - 4. Basic volcanics (plateau basalts?), in thick sequences. - 5. Qusheh Dagh granitic rocks (Tertiary).

Fig. 1. — Generalized geological sketch map of the Savalan district (boundaries are approximate).

(1952) wondered whether anybody had reached the second highest peak, and whether a crater was hidden there. Our 1970 expedition gave an answer to this and other questions.

In the summer of 1972 another party to the Savalan volcano was arranged with a financial contribution by the Italian National Research Council (C.N.R.), and material support again by the Italian

Alpine Club, « Sezione XXX Ottobre » of Trieste. Work was extended to other parts of the volcanic group.

The petrographic study and chemical analyses reported here are based on samples collected during the 1970 expedition. Work on samples from the last expedition is in progress. This first contribution to the knowledge of the Savalan volcano deals only with volcanics of the upper parts of the structure.

For an adequate appraisal of our data, brief mention will first be made of the general geological and volcanological framework.

Outlines of geology and volcanology.

The tectonic setting of the Savalan volcano has not yet been investigated. Only large-scale maps are available (N.I.O.C., 1959), and they show that the volcano is situated at the eastern extremity of a WNW-ESE trending granitic ridge (Qusheh Dagh, reaching 3,419 m), to which a Tertiary age is assigned (e.g., Tectonic Map of Europe: International Subcommission for the Tectonic Map of the World, 1962). The surrounding 1,000 to 1,500 m high plateau is largely covered by recent Plio-Pleistocene pyroclastic rocks, and close to the Savalan volcano near Nir (SW of Ardabil) there are outcrops of clastic sedimentary rocks (? Miocene). From inspections made in a few districts at the base of the volcanic edifice it appears that the plateau is actually built by an imposing series of basaltic to intermediate, generally flat-lying, rocks, over which locally rise minor, sometimes perfectly preserved volcanic cones and domes. Block faulting is well developed, often resulting in differential tilting of adjacent blocks so that the topography is most complicated. A regional tilting to S and E is mentioned by Fisher (1968) but water drainage is not always controlled by it, all streams in the Ardabil district (including most of the plateau around Savalan) being for example tributaries of the Kareh Su river which flows to the NE. No contact or stratigraphic relation with sedimentary rocks of known age can as yet be reported.

The present volcanic edifice is, even when neglecting the minor peripheral bodies, a rather complex structure. It is built by several centers, many of which are easily recognized today as exogenous domes, plug domes, cinder cones and small lava cones. At least one endogenous dome has also been observed. The cones, which are rarely higher than a few hundred meters, are arranged along an irregular belt approximately encircling the central upper part of the massif, including the Savalan s.s., Haram and Haram Buzurk peaks, with an area slightly less than 100 sqkm. They mostly occur at an altitude of 3,000 to 3,700 m. Domes are tipically developed in the central, upper part, but their actual number and size is obscured either by erosion or by a cover of talus and of younger flows.

Both on morphological and on volcanological grounds an easy distinction can be made between the lower parts of the Savalan structure, which are characterized by smooth slopes regularly cut by wide fluvial valleys, and the upper part where slopes are steep, extensively mantled by crumble breccia and variously dissected by glacial erosion. Rugged peaks and irregular crests well above 4,000 m occur here; volcanic sequences in walls up to 400 m high are occasionally well exposed. The vertical dimension of volcanic bodies can then be adequately viewed. Elsewhere an extensive scree development, if not glacier ice and snow, conceals the underlying volcanic sequences.

It must be stressed that by far the greatest part of the volcanic structure is built by a succession of ignimbrite-type sheets, the mean inclination of which is 7° to 8°, with a locally considerably steeper gradient. Lahar and tephra deposits are widespread at the base of the volcano, especially on the northern flank. In short, the Savalan volcano is a strato—volcano with a shape typical of shield volcanoes, on whose top there is a capping of much steeper, sharply distinguishable volcanic bodies.

