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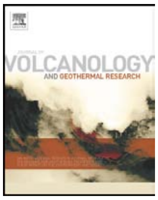

Density and lithospheric strength models of the Yellowstone–Snake River Plain volcanic system from gravity and heat flow data

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ABSTRACT

The structure and composition of the Yellowstone–Snake River Plain (YSRP) volcanic system were analyzed using gravity data taken at over 30,000 stations in the YSRP and surrounding region. Additional constraints were provided by tomographic seismic velocity models, new heat flow and temperature information, GPS-derived strain rates, earthquake locations, and chemical analyses of volcanic rocks. P-wave velocity models and velocity–density data based on petrologic information were used to constrain three-dimensional density models. Rheology and strength properties were calculated at selected locations and compared to earthquake focal depths. Results of this study suggest that the lower crust of the Snake River Plain (SRP) has been thickened by the addition of an underplated layer composed primarily of clinopyroxene, having a density of 3200 kg/m^3. A mid-crustal high-density sill is composed of a series of gabbroic lenses inter-fingering with the granitic upper crust. This geometry yields a bulk composition comparable to diorite and a density of 2900 kg/m^3. The mid-crustal sill varies from 4 to 11 km in thickness, resulting in a series of SE-NW-trending gravity highs observed along the axis of the SRP. The mid-crustal sill extends up to 20 km southeast of the SRP volcanic field and causes asymmetry of the gravity field. The Yellowstone Plateau volcanic field density model reveals low-density partial melt 10 km beneath the caldera that shallows under the northeastern caldera, and continues laterally 20 km north of the caldera boundary and notably increases the previously estimated size of the magma reservoir by ~20%. The caldera melt body has a density of 2520 kg/m^3 and a significantly lower value of 2470 kg/m^3 for the northeastern caldera melt body. Southwest of Yellowstone, the crustal section occupied by the mid-crustal sill in the SRP and the partial melt in Yellowstone constitute a transition area between the active Yellowstone magma system and the now volcanically quiescent SRP, with a density of 2820 kg/m^3. Strength models show that the crust of the YSRP becomes progressively stronger and cooler with increasing distance from Yellowstone, and tectonic earthquakes within the Yellowstone caldera are unlikely to nucleate below 4–6 km depth, thus limiting the maximum magnitude of earthquakes to $M \leq 6.5$.

1. Introduction

1.1. Volcanic and tectonic history

The Yellowstone–Snake River Plain volcanic system (YSRP, Fig. 1) provides a unique area to observe the processes of an active continental hotspot and its interaction with a continental plate. In its 17 million year history the Yellowstone hotspot has dramatically modified the landscape from southeastern Oregon to northwestern Wyoming, destroying mountain ranges, producing a chain of bimodal basalt–rhyolite volcanic centers, and forging the world famous hydrothermal features of Yellowstone National Park. These features are the collective product of hotspot derived basaltic–rhyolitic volcanism that has and continues to reconstruct large portions of the deep continental interior. The striking surface features of the YSRP reflect the interaction of volcanic and tectonic processes that have been widely studied but remain poorly understood.

The study area for this analysis encompasses the YSRP, the adjacent Basin and Range province to the south, the Idaho batholith to the northwest, and the Rocky Mountains to the north and east (Fig. 1). This area is geologically and tectonically diverse and provides a framework in which to study the regional effects of hotspot volcanism on continental lithosphere. We note that the volcanism of the YSRP also extends northwest into the High Lava Plains of Oregon to the Newberry caldera, but our study only considers the eastern SRP and Yellowstone components of the system. Moreover we refer the reader to detailed summaries of the geology and tectonics of the YSRP as background information for our papers (see the multiple papers in this volume and Armstrong et al., 1975; Bonnichsen, 1982; Leeman, 1982; Christiansen, 2001; Camp and Ross, 2004).

