Gas geochemistry of fumaroles from Irruputuncu volcano, northern Chile.

Marcela Pizarro[*(1,2)], Felipe Aguilera[(1,2)], Franco Tassi[(3)], Ornella Saltori[(1,2)].
1. Facultad de Ingeniería, Departamento de Geología, Universidad de Atacama, Chile
2. Centro de Excelencia en Geotermia (CEGA), Universidad de Chile, Chile
3. Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Italia

* *email: mconsuelo.pp@gmail.com*

Abstract. Irruputuncu is a composite stratovolcano (5165 m.a.s.l.) located in the Central Andean Volcanic Zone (CAVZ), on the border between Chile and Bolivia (20º45'S – 68º34'W). The volcano has two nested craters, being the southernmost the active (~300 m diameter), which presently shows a persistent fumarolic activity. The source of fluids present in the volcano is mainly magmatic (high concentrations of SO_2 and N_2) with a restricted hydrothermal component. The origin of water is predominantly "andesitic water" with low contributions from meteoric water. This volcanic system is dominated by vapor phase in a highly oxidant environment (deep temperatures between 491 and 781ºC), although there is a poorly developed hydrothermal system, dominated by two phases (vapor + liquid), and where the fluids are in equilibrium with the liquid at ~340ºC.

Keywords: Fluid Geochemistry, Magmatic gases, Irruputuncu, Chile.

1 Introduction and Geological Setting

Located in central portion of the Central Andean Volcanic Zone (CAVZ), Irruputuncu (20°45'S – 68°34'W) (Fig. 1) is a composite stratovolcano (5165 m.a.s.l.) located in the SW part of a volcanic chain oriented NE-SW (de Silva and Francis 1991). The main edifice is built in the SW side of an amphitheatre of pre-Holocene collapsed volcano, and have two nested craters, being the southernmost the active (~300 m diameter), which presently shows a persistent fumarolic activity (González-Ferrán 1995). This volcano is constituted mainly by short and coarse andesitic to dacitic lava flows, dacitic lava domes, andesitic pyroclastic flows and dacitic block-and-ash flows deposits (de Silva and Francis 1991; Wörner et al 2000). The youngest unit, a block-and-ash flow deposit on the southwestern flank, has been dated in 1570±90 years BP (Stern et al 2007). In the active crater are present extensive sulphur deposits, where have been recognized pahoehoe-type sulphur flows poorly developed (Aguilera 2010). Irruputuncu is built above an underlying basement constituted by the Ujina and Pastillos ignimbrites (Upper Miocene and Pleistocene, respectively), formed mainly by welded dacitic tuffs and cineritic deposits (Vergara 1978; Vergara and Thomas 1984). The historical activity is characterized by the emission of a permanent gas column (~200 m above crater). However, phreatomagmatic explosions were observed in December 1989 and November 1995 (BGVN 1990; 1997). Thermal activity has been observed in the NW flank of volcano, where a single hot spring is present (Riso Patrón 1924; Hauser 1997).

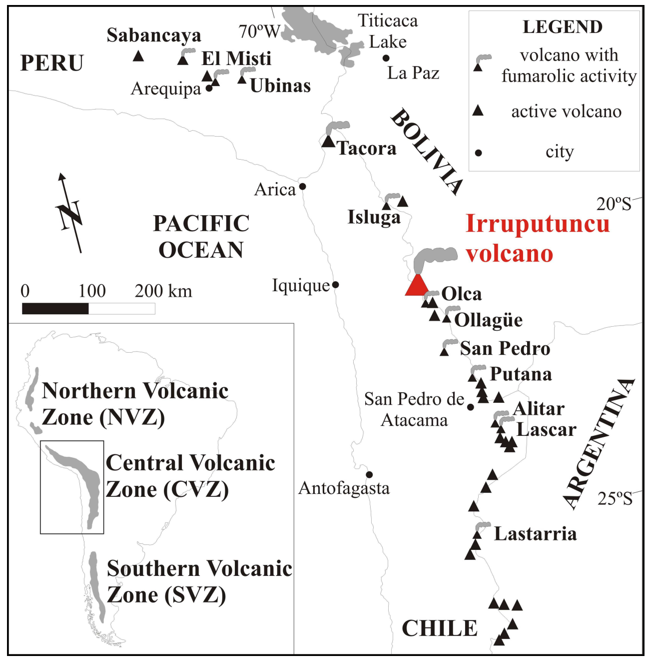

Figure 1. Location map of the study zone.