The main volcanic units display common features throughout the edifice, but they are better exposed in the upper part. They are porphyritic, dark grey to brownish, seemingly andesitic rocks, with plagioclase, amphibole and biotite phenocrysts, all reaching a maximum length of a few centimeters, plagioclase by far being the most abundant. Flow banding, ranging in thickness from 1 cm to a few meters, can occasionally be seen. Vesicle content is variable though usually limited to some bands; vesicles are rather small, elongated (maximum elongation: 2-3 cm) and arranged in such a way as to suggest laminar flow; they often are aligned subparallel to the flow bands. Field evidence does not allow a clear distinction between true ignimbrites, froth flows and tuff-lavas. Thickness of these volcanic units in the central, upper part of the volcano cannot be ascertained but certainly exceeds 100 meters. Columnar jointing is widespread, and tipically develops very large prismatic columns; but conchoidal or spheroidal fracturing is even more common.

As mentioned above, the central upper part of the Savalan volcano is characterized by domes, which form the largest part of the three main peaks (see fig. 2).

They appear to be emplaced over the ignimbritic sheets, and the largest ones (estimated to be several hundred meters across at the

Fig. 2. — The central upper part of the Savalan volcano facing North. Central, broad peak, is the Haram Buzurk, which is capped by a well-preserved crater. Peak on the right is the Haram, a highly dissected dome.

base) seem to occur along an alignment some 4 km long and pointing approximately NE-SW. Flows are also discernible as shown in fig. 3, and three main craters, besides some minor vents, have been identified. One is located on the summit of the Savalan s.s., on a crest some 600 m in length built by a filled fissure along which a major, elliptical crater is well preserved (on warm summer days the crater of 110×70 m is filled by a lake). The other two craters are located on the summit of Haram Buzurk, and on the rugged area immediately to the West of Haram and at a somewhat lower altitude (but still well above 4,200 m). The peak (and crest) named Haram appears to be but a remnant left over by erosion of a dome.

The last two craters have a diameter of about 200 meters and are completely filled by mm- to cm-sized unconsolidated volcanic debris, with a few blocks and boulders.

The youngest flows generally have formed block lava and have dark brown to black color due to development of a thin (a few mm) crust with a bronze-like luster as a consequence of rapid chilling; they

Fig. 3. — The Haram Buzurk seen from West. The young flow in the center is several tens of meters thick, and shows frequent spines.

are characterized by a high frequency of spines or pinnacles several meters high (fig. 4), where the joints may be planar and/or irregular or conchoidal. The most recent flows have remarkable thickness (tens of meters) even on steep slopes.

The volcanics belonging to the upper part of the Savalan volcano are called here the « Upper Series », and though this term has initially been used only as a field term, it has been upheld because of the remarkable homogeneity of texture and mineral composition of rocks throughout the central upper part of the massif. We would like to point out, however, that rocks of the Upper Series do not necessarily belong to the same type of volcanic unit, but may belong to fragmental flows, domes and lava flows as well.