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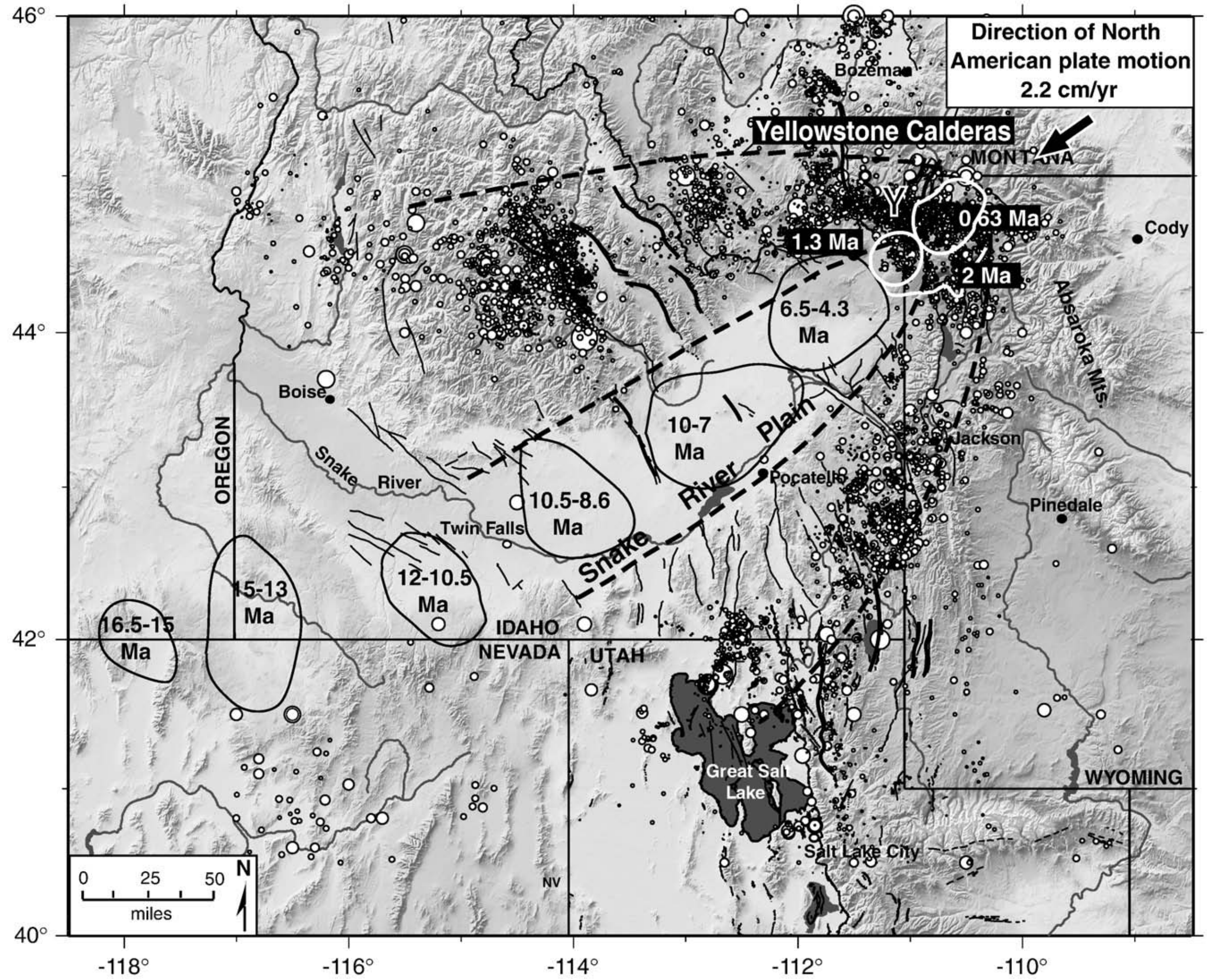

Fig. 1. Volcanic and tectonic features of the Yellowstone–Snake River Plain (YSRP) system. The YSRP study includes southern Idaho, western Wyoming, and southwestern Montana. Y = Yellowstone National Park. Figure after Smith and Siegel (2000), Humphreys et al. (2000), and Christiansen et al. (2002).

The YSRP volcanic system provides the record of both past and present intraplate volcanism. The time transgressive nature of YSRP volcanism was first documented by K–Ar dating of volcanic rocks in the SRP (Armstrong et al., 1975). As the North American plate has moved southwest at ~2.5 cm/yr over the hotspot, it has left an 800 km track of giant-caldera forming volcanoes in its wake (Smith and Braile, 1993). More than ~150 giant caldera-forming eruptions are concentrated in a dozen volcanic centers and the entire area was later covered with Late Quaternary basalt flows that form the dominant surficial features of the SRP (Perkins and Nash, 2002). Two million years ago, the Yellowstone hotspot reached its current position at Yellowstone National Park, creating the Yellowstone Plateau volcanic field as a product of plume plate interaction and three giant silicic eruptions at 2.1, 1.2, and 0.64 Ma (Christiansen, 1984). The youngest of the cataclysmic eruptions formed the modern Yellowstone caldera in Yellowstone National Park (Christiansen and Blank, 1969).

1.2. Regional geophysics

The varied geologic history of the study area is reflected in its geophysical signatures. A companion paper by Smith et al. (2009-this volume) provides more detail on geophysical properties of the YSRP. This paper focuses on compositional, thermal, and strength properties illustrated in gravity, seismic, and heat flow data.

Many gravity studies have been done for the YSRP, particularly in Yellowstone. Carle et al. (1990) most recently summarized the results of these surveys. Yellowstone exhibits a large negative Bouguer anomaly of about 250 Mgal. Schilly et al. (1982) resolved a mid-crustal body of low seismic velocities that corresponds to the area of the negative gravity anomaly in Yellowstone. Seismic velocity and density are generally positively correlated, thus a decrease in velocity usually corresponds to a decrease in density. The low-velocity, low-gravity area was inferred to be an area of partial melt in the upper crust.

Gravity studies of the SRP were summarized by Mabey et al. (1974) who conducted the first comprehensive study of the crustal structure using the Bouguer gravity field of southern Idaho centered on the SRP. The locally high (−100 Mgal) gravity signature of the SRP can be attributed to a roughly trapezoidal mid-crustal sill-like body at the base of the upper crust (Sparlin et al., 1982). This body has a relatively high density of 2880 kg/m^3, approximately 200 kg/m^3 denser than the surrounding rocks. The mid-crustal body is inferred to be mafic remnants of old magma chambers associated with the basaltic–rhyolitic volcanism of the YSRP.

Earthquakes in the study area are concentrated in a ~100 km wide, generally north-south-trending zone of relatively shallow events and a surrounding zone north of the SRP forming an integral part of a “tectonic parabola”. The most intense seismicity is in the Yellowstone plateau and surrounding areas. Earthquakes of the YSRP dominantly