EFFLORESCENCES IN ARID REGION OF COLCA RIVER BASIN, SOUTH PERU

JUSTYNA CIESIELCZUK[1], KRZYSZTOF GAIDZIK[1], GRAŻYNA BZOWSKA[1], JERZY ŻABA[1], ANDRZEJ PAULO[2]
[1] University of Silesia, Faculty of Earth Sciences, Bedzinska 60, 41-200 Sosnowiec, Poland, +48(32)3689336, justyna.ciesielczuk@us.edu.pl
[2] AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland

INTRODUCTION

The climate of the South Peruvian Andes is defined as tropical, continental and dry (Abele 1992, Lamb & Davis 2003). The permanent snow line lies above 5,000-5,500 m.a.s.l. and has been receding up in recent decades.

Efflorescences, which formation is strictly dependent on occurrence of water, can form only in regions of arid climate in places with regular water supply. These are geothermal spots where minerals precipitate at the hot springs or geysers and other areas with seeping, stagnant or flowing water as rivers, streams and waterfalls. Three examples of efflorescence formation are described here (Fig. 1 & 2): (1) the geyser near Pinchollo (hot water) (2) the waterfall near Panahua (cold water) and (3) the stream near Choco village. Efflorescences were identified by means of binocular microscopy, SEM-EDS and XRD methods.

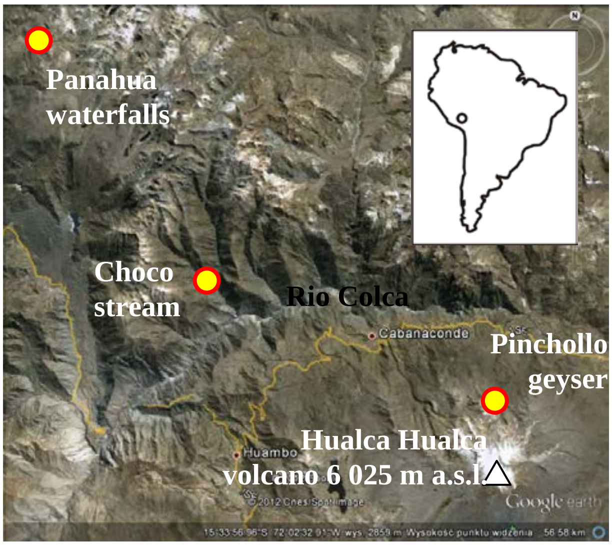

Fig. 1. Samples location at the waterfalls near Panahua, the stream near Choco and the geyser near Pinchollo.

GEOLOGY

The geyser near Pinchollo belongs to the geothermal area of Chivay (Steinmüller 2001). Its coordinates are S15°40’448 W71°51’704 (Figs. 1 & 2 a). It is located 4,353 m a.s.l. at the bottom of a river valley and is closely connected with the local fault network (Żaba and Małolepszy, 2008). It uses a fault fissure. The gushing geyser water is boiling, so its temperature, at this altitude, is ca 70-80°C. The geyser is located within the colluvium avalanche from the Hualca Hualca volcano.

Two waterfalls near Panahua (S15°21’624 W72°17’475; 4,391 m a.s.l.) are formed within Upper Cretaceous thick-bedded quartzitic sandstones (Fig. 1 & 2 c). They are scarcely interlayered by thin-bedded shale clays. Two streams follow fault planes of WE and NE-SW directions.

West of the Choco village there is a contact between silicoclastic rocks of Jurassic-Lower Cretaceous suite of the Yura Group and a granodiorite intrusion of probably Upper Cretaceous age (S15°34’393 W72°08’275; 2,722 m.a.s.l.) (Caldas, 1993). The stream flowing in the quebrada Cusca supplies cold water which oozes the mudstones at the contact.

MINERAL COMPOSITION

In the vicinity of the geyser near Pinchollo, minerals of various habits and colours have precipitated directly on the soil and dry plants at the left bank of the river (Fig. 2 b) and on the ceiling of the pothole filled with the boiling water. They are also present ca 100 m east of the geyser where a small valley has revealed the presence of precipitates around cracks and fissures in the soil.

