Mineralogy of the Hydrothermal Alteration in the Námafjall Geothermal Field (Iceland)

/ HELENA ALBERT MÍNGUEZ (1,), LORENA ORTEGA (1), ROSARIO LUNAR (1), JESÚS MARTÍNEZ FRÍAS (2), RUBÉN PIÑA (1)*

(1) Departamento Cristalografía y Mineralogía, Facultad de C.C. Geológicas, Universidad Complutense de Madrid, C/ José Antonio Novais 2, 28040 Madrid (España).
(2) Centro de Astrobiología, CSIC/INTA, asociado al NASA Astrobiology Institute, Ctra. de Ajalvir km. 4, 28850 Torrejón de Ardoz, Madrid (España)

INTRODUCTION.

Present-day rift zones in Iceland commonly develop high-temperature geothermal systems related to central volcanoes (Trønnes, 2003). This study was developed at the high-temperature geothermal field of Námafjall, located at the Iceland Northern Rift Zone, near the Krafla central volcano. In this area, the constant hydrothermal activity alters Pleistocene hyaloclastites sequences and Holocene lavas and scoria cones especially to clay minerals. Different degrees of alteration, anisotropic distribution of fissures, faults and permeable zones, and accumulation of different minerals, generates a spotty distribution of red, brown, yellow, pink and white patches, reflecting the mosaic character of hydrothermal alteration (Geptner et al., 2005, 2007).

A detailed mineralogical study of the altered volcanic rocks from the outer edge of the Námafjall geothermal field has been carried out in order to determine the surface alteration processes associated with geothermal activity, inferring pH conditions and, where appropriate, the temperature of the alteration processes.

MATERIALS AND METHODS.

A number of altered and unaltered samples were collected at two outcrops in the external area of the Námafjall geothermal field. The first outcrop was formed by hyaloclastites. At the second outcrop the samples were characterized for their different colors: red, brown, yellow and pink. The red, brown and yellow fractions consist of disgregated fragments of clayey matter. The red fraction includes also lava fragments and nodules. The pink fraction is formed by no aggregated clayey material with fragments that externally have a uniform color, but inside are banded with different colors. The pink samples were soaked in hydrothermal fluids when were collected.

The use of different analytical methods has allowed characterization of the mineral associations and variation in the intensity of the alteration related with the mosaic pattern. X-ray diffraction (XRD) analyses were performed at the Departamento de Cristalografía y Mineralogía (Universidad Complutense de Madrid, UCM), using a Siemens D500 diffractometer. For SEM study a JEOL JSM-820 microscope was employed at the CAI-Técnicas geológicas (UCM) and a JEOL JSM-6400 at the Centro de Microscopía Luis Bru (UCM). The analyses were obtained operating at an accelerating voltage of 20 kV. Discern between oxides, hydroxides and oxyhydroxides has not been possible with the SEM, as hydrogen cannot be detected with this technique. The Yellow and pink fractions were quantitatively analyzed with a TEM, model JEOL JEM-2000FX (200 kV) at the C.M. Luis Bru (UCM).

RESULTS.

Protoliths.

The hyaloclastites are mainly formed by basaltic glass and less than 1 mm size degassing vacuoles filled by calcite and minor zeolites (clinoptilolite-heulandite) with fibrous radiating habit. Some relicts of small altered Ca-plagioclase crystals with single twinning can be also observed. The sideromelane is slightly hydrated and transformed to palagonite. Palagonite can be considered a mixture of hydrated glass and trioctahedral smectites.

The lavas are commonly grey with a red patina and whitish crust of Mg-calcite exhibiting evidence of alteration. These lavas correspond to plagioclase basalt and show hypocrystalline, heterometric and porphyritic texture with moderate rate of porphyry and aphanitic matrix. Matrix is mainly glass and present evident signs of alteration. Phenocrysts and microphenocrysts consist of, in decreasing order of abundance, anorthite and bytownite, chrysolite and augite. Chrome-spinel, epidote and titanomagnetite are scarce.

Hydrothermal Products.

