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GEOCHRONOLOGY OF THE EASTERN AZERBAIJAN VOLCANIC PLATEAU (NORTH-WEST IRAN) *****

RIASSUNTO. — Vengono forniti dati radiometrici (K/Ar) relativi al plateau vulcanico dell'Azerbaijan orientale (Iran nord-occidentale). Mentre in tale settore si ammettevano finora due cicli vulcanici di età recente, uno attribuito al Terziario inferiore (Eocene) e l'altro al Plio-Quaternario, le datazioni K/Ar hanno permesso di stabilire un'età attorno ai 40 m.a. (passaggio Eocene-Oligocene) per un'estesa copertura lavica alcalina nella parte settentrionale del citato plateau, successivamente interessato da masse filoniane (circa 9 m.a. più tardi), ed un'età intorno ai 10-11 m.a. (Miocene superiore) per le vulcaniti della zona meridionale. Successivamente si è impostato il ciclo calc-alcalino (Pliocene-Quaternario) altamente esplosivo che ha dato origine alla grande struttura del Savalan ed ai corpi minori situati ad est e ad ovest dello stesso vulcano.

ABSTRACT. — Radiometric (K/Ar) ages have been taken from rocks of the volcanic plateau of Eastern Azerbaijan (N-W Iran). In this area, so far only two young (Tertiary and Quaternary) volcanic cycles, one attributed to the Eocene and the other to the Pliocene-Quaternary, have been assumed. The K/Ar age (whole rock) determinations have proved a 40 m.y. age (Upper Eocene to early Oligocene) for a wide alkaline plateau in the northern part, followed by the emplacement of dyke swarms some 9 m.y. later, and a 10 to 11 m.y. age (whole rock and anorthoclase) for a volcanic tableland in the southern area. Subsequently the calc-alkaline, highly explosive Plio-Quaternary volcanic cycle gave origin to the big Savalan structure and to minor occurrences both to the east and west of the same volcano.

Introduction

Wide expanses of subaerial lava flows and other volcanic products, generally attributed to the lower Tertiary (Eocene: N.I.O.C. Map, 1959; Tectonic Map of Iran, 1973) occur in Eastern Azerbaijan (NW Iran), where they cover an area of several thousand sqkm. They extend with continuity into neighbouring regions

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to the Ne (beyond the URSS-Iran border) and to the SE, thereby joining a volcanic belt well exposed along the southern flank of the Alborz chain. The latter belt is also attributed to the Eocene (« Kharaj Formation »; see for instance PAZIRANDEH, 1973).

In Eastern Azerbaijan, volcanic activity has also taken place in more recent time, notably in the late Pliocene and Quaternary, during which were built two of the biggest volcanoes of Iran, the Savalan and the Sahand (GANSSER, 1966). The area covered by these recent volcanics in Eastern Azerbaijan is about 10,000 sqkm.; but this figure — as well as the previous one regarding the older volcanics — is a very rough estimate owing to the lack of published maps or accounts in most parts of NW Iran.

A glance at a geological map of Iran reveals not only the enormous extent of the young (Tertiary and Quaternary) volcanics, but also that Eastern Azerbaijan lies at the junction of two major volcanic belts, each consisting of more than one volcanic cycle, one running along the southern margin of the Alborz range as mentioned above (as well as further to the east), and the other running from NW to SE, stretching troughout central Iran parallel to the Zagros trend. Accurate information on the age relations of the volcanics of the two belts is of foremost importance to any reconstruction of the geodynamic evolution of the whole area. Models of such evolution have been proposed by some authors (e.g. McKENZIE, 1972; TAKIN, 1972; NOWROOZI, 1972; CRAWFORD, 1972; JUNG et al., 1974; HAYNES & McQUILLAN, 1974), but it appears that they lack the support of basic data regarding not only the age relations, but also the nature of volcanism in several key districts.