2 Results

The outlet temperatures of the fumaroles are between 83.4 and 202ºC. Water vapor ranged from 96.05 to 97.95 % vol. The composition of dry gas fraction is characterized by CO_2 as more abundant specie (up to 886,467 µmol/mol), presence of high contents of acid gases like SO_2 (up to 169,569 µmol/mol), HCl (up to 13,529 µmol/mol) and HF (up to 1,832 µmol/mol). Other important species correspond to N_2 (up to 106,603 µmol/mol), H_2S (up to 52,120 µmol/mol) and H_2 (up to 13,959 µmol/mol). Low content species correspond to O_2 (up to 325 µmol/mol), CO (up to 141 µmol/mol), CH_4 (up to 102 µmol/mol), Ar (up to 84 µmol/mol), S (up to 11 µmol/mol) and He (up to 10 µmol/mol). The concentrations of light hydrocarbons ($\sum C_2$-C_7) range from 0.02 to 0.62 µmol/mol. The content of

$\delta^{13}C$-CO_2 varies between -7.23 and -6.53 ‰ V-PDB. The isotopic water composition range for δD between -44.1 and -35.1 ‰ V-SMOW, while fro $\delta^{18}O$ from 6.8 to 10.4 ‰ V-SMOW. Helium isotopes composition expressed as R/R_a present values up to 7.27.

3 Discussion

The fumarolic discharges of the Irruputuncu volcano can be considered as the result of a mixing process between two end-members related to a magmatic source and at variable degrees, with a hydrothermal component, especially at the periphery of the crater (Fig. 2). The magmatic source is represented by the high concentrations of SO_2 and N_2 (Fig. 3), the last related to sediments released from subducting slab, as well as the R/Ra ratio (value close to the mantle in subduction zones 8 R/Ra). Hydrothermal input is represented mainly by the presence of H_2S and CH_4 (Fig. 2), which contents are increased in the low temperature discharges.

According to the isotopic data ($\delta^{18}O$ and δD) the origin of water is a result of mixing between "andesitic water" and meteoric water, the last related to local precipitation, being the "andesitic water" the dominant end member (Fig. 4). The isotopic values of $\delta_{13}C$-CO_2 indicate that the main source of carbon is sediment released from subducting slab with scarce input from MORB source, in concordance with high contents N_2.

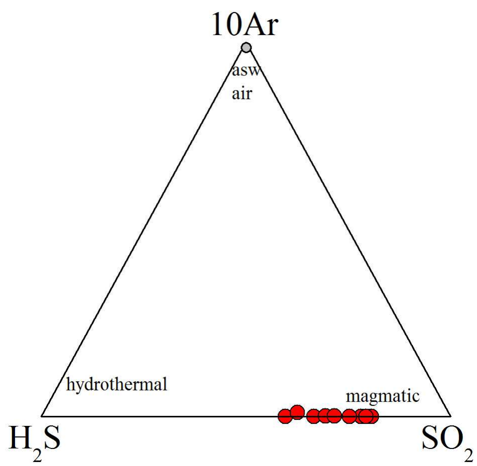

Figure 2. SO_2-Ar*10-H_2S ternary diagram for Irruputuncu fumaroles.

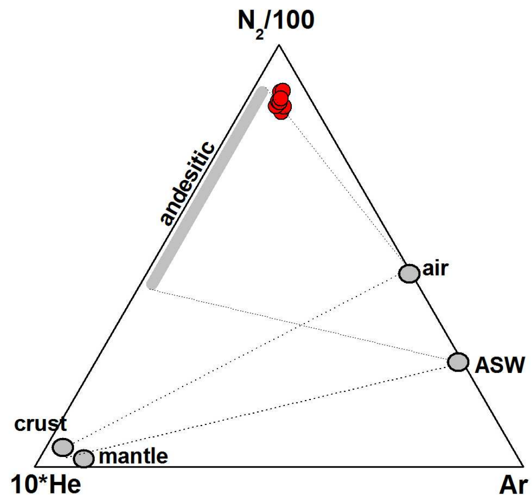

Figure 3. Ar-N_2/100-He*10 ternary diagram for Irruputuncu fumaroles. Air and Air Saturated Waters (ASW) compositions and convergent plate boundaries ("andesite") field (Giggenbach, 1996) are also reported.

