Uranium and Thorium in the Volcanic Processes

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Abstract

Distribution of radioactive elements in the Quaternary alkaline volcanites of Northern Latium has been studied and conclusions of volcanological interest, both as to differentiation of magma in the more superficial levels of the crust and as to the relationship between volcanic eruption and concentration of particular elements, have been drawn.

The following principal results are emphasized:

i) There are two well defined types of distribution of U and Th corresponding to fractional crystallization differentiation and to pneumatolytic (gaseous transfer) differentiation. From the volcanological viewpoint, this double distribution mirrors the hypomagma or pyromagma conditions of the melt, thus allowing the physico-chemical characters of the magma to be defined, in respect to the different magma chambers considered and to the different levels of the same magma chamber, before an eruption.

ii) The distribution of U and Th characterises better the different situations mentioned in i) than major elements do. In effect, in the magmatic conditions examined, the differentiation processes do not affect the magma inside the magma chamber only, but often may push on up to the surface through fumarolic activity. There ensues the selective loss of some of the major elements (K in particular): one can understand this way why the validity of information from major elements from a already cooled magma comes to being much limited.

iii) The close interdependence among gas concentration, increase in trace pneumatophyles and volcanic eruption allows basic information to be extrapolated from concentration and distribution of U and Th to the primary causes of volcanic activity and to the gaseous phase increase and exsolution.

iv) Original magma type being equal, the shape of the magma chamber influences strongly on the kind of differentiation and on the type of volcanic eruption.

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Foreword

The Quaternary alkaline (potassic) volcanites of Latium (Central Italy) are being explored for U and Th by CNEN and 180 analyses of U and Th have been carried out so far (1). The general geologic, geochemical and minerogenetic results of these studies have formed the subject of a detailed paper (E. LOCARDI and S. SIRCANA, 1967). Many aspects both of the distribution and of the absolute quantity of the radioactive elements are closely connected wit the volcanological evolution of the region considered. In this paper it will be attempted to cast more light on the relationship existing between the distribution of the radioactive elements and the processes which involve the magmas in the more superficial levels of the earth crust.

Introduction

The Quaternary magmatism of the Apennine range is represented by products of such a particular chemical composition as to warrant their being classified under a separate serial group. These are the rocks of the « Mediterranean » suite, as distinguished from the rocks of the « Atlantic » and « Pacific » suites, chiefly because of their strong K-content and of their low silicification.

Leucitic rocks, regarded as characteristic of the « Mediterranean » magmas, are geographically, geologically and petrographically connected to the South with products of the « Atlantic » suite (part of the Aeolian Islands, Etna, etc.) and to the North with acid anatectic calc-alkaline volcanites (Mt. Amiata, Mt. Cimino, etc.). Magmatologists start from these two opposite situations to derive the genesis of potassic magmas either from oceanic-type basalts or from melts of the anatectic crustal type.

The particular chemical composition of the Mediterranean rocks also results in a characteristic volcanic activity. RITTMANN's classic studies on Vesuvius, the Phlegraean Fields and Ischia (1933) have stressed the strong explosiveness of the Mediterranean volcanism and the intensive volcano-tectonic activity which attends the effusive ac-

(1) The analyses were made by γ-spectrography. U gas calculated from the area of the photopeak corresponding to Bi^{214}-RaC (.610 *MeV*) and Th from the PB^{212}-ThB photopeak (.240 *MeV*). The rocks are considered in equilibrium, and therefore the U content is extrapolated to Ra content. Under routine conditions, error is less than 10 %.

tivity. Recent researches, however, have shown that the volcanic cones formed by strongly undersaturated and mafic lavas account for the smaller portion of the products of Mediterranean volcanism. This volcanism, in effect, has also involved a large series of effusive processes quite different in type and chemical composition from that so far considered as typically Mediterranean. The few leucititic and mafic strato-volcanoes are blanketed with thousands of square kilometers of foam lavas and ignimbrites of potassic trachytes (« tufo litoide », Latium; « tufi gialli e grigi », Campania) (LOCARDI, 1965; MARINELLI and MITTEMPERGHER, 1966; LOCARDI and SIRCANA, 1967). This fact has made it possible to shift the focus of the investigation from the individual volcanic cones, whose lavas reflect of the local particular geologic conditions of the reservoir, to the magma most widely represented in the region (trachytic magma).

This magma, absolutely predominant and comparatively homogeneous as chemical type and type of effusion, can be regarded as characteristic of Central Italy and the most widely dissimilar differentiates can then be related to this « fundamental » magma. This provides a better framework for the products, from tephritic to leucititic, forming the volcanic structures which, by order of emission, precede the great effusions of trachytic foam lava-ignimbrite. The leucite tephrites and the leucitites, according to RITTMANN (1933), derive from the assimilation of limestones by a magma (trachytic) rising towards the surface. The great effusions which follow represent in fact the « trachytic » magma purified from the products of reactions with the wall rocks.

The term « purified » relates solely to the elements which have altered the characteristics of the trachytic magma after the major processes which have contributed to its formation, and which are unconnected with the rapid exchanges which may take place in a more crustal and properly volcanologic medium.

Distribution of U and Th in Northern Latium

The above mentioned reorganisation of the geology of Quaternary alkaline volcanites proved essential with a view to approaching in an organic and pertinent manner the study of the distribution of U and Th. The Mediterranean magmatism manifests itself along the system of peri-Apenninic fissures; so far we have investigated its products in the areas farther North (Vulsini, Vico and Sabatini volcanoes), over about 4,400 square kilometers of territory. Thanks to the limited number of large effusions which, with fairly similar characters, radiate from the three major effusion centers, 180 analyses proved sufficient to provide a meaningful balance of the distribution of U and Th in the fundamental magma of this region. Such analyses also include numerous lavic products of the early stage of volcanic activity, syntectic by assimilation of carbonates.

