# OXYGEN AND HYDROGEN ISOTOPE VALUES FOR UNALTERED AND HYDROTHERMALLY ALTERED SAMPLES FROM THE CRETACEOUS LINGA PLUTONIC COMPLEX OF THE PERUVIAN COASTAL BATHOLITH NEAR ICA


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## INTRODUCTION

A portion of the Peruvian Coastal Batholith near Ica, is being studied using stable isotopes to determine the source of hydrothermal fluids that caused propylitic, phyllic, and potassic alteration in the mineralized Linga plutonic complex (Figure 1). Sources of hydrothermal fluids as well as water/rock ratios are analyzed to understand the role and magnitude of such fluids in alteration during cooling. A set of 64 mineral analyses from 18 igneous samples, 7 unaltered, and 11 altered, were analyzed for D/H and $^{18}O/^{16}O$ isotopes.

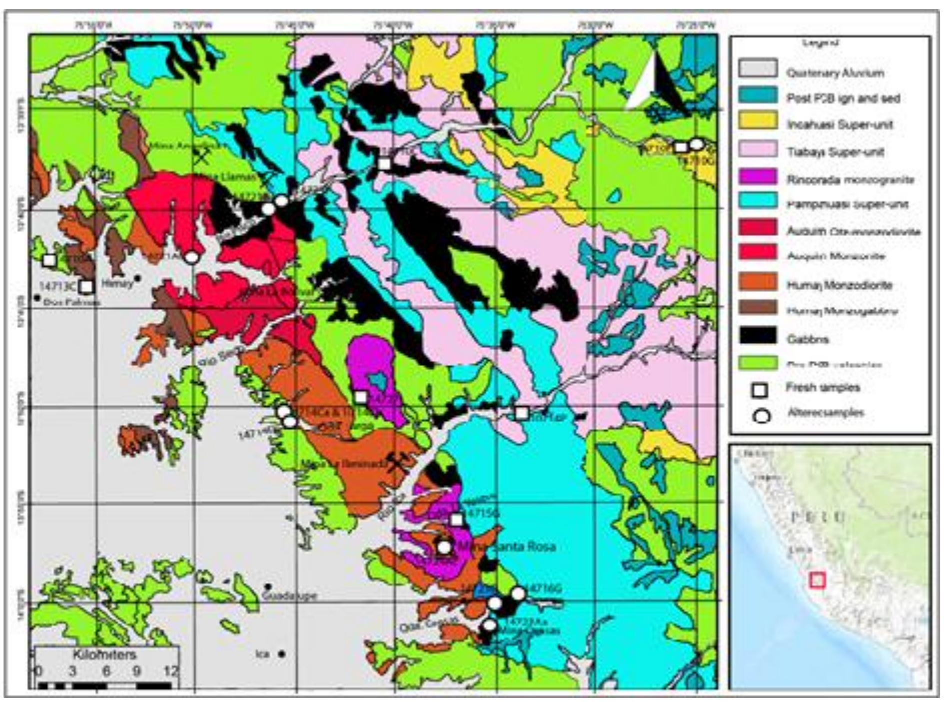


Figure 1: Geologic maps showing the main Super-units in the Ica-Pisco area and geographic location of the samples in this study.

**FRESH SAMPLES**

Considering that the plagioclase $\delta^{18}O$ isotopic values are a good representation of the whole rock $\delta^{18}O$ isotopic values, all fresh samples in this study are in the normal range for igneous rocks, i.e. +6‰ < $\delta^{18}O$ < +10‰ (Taylor, 1978). In addition, when mineral isotopic values are measured for a single rock sample, they vary as expected for isotopic thermal equilibrium at the time of crystalization (Bottinga and Javoy, 1975; Faure and Mensing, 2009; Javoy, 1977; Javoy et al., 1970; Sharp, 2007), and indicate that equilibrium has not been disturbed by later alteration events.

Fresh samples in Figure 2 are ordered from west to east. The $\delta^{18}O$ values in this plot do not show as striking a west-east increasing trend as occurs in other ranges of the American Cordillera. A west-east increasing isotopic trend could suggest increasing crustal contamination to the east (Clausen et al., 2014; Schmidt and Paterson, 2002; Silver et al., 1979) . Nevertheless, as displayed in Figure 2, the greatest $\delta^{18}O$ value for a fresh sample in this analysis of 7.9‰, belongs to the Tiabaya granodiorite 10714P, suggesting that this sample has some crustal contamination (Clausen et al., 2013).