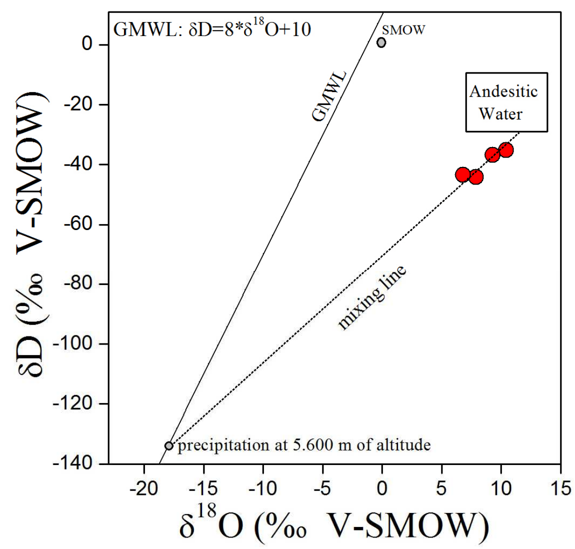

Figure 4. $\delta^{18}O$-δD diagram for condensates from Irruputuncu fumaroles. The "andesitic water" field (Taran et al., 1989; Giggenbach, 1992), the Local Meteoric Water Line (Chaffaut et al., 1998) and the calculated composition of the local precipitation are also shown.

According to geothermometric calculations, Irruputuncu volcano is a vapor-dominated system where the fluids are released from highly oxidant magmatic environment and are buffered by SO_2/H_2S magmatic buffer at temperatures that range between 491 and 781 ° C (Fig. 5). A limited two phases zone is probably restricted to a poorly developed hydrothermal system, where vapor is separated from a boiling aquifer (liquid phase). In this case, the fluids are in equilibrium with the boiling liquid at temperatures of ~340° C (Fig. 6).

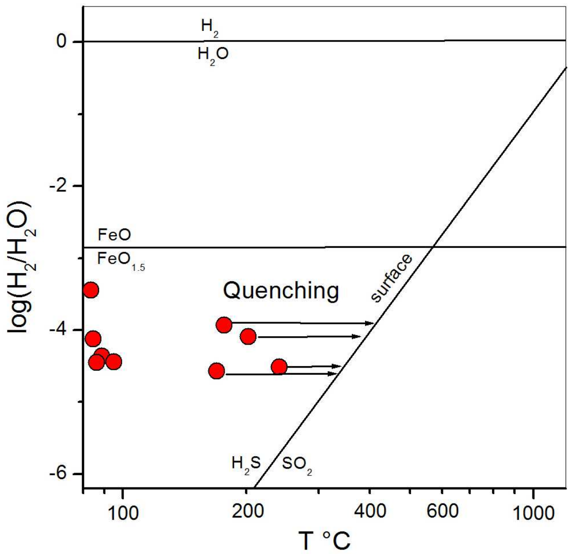

Figure 5. Log(H_2/H_2O) vs. outlet temperature (°C) diagram for Irruputuncu fumaroles. Solid lines refer to equilibria controlled by the magmatic SO_2–H_2S and FeO–$FeO_{1.5}$ redox pairs.

