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# Mantle plume and uplift tectonic of Borneo, Southeast Asia

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## Abstract

The island of Borneo includes the territories of Kalimantan Indonesia, Serawak-Sabah Malaysia and Brunei Darussalam. The region is highly dynamic in terms of tectonic and delicate in terms of climate. The island is characterized by tropical rain forests, dense vegetation, high humidity and hostile terrain, indicated by high rates of denudation which resulted from rapid uplift of the crustal rocks. Mechanisms have been set forth by previous geological studies to explain the rapid uplift of the region. The present study, using topography and gravity data, attempts to elucidate that, the origin of the uplift tectonic is the upward buoyant force of the low-density mantle-plume structure situated at the lithospheric depth beneath Borneo Island.

Results of the analysis of the Bouguer gravity show the presence of the mantle-plume structure at a depth of about 160 km below sea level. The structure is about an elliptical in shape, striking SW-NE in the central northern part of the island, the Central Range Region, approximately 600 km long, 300 km wide and about 40 km thick. Results of the analysis of free-air gravity and topography with the mantle plume at depth, indicates that the Central Range Region is in the status of isostatic disequilibrium. The crustal and lithospheric column analysis indicates that the thickness of the present-day crust beneath the Central Range Region is 15.7 km. Adopting the standard thickness of granitic crust of 30 km, this implies that approximately 14.3 km granitic crust has been uplifted, exposed, eroded, emplaced at surface and subjected to further processes of erosion, weathering and transports of detrital materials. This uplift tectonic may have been continuing since about 2 Ma, suggesting the rate of uplift of about 7.15 $mm.a^{-1}$ in the Central Range Region of Borneo.

**Keywords:** Mantle-plume structure, rapid uplift, Borneo Island.

## Introduction

Borneo rests in a region at which three lithospheric plates of the world collide and interact. The Philippine Sea Plate, the Indo-Australia Plate and the Eurasia Plate. The convergence vector of the Philippine Sea Plate directed NW at a rate of about 105 km/Ma, the Indo-Australia Plates moves NNE at about 75 km/Ma and the Eurasia Plate is considered as relatively stationery. The resultant of these convergence vectors of the plate movements at the region of a triple junction runs SWW at a rate of about 130 km/Ma[7]. Borneo is recognised to have experienced an intraplate setting since Late Miocene[1]. The region underwent constant and continuous uplift owing to the break-off of the subducted slab beneath NE Borneo. Other explanations for the cause of recent tectonic of Borneo include the subduction of the South China Sea plate beneath Sunda land during the Middle Eocene until the Late Neogene or present day, regional compression and extension in the surrounding regions, ongoing convergence of major lithospheric plates, inheritance from former subduction or far-field stresses and strains as well as possible large-scale mantle processes[6]. Reactivation of the frontal thrust and the feedback of a terrestrial landscape subject to tectonic uplift and lateral precipitation gradient resulting from orographic effects were also reported recently[6].

## Materials and methods

The present study made used of topography and free-air gravity data set downloaded from https://topex.ucsd.edu in the form of ASCII grid text files, with a grid size of 1 minute of arc.

Transformation of coordinates from geographic longitude-latitude to the UTM Zone 49N were carried out prior to the processing of the data. Free-air gravity were converted to the complete Bouguer gravity through the standard procedure involving the corrections of the Bouguer slab and the corrections of the regional terrain effects[9]. The analysis of the depth of the lithological boundaries were carried out employing the grouping of the clusters of power spectrum of the Bouguer gravity grid[8]. Evaluation of the status of isostacy were performed through the computation of the gravity effects of the crustal and lithospheric columns beneath the Central Range Region. Results of the study are presented in Figure 1 and Figure 2.