The overall balance shows that in all products considered, whatever their degree of differentiation, U and Th are contained in a quantity at least five times as large as that proper of rocks of similar chemical composition, with the same potassium percentage. Starting from these anomalous quantities, the enrichment in U and Th follows the path indicated by other researchers, *i.e.* it occurs apace with the proceeding of the differentiation from the mafic to the acid types.

The highest contents reached through differentiation by fractional crystallisation, however, are doubled in certain trachyphonolitic rocks, or in other rocks which, because of their chemical characters, would be hardly distinguishable from those of the normal series.

In effect, from the comulative frequency diagrams (Figs. 1 and 2) [2] two clearly defined and regular distribution curves are plotted. The former, corresponding to the agerage values of 25 ppm of U and 110 ppm of Th, relate to the more general case of the « fundamental magma » being differentiated from latitic to alkali-trachytic types. The latter, instead, corresponding to average values of 45 ppm of U and 210 ppm of Th, reflect more particular situations added to the normal differentiation and evidenced by the U and Th contents much more than by other parameters. Let us consider them in greater detail describing briefly the various volcanic enviroments and by relating them to U and Th contents.

The Latera Volcano

From the Vulsini volcanic system we shall take as an example the Latera Volcano, which is its largest and better preserved volcanic edifice.

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[2] The histograms were made by attributing to each value a rectangle with constant height having the base equal to the analytic error and centered in respect to the experimental result.

In an area where the magmas have risen over a large area from a great number of vents, Latera is the only one where a large series of products were emitted from a main pipe. Therefore, it is the only

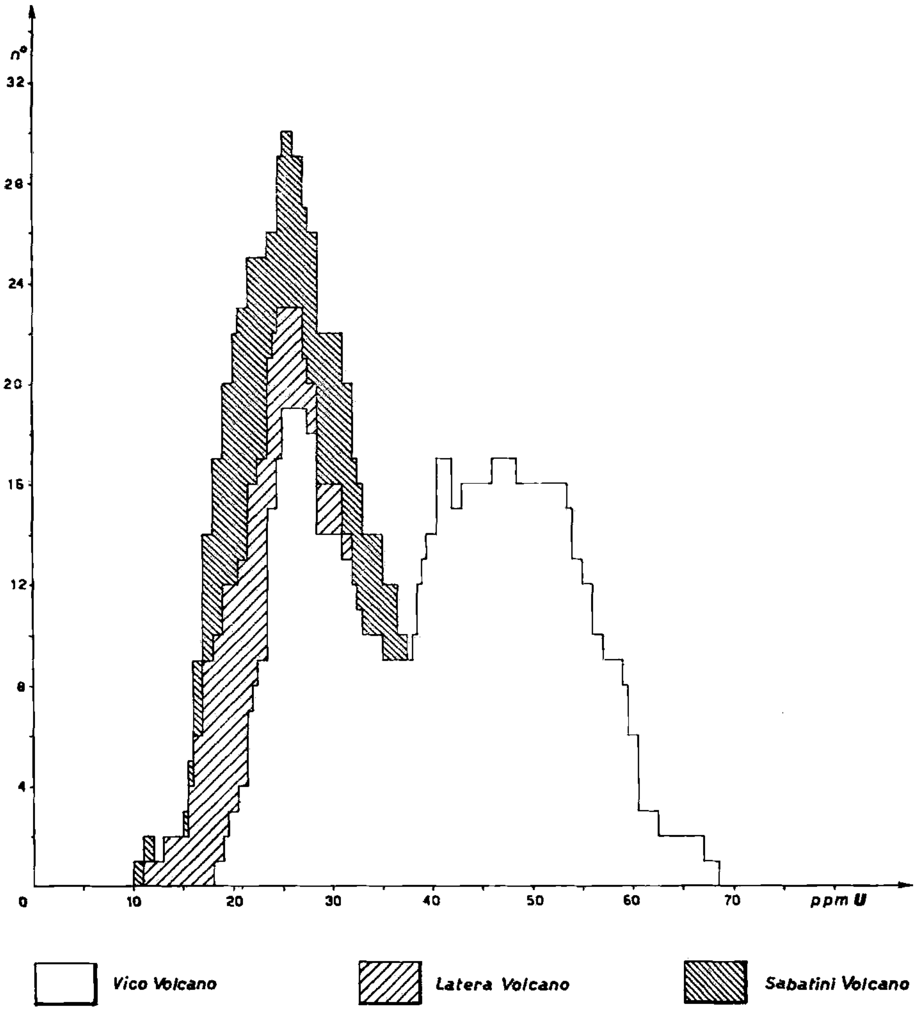

FIG. 1 - Uranium distribution in Northern Latium ignimbrites.

volcano for which petrographic and volcanological correlations on the effusive succession can be made.

The Latera products are many; however, considering our research approach of taking into consideration only the major magma manifestations, the main stages in the evolution of this volcano can be reduced to relatively simple pattern [3].