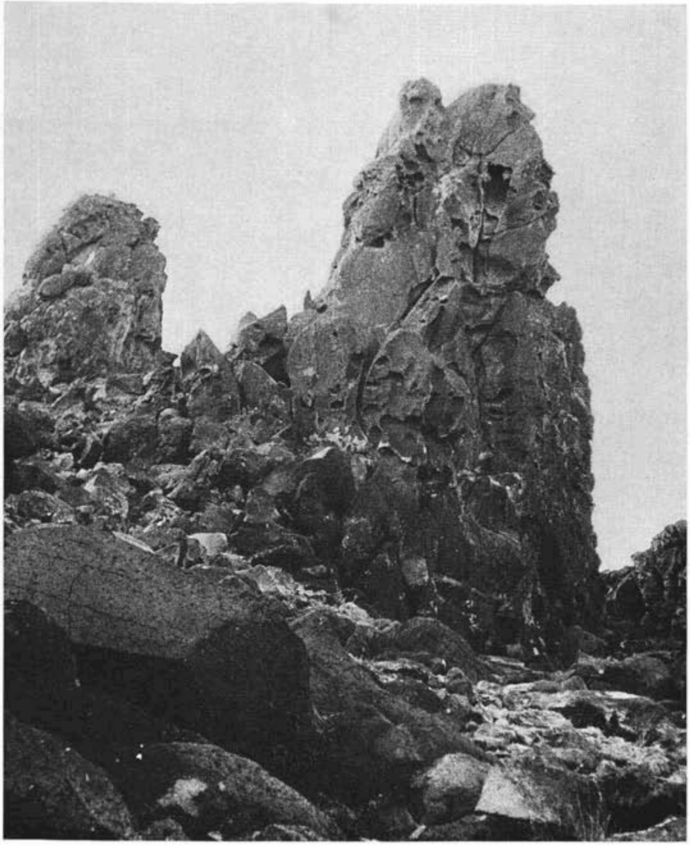


Fig. 4. — Typical spine occurring on a young flow.

Today the Savalan volcano is extinct. Only a few thermal (Meyur on the northern flank, Sarein on the lower slopes of the south-eastern flank) and sulphurous (Qotor-Su, north-eastern flank) springs can be found. Thermal-spring activity seems to have been far higher in the past century: for example, GREWINGK (1853) makes mention of at least 6 localities with hot or sulphurous springs. Seismic activity is well known in the Ahar-Ardabil district and at least part of it might be of volcano-tectonic origin; it probably does not reach the frequency mentioned by GREWINK, who speaks of at least one major quake every year.

As for the age of Savalan, very little can be added at present to the long-held idea of a Quaternary age. It might be recalled for example that BIRMAN (1968), on the basis of observations on Mount Ararat (350 km to the WNW of the Savalan, at a negligibly higher latitude) and elsewhere in Anatolia, tentatively correlated the only recognizable glaciation with the Wisconsin of North America, which in turn can be correlated with the European Würm (e.g. VAN EYSINGA, 1972). Similar conclusions are drawn by VITA-FINZI (1969) for the Mediterranean area and the Middle East, although he stresses the doubtful character of such correlations. Some of the latest flows issued from the 3 main craters of the upper edifice of the Savalan are certainly post-glacial and thus probably sub-recent. In view of the prolonged activity (often from the Miocene) recorded for some of the big volcanoes mentioned in the introduction, an older age than the Quaternary could nevertheless be considered for at least part of the old Savalan edifice. But certainly the late Pleistocene glaciation would have allowed sufficient time in the early Pleistocene for the building up of the main volcanic body.

The following paragraphs take into account the general characteristics of the Upper Series excluding the differentiated types (as inferred from microscopic study) occurring as small plugs, some dikes and minor irregular bodies which cannot be traced with continuity for more than a few tens of meters at the most. These rocks are generally aphanitic and largely glassy, rarely olocrystalline and fine-grained (microdiorites) with recognizable biotite and amphibole (both a few mm long) set in a felsic groundmass. They are also to be found as pipe filling or partial crater filling. In the latter case they occur mostly as unconsolidated debris. Few subrounded inclusions or nodules, never exceeding a few cm in diameter, occasionally are observed within the higher units of the Upper Series and belong to the same types mentioned above.

Petrography of the Upper Series.

Lavas of the Upper Series are porphyritic, with phenocrysts of plagioclase, amphibole, biotite and a calcic clinopyroxene. Most of the textures are porphyritic seriate. Pyroxene crystals occasionally cluster giving origin to small clots or aggregates. Ubiquitous accessories are well-shaped, big crystals of sphene and apatite, and titanomagnetite

Fig. 5. — Typical texture of rocks of the Savalan Upper Series. Crossed nicols, × 19.

occasionally with ilmenite exsolutions. Groundmass is largely glassy and hyalopilitic, grading into pilotaxitic. No clear evidence of eutaxitic or other clastic structures has been observed (fig. 5).

