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The long term objective of this project was to understand the processes responsible for the formation and evolution of the oceanic crust. In order to achieve this goal, we initially focused our efforts on understanding the relationship between the physical properties of the upper oceanic crust and the physical and chemical processes that control those properties. The aim of this research was to test the hypothesis that the seismic properties of the upper oceanic crust are controlled by the porosity and chemical alteration of the crust.

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Processes Of Crack-Filling In The Shallow Oceanic Crust: Constraints From Mineralogical And Geochemical Studies

Final Report for Grant No. N900014-92-J-1207

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Long Term Scientific Objectives

The long term objective of this project was to understand the processes responsible for the formation and evolution of the oceanic crust. In order to achieve this goal, we initially focused our efforts on understanding the relationship between the physical properties of the upper oceanic crust and the physical and chemical processes that control those properties. The aim of this research was to test the hypothesis that the seismic properties of the upper oceanic crust are controlled by the porosity and chemical alteration of the crust.

Background

One of the fundamental observations of oceanic crustal structure is that the seismic structure of the uppermost crust changes with age. As crustal segments move off-axis, velocities gradually increase within layer 2A and eventually it is impossible to distinguish Layer 2 A and 2B. The rate of velocity increase within Layer 2A varies geographically, ranging from a few to tens of million years. Possible mechanisms for reducing porosity include off-axis volcanism, compaction due to lithostatic pressure and infilling of cracks with sediment; most investigators conclude, however, that the crack-size distributions is the most plausible explanation. The porosity structure of the oceanic crust varies in spatial scale and includes a wide variety of cracks and pore sizes within and between volcanic units. Modeling of velocity-porosity relationships has predicted that seismic velocities may be doubled with only a small (5%) reduction in porosity. Modification of geometries by infilling small cracks with low aspect ratios most easily achieves the observed velocity increase. Reduction in porosity as well as change in crack geometry is best facilitated by the precipitation of secondary minerals within these voids.

Approach

Sequential deposition of minerals in voids documented for DSDP/ODP drillcores shows that the effective porosity of the upper oceanic crust is progressively reduced during crustal aging. Because a variety of variables influence mineral precipitation, it is probable that the rate of change of porosity and, thus, the rate of change of seismic velocity is also greatly influenced by these variables. We conducted a systematic study of porosity as a function of crack-filling in volcanic sequences recovered by the DSDP and ODP. Based on a synthesis of the DSDP/ODP database, we selected 25 sites from regions with high and low sedimentation rates, a wide range in age, spreading rate, and those that show evidence for off-axis re-heating. The evolution of crack-filling and the conditions of alteration (e.g., temperature, fO_2) were investigated through the study of thin sections, x-ray diffraction of separated materials and electron microprobe analysis. The rare earth element content and Sr-isotopic ratios of carbonate samples were analyzed in order to evaluate if they precipitated directly from seawater or seawater-derived hydrothermal fluids and the timing of deposition, respectively.

Accomplishments and Results

A consistent sequence of crack-filling was observed in the studied basement cores:

clay minerals → zeolites → carbonates

The presence of specific varieties and compositions of these mineral groups is influenced by water/rock ratios, temperature, open versus closed circulation, and duration of reaction.

In areas of low sedimentation, the shallow crust may remain open to circulation of cold seawater for tens of millions of years. Comparison of several basement cores of varying age recovered in areas of low sedimentation shows that an oxidative alteration front, commonly referred to as seawater weathering, migrates down into the volcanic pile as the crust ages. Alteration and crack-filling is most pervasive in this zone. Development of the seafloor weathering zone is dependent on seafloor topography such that topographic highs and volcanic edifices remain open to seawater for prolonged periods of time. Moreover, abyssal hills act as sites of hydrothermal discharge of upwelling, chemically modified seawater. The volcanic units recovered at DSDP Hole 417A, drilled on a topographic high, are much more pervasively altered and veined than DSDP Hole 417D, drilled only 450 m away in a topographic low. In areas of high sedimentation, the crust may be sealed from cold seawater penetration early in its history.

In regions of high sedimentation, the crust may become sealed from cold seawater penetration early in its history (<5 million years). Where the crust is permeable at the time of sealing, closed circulation leads to the deposition of minerals that are different from those that precipitated in an open environment. Whether or not this leads to significant crack-filling has not been resolved.

In regions where the transition from open to closed circulation occurred early in its history, such as mid-ocean ridge systems proximal to continental margins, rocks initially altered at low temperatures may be subjected to conductive reheating. Our work on basement cores recovered at ODP Hole 765B, drilled in ~140 Ma crust in the Argo Abyssal Plain, shows that this section of crust was initially altered at low temperatures and was subsequently re-heated to ~100°C. This re-heating event did not involve addition crack-filling. Study of Hole 504B by other investigators show that the lowermost volcanics have also been re-heated but that no additional crack-filling has occurred. Thus it is unlikely that off-axis re-heating events result in a significant change in crustal porosity.