The succession of the Latera products seems to reflect the emp-

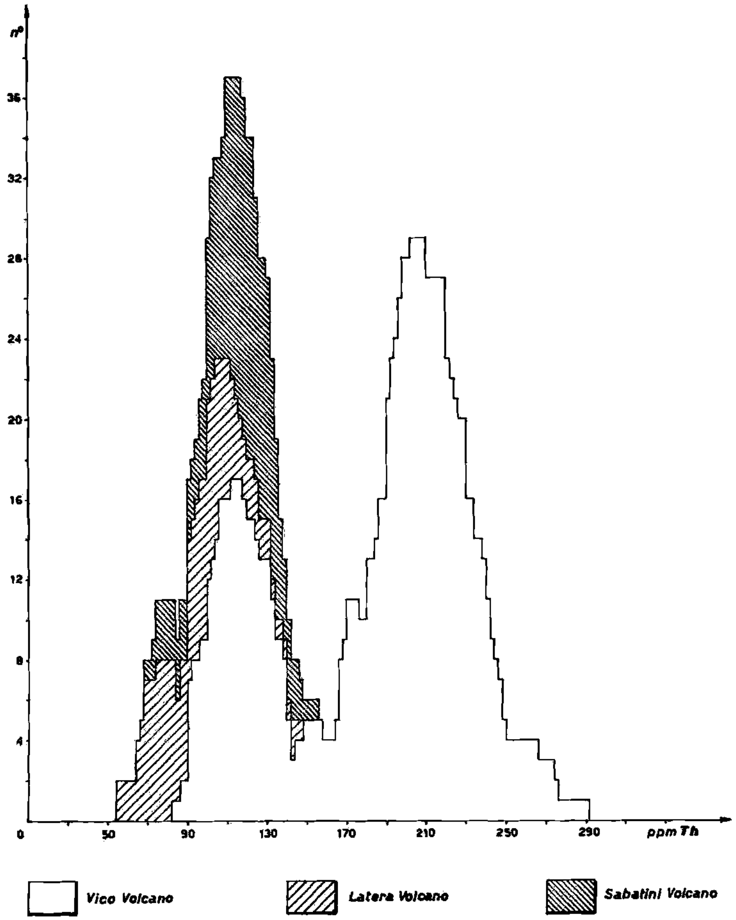

FIG 2 - Thorium distribution in Northern Latium ignimbrites.

tying of a magma column in which had occurred a stratification of magma types, due to differentiation processes. The trachyte-latite-trachybasalt succession would seem to indicate that the prevailing

(3) The information given here is based on a series of observations and chemical analyses (unpublished) carried out in the course of these researches to supplement bibliographic indications (MODERNI, 1903; SABATINI, 1912; SCHNEIDER, 1965).

differentiation was that by fractional crystallisation. A slight tephritic tendecy (undersaturation of silica), involving chiefly the intermediate terms of this series, would seem to suggest a concurrent pneumatolytic differentiation. The latter, however, was not very advanced, perhaps due to the rapid succession of the effusions interspersed with explosive manifestations, which did not leave the gaseous phase sufficient time to cause substantial chemical changes in the magma.

The magma succession observed, therefore, should indicate the zonality of the processes of differentiation of a magma under relatively superficial conditions.

The pattern of U, Th and K contents and of their relations is in accord with the available data on other types of magma subjected to similar processes (Heier *et al.*, 1964), except as regards the exceptionally high U and Th contents.

Table 1 - Average contents of U, Th and K in the major effusions of Latera volcano.

	No. of samples	U, ppm	Th, ppm	K, %	$Th \cdot 10^4/K$	$U \cdot 10^4/K$	Th/U
Trachyandesites and trachybasalts (*)	3	8	40	3.5	11.4	2.2	5
Latites (Form. 3)	7	16	76	6.9	10.7	2.3	4.6
Trachytes (Form. 2)	11	21	89	7.7	11.4	2.7	4.3
Alkali-trachytes (Form. 1)	7	24	106	7.1	14.9	3.4	4.4

(*) The contents of this group correspond to the lower limit of the method of analysis adopted as routine; the data shown have therefore an indicative value.

In other words, in the differentiation series, the increase in U and Th contents is proportional to that of K, with a slight relative increase which causes the Th/K and U/K ratios to increase progressively. The decrease in K occurring in alkali-trachytes is compensated by an increase in Na, whereby we can consider as respected the general rule and the order-of-magnitude of the increase in U and Th contents as the differentiation proceeds, the degree of which is represented by the alkali contents.

This is what appears from a comparison of the averages of the values relating to each effusive unit considered. If instead the individual values are arranged in a histogram (Fig. 3), we will see that for both U and Th the values tend to come together along a single distribution curve, in which the contents of Formation 1 (al-

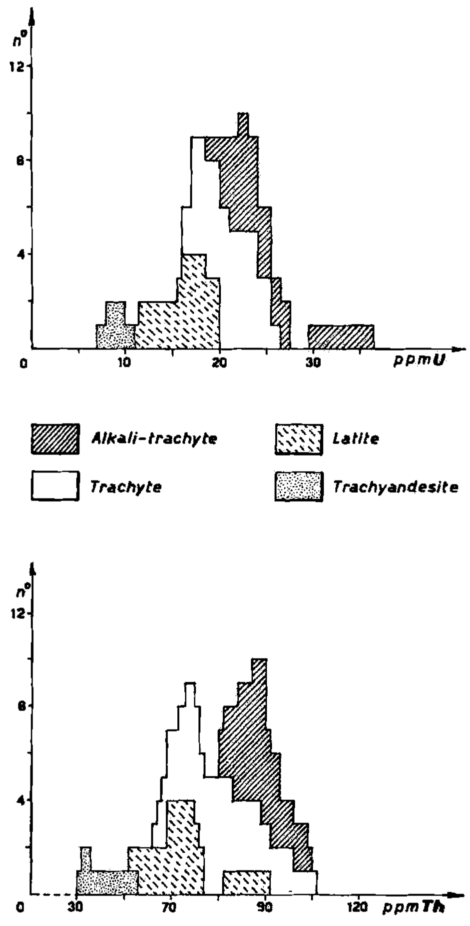

FIG. 3 - Uranium and Thorium distribution in the Latera volcano products.

kali-trachytes) are higher than those in Formation 2 (trachytes) to the same amount by which the latter are higher than those in Formation 3 (latites). The continuity and regularity of distribution in the phases of differentiation considered indicate the homogeneousness of the differentiation processes in that magma reservoir.

