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G. M. Di Paola (*), M. Puxeddu (*), R. Santacroce (**)

# K-Ar AGES OF MONTE ARCI VOLCANIC COMPLEX (CENTRAL-WESTERN SARDINIA)

Riassunto. — Nella Sardegna Centro-Occidentale, la regione dove attualmente affiorano sedimenti marini oligo-miocenici e depositi continentali quaternari (Trexenta, Marmilla e Campidano), rappresenta un esteso graben a direzione NNO-SSE. In questa area si sono avute manifestazioni vulcaniche durante il Miocene medio e durante il Plio-Pleistocene.

Il Monte Arci è un complesso vulcanico allungato in direzione N-S situato sull'asse mediano di questo graben continentale terziario. I nuovi dati geocronologici e il rilevamento geologico indicano l'esistenza di due distinti periodi di attività vulcanica: il primo, di età medio-miocenica (15-16 milioni di anni), è costituito da prodotti sottomarini di affinità calco-alcalina, mentre il secondo (3,5-3 milioni di anni), è rappresentato da eruzioni fissurali subaeree di lave subalcaline associate a prodotti di tendenza alcalina più marcata. Il vulcanismo calco-alcalino non è geneticamente legato alla formazione della struttura distensiva principale che probabilmente preesisteva all'inizio dell'attività vulcanica.

La tettonica Plio-Quaternaria legata allo sprofondamento del Mar Tirreno è probabilmente responsabile della formazione del graben del Campidano sensu strictu; si ritiene che questa recente attività tettonica distensiva sia anche correlata al vulcanismo subaereo recente del Monte Arci e di altre aree della Sardegna.

Abstract. — In Central-Western Sardinia the region presently occupied by Oligo-Miocene marine sediments and by Quaternary continental deposits (i.e. Trexenta, Marmilla and Campidano) is an important NNW-SSE graben structure. This area has been the site of volcanism during Lower and Middle Miocene and during Plio-Pleistocene times.

Monte Arci is a volcanic complex set along the median axis of this Tertiary continental graben.

New geochronological data and field evidences indicate two distinct periods of volcanic activity. The former is Middle Miocene in age and represented by submarine calc-alkaline basic lavas whilst the latter is Plio-Pleistocene and represented by subaerial fissural eruptions of subalkaline lava-flows associated to more alkaline products.

The calc-alkaline volcanism is not related with the formation of the main graben structure which probably pre-existed in this part of Sardinia.

The Plio-Quaternary tectonics related to the foundering of the Tyrrhenian Sea is probably responsible for the formation of the recent Campidano s.s. graben. This recent tensional tectonic activity is also responsible for the Monte Arci subaerial volcanism and for that of other areas of Sardinia.

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(*) Istituto Internazionale di Vulcanologia, C.N.R., Catania.
(**) Istituto di Mineralogia e Petrografia, Università di Pisa.

## Introduction

Monte Arci is a Late Tertiary volcanic complex located in Central-Western Sardinia about 20 km SE of the town of Oristano. It is elongated in a roughly NS direction for about 25 km while its average width is of about 6-7 km. This volcanic complex reaches a maximum elevation of 812 m. a.s.l. to the West, while to the East its products are not found at an elevation less than about 500 m. a.s.l.. The total surface of the Monte Arci volcanic complex is of about 150 km$^2$.

Some geological and petrochemical data of the western part of M. Arci volcanic complex have already been given by Washington (1913). Descriptions of the geology of part of the eastern border of M. Arci can be found in Atzeni (1958; 1959) whilst Maccioni (1965) has described some Miocene volcanic products outcropping in the Marmilla area (East and South-East of M. Arci). Geological maps at a sufficiently detailed scale as well as geologic and stratigraphic descriptions of the M. Arci volcanic complex as a whole, are still lacking. Although some geochronological data concerning M. Arci and other volcanic products of this part of Sardinia are presently available (Bigazzi et al., 1971; Belluomini et al., 1970; Civetta personal comunication), the stratigraphic relations existing among the different products of M. Arci and the older lavas outcropping in this area are not satisfactorily clear. A summary of the volcanology and tectonics of M. Arci volcanic complex together with 10 new K-Ar ages of the lavas of this area are presented in this paper with the purpose to better define the magmatic events which occurred in this part of Sardinia since Middle Tertiary up to Pleistocene.