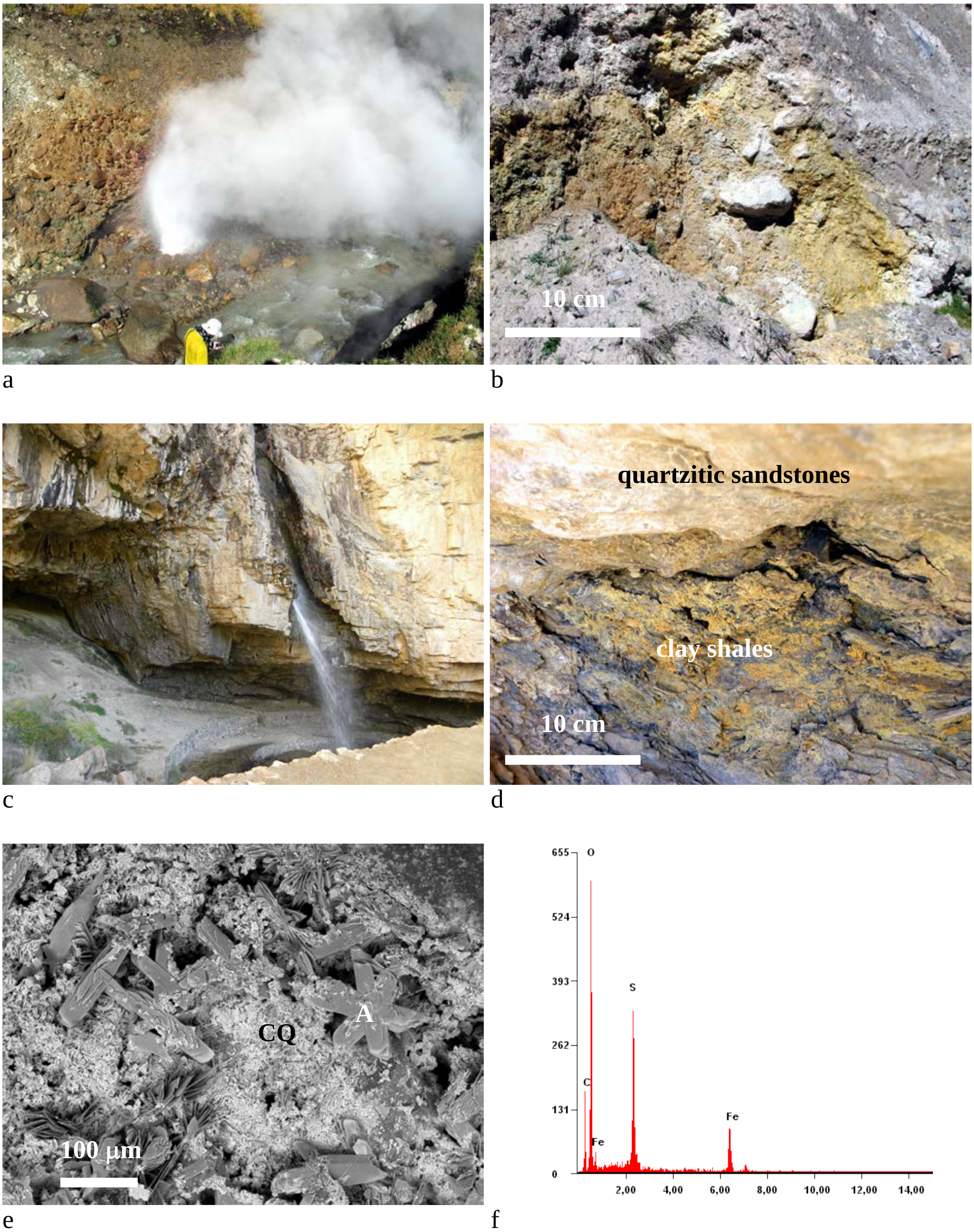

Fig. 2. a – Pinchollo geyser water spurt 10 m high; b – Efflorescences at the left bank of the river; c – Panahua waterfall dropping from a thick-bedded quartzitic sandstone; d – White and orange precipitates on the clay shales interlaying quartzitic sandstones; e – SEM micrograph of alunogene A and coquimbite CQ; f – EDS spectrum of iron sulphate.