Though radiometric dating of young volcanic rocks is being actively pursued in several regions of Iran, it appears that no data, other than stratigraphic ones, are as yet available about the age of volcanics from NW Iran. PAZIRANDEH (1973), quoting TARAZ (1968), records « basaltic and trachytic tuff » of the middle and upper Eocene south of the Dasht-e-Moghan, which is a tableland grading down to the flat, alluvial plains of the Araxes river marking the boundary between Iran and the USSR (Republic of Azerbaijan). The 1959 Geological Map of Iran (N.I.O.C., 1959) shows in Eastern Azerbaijan a very wide cover of unspecified « intermediate » effusive rocks (the age is not recorded), but from the interfingering in the SE area with Karaj Formation we can infer that these rocks are Eocene. Petrological data have been recently given by ALBERTI & STOLFA (1973) and ALBERTI et al. (1975) on the Plio-Quaternary Savalan complex; these authors pointed out the calcalkaline character of the last volcanic cycle.

This report provides information on the absolute dating of volcanics from the older (i.e., supposedly lower Tertiary) volcanic plateau of Eastern Azerbaijan, which forms the basement over which the recent (Plio-Quaternary) volcanics have been extruded.

Geological setting

As a first approximation it can be stated that Eastern Azerbaijan and adjacent areas to the north and to the south (the eastern boundary being the Caspian coast) can be divided into two parts by a line roughly running from the middle part of Lake Rezayeh through Tabriz to Ahar and further beyond to the north. While the western part is tectonically very complicated, and the stratigraphic record

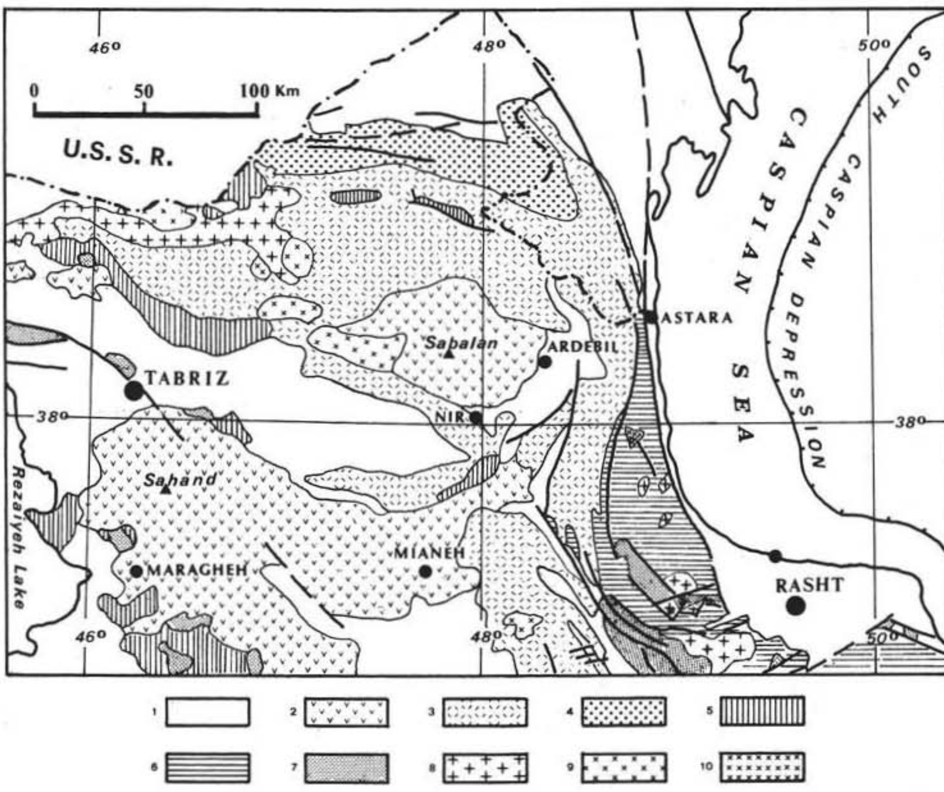

Fig. 1. — Geological sketch map of Azerbaijan between Rezaiyeh Lake and the Caspian Sea (from Tectonic Map of Iran, 1972, modified).
1 - Sediments deposited on pre-Oligocene folded substratum, folded in Pliocene time (Neogene marine and continental deposits of the Caspian coastal region; post-Eocene red beds, evaporites and conglomerates; Tabriz depression affected by strong Neogene-Quaternary subsidence). — 2 - Neogene-Quaternary volcanic rooks and tuffs. — 3 - Eocene volcanic sequence. — 4 - Eocene sedimentary sequence. — 5 - Lacunar Cretaceous sequence. — 6 - Jurassic-Cretaceous sedimentary sequence. — 7 - « Infracambrian ». — 8 - Methamorphic rocks. — 9 - Tertiary « granites and granodiorites ». — 10 - Mesozoic « granites ». — Heavy and dashed lines: major faultes.