## Tectonic setting

The paleozoic basement of this part of Sardinia is affected by a system of NNW-SSE normal faults which have produced a typical graben structure: the well known Campidano graben. However it has to be pointed out that the Campidano (s.s.) graben, although more depressed and better defined, represents the western part of a more important graben structure corresponding to a region presently occupied by Oligo-Miocene marine sediments and Quaternary continental deposits (Marmilla, Trexenta and Campidano itself) (Fig. 1). This main structure already existed in Late Oligocene time whilst the Campidano s.s. graben is the result of a more intense tectonic activity which affected asymmetrically this area during (according to Pecorini and Pomesano-Cherchi, 1969) Plio-Pleistocene time. At its Northern limit the Campidano-Marmilla-Trexenta graben is interrupted by a system of NE-SW trending lineaments; at the intersection between the two main tectonic directions (NE-SW and NNW-SSE) a Plio-Quaternary alkaline volcanic complex exists: Montiferru. M. Arci is located not far from the north-western limit of this structure and it has always been considered (Washington, 1913; Atzeni, 1959) as bordering to the NE the Campidano graben. This, in fact, is its position if one

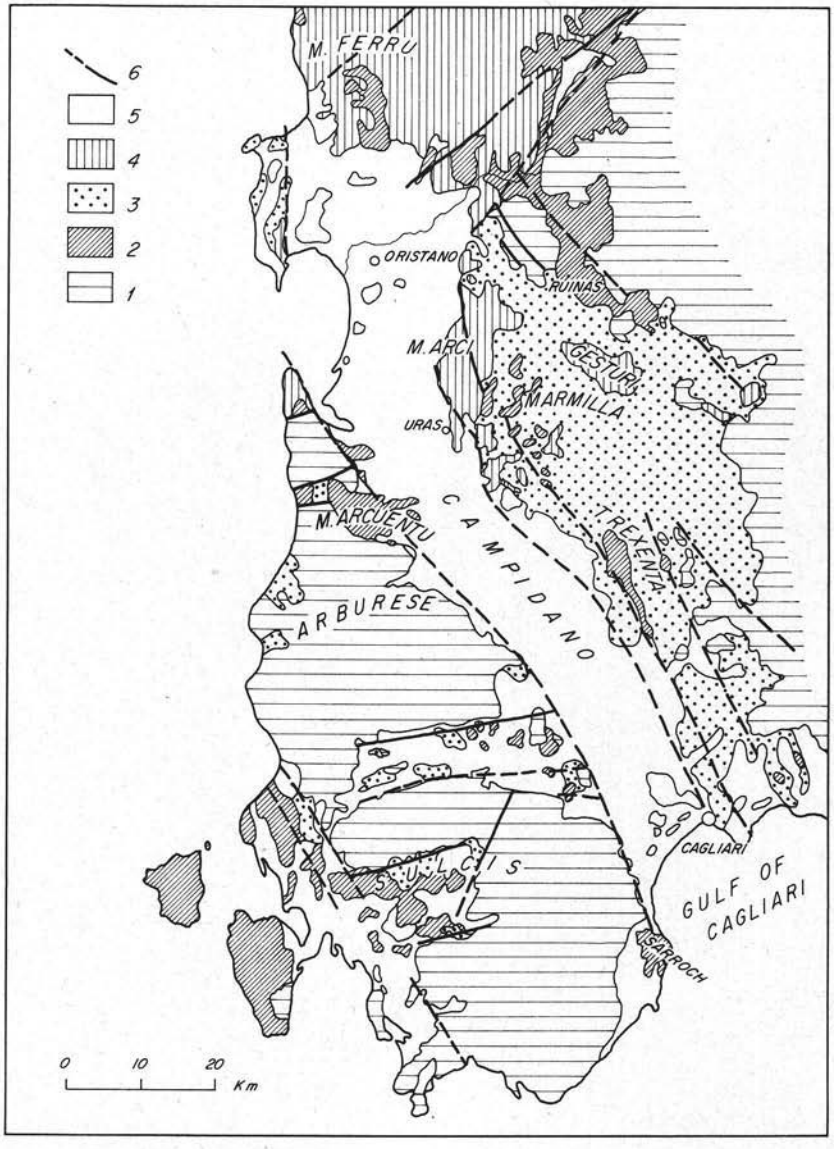


Fig. 1. — Stratigraphic-structural sketch map of South-Western Sardinia (after T. Cocozza, 1973, modified).
1) Pre-Tertiary basement; 2) Lower-Middle Miocene calc-alkaline volcanics; 3) Tertiary sediments; 4) Plio-Pleistocene volcanics; 5) Quaternary continental deposits; 6) Major faults.

takes into account only the youngest structure (i.e. the Campidano s.s. graben). However considering the real extension of the graben as a whole, actually M. Arci must be considered as tectonically set along the median axis of the main structure. The presence of the more depressed Campidano s.s. graben makes the western part

