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Deep-crustal magma reservoirs beneath the Nicaraguan volcanic arc, revealed by 2-D and semi 3-D inversion of magnetotelluric data

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A B S T R A C T

A long-period magnetotelluric (MT) experiment was conducted in early 2009 in western Nicaragua to study the electrical resistivity and thus fluid/melt distribution at the Central American continental margin where the Cocos plate subducts beneath the Caribbean plate. Strike analysis yields a preference direction perpendicular to the profile, with moderate deviation from two-dimensionality, however. Two-dimensional modeling maps the sediments of the Nicaraguan Depression and a high-conductivity zone in the mid-crust, slightly offset from the arc. Further conductors are modeled in the backarc. However, these features are probably artifacts when a 2-D program is applied to data which show moderate 3-D characteristics. 3-D inversion clarifies the situation, and the major remaining conductive structure is now quasi directly beneath the volcanic chain and interpreted as a deep-seated magma deposit. Conductivity in the backarc is also relatively high and may either be caused by still existing partial melts beneath the Paleocene to Miocene volcanic arcs or by related metallic deposits in the aureoles of hydrothermal alteration.

1. Introduction

Long-period magnetotelluric (MT) data were collected in early 2009 in western Nicaragua along a profile from the coast of the Pacific Ocean to the Nicaraguan Highland, crossing the Nicaraguan Depression with the active volcanic arc (Fig. 1). The aim of this study is to gain insight into the electrical resistivity structure and thus fluid/melt distribution at the Central American continental margin, formed by subduction of the Cocos plate beneath the Caribbean plate. A particular goal is the detection of deep-crustal magma reservoirs beneath the arc and possibly the backarc. The measurements complement earlier MT investigations in NW Costa Rica across the Guanacaste volcanic range (Brasse et al., 2009; Worzewski et al., 2011).

Before we describe the actual MT investigations, we briefly summarize the geologic/tectonic background of the study area which is relevant for electromagnetic deep sounding (for an overview, see Mann (2007)). The Cocos plate subducts slightly obliquely in a northeastern direction with a convergence rate of ~8.5 cm/a (DeMets, 2001). Depth of the Middle America Trench (MAT) offshore Nicaragua is around 5000 m. This would produce a large coast effect in long-period MT soundings; however, the trench is relatively far from the coast (~140 km). On the other hand, the wide continental shelf encompasses the Sandino Basin (Walther et al., 2000) which may enhance the effect again – an offshore MT study ~80 km farther south of our profile (Naif et al., 2013) shows a thick pile of conductive sediments. On the continent, crustal thickness varies from less than 30 km beneath the Nicaraguan Depression to around 40 km in the backarc (Elming and Rasmussen, 1997; MacKenzie et al., 2008). In response to oblique subduction the forearc moves parallel to the trench with velocities of roughly 1 cm/a relative to a fixed Caribbean plate reference frame as determined from GPS measurements (LaFemina et al., 2009).

Several volcanic fronts have been identified in Nicaragua, which migrated since the Paleocene to the present position (Alvarado

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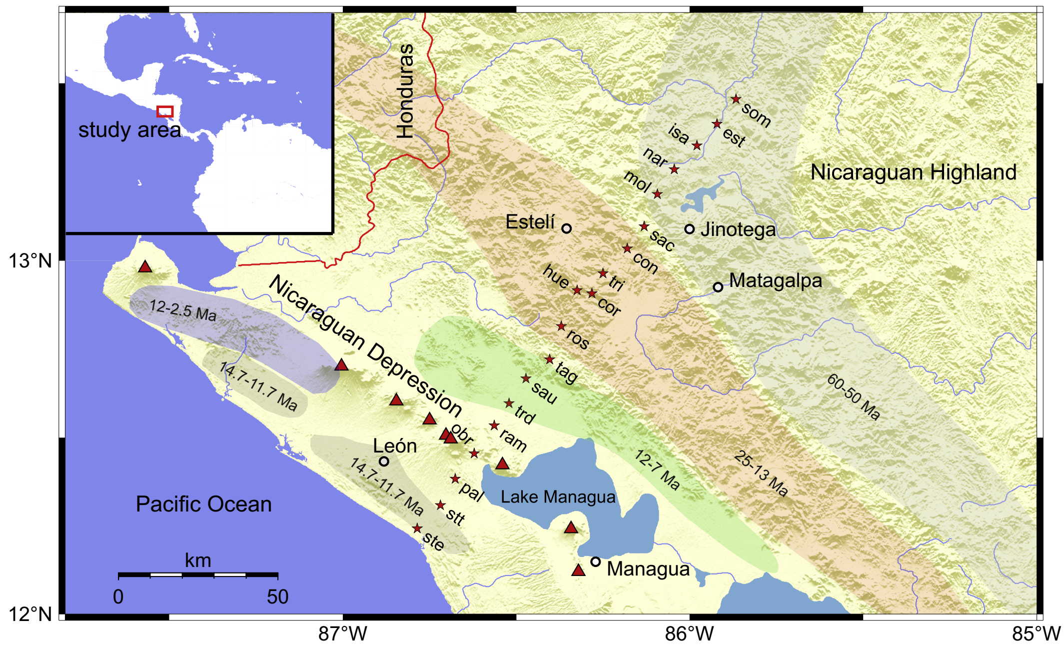