shows a sequence of formations ranging from Infracambrian to Quaternary with several gaps and orogenic episodies, the eastern part is much simpler (see sketch-map, fig. 1). Its most important feature by far, is given by the repeated outpourings of volcanic products from Tertiary (possibly also from the Cretaceous) to Quaternary, subrecent times. Up to 80 % of the whole area — apart from the alluvial deposits — is today covered by volcanics. Except for a few exposures in the Morati village district in the tableland north of the Savalan volcano (tuffaceous and tuffitic rocks intercalated in lacustrine deposits) all of this volcanic activity appears to be subaerial. Most of the area from the Cretaceous onwards has clearly mantained a platform character.

Marine sedimentary deposits (generally epicontinental or lagoonal) occur with continuity in the northern part of the area and in other scattered localities, where tectonism was a major controlling factor. Unspecified Cretaceous rocks, associated with volcanics, lie on an east-west strip (Rashteh-ye-Salavat: most probably an elongated block of tectonic origin), occuring close to the northern margin of the volcanic plateau. This Cretaceous volcanic occurrence has not yet been studied, and hence its relationship to the later Tertiary volcanic phase is not known. Further to the north there is an Eocene sedimentary sequence, followed towards the USSR border (in the Dasht-e-Moghan area) by Oligo-Miocene marine deposits, folded in Pliocene and Quaternary time.

Sediments of very limited total thickness and areal extension (mainly shales: not recorded in the sketch map of fig. 1) occur SW of Ardebil. To the east of Tabriz a major young depression, elongated in a east-westerly direction for some 100 km., shows marine deposits including red beds and evaporites (salt domes occur close to Tabriz) of Miocene age. Like other depressions in central Iran, it is affected by strong Neogene-Quaternary subsidence.

The eastern boundary of the plateau is marked, from the morphological point of view, by a steep scarp some 1500 meters high, delimiting the Caspian depression from the highlands lying to the west. The escarpment appears to be tectonically complex, being controlled by N-S faults which delimit a strip of Mesozoic rocks consisting of a conformable Jurassic-Cretaceous sedimentary sequence (including Cretaceous volcanics which occur in many parts of the central and western Alborz north flank).

The large-scale structure of the area is easily simplified as follows: the overall pattern is controlled by the subhorizontal thick pile of the Tertiary and Quaternary volcanic products. Structural details may be rather complicated by repeated faulting, so that an irregular plateau with an average height of 1200-1500 meters has resulted. The plateau is divided into two parts by two majojr E-W trending ridges:

a) a central ridge which includes in the east the Plio-Quaternary Savalan volcano (4811 m) and in the west the Qusheh Dagh (3149 m) plutonic body; the latter is attributed, in the Tectonic Map of Iran (1973), to the Tertiary (« Tertiary granites and granodiorites »);

b) a southern ridge (Kuh-e-Bozqush, 3306 m), with a limited Cretaceous sedimentary sequence at its eastern extremity, roughly marking the southern margin of the Azerbaijan plateau.

A minor, NW-SE trending ridge (Talishinakiye Gory, 2490 m) runs along the Iran-USSR border from the Caspian coast to the Dasht-e-Moghan lowlands; only Tertiary volcanics are shown to occur here by the above mentioned maps.