The red fraction consists of extremely porous and friable nodules and disgregated material, product of alteration of the original protolith. These nodules are mainly formed by Fe-rich beidellite and nontronite. The disgregated fraction contains Fe-rich beidellite, nontronite and saponite. The presence of maghemite has been detected by DRX. Both materials are composed by aggregates of laminar smectite particles. The aggregate structures have mainly spherical morphologies (cellular texture) connecting by smectite particle bridges. The analyses indicate that the smectite aggregates are usually coated by iron oxides sometimes with Ti. In the nodules smectite particles are smaller. Halloysite and $CaCO_3$, both with prismatic habit, and quartz grains also have been found.

The disgregated brown fraction is mainly formed by nontronite and Fe-rich beidellite and minor kaolinite. Morphology and texture are very similar to red fraction's samples, but the particle size is smaller. Iron oxide coatings are common. The smectite shows honeycomb and cornflake textures. Scarce cylindrical smectite aggregates are also found.

The disgregated yellow fraction consists of beidellite and traces of kaolinite. The smectite has a mean (n = 13) structural formula of $Si_{7.63}Al^{IV}_{0.37}(Al^{VI}_{2.75}Fe^{3+}_{0.74}$

palabras clave: Alteración hidrotermal, Campo geotérmico, Esmectita, Caolinita, Islandia, Námafjall.

key words: Hydrothermal alteration, Geothermal field, Smectite, Kaolinite, Iceland, Námafjall.

* corresponding author: hln.albert@gmail.com

$Mg_{0.75}Ti_{0.04})O_{20}$ $(OH)_4Ca_{0.12}$. Like in the others samples, smectite aggregates take spherical morphologies, but the particle size is smaller than in the brown fraction and iron oxide coatings are occasional.

The pink fraction consists of disgregated material and fragments entirely composed by kaolinite with a mean (n = 12) structural formula of $Si_{3.92}Al^{IV}_{0.08}$ $(Al^{VI}_{3.88}Fe^{3+}_{0.09}Ti_{0.05})O_{10}$ $(OH)_8$. Kaolinite laminar particles lower than 1µm make up a network of spherical aggregates (Fig. 1A). Some of these aggregates grow around a nucleous of Fe-oxide (Fig. 1B). Scarce grains of $CaCO_3$ can be observed (Fig. 1B).

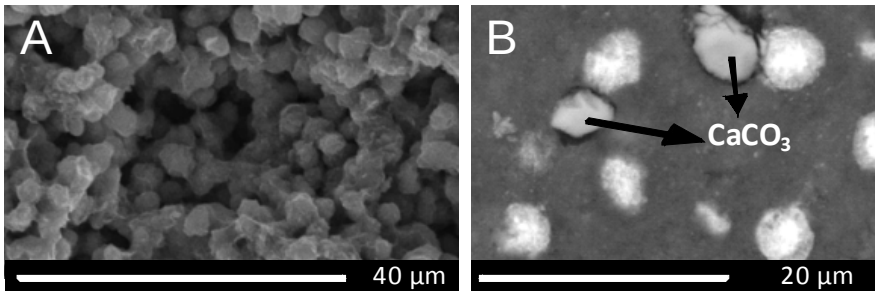

fig 1. A. Spherical aggregates of kaolinite. B. Aggregates of kaolinite grown around a nucleous of Fe-oxide and two grains of $CaCO_3$.

DISCUSSION.

Smectite and kaolinite are the two main products of hydrothermal alteration in the studied area. Smectite mean compositions from the different fractions are shown in Fig. 2. The wide compositional range between smectites reflects the varying compositions of the protoliths. The yellow fraction consists only of Al-rich smectite, suggesting a stronger leaching process with decrease in Fe^{3+} and Mg (geochemically mobile elements) and relative increase in Al (more immobile). Kaolinite occurs as major component in the pink fraction, as minor one in the brown fraction and accessory in the yellow fraction. Fe oxidation and Mg and Ca migration on the surface of the hydrothermal system contribute to generate a mosaic pattern with different colors and accessory mineral composition.

