SUBDUCTION DYNAMICS AT THE MIDDLE AMERICA TRENCH: NEW CONSTRAINTS FROM SWATH BATHYMETRY, MULTICHANNEL SEISMIC DATA, AND ^{10}BE

By

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This thesis is dedicated to my parents

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ABSTRACT

The cosmogenic radionuclide ^{10}Be is a unique tracer of shallow sediment subduction in volcanic arcs. The range in ^{10}Be enrichment in the Central American Volcanic Arc between Guatemala and Costa Rica is not controlled by variations in ^{10}Be concentrations in subducting sediment seaward of the Middle America Trench. Sedimentary ^{10}Be is correlated negatively with ^{143}Nd/^{144}Nd, illustrating that ^{10}Be concentrations varied both between and within cores due to mixing between terrigenous clay and volcanic ash endmember components. This mixing behavior was determined to be a function of grain size controls on ^{10}Be concentrations. A negative correlation of bulk sedimentary ^{10}Be concentrations with median grain size and a positive correlation with the proportion of the sediment grains that were <32 μm in diameter demonstrated that high concentrations of ^{10}Be in fine-grained, terrigenous sediments were diluted by larger grained volcanogenic material.

The sharp decrease in ^{10}Be enrichment in the Central American Volcanic Arc between southeastern Nicaragua and northwestern Costa Rica correlates with changes in fault structure in the subducting Cocos plate. Offshore of Nicaragua, extensional faults associated with plate bending have throw equal to or greater than the overlying subducting sediment thickness. These faults enable efficient subduction of the entire sediment package by preventing relocation of the décollement within the downgoing sediments. Offshore of Costa Rica, the reduction of fault relief results in basement faults that do not penetrate the overlying sediment. A conceptual model is proposed in which the absence of significant basement roughness allows the décollement to descend into the subducting sediment column, leading to subsequent underplating and therefore removal of the bulk of the sediment layer that contains ^{10}Be.

Basement fault relief was linearly related to plate curvature and trench depth. The systematic shoaling of the plate from southeastern Nicaragua to northwestern Costa Rica is not explained by changes in plate age for this region. Instead, it is hypothesized that the flexural shape of the plate offshore of southeastern Nicaragua and northwestern Costa Rica represents a lateral response to a buoyant load caused by the thick crust and elevated thermal regime in the Cocos plate offshore of southeastern Costa Rica.

Chapter I

Subduction Dynamics at the Middle America Trench: New Constraints from Swath Bathymetry, Multichannel Seismic Data, and ^{10}Be

1. Background and Motivation

Subduction zones control geochemical recycling between different earth reservoirs. The complex relationships between slab and sediment geochemistry, fault structure, and their secondary effects such as volatile input, dehydration reactions, and sediment dynamics (accretion, tectonic erosion, or subduction) play a crucial role in the global distribution of geochemical constituents. These interconnected mechanisms of recycling in turn influence the behavior of the seismogenic zone and arc magma genesis and evolution, making the study of subduction zones socially relevant to assess potential catastrophic hazards such as earthquakes, tsunamis, and volcanism. The goal of this thesis research was to focus on the processes governing recycling of an integral tracer of sediment subduction at convergent margins, providing a building block that will contribute to our broader comprehension of these important tectonic systems.

^{10}Be is a cosmogenic radionuclide generated from cosmic ray spallation reactions on oxygen and nitrogen in the atmosphere. As ^{10}Be has a relatively short half-life of 1.5×10^6 yrs (Yiou and Raisbeck, 1972), it is only found in significant concentrations in the upper tens of meters of marine sediment. Enriched concentrations of ^{10}Be have been detected in arc volcanic lavas, but not in other mantle-derived rocks such as MORB, OIB, and continental flood basalts (Brown et al., 1982; Tera et al., 1986; Ryan and Langmuir, 1988; Monaghan et al., 1988; Morris and Tera, 1989; Morris et al., 1990). ^{10}Be was therefore recognized as an important tracer of sediment subduction in arc petrogenesis because its presence in arc lavas implies subduction of surficial sediments to the roots of the arc system (e.g., Tera et al., 1986; Morris et al., 1990).