The northern plateau exhibits a « stair » topography which is due to block-faulting, with single blocks often showing remarkable tilting. The main faults trend N-S, and the dip of the tilt is to the west. The fault scarps show thicknesses of extrusive rocks locally exceeding 800 m, but the writers have nowhere been able to see the nature of the basement of the upthrown lava piles. Large fault valleys and downthrow basins played a major role in the evolution of the landscape, but several valleys have also been carved out by fluvial erosion. In this way a

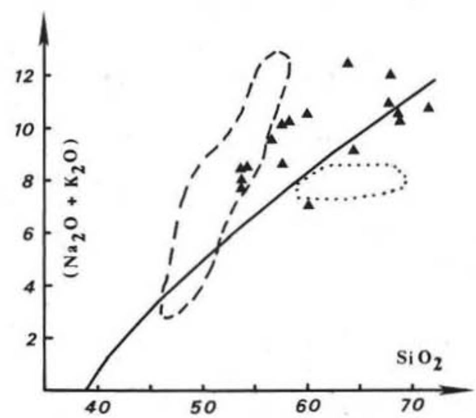

Fig. 2. — Alkalies-silica diagram for eastern Azerbaijan volcanites. Solid line separates the alkali from the subalkaline fields after IRVINE & BARAGAR (1971). Existing chemical analyses (37) of the Northern plateau fall in the field outlined by the dashed line; the field for the Savalan volcanics (36 chemical analyses) is outlined by dots; triangles represent samples of the southern district.

number of gorge like valleys due to deeply incided streams (especially close to the Savalan foothills) have resulted. The main morphological feature of the northern plateau in several districts is therefore given by « mesa »-like structures.

Work in progress on the volcanism of the plateau has shown that while there is a remarkable continuity from east to west of the structural pattern of the faulted tableland north of the Savalan-Qusheh Dagh ridge, there seem to be both a different structure and a different volcanological evolution in the plateau to the south of the Savalan volcano, possibly reaching the Kuh-e-Bozqush ridge. In the northern area fluid, comparatively thin (2 to 5 meters) basic to intermediate, alkaline lava flows have flooded the countryside, and only in a few places small volcanic plugs or domes and other central-type volcanic structures can be observed; in the southern area thick, mostly intermediate and mildly alkaline, lava units and tuffaceous to ignimbritic oversatured sheets reach considerable thickness (up to 50 meters in single units) and may give origin to large central-type volcanoes suck as the Ghasr Dagh to the west of Nir. Subvertical faulting also occurs in the southern tableland and is especially evident in the Nir district, but the bulk of the volcanic succession does not appear to be as disturbed as in the northern plateau.

A network of vertical dykes cuts through the northern plateau. Dykes are conspicuously missing in the southern area: this fact underlies the idea that the northern plateau was not only formed under different conditions from those that gave origin to the southern tableland, but also that it had a different history subsequent to the extrusion of the lavas.

The above observations point to a distinctly fissural volcanism in the northern plateau, whereas in the southern area the structural relations appear to be rather complex. Petrochemical features, highlighting the difference between the above mentioned areas are shown in the alkalies-silica diagram of fig. 2, where the distribution field of the northern plateau lavas and selected analyses of the southern area, as well as the field of the calc-alkaline Savalan suite (ALBERTI et al., 1975), are reported.

It must be stressed that the areal extension of the Plio-Quaternary calc-alkaline effusive rocks is not restricted to the Savalan volcano. Small cupolas and minor tuffaceous to ignimbritic sheets occur for instance near Namin (some 25 km east of Ardebil) and in the district to the north of the Savalan complex, as well in the west of the same volcano.

The general geological pattern of Eastern Azerbaijan outlined above closely reflects the general conditions of Central Iran during Tertiary and Quaternary times described by STÖCKLING (1968). Though being characterized by great mobility, this area at large witnessed a very incomplete geosynclinal development, and was affected by irregular and discontinuous subsidence with predominantly epicontinental to continental sedimentation. Basins and true troughs of limited areal extent developed only locally, and were also very restricted in time.

Repeated volcanic activity took place in Central Iran during the same periods (FÖRSTER et al., 1972; JUNG et al., 1975) but as mentioned above satisfactory data on the nature of volcanism and its time and space relationships are still lacking from a number of districts.