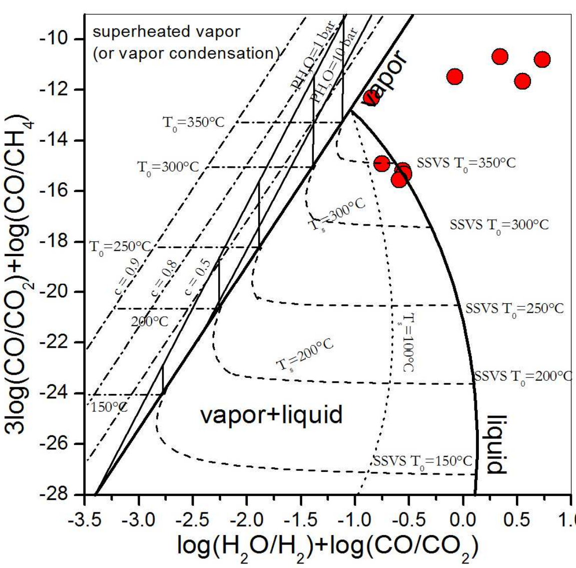

Figure 6. [3log(CO/CO_2) + log(CO/CH_4)] vs. [log(H_2O/H_2) + log(CO/CO_2)] diagram for Irruputuncu volcano fumaroles. The theoretical values for a single saturated vapor phase (vapor) and single saturated liquid phase (liquid) are shown.

Acknowledgements

This work have been funded by FONDECYT N° 11100372 and FONDAP Nº 15090013 - Centro de Excelencia en Geotermia de los Andes (CEGA).

References

Aguilera, F. 2010. Sobre el origen, naturaleza y evolucion de los fluidos en volcanes, campos geotermicos y fuentes termales de la Zona Volcanica Central (ZVC) en el norte de Chile (17º43'S-25º10'S). Concurso Bicentenario Tesis Doctoral 2008, Vol. I. Andros Impresores, Santiago. 468 p. ISBN: 978-956-7892-31-0

Bulletin of Global Volcanism Program. 1990. Irruputuncu. Volcanic Activity Reports. BGVN 15:03. http://www.volcano.si.edu

Bulletin of Global Volcanism Program. 1997. Irruputuncu. Volcanic Activity Reports. BGVN 22:07. http://www.volcano.si.edu

Chaffaut, I., Coudrain-Ribstein, A., Michelot, J., Pouyaud, B. 1998. Précipitations d'altitude du Nord-Chile, origine des sources de vapeur et données isotopiques. Bull Inst Fr Etudes Andines 27:367–384.

de Silva, S., Francis, P. 1991. Volcanoes of Central Andes. Ediciones Springer-Verlag, 216 p. Berlín

Giggenbach, W. 1992. Isotopic shifts in waters from geothermal and volcanic systems along convergent plate boundaries and their origin. Earth and Planetary Sciences Letters 113:495–510

Giggenbach, W. 1996 Chemical composition of volcanic gases. In: Scarpa M, Tilling RJ (eds) Monitoring and mitigation of Volcanic Hazards. Springer, Heidelberg, pp 221–256

González-Ferrán, O. 1995. Volcanes de Chile. Instituto Geográfico Militar, 639 p. Santiago

Hauser, A. 1997. Catastro y caracterización de las fuentes de aguas minerales y termales de Chile. Servicio Nacional de Geología y Minería, Boletín Nº 50, 90 p.

Riso Patrón, L. 1924. Diccionario jeográfico de Chile. Imprenta Universitaria, 958 p. Santiago

Stern, C., Moreno, H., López-Escobar, L., Clavero, J., Lara, L., Naranjo, J., Parada, M., Skewes, A. 2007. Chilean Volcanoes. In Geology of Chile, Moreno, T., Gibbons, W. (ed.). Geological Society of London. P. 289-308

Taran, Y., Pokrovsky, B., Esikov, A. 1989. Deuterium and oxygen- 18 in fumarolic steam and amphiboles from some Kamchatka volcanoes: "andesitic waters". Doklady Akademii nauk SSSR 304:440–443

Vergara, H. 1978. Cuadrángulo Ujina: Región de Tarapacá, escala 1:50.000. Instituto de Investigaciones Geológicas, Nº 33, 63 p.

Vergara, H., Thomas, A. 1984. Hoja Collacagua: Región de Tarapacá, escala 1:250.000. Servicio Nacional de Geología y Minería, Nº 59, 79 p.

Wörner, G., Hammerschmidt, K., Henjes-Kunst, F., Lezaun, J., Wilke, H. 2000. Geochronology (40Ar/39Ar, K-Ar and He-exposure ages) of Cenozoic magmatic rocks from northern Chile (18-22°S): implications for magmatism and tectonic evolution of the central Andes. Revista Geológica de Chile, Vol. 27, p. 205-240.