

# Influence of subducted carbonate-rich sediments along Costa Rica volcanic arc

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## INTRODUCTION

Material transfer between the surface and Earth's interior controls element chemical cycling, affecting the planet from core to atmosphere. Subduction zones comprise the largest vertical mass transfer between the oceanic crust and mantle, where slab-derived fluids (aqueous fluids or hydrous melts) facilitate the element transfer into the mantle wedge, imparting a distinctive geochemical signature to subduction-related lavas (Hermann et al., 2006). This study aims to explore to what extent different subducted lithologies, like carbonate-rich sediments, contribute to chemical exchanges between Earth's exterior and interior, examining both the input and output components.

The Costa Rica (CR) volcanic arc is an ideal natural site to investigate the influence of carbonate contributions during subduction. The arc extends from the Mexico-Guatemala border to Panama, where the Cocos Plate subducts underneath the Caribbean Plate. To the north, Ocean Drilling Program (ODP) cores of the Nicoya Peninsula reveal a consistently thick carbonate package below a hemipelagic sediment layer. The mid-Miocene carbonates rank among the top five largest volumes of subducting sediments worldwide (Plank, 2014). On the southeastern side, alongside the seamounts from the Galapagos hotspot track, International Ocean Discovery Program (IODP) cores reveal a thinner layer of hemipelagic and carbonate sediments, with a thicker igneous volume reaching down the Caribbean plate.

We investigate the trace elements systematics along the Costa Rica volcanic front (VF), including mafic volcanic samples, mainly basalts and basaltic andesites from all three main areas (Guanacaste, Tilarán, Central). Our study includes the subduction input with samples from the ODP exp. 170 site 1039 and the IODP exp. 334 site U138.

## RESULTS

The NW Costa Rica subducting material consists of 100 m of hemipelagic sediment, composed of clay- and silt-sized terrigenous grains with some biogenic material. Characterized by low strontium (Sr) and enriched in alkali elements (Li ~70 ppm). From 100 meters below the seafloor (mbsf) to 180 mbsf, there is a transitional zone where hemipelagic sediments are intercalated with biogenic phases (carbonaceous sediments), showing an increase in Sr content with depth and a highly enriched barium content (up to 7000 ppm). Below the transitional zone lies a package of pure carbonaceous phases extending to 450 mbsf, transitioning into a carbonaceous breccia in the lower part. Below 450 mbsf the basaltic oceanic crust occurs. In the southeast, near the Galapagos hotspot track, a thinner 90-meter sediment layer covers the oceanic crust. The upper 45 meters consist of clay-rich sediment enriched in alkalis and depleted in Sr, followed by a thin transitional zone leading to a carbonate-rich layer enriched in uranium.

Systematic variations in trace element compositions and ratios are observed in samples from the VF. Ratios of LILE elements to HFSE and REE (eg., Ba/La (Th), U/Th) vary systematically along the VF, decreasing from NW to SE Costa Rica. On the other hand, Light (L) to Heavy (H) REE ratios (eg., La/Yb,) increase towards Panama, reflecting a lower LREE and higher HREE in NW Costa Rica. The lavas from Guanacaste range have the highest Ba/Th and Ba/La ratios but lower Ba/Th than subducting carbonates in the NW region. In contrast, SE arc lavas (Central range) are close to the primitive mantle (PM) value. Additionally, there is an observed increase in the K anomaly (K/K\*) and a decrease in the Nb anomaly (Nb/Nb\*) in lavas towards the NW.

Ratios between HFSEs have been observed along the Costa Rican arc, with the Nb/Ta ratio increasing towards the NW, except for Turalba and Irazú volcanoes, which show higher Nb/Ta values than the other Central volcanoes.

## DISCUSSIONS AND CONCLUSIONS

Central American arc lavas inherit distinct elemental and isotopic signatures from subducted materials (e.g., Patino et al., 2000). Sediment subduction recycling results in high Ba/Th and Ba/La ratios in arc lavas, with regional variations indicating stronger fluid influence towards northwest Costa Rica.

The key question is what influence carbonate-rich sediments have on the composition of arc lavas. Recent high-precision HFSE data show that elevated Nb/Ta ratios are linked to carbonate-rich metasomatism from subducted materials, making Nb/Ta a geochemical tracer of subducted carbonates (Bragagni et al., 2024). Although Nb and Ta are considered fluid immobile elements, carbonate-rich metasomatic fluids have been proposed to mobilize Nb more readily than Ta. Experimental studies confirm that carbonate-rich fluids solubilize Nb, further increasing Nb/Ta in the affected mantle (Green, 1995). While the Nb/Ta ratio remains constant during magmatic processes, high Nb/Ta ratios in some arc magmas are often linked to residual rutile in subducted slabs. During crystal/melt fractionation, Ti-rich minerals like rutile, sphene, Ti-magnetite, and ilmenite preferentially incorporate Ta over Nb, raising Nb/Ta ratios in the residual melts (Green, 1995).

Potassium enrichment with  $K/K^* > 1$  of arc lavas are often considered to result from mantle metasomatism by subduction-derived fluids (Halliday et al., 1995), while  $K/K^* < 1$  suggests a primitive mantle or a mantle source minimally affected by subduction-related fluids or melts. In CR arc lavas,  $K/K^*$  increases towards the NW, indicating enhanced fluid interaction consistent with the elemental enrichment of LILEs. The Nb/Ta ratio can fractionate when rutile interacts with aqueous fluids, retaining Nb while Ta becomes more mobile. This typically leads to low Nb/Ta ratios in fluids metasomatizing the mantle wedge, which contradicts the observed high Nb/Ta values in Costa Rica. Therefore, we conclude that elevated Nb/Ta and high  $K/K^*$  ratios strongly indicate an increasing contribution of carbonate-rich metasomatic fluids towards NW Costa Rica, where these sediments are being incorporated into the mantle. Future studies of heavy stable isotopes in Granada will provide deeper insights into carbonate recycling within the Costa Rican subduction zone, with broader implications for global carbon (re)cycling.

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