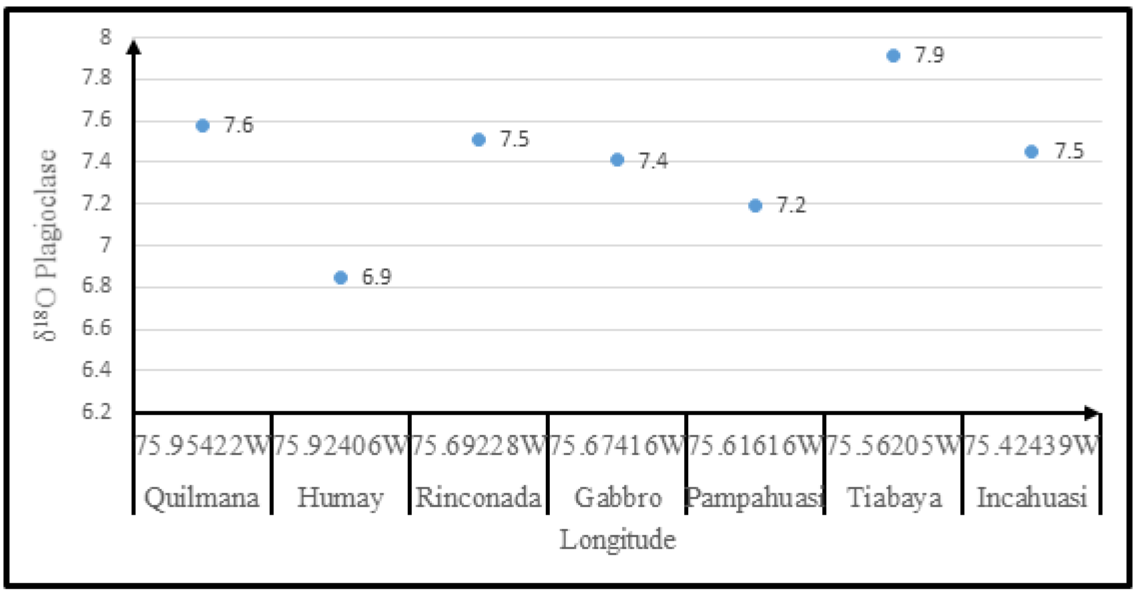


Figure. 2: Values of $\delta^{18}O$ for fresh samples in this analysis ordered from west to east. Note that a remarkable west-east trend is not noticeable here as in other parts of the American Cordillera (Clausen et al., 2014; Schmidt and Paterson, 2002; Silver et al., 1979)

**ALTERED SAMPLES**

It is worth nothing that 5 out of 7 $\delta^{18}O$ plagioclase values for the altered samples belong to the normal range suggested by Taylor (1978), meaning that the alteration assemblages in these samples were caused primarily by hydrothermal fluid of magmatic origin (Sharp, 2007; Sheppard, 1986).

The highest $\delta^{18}O$ value of +9.3‰ for plagioclase in an altered sample belongs to the sample 14716G, collected from a metamorphic aureole close to the contact between the Pampahuasi suite and the Quilmana volcanic. This value is probably due to some additional influence on the rock from metamorphic or low temperature hydrothermal fluids (Taylor, 1979; Turi, 1988; Valley et al., 2005).Altered samples in this study whose $\delta^{18}O$ values of plagioclase fit in the low $\delta^{18}O$ interval are the Yura volcanic 14710G ($\delta^{18}O$ = +2.6‰) and the altered sample 14724Ac ($\delta^{18}O$ = +5.7‰) from a dike of Rinconada intruding Humay. The low values for $\delta^{18}O$ in these rocks might be explained by the remelting or assimilation of preexisting low- $\delta^{18}O$ supra-crustal materials, diffusive exchange with heated meteoric water or direct meteoric water injection into the magma (Bindeman et al., 2008; Gilliam and Valley, 1997; Wanj et al., 2013).

## DIRECTION OF ALTERATION AND WATER/ROCK RATIO CALCULATIONS

Oxygen isotope ratios of hydrothermally altered igneous rocks provide effective data for determining the amount of water which has interacted with the rock (Taylor, 1977).

Figure 3 shows the magnitude and direction of change of the initial $\delta^{18}O$ plagioclase value for the altered samples, and the probable water/rock ratio involved in the alteration, using the material balance equation given by Taylor (1974).

| Unit | Rock type | Sample | $\delta^{18}O$ (‰) | W/R | Type of fluid |
|---|---|---|---|---|---|
| Yura Group* | Volcanic | 14710G | 7.5 → 2.6 | 1.6 | Meteoric |
| Quilmana | Andesite | 14710A | | | |
| Quilmana* | Volcanic | 14714Cb | 7.6 → 7.4 | 0.03 | Meteoric |
| Gabbros | gabbro | 14710C | | | |
| Humay | Monzogabbro | 14713C | | | |
| Humay* | Monzodiorite | 14714Eb | 6.7 → 8.2 | 0.1 | Metamorphic |
| Humay* | Monzodiorite | 14714Ca | 6.7 → 7.6 | 0.08 | Metamorphic |
| Auquish | | | | | |
| Auquish* | Monzonite | 14721Ac | 7.5 → 5.5 | 0.3 | Meteoric |
| Auquish* | Mineralized | 14721B | 7.5 → 7.1 | 0.05 | Meteoric |
| Rinconada | Granite | 14727U | | | |
| Rinconada* | In a vein | 14724Ac | 7.5 → 5.7 | 0.3 | Meteoric |
| Pampahuasi | Tonalite | 14715G | | | |
| Pampahuasi* | Host rock | 14723Aa | 7.2 → 8.4 | 0.1 | Metamorphic |
| Pampahuasi* | Mineralized | 14725F | 7.2 → 6.9 | 0.04 | Meteoric |
| Pampahuasi* | Diorite | 14723D | 7.2 → 6.8 | 0.05 | Meteoric |
| Pampahuasi* | Met aureole | 14716G | 7.2 → 9.3 | 0.2 | Metamorphic |
| Tiabaya | Granodiorite | 10714P | | | |
| Incahuasi | Granodiorite | 14710F | | | |

Figure. 3: Plot showing the magnitude and direction of alteration as measured by $\delta^{18}O$ in plagioclase, the water/ rock ratio involved in the interaction and the probable type of fluid involved in the interaction. (Blue color means estimated values; (*) means altered samples).

## CONCLUSIONS

The present study examined the stable isotopic composition of 18 igneous samples from the PCB near Ica, 7 unaltered and 11 with alteration. The analyses lead to the following conclusions:

1. Most of the fresh samples show isotopic equilibrium with the magma.
2. This new data indicate that the Linga Complex was primarily influenced by magmatic hydrothermal fluids; however, metamorphic and meteoric water have also had some impact in producing alteration assemblages.
3. Our data suggest that any hydrothermal fluid cooling of the batholith was primarily of magmatic origin.
4. These data provide a base line for a wider analysis of the several variables involved in both the alteration and the cooling process of the Linga Batholith.

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