The presence of kaolinite and smectites as major alteration minerals corresponds with an intermediate argillic alteration. Variation in kaolinite and smectite proportion at the different fractions should be reflecting changes in the acidity of the fluids and/or distance from the pathway of hydrothermal fluids. Kaolinite represents lower pH and more intense hydrothermal alteration than smectite, thus it could be related to the hydrothermal fluids channeling.

Above 300°C kaolinite becomes pyrophyllite. This phase has not been observed in the studied zone, thus implying that hydrothermal fluids emerged at temperature not higher than this. Above 200°C smectite becomes smectite and illite interstratified. These interstratified have not been identified in the area, so it is considered that the upper temperature limit in the smectite patches would be 200°C.

Textural features of kaolinite and most of smectites in the most intensely altered zones indicate dissolution of the previous rock. This is reflected in the pervasive nature of the alteration and the complete destruction of the original igneous textures.

The presence of calcite in the pink fraction, which corresponds to the most acid alteration, could be related with the Krafla Fires episodes (1975-1984) (Gudmundsson et al., 2002 and 2005) and may be interesting for studies of analogs of the Mars environment.

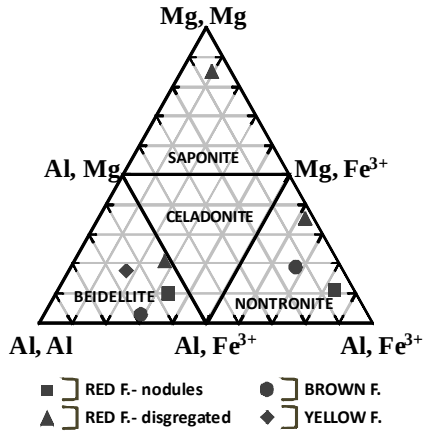

fig 2. Projection of means of smectite analyses plotted in a compositional diagram (Güven, 1988) which considers the proportion of Fe^{3+}, Al and Mg in the tetrahedral and octahedral positions. For the yellow fraction only TEM data have been taken.

CONCLUSIONS.

The alteration mineralogy consists of smectite, kaolinite and iron oxides and, as accessory minerals, carbonate and silica. This assemblage corresponds to an intermediate argillic alteration, typical of acidic pH and temperature below 200ºC.

Kaolinite-rich zones correspond to the pathways of channeling of hydrothermal fluids, whereas the surrounding areas represent the movement of these fluids with different degrees of neutralization.

ACKNOWLEDGMENTS.

Sampling of the Námafjall geothermal field was possible thanks to funding of the Research Group 910197 by the UCM.

REFERENCES.

*Geptner, A., Ivanovskaya, T., Pokrovskaya, E Lyapunov, S., Savichev, A., Gorbunov, A., Gor'kova, N. (2007): Hydrothermally Altered Hyaloclastites at the Earth's Surface in the Rift Zone of Iceland: Problem of the Biochemogenic Accumulation of Trace Elements. Lithol. Miner. Resour. (Engl. Transl.), **42**, 453–476.*

*Geptner, A., Ivanovskaya, T., Pokrovskaya, E. (2005): Hydrothermal Fossilization of Microorganisms at the Earth's Surface in Iceland. Lithol. Miner. Resour. (Engl. Transl.), **40**, 505–520.*

*Gudmundsson, B. & Arnórsson, S. (2002): Geochemical monitoring of the Krafla and Námafjall geothermal areas, NE-Iceland. Geothermics, **31**, 195-243.*

*Gudmundsson, B. & Arnórsson, S. (2005): Secondary mineral–fluid equilibria in the Krafla and Námafjall geothermal systems, Iceland. Applied Geochemistry, **20**, 1607-1625.*

Güven, N. (1988): Smectites. Hydrous Phyllosilicates (Exclusive of Micas) (S.W. Bailey, editor). Reviews in Mineralogy, 19. Mineralogical Society of America, Washington, D.C., pp. 497 – 559

Trønnes, R. (2002): Geology and geodynamics of Iceland, Nordic Volcanological Institute, University of Iceland, pp. 1-19.