The Vico Volcano

The Vico Volcano is located some 30 miles SE of Latera Volcano, and similarly to the latter it is a strato-volcano covered with great sheets of trachytic foam lava-ignimbrite. Unlike Latera, it has a very large vertical development and constitutes the only centre of emission of the « fundamental magma » in a very wide area. Its conduit is therefore likely to have been much longer than Latera's. Furthermore, its pyroclastic products are very rare both in the first volcanic stage (emission of progressively more acid syntectic lava) and in the second stage of activity (effusion of large masses of foam lava-ignimbrite, followed by a caldera collapse).

The effusion cycle in the second phase develops in the following order: 1) tephritic trachyphonolites (Formation A); 2) saturated trachytes (Formation B); 3) latitic trachyphonolites (Formation C); 4) trachyphonolites (Formation D).

In this case, we are no longer dealing with the rapid eruption of the various levels of a magma already differentiated in that order, as it happens at Latera, but with a series of effusions (A, B, D) of the top portion of a magma reservoir, the deeper portion of which was emitted due to particular volcano-tectonic conditions, with eruption C (LOCARDI, 1965; LOCARDI and SIRCANA, 1967).

In the volcanic cycle of Vico, Formation A is the first great effusion of the fundamental magma, no longer syntectic by assimilation of limestones. The magma emitted reached about 1 cubic kilometer, corresponding to about 3 cubic kilometers of rocks of various degrees of porosity. Formation A presents some inhomogeneousness, both as chemical composition and emplacement manner of its products. Chemical composition ranges from trachylatitic to trachytic; the silicification is variable, sometimes resulting in the presence of tephritic-phonolitic types. Probably, a pneumatolytic differentiation indirectly desilicising the magma by alkali increase was superimposed on the differentiation by fractional crystallisation. Thus, the normal trend from trachyte to latite was shifted to tephritic phonolite. The effect of these processes on the distribution of U and Th can be easily represented, due to the particular modes of effusion of Formation A. The beginning of the effusion is marked by vitroclastic ignimbritic rocks, which derive from the gas-richer parts of the magma reservoir, being the poorest in heavy minerals. There follows, in the form of foam-lava gradually turning into lava, the portion corresponding to the deeper sector of the magma. The U and Th histograms (Fig. 4) confirm this zone pattern, showing two homogeneous distributions relating to the magma solidified as ignimbrite and to that solidified as foam lava; *i.e.* relating to the upper and lower portions of the effused magma column. In the ignimbritic facies, the U and Th contents form regular distribution curves around the average values of U = 50 ppm; Th = 220 ppm. In the foam-lava facies, instead, the U and Th contents are regularly distributed around averages of respectively 40 and 200 ppm.

There follows Formation B, which is composed of several flows of ignimbrite and foam lava rapidly succeeding each other in time, involving a total of 0.5 cubic kilometer of rock (approx. 0.2 cu.km of magma). As compared to Formation A, the chemical composition has evolved in a more acid sense (increase in silica and decrease in mafic components). Within Formation B, however, a continuous variation is observed between saturated trachytes and trachyphonolites, due to small variations in silica. The sector of magma effused with Formation B probably represents the top differenziate of the magma which was evolving in a trachytic sense. In the top sector considered, however, there was developing a pneumatolytic differentiation, which resulted in a widely varying silicification. This situation had certain effects on the distribution of U and Th (Fig. 5). The main emitted mass has contents regularly grouped around average values of 47.5 ppm of U and 208 ppm of Th, while other lesser flows, more highly silicified, show progressively lower contents (averaging U = 27.5 ppm and Th = 130 ppm).

Subsequently there comes the great effusion of Formation C. In this stage, more than 3 cubic kilometers of magma effused (approximately 10 cubic kilometers of foam lava-ignimbrite). The chemical composition varies from latitic to trachytic, always more mafic than the preceding effusion, with the sporadic presence of tephritic-phonolitic types. The crystallisation of this magma is very low, and its general characteristics are those of the magma type most widely represented in Northern Latium. This is therefore the « fundamental magma », little or not at all altered by the top differentiation processes which acted on the preceding effusion products. These peculiarities are in accord with the type of U and Th distribution. In effect, through the entire 10 cubic kilometers of rock, the values depart but little from the average (U = 27 ppm; Th = 118 ppm), as though with this Formation there had been emitted rapidly that