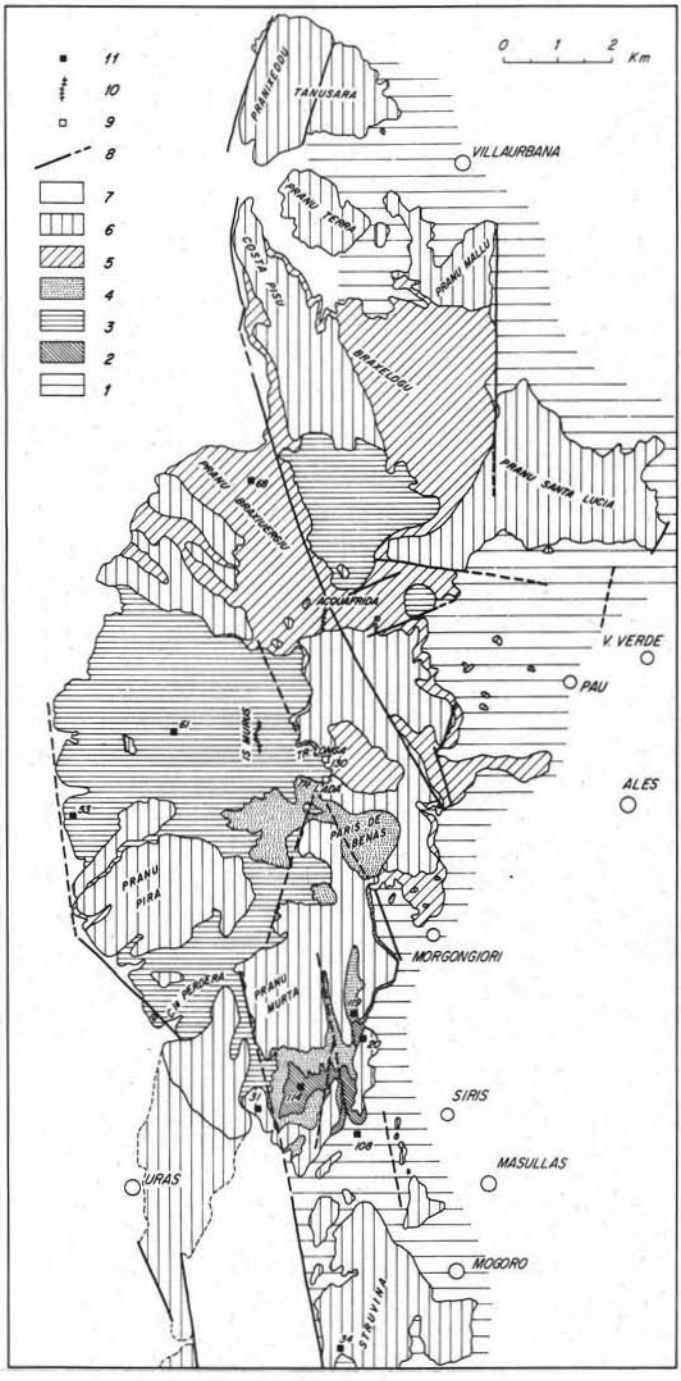


Fig. 2. — Geological sketch map of the Monte Arci volcanic complex. 1) Miocene marine sediments with pillow-lavas and hyaloclastites intercalations; 2) Pillow-breccias with minor hyaloclastites; 3) Rhyolitic lava-flows; 4) Alkali-trachytic lava-flows; 5) Latitic lava-flows; 6) Basaltic lava-flows; 7) Quaternary continental deposits; 8) Normal faults; 9) Volcanic necks; 10) Major dikes; 11) K-Ar age samples location.

of M. Arci rather abrupt with difference of elevation from the top to the bottom of more than 700 m. The erosion has consequently cut deep narrow stream valleys in this part of the volcano. On its eastern part, on the contrary, the difference of elevation between the top and the base is much less important; in fact here the morphology is that of an almost flat plateau.

Monte Arci is not the only volcanic manifestation which occurred in the Campidano-Marmilla-Trexenta area during Tertiary and Quaternary times. In fact in this region volcanic activity in both submarine and subaerial environments has been rather important during Lower-Middle Miocene and during Plio-Pleistocene as testified by Monte Arcuentu, Sarroch, Ruinas, Marmilla, Trexenta, Gesturi, Isili, Struvina and other minor outcrops.

## Volcanological and petrographic outline

Monte Arci is not an individual central volcano but a complex, although small, range of fissural products mainly generated by eruptions along NNW-SSE and N-S trending fissures. No centers of activity are clearly visible with the exception of two basaltic necks probably related to the last eruptions (Trebina Longa and Trebina Lada). The M. Arci volcanic complex is affected by faults and fractures mainly parallel to the main tectonic trend of this part of Sardinia (i.e. NNW-SSE). Some of the NNW-SSE normal faults clearly cut even the youngest products of M. Arci indicating that the tectonics of Campidano area has been active also in very recent time. Some other faults with an approximate E-W direction also exist. Some faulted blocks are slightly tilted towards the Campidano graben. Positive dykes are rather common and some of them (Is Murus, Acquafrida) are very spectacular, sticking out for about five-ten meters or more, elongated in a zig-zag pattern for about 1 km in a N-S direction. At M. Arci