Imaging Electrical Conductivity Structure of Crustal Magma at the East Pacific Rise

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Summary

New oceanic crust is formed at mid-ocean ridges as crustal magma chambers erupt and cool to create the lavas, dikes, and gabbros that form the seafloor. We collected both marine MT and CSEM data across the East Pacific Rise at 9° 30' N, a fast spreading center with a half-rate of 55 km/My. The 200 km aperture MT array, consisting of 29 ocean bottom electromagnetic recorders, imaged a symmetrical, triangular shaped melt region beneath the ridge axis extending to depths of about 90 km, interpreted as passive melt flow focusing toward the ridge. During the MT experiment we deployed a CSEM transmitter, collecting data along a 35 km line occupied by 18 ocean bottom instruments. We towed the transmitter 5 km north of the receiver line in order to record both radial and azimuthal data modes, so the data were rotated into the receiver line (Ey electric and Bx magnetic modes) and perpendicular to the line (Ex and By modes). Both amplitude and phase data were inverted to isotropic electrical resistivity using MARE2DEM, yielding resistivity structures that span nearly three orders of magnitude and extending to 8 km below the sea floor, into the uppermost mantle. A joint inversion of the CSEM data with MT data produces a similar crustal resistivity model and extends into the melt upwelling in the mantle. Although the CSEM and MT are clearly compatible, balancing the misfit budget between MT and CSEM data reduces the resolution in the crust, and so the CSEM only inversion is preferred for studying crustal structure. Inversion reveals a conductive axial magma chamber centered beneath the ridge axis and deepening away from the ridge, a geometry that would focus eruptions at the ridge axis. Our data also image a wider magma chamber in the lower crust extending to both sides of the ridge axis, with a proximity that suggests intermittent recharge of the axial chamber. This combination of shallow and deep magma chambers support a hybrid model of crustal generation that incorporates gabbro formation from crystallization in the axial magma chamber (the "gabbro glacier") and sill formation fed by melt in the lower crust ("stacked sills"). We converted resistivity to melt fraction and estimate total melt volume to be about 140 cubic kilometers of melt per kilometer along strike, or about 250 ky of crustal formation, from which we can infer a residency time. The upper edges of the axial magma chamber and the deep crustal conductors imaged by the EM data follow the 1200°C isotherm computed for conductive cooling and migration of melt through a spreading center mush zone, which implies that the upper extent of melting is determined by a conductive freezing horizon. This interpretation of melt migration and conductive cooling is supported by a lack of evidence in the conductivity images for deep hydrothermal cooling near the ridge axis.

Keywords: magma, marine CSEM, mid-ocean ridge