Description of samples

The samples have been selected both on account of their freshness and of their location. An effort has been made to cover a wide areal and stratigraphic distribution. The more alkaline differentiated rocks of the northern area (i.e. comenditic trachytes) occurring in plugs or small volcanic domes, have not been considered in this study in order to get an insight into the age relations of the main plateau-forming event.

In the northern plateau 3 samples of a 200 m thick pile (Harbab Khandi II) consisting of 10 lava flows (one from the lowermost flows: AZ 55; one from the middle part: AZ 60; and one from the top: AZ 64) have been determined in order to obtain not only the absolute age, but also an estimate of the time lapse between the bottom and the top layer. Samples AZ 47 (Harbab Khandi I) and AZ 117 (Mazaraveh, close to the village of Morati) belong to the northern plateau sequences some 40 km away from each other, and have been collected from the middle part of the lava pile.

Two dykes occurring in the central part of the northern plateau, and trending at approximately 90° from each other (the crossing place is not clear) have been sampled and turned out to be unusually fresh.

Rocks from the southern area are generally unfit for absolute dating because of alteration. Two fresh samples (20/2 and 33) have been collected from the base of the volcanic sequence building the Ghasr Dagh, a stratovolcano located halfway between the towns of Nir and Sarab. From another sample of the same volcano (GD 1), anorthoclase has been separated. The rocks 33 and GD 1 have been described elsewhere (Comin-Chiaramonti et al., 1975), and the structure of the alkali feldspar has been studied.

The geographical coordinates and the petrographic definition of the analyzed samples areas are reported below. The coordinates of the Qusheh Dagh samples (QD 2 and QD 5) are not given because they were collected from the fresh debris in the north-eastern slopes of the ridge, in a district where no fresh, reliable bedrook could be found.

Sample AZ 55: Lat. 38°29′19″ N; Long. 48°03′47″ N
Trachybasalt lava flow. Modal composition - Phenocrysts: Plagioclase 30 %; Olivine 4 %; Ore 1 %. Felsitic groundmass with mafic microlites: 63 %.

Sample AZ 60: Lat. 38°29′19″ N; Long. 48°03′47″ E
Phonolitic tephrite lava flow. Modal composition - Phenocrysts: Plagioclase 25 %. Microlites: Analcite 14 %; Ore+Mafics 12 %; Felsitic groundmass: 49 %.

Sample AZ 64: Lat. 38°29′19″; Long. 48°03′47″ E
Phonolitic tephrite lava flow. Modal composition - Phenocrysts: Plagioclase 18 %; Ore 8 %; Analcite 4 %; Olivine 3 %; Clinopyroxene 1 %. Microlites: Analcite 6 %; Ore 4 %. Felsitic groundmass 56 %.

Sample AZ 47: Lat. 38°28′46″ N; Long. 48°05′41″ E
Trachybasalt lava flow. Modal composition - Phenocrysts: Plagioclase 27 %; Olivine 1 %. Microlites: Ore 12 %; Analcite 11 %; Clinopyroxene 1 %. Felsitic groundmass 48 %.

Sample AZ 117: Lat. 38°42′57″ N; Long. 47°37′54″ E
Trachybasalt lava flow. Modal composition - Phenocrysts: Plagioclase 24 %; Olivine 1 %; Ore 1 %; Clinopyroxene 1 %. Groundmass 73 %.

Sample AZ 93: Lat. 38°42′57″ N; Long. 47°37′54″ E
Trachybasalt dyke. Modal composition - Phenocrysts: Plagioclase 33 %; Olivine 6 %. Microlites: Plagioclase 42 %; Clinopyroxene 13 %; Ore 6 %.

Sample AZ 127: Lat. 38°42′57″ N; Long. 47°37′54″ E
Trachyte dyke. Modal composition - Phenocrysts: Plagioclase 13 %; Clinopyroxene 1 %; Biotite 1 %; Sanidine 1 %; Ore 1 %. Felsitic groundmass 78 %. Glass 5 %.

Samples 33 a, 33 b: Lat. 37°57′33″ N; Long. 47°43′57″ E
Quartz-trachyte lava flow. Modal composition - Phenocrysts: Anorthoclase 10 %; Clinopyroxene 1 %. Microlites: Anorthoclase 23 %; Felsitic groundmass: 66 %.