the lava flows represent the majority of the volcanic products, pyroclastic materials outcropping only as rare localized lenses. Lava domes seem to be absent eventhough among the rhyolitic formation some dome shaped hills are visible: most of them have been recognized as eroded thick lava flows and only for few others there are not sufficient elements (owing to the thick vegetation cover) to state whether they are lava domes or remnants of eroded flows.

The chemistry of M. Arci is still poorly known and the geological sketch map of fig. 2 is mostly based on field observations and preliminary petrographic study. Therefore, the nomenclature adopted has to be regarded as an indicative one. Several stratigraphic units can be recognized. From the base to the top they are:

1) submarine pillow lavas and hyaloclastites interbedded with Miocene marine sediments;

2) monogenic volcanic breccias (submarine brecciated pillow lavas with minor amount of hyaloclastites);

3) rhyolitic lava flows;
4) alkali-trachytic lava flows;
5) « latitic » lava flows;
6) basaltic lava flows.

The lowest two units represent different episodes of submarine activity. Unit 1 is that of a typical submarine basaltic activity with pillows, hyaloclastites and marine sediments indicating a relatively deep basin. Unit 1 gradually changes upward into unit 2 which is mostly constituted by brecciated pillow-lavas without, especially in its upper parts, marine sediments and with very scarce hyaloclastic material. Unit 2 probably results from activity at a depth shallower with respect to that of unit 1. A similar transition, eventhough concerning explosive hyaloclastites, has been observed (Di Paola, 1973) for Linosa submarine basaltic products. It has to be noted that this pillow-breccias formation has exactly the same field charachteristics of the M. Arcuentu breccias (Western border of the Campidano graben). The submarine products of M. Arci have been unconformably covered by subaerial rhyolitic lavas after a long interval of subaerial erosion. These rhyolites occur in two distinct facies: a lithoidal one which is the most abundant and a perlitic one with frequent black compact obsidian cores. Rhyolites in the northern and eastern parts of M. Arci are covered by thick flows of pyroxene porphyritic « latites » (1).