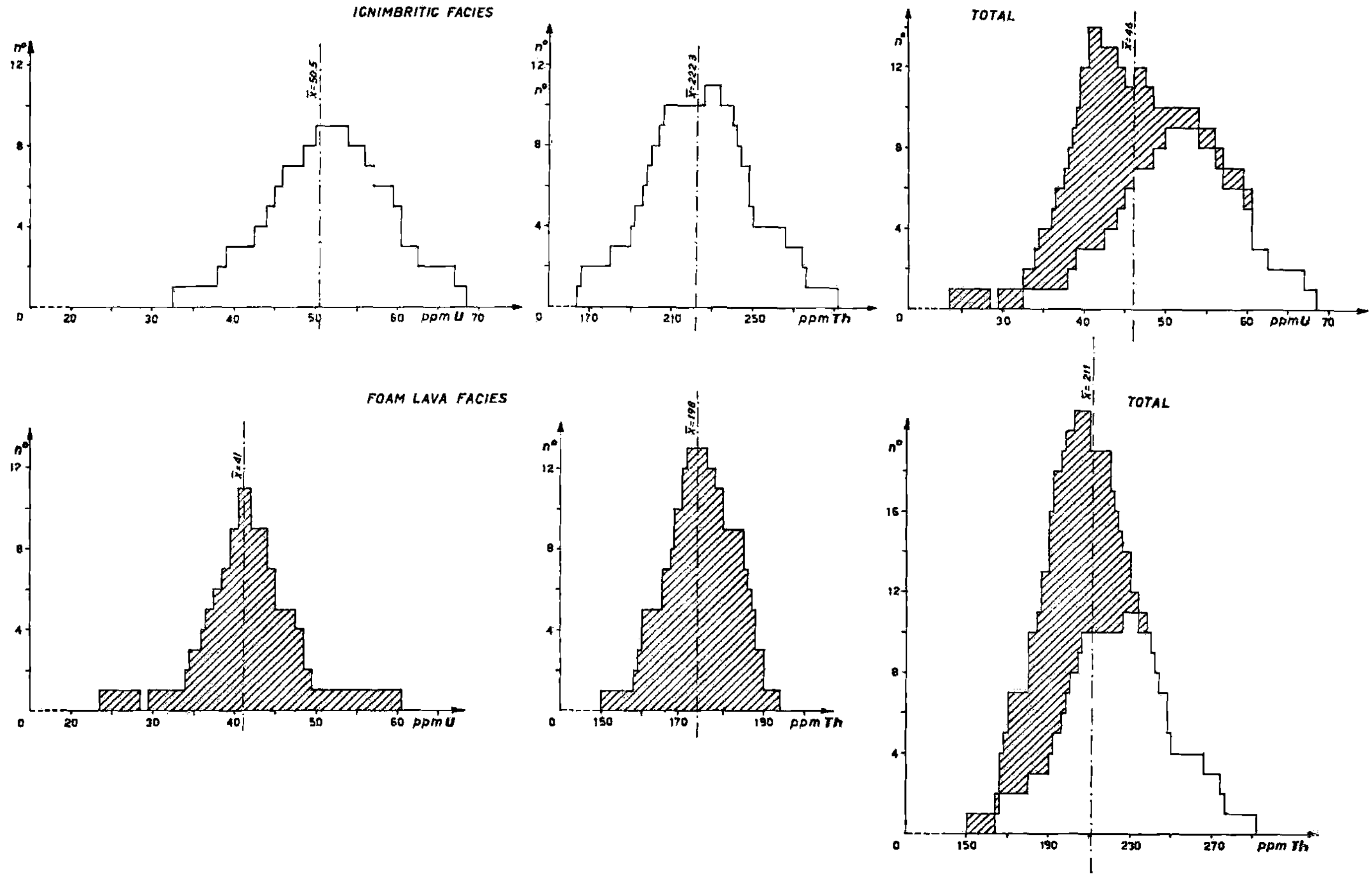

FIG. 4 - Vico Volcano. Uranium and Thorium distribution in Formation A.

portion of the fundamental magma in which the enrichment gradients were not appreciable. The higher values correspond in general to the rocks which depart from the normal differentiation trend (latite-trachytes) because of their tephritic or phonolitic tendency. These rocks, which are obviously affected by an apical pneumatolitic differentiation, are quantitatively negligible as compared to the entire effused mass, and their U and Th contents do not alter the regularity of the distribution curves.

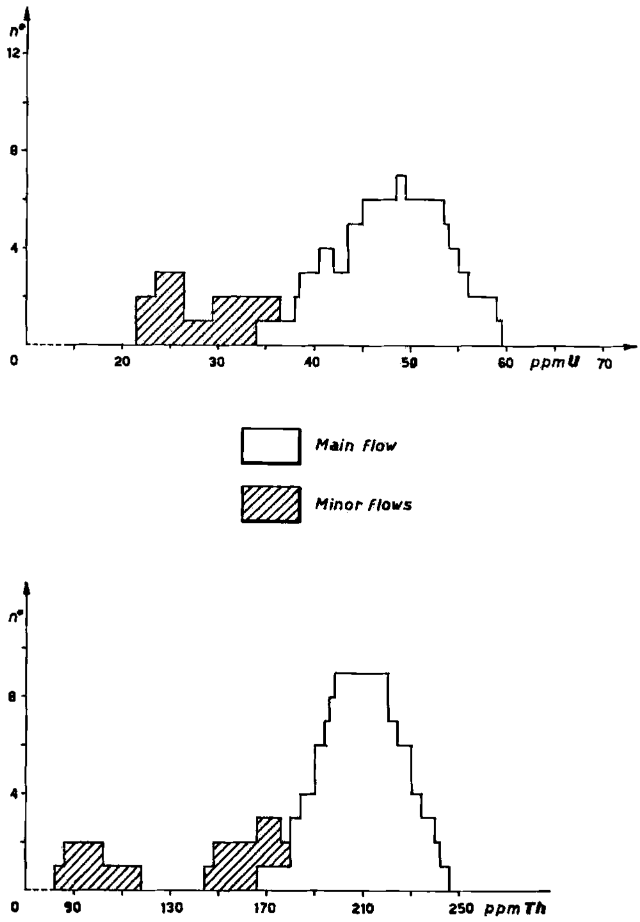

FIG. 5 - Vico Volcano. Uranium and Thorium distribution in Formation B.

This great effusion is followed by the caldera collapse accompanied by the effusion of Formation D. The magma emitted in this phase is qualitatively very similar to that of Formation B (from trachytic to trachyphonolitic in composition), although quantitatively still smaller. The few data available indicate a recovery of the U and Th enrichment as compared to Formation C, in accordance with the apical differentiation conditions reflected by this volcanite.

Summing up, it would seem that in the Vico Volcano the various effusions represent the successive top differentiates, in part pneumatolytic, of the « fundamental magma » which in the meantime was normally becoming differentiated by fractional crystallisation.