All phenocrysts are euhedral and show no reaction with the groundmass, except for plagioclase which may be partially resorbed. They range in length from a few centimeters to about 0.2 mm, plagioclase with tabular crystals, often in synneusis aggregates and twins, being by far the biggest and the most abundant. Acicular amphibole may also attain remarkable lengths.

The average of eleven modal analyses is reported in Table 1: « macrophenocrysts » have an arbitrary lower limit of 0.4 mm, while « microphenocrysts » fall within the 0.4-0.05 mm range.

The data bring out the high percentage of groundmass, in which very small plagioclase laths or microlites, pyroxene, amphibole and disseminated opaque minerals (again titanomagnetite) can be observed. But a very sizeable part is still contributed by interstitial brown glass with devitrification features. Swallow-tailed terminations of the smaller plagioclase microlites are common. Subrounded quartz xenocrysts of about 1 cm with a reaction rim of extremely small pyroxene crystals can occasionally be seen.

Optical properties — from U-Stage measurements — of amphibole (pleochroic from yellow brown to dark reddish-brown, $z/\gamma = 6\text{-}7°$; $2V_\alpha = 72\text{-}73°$; average of many measurements) and clinopyroxene (pale green to colorless, $z/\gamma = 40\text{-}46°$, $2V_\gamma = 62°$; average of many measurements) point to a common basaltic hornblende or oxyhornblende and iron-poor augite respectively. Both are zoned slightly or not at all; a faint hourglass extinction is observed only in some of the largest pyroxenes. The same mineral is occasionally mantled by hornblende. From the occurrence of an oxyhornblende as well as from the distinctly yellow to dark reddish pleochroism it can be expected that, rather than biotite, an oxybiotite (TROEGER, 1967) is actually present.

TABLE 1. — *Average of 11 modal analyses of rocks of the Savalan Upper Series.*

Macrophenocrysts:	plagioclase	16.2	Total plagioclase	25.3
	hornblende	1.9	Total amphibole	5.6
	biotite	1.7	Total biotite	1.7
	titanomagnetite	0.3	Total opaque	1.7
Microphenocrysts:	plagioclase	9.1	Clinopyroxene	0.7
	hornblende	3.7	Apatite	0.2
	titanomagnetite	1.4	Sphene	0.1
	clinopyroxene	0.7	Groundmass	64.7
	apatite	0.2		
	sphene	0.1		
Groundmass		64.7		
		100.0		100.0

Attention must be focussed on plagioclase, on which BRUNI (1972) has made many detailed U-Stage measurements. In some cases it shows a marked tendency to skeletal growth, giving rise to irregular extensions of the {010} pinacoid. Twinning is most common. It is often zoned, with zoning chiefly of the oscillatory type, and very rarely discontinuous. Normally sharp breaks in composition concern the outer rim only; occasionally they occur in the larger crystals between core and intermediate zones. The composition ranges from sodic oligoclase to calcic labradorite, but values tend to cluster in the interval 20-50 An, the most frequent composition being around 25 An. The larger phenocrysts generally have a somewhat more sodic composition, from 20 to 40 An. There seems to be no great variation of the composition between phenocrysts and microlites, though some data might suggest a systematic increase in An content in the smaller measurable (at the U-Stage) crystals. According to BRUNI (1972), 2V values do not closely conform to the curves for « volcanic » plagioclase of BURRI et Al. (1967) in the oligoclase-sodic andesine range.

From the study of a very large number of crystals, it turns out that there is no consistent pattern in the variation of composition from the center to the border of crystals, even in the same thin section. Thus, An values may rise or may decrease; they may be constant in the core and follow a sharp, if continuous, increase, or give way to an oscillatory pattern. The only recurring pattern is represented, as mentioned above, by the rather sharp increase of An content in the outer rim, which as a rule is sensibly more calcic than the inner zone.