Both latites and alkali-trachytes sometimes show a vitrophyric facies at the base of the flow, while only latites sometimes show a perlitic facies at the top of the flow. This perlitic facies of latites is very similar to that of rhyolites. Stratigraphic relations between alkali-trachytes and latites are not clear. Only in one place (near Paris de Benas) the two lavas meet, but there is not enough evidence to state which one covers the other. It is likely that these two different types of lavas have been erupted during the same period of activity, but from different centers. Aphyric to olivine-porphyritic basaltic lava-flows represent the last volcanic manifestation of M. Arci. No unconformity exists between rhyolites and alkali-trachytes or rhyolites and latites as well as between basalts and alkali-trachytes or basalts and latites. Basalts sometimes stand unconformably on rhyolites (Canale Perdera). It seems therefore that a rather important time interval must have elapsed between the first and some of the last subaerial volcanic manifestation of Monte Arci. Finally there are not geological evidences to establish the stratigraphic relations between M. Arci volcanic products and the stratoid subaerial basalts which directly cover Miocene marine sediments at Giara di Gesturi (few km East of M. Arci) and at Giara di Struvina (just South of M. Arci).

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(1) The name latite has been here used according to the classification suggested by Beccaluva et al., 1974, on the basis of unpublished chemical analyses. Rocks with somewhat different mineralogical paragenesis (« Hypersthene vitro-andesites » of Washington, 1913) outcropping in different areas of M. Arci have been grouped with the « latitic » formation in fig. 2.

The main petrographic characteristics of the different volcanic units of Monte Arci are summarized in table 1.

TABLE 1

*Main petrographic characteristics of the M. Arci volcanic formations*

| *Volcanic units* | *Texture* | *Phenocrysts* | *Groundmass* | *Rock type* | *Source of chemical data* |
|---|---|---|---|---|---|
| 1) Submarine Pillow-lavas and hyaloclastites | Porphyritic hipocrystalline | Olivine, Augitic clinopyroxene, hypersthene and minor labradoritic plagioclase | Olivine, Augite, hypersthene, plagioclase, Fe-Ti oxides and interstitial chloritized glass | Picritic variety of High-Al basalt | None |
| | Porphiritic hipocrystalline | Scarce unstable olivine, abundant labradoritic plagioclase, augite and hypersthene | Fine grained plagioclase, clinopyroxene and Fe-Ti oxides. Rather abundant interstitial chloritized glass | High-Al basalt | Maccioni, 1965<br>Baque, 1974<br>Beccaluva et al., 1974 |
| 2) Submarine Pillow-breccias | Petrographic characteristics same as unit 1 | | | High-Al basalt | None |
| 3) Rhyolitic flows | Slightly porphyritic glassy lavas (lithoidal, perlitic and obsidian varieties) | Sanidine, biotite and minor plagioclase and magnetite. Apatite and zircon | Alkali feldspar, biotite and minor quartz. Quartz feldspar intergrowth in devitrified varieties | Subalkaline Rhyolite | Washington, 1913<br>Beccaluva et al., 1974 |
| 4) Alkali-trachytic lava flows | Porphyritic hipocrystalline | Very abundant soda-sanidine with plagioclase cores. Minor hypersthene, augite and magnetite. Rare biotite. Apatite and zircon. Quartz xenocrysts | Devitrified glass with alkali feldspar, clinopyroxenes and iron oxides | Alkali-trachyte | Washington, 1913<br>Chayes and Zies, 1961<br>Beccaluva et al., 1974 |
| 5) « Latitic » lava flows | Porphyritic hipocrystalline | Andesinic plagioclase, hypersthene, augite, magnetite and ilmenite. Mafic cumulate nodules of plagioclase, hypersthene, augite and olivine. Apatite, quartz xenocrysts | Glass (often under devitrification) with plagioclase, orthopyroxene, clinopyroxene, biotite, alkali feldspar and Fe-Ti oxides | « Latite » | Beccaluva et al., 1974 |
| | Subaphyric hipocrystalline | Andesinic plagioclase and hypersthene. Quartz xenocrysts | Brownish glass with plagioclase, orthopyroxene, Fe-Ti oxides and minor clinopyroxene and sanidine | « Hypersthene andesite » | Washington, 1913<br>Beccaluva et al., 1974 |
| 6) Basaltic lava flows | Aphyric to porphyritic hipocrystalline | Hypersthene, olivine, augite and plagioclase. Quartz xenocrysts | Hypersthene, olivine, clinopyroxene, plagioclase, magnetite, ilmenite and interstitial glass | Olivine-hypersthene basalt | Washington, 1913<br>Beccaluva et al., 1974 |
| | Aphyric to porphyritic microcrystalline | Olivine, augite and plagioclase. Quartz xenocrysts | Olivine, plagioclase, clinopyroxene, Fe-Ti oxides | Olivine-basalt | Beccaluva et al., 1974 |