Efflorescences are composed mainly of white and yellow minerals. Isometric tschermigite $(NH_4)Al[SO_4]_2 \cdot 12H_2O$, triclinic alunogene $Al_2[SO_4]_3 \cdot 18H_2O$, trigonal alunite $KAl_3[(SO_4)_2|(OH)_6]$, mononoclinic pickeringite $MgAl_2[SO_4]_4 \cdot 22H_2O$ - halotrichite $FeAl_2[SO_4]_4 \cdot 22H_2O$, boussingaultite $(NH_4)_2Mg[SO_4]_2 \cdot 6H_2O$, gypsum $CaSO_4 \cdot 2H_2O$, rozenite $Fe[SO_4] \cdot 4H_2O$ and picromerite

$K_2Mg[SO_4]_2·6H_2O$ are of low hardness 1.5-3, white, transparent to translucent. They form tabular and acicular crystals which may compose rosettes. Yellow minerals are represented by triclinic copiapite $FeFe_4[(SO_4)_6|(OH)_2·20H_2O$, izometric voltaite $K_2Fe_5^{3+}[SO_4]_4·18H_2O$, trigonal coquimbite $Fe_2^{3+}[SO_4]_3·9H_2O$, jarosite $KFe_3[(SO_4)_2|(OH)_6]$ - ammoniojarosite $(NH_4)Fe_3[SO_4]_2|(OH)_6]$ (Fig. 2 e & Table 1). They are translucent and opaque. Hardness ranges from 2-4.5. Most of them are water soluble.

Table 1. Mineral precipitates identified in the vicinity of the geyser near Pinchollo, the waterfalls near Panahua and the stream near Choco. *Italics* – minerals in traces.

Location	Water temperature	Host rocks	Efflorescences
geyser Pinchollo	hot	volcanic rocks	alunogene $Al_2[SO_4]_3·18H_2O$, tschermigite $(NH_4)Al[SO_4]_2·12H_2O$, copiapite $FeFe_4[(SO_4)_6|(OH)_2·20H_2O$, jarosite $KFe_3[(SO_4)_2|(OH)_6]$ - ammoniojarosite $(NH_4)Fe_3[SO_4]_2|(OH)_6]$, gypsum $CaSO_4·2H_2O$, coquimbite $Fe_2^{3+}[SO_4]_3·9H_2O$, pickeringite $MgAl_2[SO_4]_4·22H_2O$ - halotrichite $FeAl_2[SO_4]_4·22H_2O$, mohrite $(NH_4)_2Fe[SO_4]_2·6H_2O$, boussingaultite $(NH_4)_2Mg[SO_4]_2·6H_2O$, alunite $KAl_3[(SO_4)_2|(OH)_6]$, voltaite $K_2Fe_5^{3+}[SO_4]_4·18H_2O$ - voltaite (Mg) $K_2Mg_5Fe_4[SO_4]_{12}·18H_2O$, *rozenite $Fe[SO_4]$ $·4H_2O$, picromerite $K_2Mg[SO_4]_2·6H_2O$, mascagnite $(NH_4)_2SO_4$*
waterfalls Panahua	cold	silicoclastic rocks	gypsum $CaSO_4·2H_2O$, alunogene $Al_2[SO_4]_3·18H_2O$, tschermigite $(NH_4)Al[SO_4]_2·12H_2O$, copiapite $FeFe_4[(SO_4)_6|(OH)_2]·20H_2O$, coquimbite $Fe_2^{3+}[SO_4]_3·9H_2O$, *jarosite $KFe_3[(SO_4)_2|(OH)_6]$*, opal-silica SiO_2, fibroferrite $Fe[SO_4|OH]$ $·5H_2O$, ferricopiapite $Fe_{4.619}[(SO_4)_6|(OH)_2]·20H_2O$, *hohmanite $Fe^{3+}[SO_4|OH]·3.5H_2O$*
stream Choco	cold	silicoclastic rocks/granitoid	gypsum $CaSO_4·2H_2O$, hexahydrite $MgSO_4·6H_2O$, starkeyite $MgSO_4·4H_2O$