Glassy inclusions or blebs are present in many, but by no means all, plagioclase phenocrysts. There are at least 3 types of such inclusions, which may be: 1) extremely fine, barely distinguishable at high magnification, 2) dendritic, and 3) patchy or lobate. Attempts to correlate type of inclusions, zones and corresponding compositions of many crystals did not reveal any consistent pattern. Any of the three types may occur in the core, in the intermediate zones or in the outer ones. But the outermost rim besides being sensibly more calcic as noted above, is always completely free of inclusions. Just as it has been observed in the case of composition, crystals with quite different types and sites of inclusions may be present in the very same thin section.

An interesting feature of some plagioclase phenocrysts is their « finger-print » fusion texture, generally very thin, surrounding the whole crystal (fig. 6). This is comparatively rare and affects a few crystals: it does not for example show up in all plagioclase phenocrysts of the same thin section. In a few cases it is very wide and may affect the whole plagioclase: the composition then is albitic. If pre-

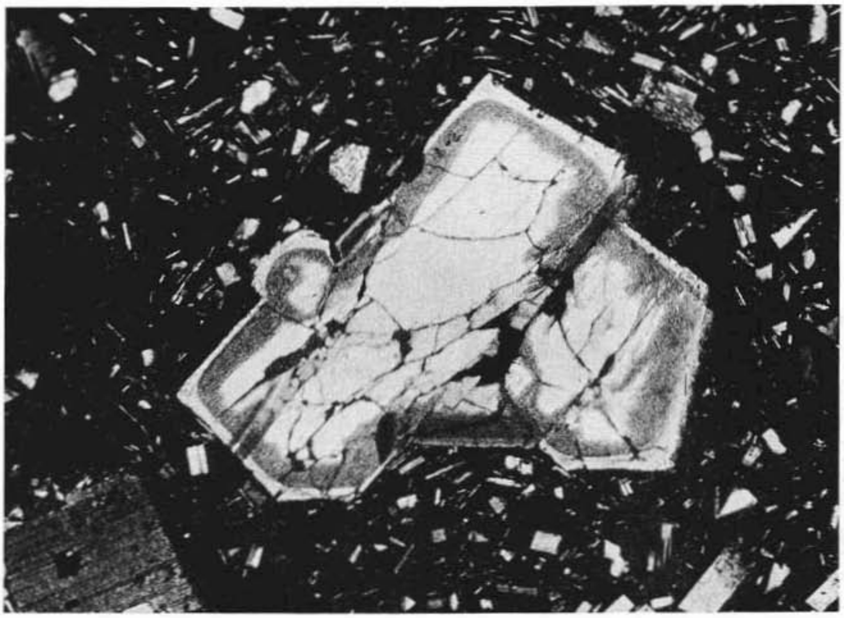


Fig. 6. — « Finger-print » texture in plagioclase phenocrysts. Note synneusis relation pointing to incipient fusion prior to aggregation. Crossed nicols, × 28.

vious interpretations of such texture, which elsewhere (e.g. SIGURDSSON, 1971) has been considered to be an effect of mixing of different magmas should be entertained here, a set of difficult problems would be raised for the whole Savalan Upper Series.

Chemistry of the Upper Series.

Analytical methods.

The chemical analyses were carried out using various techniques. Silica was determined by the standard gravimetric method, phosphorus by colorimetry, ferrous iron titrimetrically by redox titration, and the other elements by atomic absorption spectrophotometry.

For the determinations by atomic absorption spectrophotometry the sample decomposition technique was essentially that described by BERNAS (1968), in which samples are digested in aqua regia and hydrofluoric acid in a sealed teflon bomb and the analyses carried out in a fluoboric-boric acids matrix. The sample solutions were aspirated into a nitrous oxide-acetylene flame for aluminum, titanium, calcium and magnesium determination and into the air-acetylene flame for iron, potassium, sodium and rubidium.