Fig. 1. Map of western Nicaragua with location of long-period MT sites (stars). The profile commences near the Pacific Ocean, crosses the chain of highly-active Holocene volcanoes (major edifices marked with triangles) of the Cordillera de Maribios in the Nicaraguan Depression, and extends far into the backarc of the Nicaraguan Highland. Shaded areas outline the extension of Paleogene–Neogene volcanism after Alvarado et al. (2007) and Saginor et al. (2011).

et al., 2007). The Central American Tertiary Ignimbrite Province, extending from western Guatemala to southern Nicaragua, was formed from large-scale silicic eruptions during the Eocene and the early Miocene at the southwestern margin of the Paleozoic–Precambrian Chortis block (Jordan et al., 2007), covering much of the southwestern Nicaraguan Highland. These ignimbrite flare-ups were followed by andesitic/basaltic volcanism in the middle-late Miocene (Coyol Formation north of Lakes Managua and Nicaragua, see Saginor et al. (2011)). The current volcanic arc of western Nicaragua developed around 350 ka ago, and is underlain by an ignimbrite shield complex. A second line of volcanoes is only weakly developed in Central America, but backarc volcanism (sometimes termed BVF = behind the volcanic front volcanism) extends to over 200 km behind the front (Carr et al., 2003). In Nicaragua, however, the only expression of recent backarc volcanism is found near the Caribbean coast (Volcán Azul).

The present, highly-active Nicaraguan volcanic arc is unique in several aspects: it is located over a very deep (150 km and more) segment of the Wadati–Benioff zone (Syracuse et al., 2008), and constitutes a very narrow volcanic chain, the Cordillera de Maribios, in the center of an elongated sedimentary basin, the Nicaragua Depression. The arc is characterized by abundant upper-crustal earthquake activity (Funk et al., 2009). Near the border with Costa Rica, the volcanic setting changes abruptly, i.e., volcanoes in the Costa Rican Cordillera de Guanacaste sit in a "normal" position above the subducted oceanic plate, which is at nearly 100 km depth (Rychert et al., 2008; Syracuse et al., 2008). It's unclear what causes this shift since the contours of the downgoing slab change only gradually (see discussion in Funk et al. (2009)). Geochemically, the Central American arc is highly variable, with western Nicaraguan volcanoes displaying the strongest slab signal determined, e.g., from Ba/La ratios as an indicator of fluid flux into the overlying asthenospheric wedge (Carr et al., 2003). Phipps Morgan et al. (2008) postulate arc-normal extension in western Nicaragua and a high influx of magmatic material into the crust compared to neighboring arcs in Costa Rica and El Salvador/Guatemala, respectively. If such a magmatic reservoir is currently present beneath the arc, it should be detectable by deep geoelectromagnetic sounding due to its largely enhanced electrical conductivity.

We present here first results of long-period MT measurements at 19 sites along a profile of ~167 km length from the Pacific Ocean far into the Nicaraguan Highland (Fig. 1), covering a period range from 10 s–10,000 s. It crosses the volcanic arc between Momotombo and El Hoyo volcanoes, and coincides with one of the lines of the TUCAN seismological project (Syracuse et al., 2008). Several high-frequency stations were also deployed; they were used for near-surface studies and are not treated here. This study is thus an extension of a former (basically parallel) MT transect measured by Elming and Rasmussen (1997) in Central Nicaragua across the volcanic arc near the capital city of Managua.

2. Induction vectors and electrical strike

Data processing was carried out by employing the robust remote-reference scheme of Egbert (1997). The transfer functions comprise impedances (the ratio of horizontal electric and magnetic fields) and tipper (the ratio of vertical to horizontal magnetic fields). From the latter induction arrows or vectors are derived; their real parts point away from highly conductive zones over a two-dimensional (2-D) subsurface. They are displayed for short, intermediate and long periods in Fig. 2 (top) at all 19 sites.

The most surprising characteristic of these vectors is their small magnitude, nowhere exceeding a value of 0.3 even near the coast of the Pacific Ocean. This is in striking contrast to NW Costa Rica, where they reach a magnitude of slightly over 1 on Nicoya Peninsula (Brasse et al., 2009). The underlying cause may be twofold: (1) the coast line is relatively far away from the continental slope with ocean depths above the Sandino Basin not exceeding several hundred meters, and (2) a large anomaly may exist on the continent. The small vectors in the backarc require additional conductors beneath the Nicaraguan Highland. As can be seen from Fig. 2 (top), real vectors point largely in profile direction, but with significant deviations near the coast and in some parts of the

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