Sample GD 1: Lat. 37°57′33″ N; Long. 47°43′57″ E
Quartz-trachyte lava flow. Modal composition - Phenocrysts: Anorthoclase 19 %; Clinopyroxene 1 %. Felsitic groundmass 80 %.

Sample 20/2: Lat. 37°57′33″ N; Long. 47°43′57″ E
Trachyte. Modal composition - Phenocrysts: Plagioclase 27 %; Clino+Ortopyroxene 4 %; Ore 1 %. Glass 68 %.

Sample QD 5: *Monzonite*. Modal composition - Plagioclase 48 %; Alkali-feldspar 33 %; Biotite 8 %; Clinopyroxene 4 %; Amphibole 3 %; Quartz 2 %; Ore 1 %; Titanite 1 %.

Sample QD 2: *Monzonite*. Modal composition - Plagioclase 47 %; Alkali feldspar 38 %; Amphibole 6 %; Clinopyroxene 3 %; Biotite 3 %; Ore 2 %; Quartz 1 %.

Analytical methods and experimental results

The K-Ar age determinations were carried out on whole rock and on crystals of biotite and anorthoclase separated with standard enrichment methods (heavy liquids and magnetic separator). Potassium was determined by flame spectophotometry; controls have been carried out using international standards as reference. Argon was determined by the methodology used in previous studies (Nicoletti and Petrucciani, 1974), using as reference standards muscovite P 207, muscovite Bern 4 M, phonolite M 2 and obsidinan M. Arci (our internal laboratory standard). These standards have given the following values (standard in parentheses): 80.2 ± 1 (81 ± 1); 18.1 ± 0.8 (18.7 ± 0.5); 7.7 ± 0.4 (7.4 ± 0) and 2.95 ± 0.2 (3 ± 0.2).

Table 1

K/Ar ages of eastern Azerbaijan volcanites

Material used for the dating: B = biotite; A = anorthoclase; W.R. = Whole rock

Sample no.	material dated	^{40}Ar rad/g x 10^{-6}	K %	^{40}Ar rad %	Age (m.y.)
AZ 127	W.R.	6.390	4.78	59.90	33.2 ± 1.0
AZ 93	W.R.	2.815	2.42	43.13	29.0 ± 1.5
AZ 47	W.R.	6.350	4.09	60.25	38.4 ± 1.2
QD 5	B.	7.271	6.20	70.46	29.2 ± 0.5
AZ 64	W.R.	7.174	4.62	76.23	38.4 ± 0.8
AZ 60	W.R.	3.953	2.53	69.60	38.7 ± 1.2
AZ 55	W.R.	6.202	3.85	87.84	39.9 ± 0.8
AZ 117	W.R.	6.213	3.60	82.27	42.7 ± 1.3
33 a	W.R.	1.778	4.22	50.13	10.5±0.3
33 b	W.R.	1.750	4.22	54.97	10.3±0.3
QD 2	B.	2.517	6.42	26.33	9.8±0.8
GD 1	A.	1.762	3.86	68.65	11.4±0.3
20/2	W.R.	1.615	3.65	48.00	10.7±0.5

The results are summarized in Table 1 and are shown in the diagramm of fig. 3. It can be seen that while the age of the rocks of the northern plateau is very close to 40 m.y. (upper Eocene, almost at the onset of Oligocene according to VAN EYSINGA, 1975) a younger age of about 29.my. (middle Oligocene) must be attributed to the dykes. The age of the Ghasr Dagh, in the southern tableland, is around 11 m.y. (middle to upper Miocene).

Somewhat puzzling results have been obtained for the biotites of the Qusheh Dagh monzonites, for which in spite of the remarkable petrographic similarity a widely different age (9.8 ± 0.8 and 29.2 ± 0.5 m.y.) has been determined.