Chemical data.

Composition for major elements and rubidium of six typical samples of the Upper Series, are reported in Table 2.

The data stress the homogeneity of the rocks of the Upper Series and point to a notable similarity to common dacitic types of the calc-alkaline association.

Concluding remarks.

On the basis of the diagram proposed by STRECKEISEN (1967) using the normative alkali feldspars/plagioclase/quartz ratios the volcanics of the Savalan Upper Series are classified as quartz-bearing latite-andesites. Although the Streckeisen classification for andesitic-type rocks has some drawbacks, we use it for purposes of comparison and because of its wide acceptance.

In this regard we point out that the application of the Rittmann norm (RITTMANN, 1973) to our samples leads practically to the same result, classifying the rocks as quartz-bearing latite-andesites. This result does not vary substantially subtracting the components crystallized during the intratelluric phase (Rittmann, personal written communication) (*). Following the MIDDLEMOST (1972) classification, very interesting for its semplicity and specific character, it turns out that these volcanics are « high-lime » dacites, falling in the dacitic class close to the boundary between dacitic and andesitic rocks.

Discussion of the genesis of these rocks is strictly linked to the composition of rocks of the other parts of the volcanic structure, in some cases possibly belonging to earlier volcanic stages, and is not considered here. In this note we merely wish to report on the notable

(*) We gratefully thank prof. A. Rittmann for his personal communication.

TABLE 2. — *Chemical analyses* (*).

Major elements in weight %

	S-6	S-8	S-29	S-32	S-39	S-46
SiO_2	62.85	62.93	62.80	62.35	62.89	62.95
TiO_2	0.55	0.60	0.60	0.57	0.55	0.60
Al_2O_3	16.90	16.84	16.80	16.75	16.83	16.73
Fe_2O_3	3.08	3.20	3.22	3.38	3.34	3.70
FeO	0.73	0.57	0.57	0.66	0.36	0.27
MnO	0.05	0.05	0.06	0.06	0.06	0.06
MgO	2.00	1.82	2.09	1.86	1.99	1.72
CaO	4.22	4.15	4.28	4.36	4.20	4.28
Na_2O	5.14	5.14	5.02	5.20	4.98	5.38
K_2O	2.35	2.65	2.45	2.75	2.62	3.17
P_2O_5	0.38	0.37	0.37	0.40	0.45	0.42
L.O.I.	1.23	1.18	1.20	1.27	1.20	0.40
	99.48	99.50	99.46	99.61	99.47	99.68
Rb (p.p.m.)	41	65	48	58	45	72
K/Rb	476	338	424	394	483	365

C.I.P.W. NORM

	S-6	S-8	S-29	S-32	S-39	S-46
Q	13.62	13.20	13.74	11.76	13.74	10.56
or	13.90	15.57	14.46	16.12	15.57	18.35
ab	43.49	43.49	42.44	44.01	41.92	45.59
an	16.12	15.01	16.12	14.18	15.85	12.23
wo } di	0.81 } 1.51	1.16 } 2.16	0.93 } 1.73	1.97 } 3.67	0.81 } 1.51	2.20 } 4.10
en } di	0.70	1.00	0.80	1.70	0.70	1.90
en	4.20	3.50	4.30	2.90	4.20	2.40
mt	0.93	0.46	0.46	0.70	—	—
il	1.06	1.06	1.06	1.06	0.91	0.61
tn	—	—	—	—	0.20	0.59
hm	2.40	2.88	2.88	2.88	3.36	3.68
ap	1.01	1.01	1.01	1.01	1.01	1.01

(*) Samples dried at 110°C.

homogeneity of mineralogical and chemical composition of the rocks of the Savalan Upper Series. Though they belong to different eruption centers and cover an area close to 100 sqkm with thicknesses up to 1000 meters, the results point to a practically identical magma source and to a fundamentally common volcanic episode.

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