# Genesis of acid volcanism in continental rift environments: a case in the Ethiopian Rift Valley

**A. Peccerillo** *Istituto di Scienze della Terra, University of Messina, C.P. 54, 98166, Messina-S.Agata, Italy*

**Y. Gezaegn**
**A. Dereje** *Department of Geology and Geophysics, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia*

## Introduction

Intracontinental regions affected by extensional tectonics are often associated with widespread magmatic activity. In most cases, acid volcanics are by far the most abundant lithologies, followed by minor amounts of basalts and scarce intermediate volcanics (Kampunzu and Mohr, 1991). The presence of a Daly gap and the huge volumes of salic rocks have made the genesis of acid magmas in continental rift areas a much debated issue (see Davies and MacDonald, 1987). One class of hypothesis suggests that acid magmas are the products of partial melting of the lower crust, a hypothesis which explains the large predominance of acid over basic and intermediate rocks. Other hypotheses suggest a derivation from mafic parents by extensive fractional crystallization or AFC.

The Ethiopian Rift Valley is a key place where these problems can be investigated. In this zone extensive peralkaline rhyolitic and trachytic volcanism is associated with minor basalts and scarce intermediate rocks (Di Paola, 1972). In this paper we report on petrological and geochemical data on a suite of basic to acid rocks coming from Gedemsa, a composite volcano sited in the norther part of the Ethiopian rift. The bearing of these data on the genesis of acid magmas in rift environments is discussed.

## Volcanological outlines

The Gedemsa is a 0.8 to 0.1 mA old volcano located about 100 km southwest of Addis Abeba in the axial zone of the Rift Valley. Eruption of lava domes and flows, plinian pumice fallouts and ignimbrites built up the bulk of the volcanic sequence. These were followed by the formation of a large polygenic central caldera and by the emplacement of intra-caldera lavas and pyroclastics. The intracaldera products contain inclusions of mafic material which is intermingled with the rhyolitic magma and testifies for the coexistence of basaltic and acidic magmas in the volcanic system.

A separate, late stage basaltic activity occurred along the distensional fault system parallel to the rift and formed surge deposits and numerous cinder cones and lava flows, both inside and outside the caldera depression.

## Results

Major and trace element data have been obtained on a suite of samples coming from various stratigraphic levels. The Gedemsa rocks consist almost totally of peralkaline trachytes and rhyolites. The mafic inclusions intermingled with the post-caldera volcanics range from Na-transitional basalts to mugearite and benmoreite. The late volcanics associated to the distensional faults consist of Na-transitional basalts and minor mugearites.The basaltic and intermediate rocks are poorly to strongly porphyritic with variable amounts of olivine, plagioclase and clinopyroxene. Trachytes are mostly characterized by mingled textures given by the presence of two lithologies, respectively salic and mafic in composition. The mafic material is present in a subordinate amount with respect to salic one, and generally occurs as elongated shards sometimes in an advanced stage of disaggregation. Rhyolites are holohyaline or hypocrystalline and consist of phenocrysts of sanidine, biotite, green clinopyroxene and aenigmatite set in a glassy groundmass.

Harker diagrams for major elements indicate that there is a continuous decrease in MgO, CaO, $FeO_{total}$, and $Al_2O_3$ and an increase in $K_2O$ passing from mafic to salic rocks. $TiO_2$ and $P_2O_5$ decrease with silica but display a large range of values in the mafic rocks. $Na_2O$ exhibits a positive trend from mafic to acid rocks and decreases abruptly in the rhyolitic field. Some of the low-$Na_2O$ rhyolites have high LOI values (3.5–7%), suggesting deuteric mobilization of Na.

Trace element variation diagrams show that Rb, Nb, Zr, F and Y increase smoothly from basic to acidic samples with very steep positive trends in the rhyolitic field. Ni and Cr have an opposite trend. Sr and Ba increase from basic to intermediate rocks, but drop to values of a few ppm in the silicic samples. Some acid rocks have relative high values of Ni and Sr which make them to fall ouside the main trends.

## Discussion

The most important petrogenetic problem at Gedemsa is that of understanding whether the acid magmas are related to basic ones by some kind of evolutionary processes, or if they represent petrologically independent melts generated by crustal anatexis.

*Crustal Melting* Preliminary Sr isotopic determinations on acid rocks gave values around 0.705. These ratios are much lower than those typical of old upper continental crust (e.g. Taylor and McLennan, 1985) and, in the context of crustal anatexis, may suggest a derivation from unradiogenic lower crustal material. Such a material could be represented by young basaltic rocks formed by underplating during previous stages of magmatism.

Calculated batch melting models of lower crust show that the incompatible element abundances increase with decreasing degrees of partial melting, whereas compatible elements, such as Sr, decrease. However, incompatible element abundances rarely reach the high concentrations which are observed in the Gedemsa acidic rocks. Moreover, these high concentrations are attained only for very low degrees of partial melting (<5%), which would make anatectic liquid to be unable to separate from the residue (e.g. Clemens and Mower, 1992). Partial melting is also unable to give liquids with extremely low abundances of compatible elements. For instance, melts with Sr concentration lower than a few tens ppm are never obtained, also if $D_{s/l}$ for Sr as high as 20 is assumed. These conclusions also hold true if an average intracontinental basalt is chosen as starting composition. A possibility could be that trachytic magmas were formed by crustal melting and these evolved to rhyolitic composition by fractional crystallization or AFC. However, in this case, large degrees of fractional crystallization (more than 70–80%) would be necessary to drive liquid composition to that of the most fractionated rhyolites. This should be reflected by the occurrence of a small amount of rhyolitic rock with respect to trachytes, the opposite of what observed in the field. Moreover, textural evidence suggests that trachytes represent mingled products between rhyolites and mafic magmas rhater than primary crustal anatectic liquids.

*Fractional Crystallization* Models of fractional crystallization show that incompatible elements increase slightly during the early stages of fractionation and display strong increase during the latest stages of evolution, reaching easily values comparable or higher than those observed in the analysed acid rocks. On the contrary, the compatible elements decrease sharply and reach values of a few ppm in the most fractionated liquids. Overall, these trends closely match those shown by the Gedemsa rocks. This leads to conclude that the variation trends of trace elements in the Gedemsa volcanics are generated by fractional crystallization processes starting from mafic parents. Large degrees of fractionation (about 80%) are necessary to drive liquid compositions from basalt to rhyolites. It is possible that assimilation of crustal material also played a role during magma evolution.

This hypothesis raises the problem of the huge amounts of rhyolites, as compared to mafic and intermediate rocks. This difficulty can be overcome by hypothesizing that evolution occurred in a huge zoned magma chamber in which basic magma occupying the bottom of the reservoir was unable to rise to the surface because of the presence of lighter acid liquid at the top of the reservoir. Only during the latest stages of the evolution, when the volume of the magma reservoir was strongly reduced by the caldera collapse, the mafic magma was brought to the surface intermingled with the acid one.

*Magma mixing* The presence of intermingled products indicate that magma mixing may have been an important process during the evolution of the Gedemsa volcano, especially during the latest stages of the post-caldera activity. However, variation diagrams of major and trace elements against silica show curved trends, typical of fractional crystallization. It has been also observed that some compatible elements such as Ni and Sr show scattering in acid lavas, with some samples displaying rather high values. It is suggested that the latter features are the result of mixing between salic and mafic magmas. Accordingly, mixing had a role in determining the composition of some magmas, especially those which were at the interface between the acid and mafic magmas, but had a minor effect on the overall evolution of the Gedemsa suite.

## References


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