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El Hierro Island Model-Canary-On a Basis of Joint Interpretation of Microseismic Sounding and Gravity Inversions

A.V. Gorbatikov (Institute of Physics of the Earth, Rus.Acad.Sci.), F.G. Montesinos (Institute of Astronomy and Geodesy, Madrid Univ.), J. Arnoso (Institute of Astronomy and Geodesy, Madrid Univ.) & M.Y. Stepanova* (Institute of Physics of the Earth, Rus.Acad.Sci.)

SUMMARY

To study the deep structure of El Hierro Island, Canary Archipelago, we used a new microseismic sounding method based on the fact that Earth's crust heterogeneities disturb in their vicinity the spectrum of low-frequency microseismic field. At the Earth s surface above the high-velocity heterogeneities the spectral amplitudes of definite frequency f are decreasing, and above the low-velocity ones they are increasing. The frequency f is connected with depth of heterogeneity deposition H and velocity of fundamental Rayleigh mode VR(f) by the following relation H = K*VR(f) /f, here K- is numerical factor close to 0.4. From microseismic data two large intrusive bodies were revealed beneath El Hierro Island. Joint interpretation of microseismic and gravimetric data and their comparison with previously obtained geological and geochemical data by other authors enables supposing that the eastern intrusive body relates to the early stage of the island formation. In the western body at the depths ~15 km the area with lowest seismic velocities could be revealed. We suggest that a modern magmatic chamber is located there.

Introduction

The Canary Islands are a volcanic archipelago that comprises seven mayor islands located at the North-West coast of Africa. The age of the islands presents a westward progression, coming to 20 Ma for Lanzarote and Fuerteventura and to 1.2 Ma for El Hierro, which is the westernmost island (Fig1). Maximum elevation above the sea level for El Hierro constitutes 1501 m.The sea depth in the island area is about 4000 m. A large-scale model obtained by seismic tomography data shows a mantle plume below Canary Islands and recent geophysical and geological evidence supporting a mantle plume origin for the Canarian Archipelago. To study the deep structure of El Hierro Island, Canarian Archipelago, we used a new microseismic sounding method.

Method and technique

Earth's crust heterogeneities disturb in their vicinity the spectrum of low-frequency microseismic field. At the Earth's surface above the high-velocity heterogeneities the spectral amplitudes of definite frequency f are decreasing and above the low-velocity ones they are increasing. It was found in the experiments and munerical modeling that frequency f is tied to the heterogeneity depth and to velocity of the Rayleigh waves fundamental mode $V(f)$ as $H=0.4V(f)/f$. The proposed technique of microseismic sounding allows defining the deep structure of complicated geological objects on the basis of background microseismic field utilization (Gorbatikov et.al., 2008). The technique including measurements and processing implies: 1) Measurement of statistically stable microseismic spectra in all the points of a network or a profile. In order to achieve a statistical stability the microseismic signal is accumulated during stationarity period determined experimentally and equal approximately to 2 hours; 2) Plotting the map or profile of microseism intensity distribution for each frequency in the spectrum; 3) Corresponding of the map or profile intensity plot to a depth proceeding from a relation: $H(f) \approx 0.4\lambda(f) = 0.4\ V_R(f)\ /\ f$, where $H(f)$ – the depth of a layer for which the image is under construction, $\lambda(f)$ - the wavelength of fundamental Rayleigh mode, $V_R(f)$ - velocity of fundamental Rayleigh mode, f- frequency in the spectrum of microseismic signal which calculation is made for. In an ideal case function $V_R(f)$ should be measured at each investigation area in order to reduce possible errors in location of geological objects in resulting cross-sections. In the present case of limited horizontal dimensions of the island, its high elevation gradient and relief irregularities we used only a generalized evaluation of function $V_R(f)$ which was obtained for other areas of the Earth with similar geological genesis.

