Contributions to Mineralogy and Petrology

Major, trace element and Sr isotopic composition of lavas from Vico volcano (Central Italy) and their evolution in an open system

M. Barbieri1, A. Peccerillo2, G. Poli3, and L. Tolomeo1

1 Dipartimento di Scienze della Terra, Universita' La Sapienza, I-00100 Roma, Italy
2 Istituto di Scienze della Terra, University of Messina, I-90100, Messina, Italy
3 Dipartimento di Scienze della Terra, I-06100 Perugia, Italy

Abstract. Major, trace element and Sr isotopic compositions have been determined on 21 lava samples from Vico volcano, Roman Province, Central Italy. The rocks investigated range from leucite tephritic phonolites to leucite phonolites and trachytes. Trace element compositions are characterized by high enrichments of incompatible elements which display strong variations in rocks with a similar degree of evolution. Well-defined linear trends are observed between pairs of incompatible trace elements such as Th-Ta, Th-La, Th-Hf. A decrease of Large Ion Lithophile (LIL) elements abundance contemporaneously with the formation of a large central caldera is one of the most prominent characteristics of trace element distribution. Sr isotope ratios range from 0.71147 to 0.71037 in the pre-caldera lavas and decreases to values of 0.70974-0.70910 in the lavas erupted after the caldera collapse. Theoretical modelling of geochemical and Sr isotopic variations indicates that, while fractional crystallization was an important evolutionary process, AFC and mixing also played key roles during the evolution of Vico volcano. AFC appears to have dominated during the early stages of the volcanic history when evolved trachytes with the highest Sr isotope ratios were erupted. Mixing processes are particularly evident in volcanicites emplaced during the late stages of Vico evolution. According to the model proposed, the evolution of potassic magmas emplaced in a shallow-level reservoir was dominated by crystal fractionation plus wall rock assimilation and mixing with ascending fresh mafic magma. This process generated a range of geochemical and isotopic compositions in the mafic magmas which evolved by both AFC and simple crystal liquid fractionation, producing evolved trachytes and phonolites with variable trace element and Sr isotopic compositions.

Introduction

Vico is a Quaternary composite volcano sited in the northern part of the Roman Comagmatic Province, Central Italy (Fig. 1). It consists of abundant lava flows and huge pyroclastic deposits which make up a flat volcanic edifice containing a lake-filled caldera depression at the top. Previous investigation (e.g. Locardi 1965; Cundari and Mattias 1974) recognized the occurrence of leucite-bearing potassium-rich rocks ranging in composition from leucite-tephrits to trachytes and leucite-phonolites. These rocks have been the subject of petrological investigations aimed at shedding light on the evolution processes which generated the Vico suite. Earlier studies (e.g. Cundari and Mattias 1974; Cundari 1975; Locardi 1986; Villemant and Palacin 1987) suggested that the whole range of composition of the Vico lavas was essentially generated by processes of crystal-liquid fractionation with some role of gaseous transfer. Attention was focused essentially on major element compositions of lavas and minerals with a few trace element data reported by Cundari and Mattias (1974), Locardi (1986) and by Villemant and Palacin (1987); Sr isotope data for these rocks are still almost completely lacking.

In the last few years, however a growing body of petrological and geochemical data has led several authors to
suggestions that closed-system crystal fractionation alone is seldom responsible for magmatic evolution in volcanic systems and that magmas evolve by complex processes which include repeated episodes of fractionation, mixing between different batches of magmas and assimilation of wall-rocks (O'Hara 1977; O'Hara and Mathews 1981; Elthon 1984; De Paolo 1985; Elthon and Casey 1985; Turner and Campbell 1986). These studies, and many others, have shown that classical petrological investigations based on major element chemistry of lavas and on mineral phase compositions are often inadequate for unravelling complex evolution processes, and integrated petrological, geochemical and isotopic studies are needed in order to clarify the relative roles played by the different processes.

In the present paper, major, trace element and Sr isotopic data of a series of rocks emplaced at different stages of the Vico activity are reported. Attention is focused on lava flows, which represent the most typical products of a large period of activity of Vico volcano. Study of geochemical and isotopic characteristics and theoretical modelling of Sr isotopes and trace element variations are combined in an attempt to set better constraints to the processes that were responsible for the magma evolution in the Vico volcanic system.