Waterfalls and streams near Panhaua deliver cold water which flows through the series of quartzitic sandstones and 30 cm thick thin-bedded clay shales (310/2), which are usually wet as its properties allow capillary ascent of water. Regular supply of water enriches it in elements and ions leached from the rocks and evaporation under the operating sun and dry air has caused precipitation of minerals strait on the shales (Fig.2 d). The efflorescences are of white and orange colours. The main component of the white efflorescences is gypsum. Minor components consist of tschermigite $(NH_4)Al[SO_4]_2·12H_2O$, quartz SiO_2, opal-silica, illite and kaolinite. The orange precipitates consist of alunogene, trigonal fibroferrite $Fe[SO_4|OH]$ $·5H_2O$, copiapite $FeFe_4[(SO_4)_6|(OH)_2]·20H_2O$, ferricopiapite $Fe_{4.619}[(SO_4)_6|(OH)_2]·20H_2O$, coquimbite $Fe_2^{3+}[SO_4]_3·9H_2O$, and minor triclinic hohmanite $Fe^{3+}[SO_4|OH]·3.5H_2O$, quartz, and illite. Jarosite is also identified in traces in both kinds of the efflorescences (Table 1).

The efflorescences near the Choco village have precipitated on the claystones at the contact with a granodiorite intrusion. They are white, fragile and soft. They are composed of calcium and magnesium sulphates as: monoclinic gypsum, hexahydrite $MgSO_4·6H_2O$ and starkeyite $MgSO_4·4H_2O$ (Table 1). Additionally quartz, illite, chlorite and feldspars occur there. Starkeite can be formed as a result of hexahydrite dehydtaration. Illite, kaolinite, chlorite, feldspars and quartz can derive from host rocks.

CONCLUSIONS

Efflorescences are found in South Peru accompanying hot or cold waters ascending to the surface and evaporating there. Composition of the mineral assemblages depends on local conditions, mainly on composition of the host rocks through which water ascends. Water temperature only facilitates elements leaching and causes more widespread distribution. The efflorescences blooming on the sedimentary rocks consist only of aluminium and iron sulphates, deriving from the pyrite-bearing shales, whereas these connected with magmatic rocks are complex sulphates. However, the presence and activity of hot water causes that the mineral phases are more plentiful and formation of precipitates covers larger areas than in the case of cold water. All the identified minerals are well known sublimates formed under fumarolic conditions at geysers and solfataras associated with volcanic activity, and in continental evaporate deposits.

REFERENCES

Abele, G.,1992. Landforms and climate on the western slope of the Andes. *Zeitschrift fűr Geomorphologie Supplement Band*. Bd. 84: 1-11.

Caldas, J., 1993. Geologia de los cuadrangulos de Huambo y Orcopampa. INGEMMET Boletin 46. Lima

Klinck, B.A., Palacios, M., 1985. *Mapa Geologico del Cuadrangulo de Chivay. Escala 1:100000.* Instituto Geologico Minero y Metalurgico, Peru.

Lamb, S., & Davis, P., 2003. Cenozoic climate change as a possible cause for the rise of ythe Andes. *Nature,* 425: 792-797.

Paulo, A., 2008. Geology of the Western Cordillera in Southern Peru – an outline. *Kwartalnik AGH Geologia*: 34, 2/1: 35-54 [in Polish, English summary]. Spanish translation: Novoa, Z. (ed.) 2009. Expedición Científica Polaca – Cañón del Colca. Sociedad Geográfica de Lima.

Steinmüller, K., 2001. Modern hot springs in the southern volcanic Cordillera of Peru and their relationship to Neogene epithermal precious-metal deposits. *Journal of South American Earth Sciences*, 14: 377-385.

Żaba, J. & Małolepszy, Z., 2008. Fault activity in the Rio Colca Valley in the Pinchollo-Maca Area, Central Andes, Southern Peru. *Kwartalnik AGH Geologia*: 34, 2/1: 83-106 [in Polish with English summary]. Spanish translation: Novoa, Z. (ed.) 2009. Expedición Científica Polaca – Cañón del Colca. Sociedad Geográfica de Lima. In: Novoa Goicochea Z.I. (ed.), *Expedición Científica Polaca, Cañon del Colca*. Sociedad Geográfica de Lima.