Discussion

The field relationships of the northern and southern area of the Eastern Azerbaijan plateau, outlined in the previous section on the geological setting, have brought to light fundamental structural and petrochemical differences, as well volcanological ones, of the two areas. The main result of this study lies in the

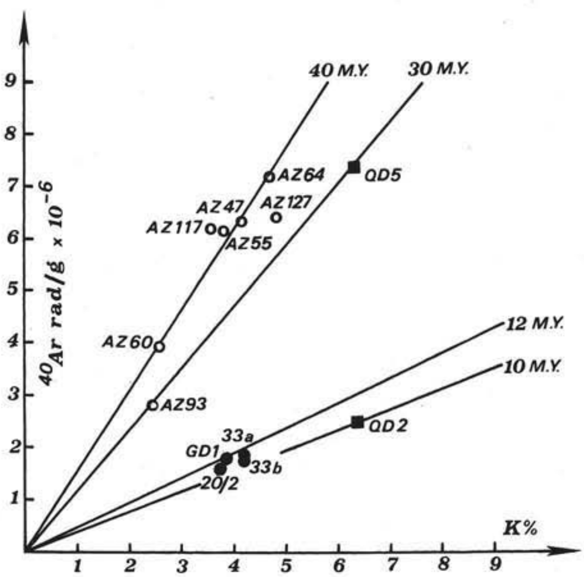

Fig. 3. — Isochronal representation of the experimental results.

proof that a very large time interval (about 29 m.y.) indeed elapsed between the main volcanic (fissural) event of the northern plateau and the volcanic activity of the southern district. A major, unsuspected volcanic phase ([1]) did therefore

([1]) In the stratigraphical tables of the Explanatory Notes of the NIOC's (1959) map an unspecified upper Miocene volcanic facies is actually recorded in the Ardebil area. It has not, however, been reported in subsequent work (see for instance Pazirandeh, 1973).

take place in Eastern Azerbaijan in the middle to upper Miocene, and this fact raises interesting new problems concerning not only its areal extent but especially its relations to the temporally comparatively close Plio-Quaternary calc-alkaline volcanic cycle.

The most important outcome of this study lines therefore in the demonstration that more than two igneous events, well separated in time, affected the area in Tertiary and Quaternary time.

The major volcanic cycle, which brought about the impressive lava sequences of the northern plateau must be attributed to a rather short time span. This is clearly implied, not only by the excellent alignement of the samples along the 40 m.y. isochrone (fig. 3), but also by the internally consistent age distribution of the three samples (Az 55, AZ 60 and AZ 64) from the same volcanic sequence (Harbab Khandi II). The results regarding the northern plateau also show that the major Azerbaijan alkaline volcanism, besides taking place in upper Eocene to early Oligocene and being attributable to an extensional period, was followed some 9 m.y. later by the emplacement of the dyke swarm. The latter possibly represents another igneous event, again to be related to a fundamentally estensional stage.

A difficult problem is posed by the age determined for the two Qusheh Dagh monzonites. These rocks were sampled in order to obtain some preliminary information about the plutonic body, which — as will be recalled from the section on the geological setting — is considered to be a Tertiary granite or granodiorite. Its emplacement in the Tertiary would imply an intrusive (although minor) event due to fundamentally compressive, orogenic — hence of calc-alkaline character — conditions, which do not fit the general geological evolution of the area. A possible explanation might be found assuming that the Qusheh Dagh is a tectonically uplifted block of either older or younger age (i.e., Plio-Quaternary, hence roughly contemporaneous to the Savalan calc-alkaline volcanism).

The ages of the two monzonite samples do, however, show truly Tertiary magmatic events. These rocks are chemically very similar to the lavas of the northern plateau, and — pending further research on the bulk composition of the plutonic body — the intrusive mass can be tentatively considered to represent a plutonic equivalent of the effusive rocks of the same plateau. If this is the case, the younger (about 10 m.y.) of the QD 2 sample might be due to rejuvenation caused by tectonism related to the 11 m.y. volcanic phase.

Clearly, at this stage only reasonable guesses can be done about the true chronological position of the Qusheh Dagh plutonic body. The present results do in any case show that in Eastern Azerbaijan a rather complex sequence of volcanic and plutonic events took place during Quaternary and Tertiary times. Any model of the geodynamic evolution of the area at large must take into account the various stages and types of plutonic activity outlined above.

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