**Geological setting and volcanology**

The Vico volcano developed entirely during Quaternary times within a graben zone located between the Apennines and the Tyrrenian sea. This collapsed area was produced as the result of a distensional tectonic regime that affected the western side of Apennines from the Upper Miocene on ward and determined the opening of the Tyrrenian basin (Scandone 1979). The rocks that underlie the volcanic pile consist of metamorphic rocks which are found in outcrop about 40 km north of the Vico district, by the Tuscan Nappe, mostly Mesozoic-Cenozoic carbonate formations, and by Cretaceous-Oligocene allochthonous flyschs that tectonically overlie the Tuscan formations. The pre-volcanic sequence is concluded by the formation of a central caldera which is presently occupied by the Vico Lake. According to Sollevanti (1983) reported K/Ar ages performed on sanidines separated from some of the lowest exposed lavas which yield values of 4.000 ± 0.008 Ma. The final stages of the growth of the volcano were characterized by explosive activity which gave four main ignimbritic deposits and several pyroclastic surge levels (Locardi 1965; Sollevant 1983). This explosive activity was accompanied by the formation of a central caldera which is presently occupied by the Vico Lake. According to Sollevanti (1983) the latest pre-caldera eruptions occurred 0.139 ± 0.016 Ma b.p.. After caldera formation, the volcanic activity occurred along the northern western rim of the depression or within the caldera itself. Pyroclastic surge deposits and cinder cones are the most typical volcanic deposits. The largest post-caldera structure is Monte Venere which rises about 200 m on the caldera floor. It is essentially a cinder cone with intercalated ashes and a few lavas. Villemant and Palacin (1987) report an age of 85000 years for the Monte Venere lavas.

**Results**

For the present work, 21 lava samples have been collected from different stratigraphic positions and analyzed for major, trace elements and Sr isotopic compositions. The results are reported in Tables 2 and 3. Classification of these rocks, based on their normative mineralogy (Streckeisen 1967), indicates that the Vico lavas consist of tephritic leucite-phonolites, phonolites and trachytes.

**Petrography**

The analyzed rocks are all invariably porphyritic in texture with phenocryst contents ranging from less than 10% to about 50% of total rock volume (Table 1). Clinopyroxene is an ubiquitous phase occurring in variable amounts both as phenocrysts and in the groundmass of all the samples analyzed. Extensive microprobe investigations on Vico lavas carried out by Cundari (1975) and Barton (1979) indicate that pyroxene phenocrysts are prevailing salic with minor amounts of diopside; both compositions were found in zoned phenocrysts. All pyroxenes are characterized by high Al2O3 contents (up to 7%), a feature typical of pyroxenes from the Roman province. At the microscope, Vico pyroxenes are pale green to colorless in the less evolved lavas. In trachytic and phonolitic rocks they are deep green, sometimes with marked pleochroism. Core-rim color changes are observed in several crystals. In some rocks (e.g. V-4) green crystals coexist with zoned and colourless clinopyroxene. Leucite is the second most common phase. It is confined to the groundmass in a few of the mafic lavas, whereas it is often lacking altogether in trachytes. In the rest of the samples it is a common phenocryst phase. In some of the analyzed sample leucite is slightly transformed to analcime (F-1, F-2, V-2, V-3). Alternation is more extensive in sample V-14. Plagioclase occurs generally as a microphenocryst or in the groundmass. Phenocrysts are zoned and are characterized by high anorthite content, even in the evolved trachytes (Cundari 1975). In some of these rocks, plagioclases are jacketted with sanidine. Brown mica is an ubiquitous groundmass phase whereas it occurs as a phenocryst only in the most evolved lavas. Cundari (1975) found a high Mg/Fe ratio indicating a plagiogropic composition. Vico micas, however, have higher Fe and Ti than typical plagiogropites of ultrapotassic rocks and contain an excess of Al (Barton 1979). Finally, sanidine is present as a phenocryst in trachytes and phonolites. It is also observed in the groundmass of some intermediate rocks. Ti-magnetite is the most abundant among minor phases. It occurs commonly as a microphenocryst and is an ubiquitous groundmass mineral. Apatite is also ubiquitous whereas zircon has been observed only in a few evolved samples.

**Major elements**

The analyzed lavas are all rather evolved in composition; rock types with low SiO2 and high Mg-number and CaO, commonly found at other Roman volcanoes (Pecceerillo and Manetti 1985), are lacking at Vico. SiO2% ranges from 51 to 60, CaO is invariably lower than 8% and MgO reaches a maximum of about 5%. The K2O abundances and K2O/Na2O ratios are high, displaying values typical of high-potassium series (HKS) rocks. TiO2 is low, as found in all Roman potassic volcanics (Pecceerillo 1985). The CIPW norms indicate a strong silica undersaturation for most of the samples, except trachytes which straddle the saturation boundary.

Variations of major elements against stratigraphic position that gives informa-