Feld measurements and results interpretation

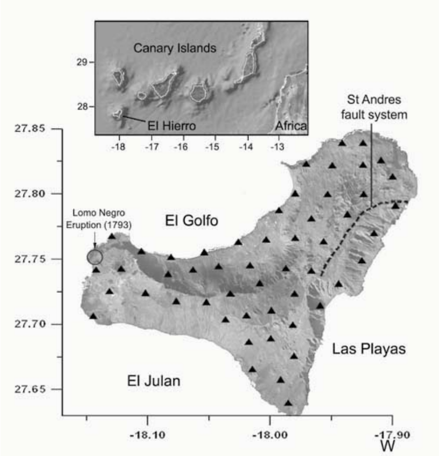

Fig. 1. *Satellite shot of El Hierro Isl. Surface. The measurement points of the microseismic network are shown with dark triangles.*

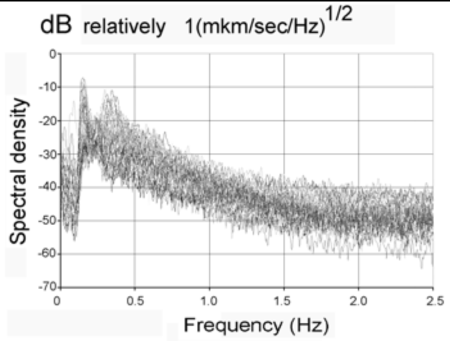

Fig. 2. *The resulting spectra for all the network measurements points. Each particular measurement represented a stacked power spectrum of microseismic field's vertical component.*

During summer 2004 we applied the microseismic sounding method for studying El Hierro Island. The measurement points of the network are shown in the Fig. 1 with dark triangles. Each particular measurement represented a stacked power spectrum of microseismic field's vertical component in the working frequency range. The averaging was done with 16 time-consequent spectral evaluations, 260 s being the duration of the signal for each one. Thus, the total duration of measurement at each particular point was about 1.2 hours. The sampling rate was 100 Hz per channel, which had a frequency band of 0.03-15 Hz. The resulting spectra for all the network measurements points are shown in **Fig. 2**. After processing records according to procedure indicated here above we obtained a 3-D model of relative velocities of shear seismic waves in parameters of relative intensity. Though there is no direct proportionality between relative intensity and velocity one can nevertheless to estimate geometry and quality of the visual objects. Increasing of relative intensity corresponds to decreasing of the velocity and vise versa.

Microseismic results we compared with earlier obtained data on detailed gravimetrical survey and inversion of the island. A good spatial coincidence of the stock-like body in the central-eastern ridge of the island and the positive gravimetric anomaly known from gravity investigations can be recognized (Fig. 3 and 4). In the area where the intrusion with increased density is implied the stock-like body could be observed in microseismic sections as well, identified as a high velocity area (low amplitudes; zone E-A in Fig. 3b). A transfer boundary from the high-velocity condition to the low-velocity one could be found at the depth 10 km. The stock-like character of the body geometry persists at all the depths, and can be traced to 30 km depth.

As regards the western intrusive body which is located where the recent volcanic eruption of Lomo Negro took place; its deep structure has some remarkable peculiarities (Fig.3b). The western intrusion is only seen in the gravimetric field fragmentarily. In the central part of the eastern intrusion, we find an area with relative intensity between 70-90 dB; which represents a maximum for all the volume under study (zone W-B in Fig. 3b). The lowest seismic velocities are found in this area, and it means that a high content of melt could exist there. If we compare our results with the ones obtained from geochemical investigations, we could propose the following classification scheme.

