The occurrence of laumontite in volcanic and volcanioclastic rocks from southern Sumatra

Anthony Hall* and Steve J. Moss†

*Dept. of Geology, Royal Holloway, University of London, Egham, Surrey, TW20 0EX; †SE Asia Research Group, Dept. of Geology, Royal Holloway, University of London, Egham, Surrey, TW20 0EX; now at School of Applied Geology, Curtin University of Technology, Perth, 6001, WA, Australia

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Abstract—Laumontite has been discovered in Tertiary and Quaternary volcanic and volcanioclastic rocks of the Gumai Mountains, southern Sumatra (Indonesia). Descriptions are given of three particularly laumontite-rich samples. The laumontite in these rocks is considered to be a product of hydrothermal alteration rather than of weathering or metamorphism.

Introduction

Zeolites are a common constituent of volcanioclastic rocks which have undergone diagenesis or hydrothermal alteration. As part of a wide ranging reconnaissance of potentially zeolite-bearing sedimentary successions, we have examined the mineralogy of volcanic sequences in southern Sumatra, Indonesia.

The zeolites which occur in lavas and clastic volcanic rocks form mainly by the alteration of an original glass phase, and can include about 5 or 6 common zeolite species and a number of other less common ones. The particular zeolite species which are present depend partly on the composition of the parental igneous rocks and partly on the conditions of zeolitization, i.e. temperature, pressure, and hydrological conditions. In an open hydrological system, clinoptilolite and mordenite are the zeolites most commonly present if the parental glass is acid-intermediate in composition, whereas phillipsite and chabazite are commonly present if the parental glass is more basic or alkaline. Large deposits of zeolite-rich pyroclastic rocks occur in several countries, and are increasingly being exploited for a variety of economic applications (Ming and Mumpton 1995).

In this note, we describe some new discoveries of laumontite in Sumatra, and discuss their significance in relation to the various possible parageneses of this mineral, i.e. its conditions of formation.

Laumontite in South Sumatra

Geological background

The samples examined are from the Gumai mountains in South Sumatra Province. This area lies on the eastern flank of the Barisan volcanic arc which extends the length of the island, and is close to several Quaternary to Recent volcanic centres such as the active Gunung Dempo and the dormant Bukit Balai, Bukit Kaba and Bukit Condong centres (Fig. 1).

The Gumai Mountains are located on the western edge of the South Sumatra basin (Figs 1 and 2) to the west of the towns of Lahat and Muaraenim. The mountains trend NW-SE and are cut by a series of SW to NE flowing rivers. Figure 2 summarises the lithostratigraphy of the area. The mountains are cored by late Jurassic to early Cretaceous sediments, volcanics and granodiorite and are surrounded by Tertiary and Quaternary continental and marine sediments and volcanics.

Description of Tertiary laumontite-bearing volcanics of the Gumai Mountains

A selection of volcanic and volcanioclastic specimens were examined by X-ray diffractometry. The only zeolite found in these rocks was laumontite, which was present in about a third of the samples examined.

Volcanics from two horizons were found to contain laumontite; they are the Eocene Kikim Formation and Quaternary deposits from the Bukit Balai volcanic centre. The Kikim Formation, the oldest Tertiary rocks encountered on the margins of the Gumai Mountains, are a sequence of volcanic breccias, andesitic lithic and crystal tufts and lavas. Many of the deposits can be described as epiclastic. These are suggested by Van Gorsel (1988) and Gafiero et al. (1992) to be Eocene in age.

Good exposures of the Kikim Formation are present along the Musi river valley in the northwest Gumai Mountains and in the Saling river on the northeast margin of the mountains (Moss 1995) (Fig. 2). The sample richest in laumontite, SJM 83–94, is from the upper part of the Kikim Formation along the Saling river at location 103 20 07'1 03 47 47' S. In outcrop, decimetre beds of reddish-purple lithic tuff-brecchia are interbedded with purple coloured claystones. Bedding is orientated 120 47' NE, in common with the entire Tertiary sequence along the Saling river section which dips and youngs toward the northeast. Unconformable upon the Tertiary formations of the Gumai Mountains are several Quaternary formations (Fig. 2). Along the Musi river valley andesitic to basaltic lava flows, tuffs, agglomerates and volcanioclastics derived from Bukit Balai volcanic centre overlie Tertiary formations of the NW margin of the Gumai Mountains (Fig. 2). Samples SJ M 38–94 and SJ M 40–94 are from...
volcaniclastics and lava flows from the Bukit Balai deposits to the southwest of Ulak Dabuk village, at 102°58.67'E, 03°41.35'S and 102°57.74'E, 03°42.75'S respectively.

Description of the laumontite-bearing samples

Within three samples investigated laumontite is a major constituent. These were an andesitic lava and two fragmental rocks with mainly volcanic clasts. These rocks have a completely unmetamorphosed appearance with no penetrative deformation. They show no veining and no recrystallization is visible in hand specimen. The main feature of the rocks are as follows.