Figure 6 shows the relations obtaining between the bottom part of the magma and its upper portions: for U and Th frequency curves representing the « fundamental magma » can be clearly distinguished from those of its top differentiates. Considering in particular in each effusion the values of the first portions emitted as compared to the last (*i.e.* those closest to the principar portions of the magma from which they have become differentiated), we will find the terms of transition towards the U and Th contents of the « fundamental magma ».

The variation of the U and Th contents in the products of this volcano therefore corresponds to the position which the emitted magma occupied in the reservoir, *i.e.* with the processes taking place in the various magma sectors. The sharpest differences are found between the top portions, where surface conditions promote a pneumatolytic differentiation (pyromagma) and the deeper portíons, where hypomagma conditions prevail.

The differences in chemical composition of the various products, however, are not such as to suggest a differentiation process which has so markedly affected the distribution of U and Th. The law of U and Th increase with K, and of the relative Th > U > K increase, which we have seen as operating in the Latera case, does not seem valid in the Vico case.

When the data are arranged by increasing U and Th contents (Table 2), the law that their ratios to K increase in the course of the differentiation is respected, but this is not true of the correlation with potassium. On the other hand, the K content follows rather closely the principal trend of the differentiation in the Vico Volcano: from average 5.8 values in the fundamental magma it rises to 6.5 in its first differentiate, to 7 in the second and to 7.2 in the third. We

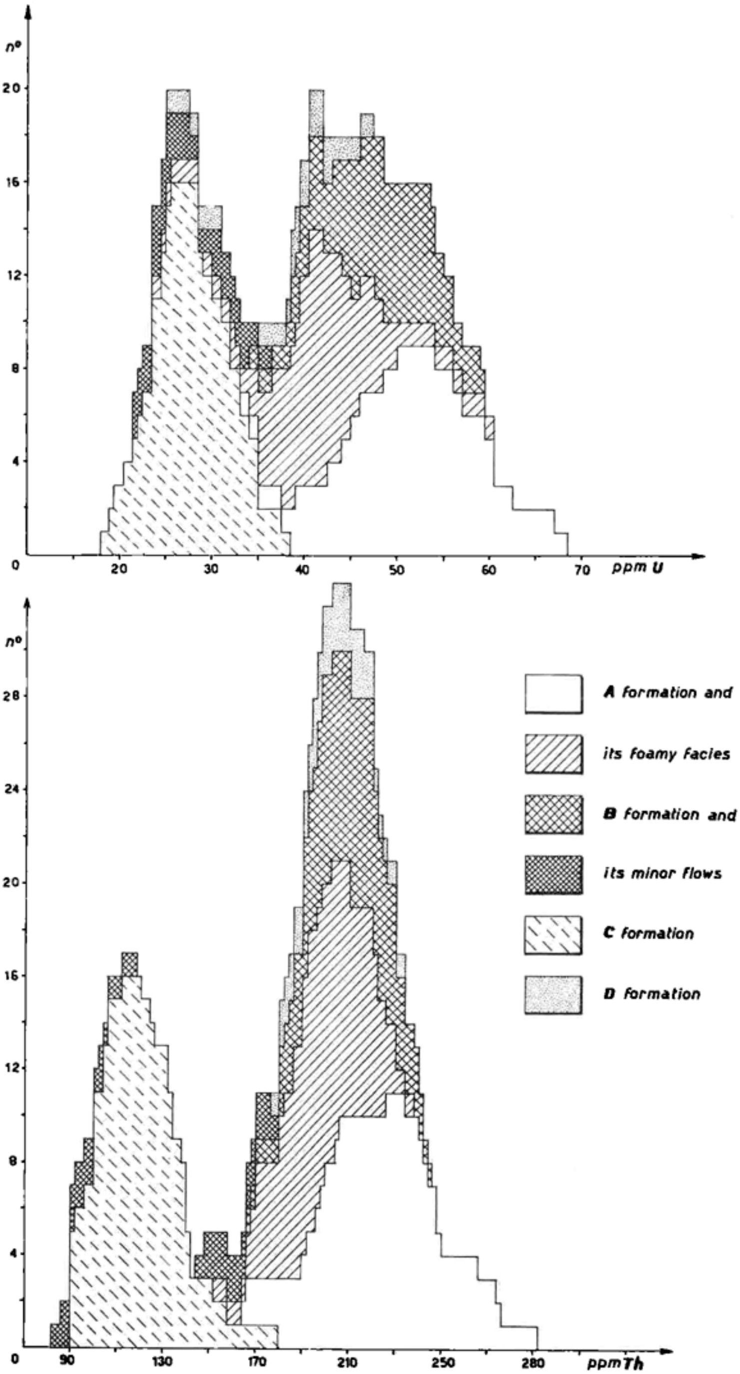

FIG. 6 - Vico Volcano. Relationship between Uranium and Thorium distribution in deep-seated magma and in its superficial differentiates.

should infer from this that the U and Th enrichment is connected not only with the magma differentiation process, as indicated by the pattern of its major components, but also with some other factor added to it.

It appears from Table 2 that, starting from the fundamental magma, the U and Th contents increase as the volume of magma emitted increases. In the absence of dynamic stresses, the volume of magma emitted coincides with the volume of pyromagma which has been forming by progressive oversaturation in the upper levels of the reservoir, *i.e.* with the time during which this process could

TABLE 2 - Average contents of U, Th and K in major effusions of Vico Volcano.