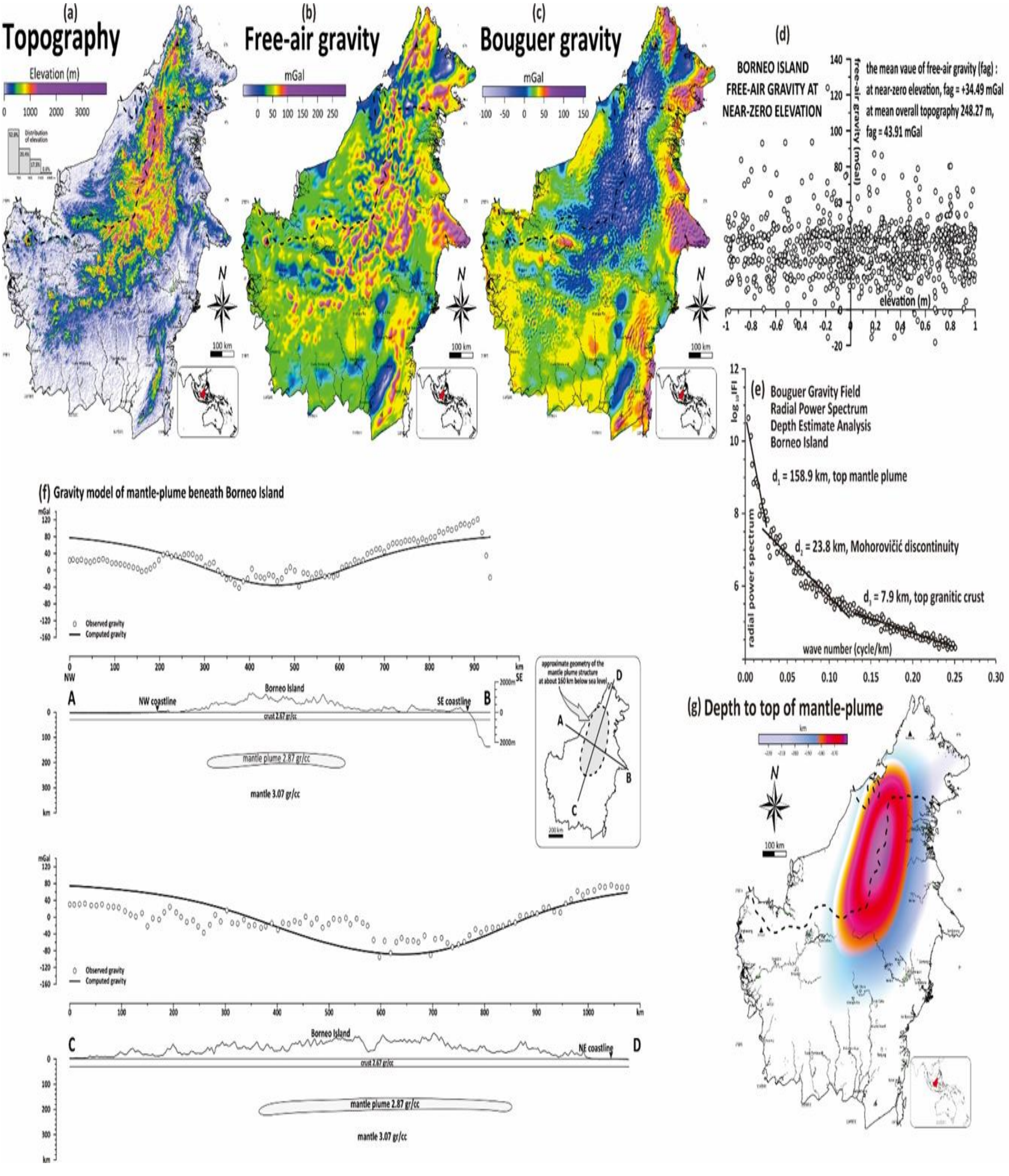

**Figure 1**: Images of topography (a), free-air gravity (b) and Bouguer gravity (c) of Borneo Island. The mean value of free-air gravity at near-zero topography (d). The radial power spectrum depth analysis of Bouguer gravity (e), the lithospheric scale gravity model of the mantle-plume structure (f) and the depth map and the approximate geometry of the mantle-plume structure (g).