Sample SJM83/94 is a lithic tuff breccia from a sequence of bedded volcanic breccia, tuff-breccia and claystones from the Eocene Kikim Formation (Fig. 2). The sample is poorly sorted and has sub-angular clasts up to 1 cm across. The most common clast types are soft, pale grey lava and a hard red lava. The matrix is a medium grey colour. Laumontite occurs in all the clast types and the matrix, but the clasts and matrix are mostly too fine-grained or too impregnated by hematite to locate much of the laumontite in thin section.

Specimen SJM38/94 is a conglomerate with poor sorting and rounded clasts in an abundant greenish-grey matrix of sand grade. The sample is from Quaternary deposits from the Bukit Balai volcanic centre. The outcrop was heavily weathered and the rock is poorly lithified and crumbly. The clasts are composed of several different types of lava, including some with fresh pyroxene phenocrysts and some with abundant vesicles. The sand-grade matrix is mainly composed of single crystals of pyroxene and plagioclase. Laumontite occurs as a cementing material between these crystals.

Specimen SJM40/94 is from a lava flow and has the appearance of a typical andesite from Quaternary volcanics associated with the Bukit Balai volcanic centre (Fig. 2). It is homogeneous in texture and contains abundant, soft, white, rectangular, idiomorphic phenocrysts up to 5 mm across, in a fine-grained, dark grey groundmass. The predominant white phenocrysts are of plagioclase, pseudomorphed from 0 to 100% by laumontite. A few small candelabral phenocrysts with the characteristic 8-sided shape of pyroxene are entirely pseudomorphed by calcite. The matrix shows flow alignment of small laths of plagioclase, and XRD reveals the additional presence of laumontite, minor smectite and zoisite in the matrix.

A chemical analysis of sample SJM40/94 (Table 1) shows that it has a broadly andesitic composition, but with abnormally high Na and low Mg contents. The immobile trace element ratios \( \text{Zr/Ti} = 0.0188; \text{Nb/Y} = 0.14 \) place the rock within the andesite field of Winchester and Floyd's (1977) magma discrimination diagram.

Discussion of the paragenesis of the laumontite

The circumstances leading to the formation of laumontite are less clear than for many of the other zeolites and, unlike the more commonly occurring zeolites, laumontite has not been produced in laboratory experiments by the alteration of natural glass. Moreover there are many regions in which altered volcaniclastic rocks are rich in zeolites without containing laumontite. Nevertheless, laumontite does occur in the altered volcanic rocks of some regions, and various explanations of its origin have been proposed. Accounts of individual
laumontite occurrences given in standard mineralogy

texts (e.g. Deer et al. 1963; Gottardi and Galli 1985)
describe evidence for three distinct parageneses for
laumontite occurring in altered igneous rocks:
weathering, hydrothermal and metamorphic. These
three possible parageneses will be considered in the light of the
available evidence.

(1) Weathering

Sumatra is a region with an extremely high annual
rainfall of around 2400 mm and high temperatures of
18-27°C throughout the year. The natural vegetation
until recent times and probably throughout the

| Table 1. Chemical analysis of laumontite-rich
| sample SJM40/94 expressed on a volatile-free
| basis, compared with the average andesite
| composition from Le Maitre (1976) |
|---|---|
| Sample | Average andesite |
| | | |
| SJM40/94 | 53.04 | 57.94 |
| SiO₂ | 53.04 | 57.94 |
| TiO₂ | 1.02 | 0.87 |
| Al₂O₃ | 17.70 | 17.02 |
| Fe₂O₃ | 8.39 | 7.76 |
| MgO | 2.32 | 3.33 |
| MnO | 0.09 | 0.14 |
| CaO | 5.50 | 6.79 |
| Na₂O | 6.04 | 3.48 |
| K₂O | 0.20 | 1.62 |
| P₂O₅ | 0.34 | 0.21 |
| H₂O | n.d | 0.83 |
| CO₂ | n.d | 0.05 |
| Nb (ppm) | 6 | 6 |
| Y | 42 | 0.36 |
| Zr | 192 | 0.40 |

Quaternary and Tertiary has been tropical rain forest.
It is a region in which deep chemical weathering affects
all rock types to a considerable depth, and many surface
exposures show the effects of lateritization.

It would not be unreasonable to propose that the
low-temperature secondary minerals which are replacing
most of the original high-temperature minerals of these
volcanic and volcanioclastic rocks are the products of
weathering. Associated minerals which are particularly
characteristic of a weathering environment are smectite
(present in most of the rocks) and hematite (typical of
lateritization). However, there are serious objections to
a weathering explanation. Basaltic and andesitic rocks
from other areas which have undergone chemical
weathering do not contain laumontite. Indeed, chemical
weathering of mafic igneous rocks under tropical
conditions invariably involves the loss of almost all the
CaO and Na₂O originally present in the rock (Faure
1992). The few laumontite occurrences that are known
from weathered rocks were formed in cold (glacial)
conditions (Capdecomme 1952; McNamara 1966).