Formation	No. of samples	U, ppm	Th, ppm	K, %	$Th \cdot 10^4/K$	$U \cdot 10^4/K$	Th/U	Magma cu.km
C	30	27	118	5.8	20	4.7	4.4	3
D	3	37	203	7.2	28	5.1	5.5	0.1
B	15	47	208	7.0	30	6.8	4.4	0.2
A	30	50	222	6.5	34	7.7	4.4	1

take place. The effect of the time factor would appear to be such as to superimpose itself on the effect of the differentiation. In effect, a pyromagma with a relatively low degree of chemical evolution (Formation A) but remaining quiescent for a long period, has allowed U and Th concentrations higher than those in a pyromagma highly differentiated (Formation D), but left quiescent for a brief period.

The Sabatini Volcanoes

The Sabatini Volcanoes consist of a multiplicity of eruption vents and calderas. There is no principal edifices (such as Latera in the Vulsini Volcanoes) on which we can conduct a close investigation of the petrogenetic evolution to be related to the U and Th distribution. Among the major effusion products, two are characteristic and are found over almost all of the vast Sabatino territory. The first great effusion (Formation I), which begins the volcanic cycle in the area, has a composition from saturated alkali-trachyte to oversaturated trachyte, close to rhyolite. The following Formation (II) has the characters of the « fundamental magma » of Latium, *i.e.* slightly undersaturated trachyte.

The U and Th distribution in Formation II is practically identical to that of the respective effusions of Vico and Latera (see Table 3).

Their contents in Formation I, instead, are exceptionally low.

From a petrogenetic standpoint, Formations I and II of the Sabatini Volcanoes could have the same meaning as Latera's Formations 1 and 2, *i.e.* represent the sectors of a magma reservoir in which the differentiation products are stratified. However, the trachyrhyolitic character of Formation I renders highly unlikely a petrochemical bond with the subsequent effused trachyphonolitic magma. Other processes must have taken place to confer on these rocks the particular chemical composition and the low concentration of radioactive elements.

TABLE 3 - Average contents of U, Th and K in major effusions of Sabatini Volcanoes.

	No of samples	U, ppm	Th, ppm	K, %	$Th \cdot 10^4/K$	$U \cdot 10^4/K$	Th/U
Form. I	5	18	100	5	25	3.1	5.5
Form. II	16	24.5	116	7.7	15	3.2	4.7

One of these processes might be the hybridation of the « fundamental magma » with acid anatectic residues. The eastern sector of the Sabatini Volcanoes contains many Quaternary acid calc-alkaline intrusions and effusions. In the same area, between the clearly calc-alkaline and the « mediterranean » types, a whole succession of products with an intermediate chemical composition can be observed. The hybridism of the trachytic differentiate could thus account for the high Si and Al contents and for the decrease in U, Th and K contents.

This arguments, however, concern more closely the processes which caused the formation of one fundamental magma than the processes of differentiation in the volcanic environment, and therefore fall outside the scope of this paper.

Conclusive Considerations

In order to obtain concrete information as to meaning of the U and Th distribution in the magma products considered, it is necessary to connect a given distribution with a given volcanologic situation, and then relate it with its petrochemical characters. To this end, certain areas have been selected which can be clearly differentiated by distribution and type of the volcanic structures. From a surface examination it was possible to deduce the main characters of the magma reservoirs in the areas considered, according to the following criteria.

In a vast volcanic area (in the order of 1,000 square kilometers), characterised by hundreds of eruption centres — none of them predominant to the point of giving a central volcanic edifice — and by several calderas, we can assume the presence, at shallow depth, of a volcanic reservoir of large horizontal extension. This assumption is supported by the high percentage of syntectic products formed by assimilation of carbonates, as it should obtain where a vast surface of magma was left in contact with the calcareous sediments of the substratum. On the contrary, if in a vast area there is a single volcanic edifice, in which syntectic rocks appear to a minor extent, then there should be a volcanic reservoir considerably extended in heigth.

In this manner we have selected and examined, in increasing detail, the conditions relating to:

1) the magma of a reservoir of large horizontal extent (Sabatini Volcanoes);

2) the magma of a reservoir predominantly extended horizontally, which finds a preferential but not exclusive eruption path (Latera Volcano in the Vulsini range), and

3) the magma of a reservoir extending vertically, flowing out of a single eruption vent, through which is emitted a quantity of products comparable to that effused under situations 1) and 2) (Vico Volcano).

From the petrochemical viewpoint, in the three situations considered the great effusions of the fundamental magma do not show appreciable differences. On the contrary, the lesser effusions which correspond to the differentiates of the fundamental magma have different chemical characters depending on the shape and depth of the sector of magma reservoir in which differentiation took place. As compared to the fundamental magma, of average Mediterranean serial character ($\sigma = 10$), its differentiates under conditions of reservoir widely extended horizontally are definitely shifted towards an calc-alkaline serial character ($\sigma = 5$). An intermediate situation obtains in the case of the differentiates of a horizontally-extended reservoir with one preferential effusion path. The top differentiates under conditions of vertically-extended reservoir tend instead towards the strong Mediterranean serial character ($\sigma > 10$).

From the standpoint of U and Th distribution, the magma products relating to the three situations considered are comprised within a distribution curve homogeneous and symmetrical with respect to the average value. An exception is provided by the top differentiates of the Vico Volcano, whose U and Th contents are grouped around an average value higher than that of the fundamental magma (Figs. 1 and 2).

When examining the situation of the fundamental magma in the three groups considered, we see that the average value (particularly for U) increases from the Sabatini to the Latera and to the Vico. This means that, the magma type being equal, the shape of the reservoirs sets in motion processes which affect the distribution of the radioactive elements, while leaving unchanged the principal chemical characters of the magma. The dispersal of this frequency curve around the average value corresponds to the differentiation range which could obtain under those conditions. The example of the Latera volcano shows the prevailing type of differentiation (fractional crystallisation) and the extent of the U and Th variations between the various terms of such differentiation.