The area found at the depths ~15 km with relative intensity higher than 80 dB may be associated with area of temporal magma accumulation before it's rising up to the Earth's surface. From its lower side, the area has a relative intensity of 70-80 dB. It continues downwards to the depths of 25 km and may be considered as magmatic area where the main fractioning is happening. The large historical eruption Lomo Negro volcano (1793) may serve as confirmation of presence of the modern magma source in the western part of the island. We suppose that differences between structures in the western and the central-eastern intrusions may be explained by considering them in the context of the historical development of the island. Both intrusions having one and the same magmatic source at the depth of some 100 km or more could rise to the Earth’s surface. After the central-eastern intrusion first reached the Earth's crust, several eruption of explosive type had happened and the Tinor volcano had appeared. This brought to sharp degassing of the intrusion, to creation of the plug, to acute fall of the pressure in both intrusions and, consequently, to suspension of the matter rising up. As a result, the central-eastern intrusion was transferred into isolated magmatic volume and cooling down in course of time.

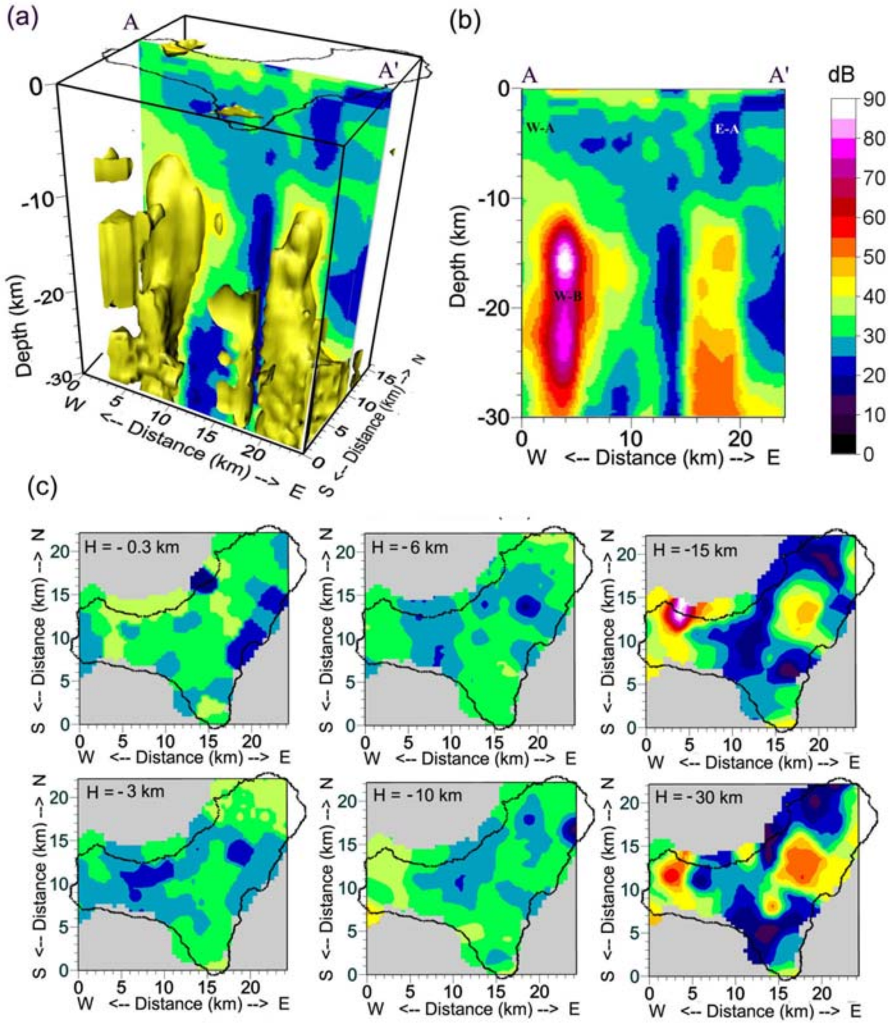

Fig. 3. *The resulting experimental 3D model of seismic relative velocities beneath El Hierro Island.* ***(a)*** *Isosurfaces built in the studied space beneath the island contour several volumes with relative intensity inside equal or exceeding the 41 dB level.* ***(b)*** *Vertical cross section along the AA' line.* ***(c)*** *Horizontal sections for different depths.*

Considering the shallow depths we point out here similarity of structures obtained from gravimetric and microseismic data at the sections of 3 km depth. For example we see in the slice of the density contrasts (Fig.4, depth 3 km) the anomalous body having increased density which has form of a horseshoe arched to the north. The similar form may be recognized in the microseismic results as the zone of decreased intensity in the slice for the depth of 3 km in Figure 3c, which corresponds to the increased seismic velocities. In this case it could be naturally supposed that spatial agreement of velocity and density fields is conditioned by the form of indurate flowed out magma possibly coming from the central-eastern intrusion.