## K-Ar ages

Ten specimens of different rocks of M. Arci volcanic complex have been selected for radiometric age determinations. The results listed in table 2 refer to whole rock analyses with the exception of sample MMR 119 which consists of separated alkali-feldspar phenocrysts. The analysed specimens were carefully selected on petrographic basis rejecting vesicular, weathered or highly porphyritic types.

Potassium determinations were made by Atomic Absorption using a Perkin-Elmer spectrophotometer mod. 303.

The assumed ratio of $^{40}K$ to total Potassium is $1.19 \times 10^{-4}$.

The Argon analyses were made by isotope dilution using a Reynolds type Mass Spectrometer statically operating. The following decay constants have been used for the age calculations:

$$\lambda\varepsilon = 0.585 \times 10^{-10}/\text{years}; \quad \lambda_\beta = 4.720 \times 10^{-10}/\text{years}.$$

In fig. 2 the location of the analysed rocks are reported.

Monte Arci rhyolitic obsidians collected at Canale Perdera (Uras) and analysed by Belluomini et al., 1970, with K-Ar method and by Bigazzi et al., 1971, with fission tracks method, show an average age of $3.0 \pm 0.2$ m.y. and $3.1 \pm 0.3$ m.y. respectively.

The geochronological data concerning the subaerial products of M. Arci do not perfectly correspond with the observed field stratigraphy probably due to Ar gain or loss in analysed samples. These data indicate only that the subaerial activity must have occurred in a relatively short time interval comprised between 3.7 and 3.0 m.y..

## Discussion

The K-Ar ages clearly indicate two distinct periods of volcanic activity in the M. Arci area. The former is represented by calc-alkaline basic rocks erupted under submarine conditions during Middle Miocene. The latter is represented by subaerial fissural lavas ranging from basalts (olivine-basalts or olivine-hypersthene-basalts) to alkali-trachytes and subalkaline rhyolites erupted during Late Pliocene. Geochronological data of the Western limit of the Campidano-Marmilla graben (Civetta unpublished data) give an age of 21.2 m.y. for a dyke cutting the M. Arcuentu lavas and 18.3 m.y. for another center of activity located in the same area (M. Fenusu).