In the case of Vico, instead, the differentiation is such as to cause the frequency split in the distribution of radioactive elements. The petrochemical study of the rocks corresponding to the two frequency maxima discloses the effects of a pneumatolytic differentiation in the more radioactive magma, superimposed on the general type of differentiation. However, the participation of the principal pneumatophyile elements in the new conditions of differentiation is not such as to suggest such a strong increase in the U and Th contents.

By comparing the various situations considered, it clearly appears that, as the reservoir assumes a more elongatee shape, *i.e.* as the pressure and temperature gradients in the magma become more appreciable, the rate of U and Th increase diverges more and more from the pattern of connections with the normal processes of petrogenetic differentiation, till it completely escapes petrochemical control.

Figure 7 shows such relations. On equal K contents considered, Th contents increase almost two-fold from the deep magmas of Latera to the deep magmas of Vico, and from the deep to the top magmas of the latter. These different situations are reflected not only by the Th content, but also by its different relations with K. The

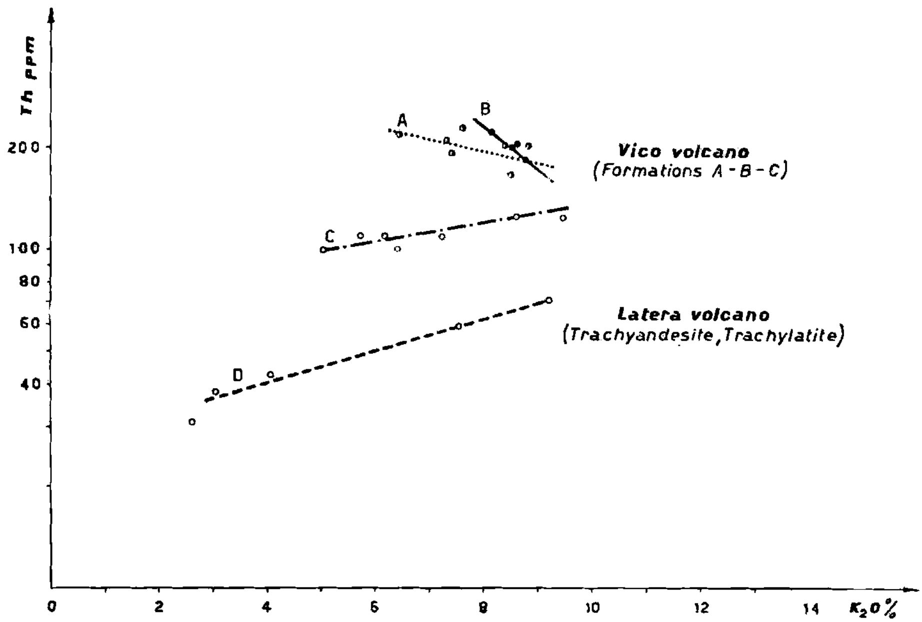

FIG. 7 - Thorium versus Potassium diagram for Vico and Latera Volcanoes.

normal increase as differentiation proceeds is indicated by line D (Latera). Line C (fundamental magma from Vico) shows a less rapid increase of Th as K increases. In the top differentiates we progressively reach a more and more marked reversal of the relations between Th and K. In effect, Th increase as K decreases, this increase being in direct proportion with the shallowness of the differentiate portion in the magma reservoir. We can conclude that the direction of the segments shown in Fig. 7 indicate, in comparative terms, the taking place in its more superficial differentiates. In this connection we concluded that the types of processes which affect the deeper portions of the magma are attributable, from a volcanologic standpoint, to a hypomagma and those in the shallower portions to a pyromagma. Since all magmas are effused in the form of pyromagma, the distinction drawn is intended to stress the different conditions of:

1) magmas whose effusion is due to the increase in partial gas pressure by retrograde boiling in a limited portion of the magma reservoir, sufficient to overcome the external pressure and to allow the effusion of the remaining and predominant magmatic mass which up to that moment was in hypomagma conditions (or even magmas whose effusion is due to external forces);

2) magmas which were effused after participating on a large scale in the release of the gaseous phase and in the consequent pneumatolytic differentiation.

In the former case a very limited portion of magma participates in the pneumatolytic differentiation, and the U and Th distribution remains basically the one which associated with the mild hypomagma differentiation processes.

In the latter case only the portion was emitted which was in pyromagma conditions prior to the effusion; since the factor is the same which causes the effusion of the magma and the enrichment in U and Th, *i.e.* the release of the gaseous phase, it ensues that there exists a strict relationship between the material erupted and certain contents of radioactive elements.

This consideration accounts for the dual distribution observed; the causes which determine the different conditions of the magma prior to the eruption will be discussed elsewhere and on the basis of an ampler documentation.

Even the limited dispersal observed in the high-content population is explainable if we consider that the process which determines of eruptibility of the magma and the buildup of radioactive elements is the same. Since the buildup of gases in the summital portions of the reservoir cannot continue indefinitely, but ends with an eruption of the magma oversaturated with gas, by the same token the enrichment of the gas-connected radioactive elements can not be indefinite.

What are the mutual relations of the pneumatolytic constituents under these extreme conditions of enrichment is still a wide-open field for investigation. This analysis is further complicated if we admit that part of the gases and of the elements tied to it can escape from the magma. This might perhaps account for the dissociation found in the enrichment in U and Th on the one side, and in K (and Na in the case of Vico) on the other, in the more superficial levels of the magma conduit. In this connection, it should be noted that the alkali content decreases in the rocks corresponding to the more superficial parts of the reservoir, and that this decrease is associated with the abrupt saturation of the rocks with alumina, as though alkalis tied to it could have been mobilised.

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