The use of arc volcanic ^{10}Be as a tracer of sediment subduction is predicated upon the assumption that the sole source of the ^{10}Be is marine sediments that have been incorporated into arc lavas during subduction. Therefore, systematic examinations of the mechanisms by which ^{10}Be could be concentrated in these rocks were conducted to determine that variations in young, subducting sediment were the likely source of arc volcanic ^{10}Be variability (e.g., Tera et al., 1986; Monaghan et al., 1988; Ryan and Langmuir, 1988; Morris and Tera, 1989). By normalizing ^{10}Be to its stable isotope ^{9}Be, effects from partial melting and fractional crystallization could be eliminated. Whole rock and mineral separate studies of $^{10}Be/^{9}Be$ ratios revealed constant ratios between phases within the same arc lava sample, implying that the ratio was imparted prior to crystallization, inconsistent with contamination of ^{10}Be by post-eruptive surface alteration (Monaghan et al., 1988; Ryan and Langmuir, 1988; Morris and Tera, 1989). Nor did ^{10}Be concentrations in arc lavas vary with degree of alteration (Tera et al., 1986). Additionally, the low concentrations of ^{10}Be in rain water and groundwater ($\leq 1 \times 10^4$ atom/g; e.g., Pavich et al., 1985; Monaghan et al., 1983) relative to arc rocks would necessitate high water:rock ratios (~100), unrealistic for these environments, to produce the $>10^6$ atom/g concentrations of arc lavas (Tera et al., 1986).

Arc lavas measured for ^{10}Be analysis are also too young to have built up large amounts of ^{10}Be via cosmic ray bombardment or alteration processes (Tera et al., 1986; Morris and Tera, 1989). Old, moderately altered lavas unassociated with subduction do not contain ^{10}Be in measurable quantities. Even for highly weathered samples in which the rinds did have ^{10}Be enrichment, the ^{10}Be disappeared when the weathered portion of the sample was removed, which is part of the established analytical procedure for volcanic rocks (Tera et al., 1986). The possibility that ^{10}Be came from near-surface assimilation of sediments was also considered and dismissed in these studies. High ^{10}Be concentrations were found in arcs that do not have young sediments in their edifices (i.e., S. Chile), and Loihi seamount lavas had no ^{10}Be enrichment despite erupting through young, marine sediments (Morris and Tera, 1989). The low to zero ^{10}Be concentrations recorded in arc lavas such as the Cascades, in which the recycling time from trench to volcano is long enough for the subducted sedimentary ^{10}Be signal to have decayed away, is also consistent with a lack of near-surface sediment assimilation (Morris and Tera, 1989). The geochemical evidence therefore strongly supports the interpretation that the source of ^{10}Be in arc lavas is subducted marine sediment.

The variations in, and occurrences of, sediment-derived ^{10}Be in volcanic arcs are not well understood in the context of the various competing factors that could influence ^{10}Be subduction recycling. There are four main processes that control ^{10}Be enrichment in arc volcanics: (1) ^{10}Be concentration in the downgoing sediments, (2) convergence rates, (3) geophysical and structural characteristics related to subduction style of the trench system (e.g., offscraping, underplating, tectonic erosion, or complete sediment subduction), and (4) geochemical processes during incorporation of sedimentary ^{10}Be into arc magmas. In the Central American Volcanic Arc (CAVA), major changes in the magnitude of ^{10}Be enrichment are observed along strike of the arc (Figure 1). The wide span of ^{10}Be values from background to highly enriched encompasses almost the entire global range of ^{10}Be concentrations observed in arc volcanics (Tera et al., 1986; Morris and Tera, 1989; Morris et al., 1990). The pattern of enrichment progresses from moderate in Guatemala to high in Nicaragua and then rapidly diminishes toward Costa Rica, which shows little to no enrichment. The abundant geochemical and geophysical data characterizing the arc also serve to make the Middle America Trench/Central American Volcanic Arc system an ideal locale to evaluate the primary processes affecting arc volcanic ^{10}Be enrichment.

The variability of CAVA ^{10}Be enrichment does not appear to relate in a simple fashion to any of the main subduction parameters, such as the thickness of the young trench sediments, the age of the subducting slab, seismicity, dip angle of the slab, and convergence rate (e.g., Carr, 1984; Tera et al., 1986; DeMets et al., 1990; Morris et al., 1990; Protti et al., 1995; Barckhausen et al., 2001). Even other geochemical tracers of the slab contribution to the arc do not uniformly vary with the arc volcanic ^{10}Be (e.g., Morris et al., 1990). Prior to this work, the sharp decrease in ^{10}Be between southeastern Nicaragua and northwestern Costa Rica had not been explained by previous investigations.

The motivation for this work originated in the observation that, in contrast to other subduction parameters, the topography and deformation of the downgoing plate change