(2) Hydrothermal

A hydrothermal origin for laumontite is generally
accepted for many occurrences of laumontite filling
veins, fractures and vesicles in igneous rocks, for
example in the well-known occurrences of large
laumontite crystals in the basalts of the Deccan plateau
or Northern Ireland. Hydrothermal occurrences are not
restricted to basalts, and vein-filling laumontite has been
recorded from granites, gabbro, serpentinite, gneiss,
amphibolite and marble (Gottardi and Galli 1985).

In making a distinction between hydrothermal
alteration and diagenesis or metamorphism, a large
circulating water and the presence of a distinct heat
source are the critical factors. It is difficult to envisage
the Sumatran occurrence as being due to the large fluid flows that characterise hydrothermal occurrences elsewhere. The rocks are not veined, and the laumontite occurs mainly in lithologies with a low permeability. In fact the andesite (sample SJM40/94) is not obviously vesicular and would have been a massive rock with negligible porosity before alteration; the laumontite in this rock is essentially replacive (e.g. pseudomorphing phenocrysts) rather than cavity-filling.

Despite this, there are similarities between the altered andesite and the type of alteration known as "propylitic". Characteristic features of propylites are a drab green colour, and the development of the mineral assemblage epidote/zoisite + chlorite + albite + calcite (Beane 1982; Hulen and Nielsen 1986; Bartos 1987). Laumontite is not usually considered to be a normal constituent of propylites, but Gigenbach (1984) has predicted that it could occur at low temperatures (~100–200°C).

(3) Metamorphic

The status of laumontite as a metamorphic mineral was first recognised in New Zealand, where zeolites, including laumontite, occur throughout the thick Triassic sedimentary succession of the Southland syncline. On the basis of studies in this region, Coombs et al. (1959) proposed the name "zeolite facies" for conditions of metamorphism beyond the realm of diagenesis in sediments but below those of the prehnite-pumpellyte and greenish facies. Subsequently, "zeolite facies" metamorphism has been recognised in Japan and other circum-Pacific regions.

The zeolite facies has not been universally accepted. P-T conditions intermediate between those of diagenesis and the greenish facies must be very widely attained, since greenish facies rocks are so common, and yet there are many regions in which no development of zeolites is recognised prior to the onset of the greenish facies.

Experiments on the stability of laumontite in the presence of quartz under water-saturated conditions (Liou 1971; Cho et al. 1987) suggest that under a geothermal gradient of 30 °C km laumontite would be stable in the temperature interval of 170–300 °C (and heulandite at a lower temperature), but laumontite could occur at lower temperatures if the geothermal gradient were higher. However, free silica is not present in the rocks from Sumatra and heulandite does not occur, so laumontite could be stable in the temperature interval of 170–200°C (and heulandite at a lower temperature), but laumontite could occur at lower temperatures if the geothermal gradient were higher. However, free silica is not present in the rocks from Sumatra and heulandite does not occur, so the experimental evidence is a poor guide to possible formation temperatures. Miyashiro (1994) pointed out the significance of the equation:

\[
\text{laumontite} + \text{CO}_2 \\
= \text{calcite} + \text{kaolinite} + 2\text{quartz} + 2\text{H}_2\text{O},
\]

and suggested that laumontite could not occur if the chemical potential of CO₂ was high, its place being taken by calcite and clay minerals. However, some of the laumontite-bearing rocks from Sumatra do contain traces of calcite.

There are two main reasons for not considering the Sumatran occurrences of laumontite as metamorphic in origin. The first is that they occur within a succession which has not been subjected to a high temperature at any time since deposition. For samples SJM38/94 and SJM40/94, from Quaternary deposits, deep burial and heating can be discounted. SJM83/94 from the Eocene Kikim Formation potentially could have been quite deeply buried and hence heated. However, the Gumai Mountains are on the western margins of the South Sumatra basin and the Tertiary section is much reduced in thickness in comparison to the basin centre, being in the order of 1–1.5 km thick. Elsewhere on the margins of the South Sumatra Basin, low values of organic maturity (generally less the 0.8% vitrinite reflectance) and the results of apatite fission-track studies suggest burial temperatures less than 100 °C (Moss and Carter 1996). The second reason is that the alteration of the andesite (Table 1) was non-isochronal in nature, since it involved a redistribution of alkali ions, which is much more compatible with hydrothermal origin.

Conclusions

Of the three possible parageneses of laumontite in igneous rocks, chemical evidence argues against a weathering origin of the Sumatran occurrences, and geological evidence argues against a metamorphic origin. A hydrothermal origin is considered the most probable, although the absence of veining within the samples is interesting to note. The localised occurrence of laumontite is also consistent with an origin by hydrothermal activity rather than weathering or metamorphism. The resemblance between the alteration present in the Gumai Mountains and the propylitic alteration associated with porphyry copper deposits in the southwestern United States suggests that the igneous bodies in this region should be considered as potential exploration targets for hydrothermal mineralization.

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