Finally we must notice that along the southern cost line of Las Playas (Fig.1) a consolidated high-velocity area could be revealed (Fig.3c; depths 0.3 and 3 km). As derived from the vertical section this area concerns to the upper consolidated part of the central-eastern intrusive body, and corresponds to extending along the San Andres fault system.

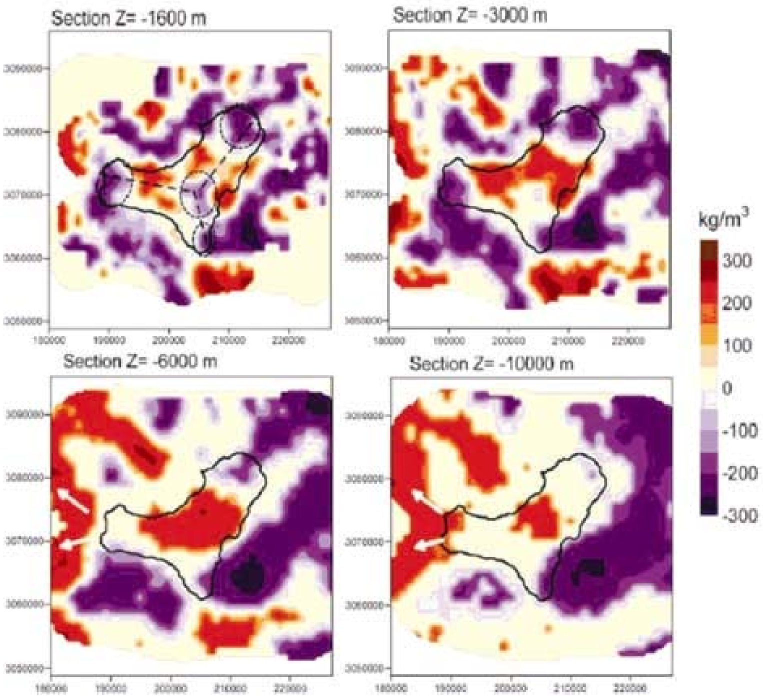

Fig. 4. *Model of density contrasts obtained by 3-D gravity inversion. (Montesinos et.al, 2006).*

Conclusions

Results of microseismic sounding reveal two large intrusive bodies beneath the island which reach the depths at least 30 km. One of the bodies within the central-eastern part of the island is spatially associated with ancient edifices - Tinor and El Golfo volcanoes. The second body located at the edge of the island western ridge is associated with the recent volcanic edifices and with the historical eruption of Lomo Negro in 1793.

Joint consideration of microseismic and gravimetric results and comparison these data with previously obtained geological and geochemical data obtained by other authors enable to suggest that the central-eastern intrusive body could be related to the earlier stage of the island formation. At present time it looks like a large stock whose upper part is consolidated at approximately the depths of 10 km. The depth is comparable with the crustal thickness at this area. The lower part of the stock contains a certain part of melt. A similar body revealed in the western part of the island has a number of peculiarities. The western low-velocity body contains an area located at the depths of ~15km and having lowest velocities along the whole volume under study. There are reasons to believe that a modern magma source is located there and the body itself had relevance to formation of the western younger part of the island. The complex consideration of geological, gravimetric, and new microseismic data allowed us to propose some considerations to the historical development scheme of the El Hierro Island relating to its deep structure.

References:

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