All the presently available geochronological data therefore seem to indicate a rather continuous magmatic activity during Lower and Middle Miocene. The occurrence within the Campidano-Marmilla continental graben of calc-alkaline rocks does not necessarely imply that the volcanism was related to the tectonic activity of the graben. Campidano-Marmilla structure most probably predates the calc-alkaline cycle of Sardinia. The M. Arci submarine pillow-braccias formation can be assumed as the end of the calc-alkaline compressive volcanism in this part of Sardinia. In

particular at Monte Arci the submarine pillow-breccias formation indicates a progressive shallowness of the sea at 14.7 m.y.B.P.. Since that time subaerial erosion affected the submarine volcanic products and related marine sediments of the same area until 3.0 - 3.5 m.y.B.P.. At this time a new cycle of volcanic activity started in the M. Arci area with eruptions of subaerial products along NNW-SSE trending fissures related to the renewal of the tectonic activity which produced an asymmetrical

TABLE 2

*K - Ar ages* (*)

| *Sample* | *Rock type* | *Locality* | *K%* | *radiog.* $^{40}Ar$ | $10^{-5}$ *ml* $^{40}Ar_{rg}$ / *gK* | *age m.y.* |
|---|---|---|---|---|---|---|
| MMR 26 | Olivine-hypersthene subaphyric basalt | Nuraghe de Inus | 0.85 | 9 % | 1.44 | 3.6 ±0.3 |
| MMR 31 | Plagioclase-hypersthene porphyritic basalt | Riu Cannas | 1.06 | 31 % | 1.45 | 3.6 ±0.2 |
| MMR 130 | Plagioclase - olivine - augite - hypersthene doleritic basalt | Trebina Longa | 0.75 | 27 % | 1.30 | 3.3 ±0.2 |
| MMR 68 | Hypersthene porphyritic vitrophiric « latite » | Mastru Lorenzu | 3.02 | 16 % | 1.24 | 3.1 ±0.15 |
| MMR 119 | Soda - sanidine phenocrysts from alkali-feldspar-clinopyroxene porphyritic alkali-trachyte | Pranu is Fogaias | 6.42 | 37 % | 1.04 | 2.6 ±0.15 |
| MMR 53 | Aphyric rhyolitic obsidian | Conca S'Ollastiu | 4.49 | 66 % | 1.30 | 3.25±0.2 |
| MMR 61 | Subaphyric rhyolitic obsidian | Riu Muras | 4.65 | 69 % | 1.33 | 3.3 ±0.2 |
| MMR 34 | Aphyric olivine-basalt | Giara di Struvina | 0.44 | 6.5% | 1.47 | 3.7 ±0.4 |
| MMR 114 | Plagioclase - hypersthene subaphyric basalt in the monogenic volcanic breccias formation | South of Su Columbariu | 1.44 | 23 % | 6.72 | 14.7 ±0.7 |
| MMR 108 | Plagioclase - hypersthene subaphyric basalt form a submarine pillow-lava interbedded with Miocene sediments | Perda Sperrada | 1.02 | 25 % | 6.33 | 15.8 ±0.8 |

(*) Analyst: A. Giuliani, Laboratorio CNR Ricerche Radiometriche - Pisa.

rifting of the area with the formation of the present Campidano s.s. graben. The renewal of the activity fairly well agrees with the beginning of volcanism in other areas of Sardinia: Dorgali and Orosei 3.1 m.y. (SAVELLI and PASINI, 1973); Campeda plateau 2.5 m.y. (COULON et al., 1974); Montiferru complex 2.8 m.y. (COULON et al., 1974). Stratigraphic considerations indicate also that some other recent volcanic areas of Sardinia (Capo Frasca, Giara di Gesturi etc.) started their activity at the same time (i.e. about 3 m.y.B.P.).

The nature of the volcanic products erupted at this time indicates that in Sardinia, Late Pliocene marks the beginning of tensional tectonics probably related

to the contemporaneous (SELLI and FABBRI, 1971) foundering of the Tyrrhenian Sea.

Owing to the exclusive fissural nature of the M. Arci subaerial products it is difficult to assume the existence of a magma chamber located at shallow depth beneath this volcanic complex, in which a basaltic parent magma could have undergone differentiation by fractional crystallization. Furthermore the M. Arci volcanic products, at least in the light of the available data, cannot be related to a single differentiation trend since apparently contrasting associations as olivine-basalts and alkali-trachytes coexist with olivine-hypersthene-basalts and subalkaline rhyolites.

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