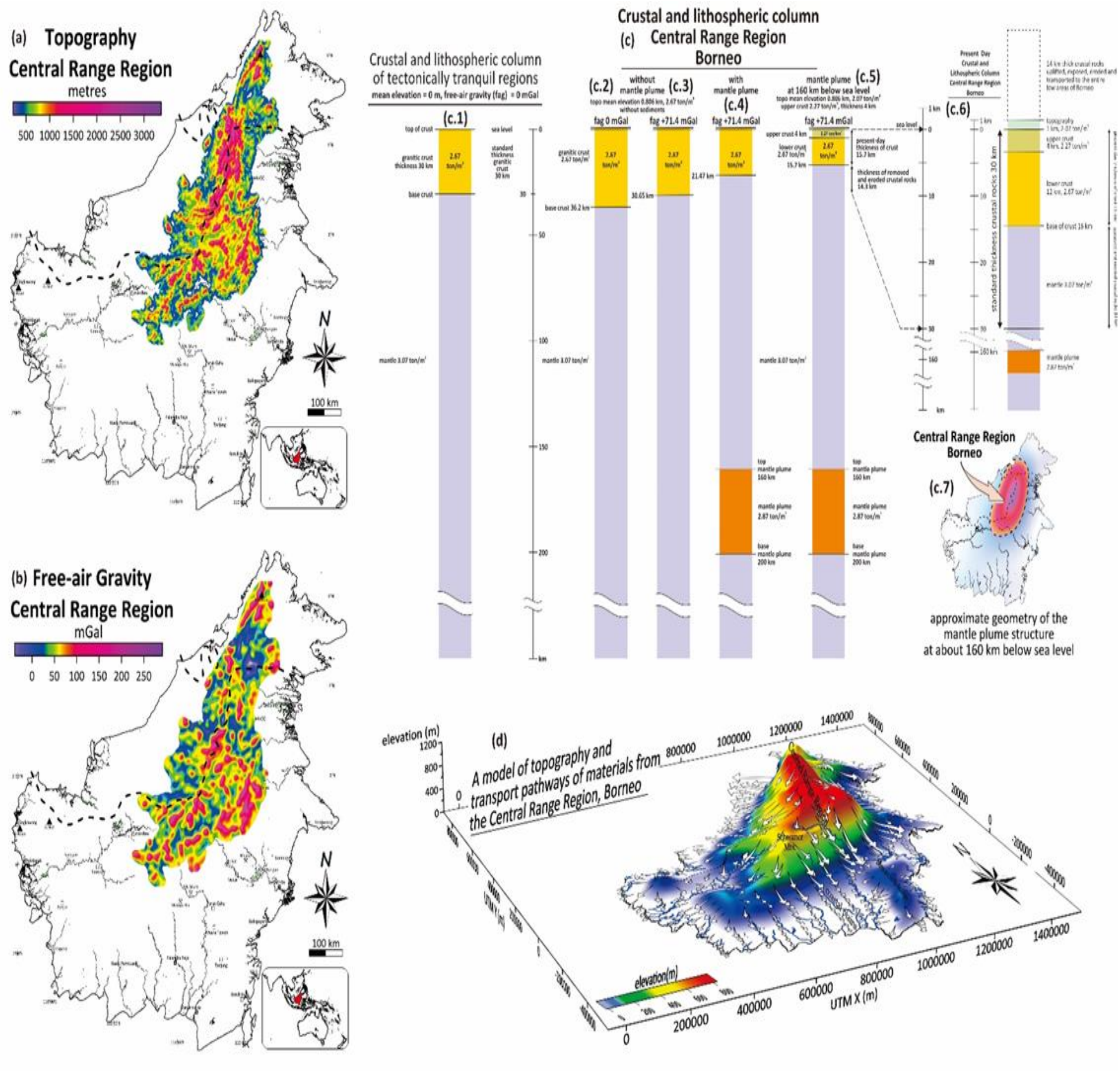

**Figure 2:** Images of topography (a), free-air gravity (b), the crustal and lithospheric column of the Central Range Region of Borneo (c), showing an example of the crustal and lithospheric column of the tectonically-tranquil regions (c.1), crustal and lithospheric column of the Central Range Region without mantle plume and sediments (c.2, c.3), crustal and lithospheric column of the Central Range Region with mantle plume at depth of about 160 km below sea lavel (c.4) and with a sedimentary layer of 4 km thick as well as a topographic layer of 0.806 km high (c.5), the Present Day of the crustal and lithospheric column of the Central Range Region with mantle plume at 160 km (c.6), approximate outline of the mantle-plume structure beneath the Central Range Region (c.6), the outline of the mamtle plume (c.7) and a model of topography depicting transport pathways (small-white arrows) of the weathered and eroded materials from the Central Range Region to the entire low areas of Borneo (d).

## Discussions

The topographic images map of Borneo is shown in Figure 1(a). Throughout the island, the topography is characterized by the elevated zones of the Central Range Region, the Muller Mountains and the Schwaner Mountains, which occupy most of the central north-eastern to the south-western parts of the island. At narrower extend, the elevated areas also occur at Mount Niut in the west, the Mangkaliat Headland in the east and the Meratus-Bobaris Zone in the southeast. The small inset, a histogram, depicts the percentages of the distribution of elevation data of the island, of which, 52.8% of topographic elevation h occurs within the range of $0 \text{ m} < h \leq 100 \text{ m}$, 29.4% elevation h occurs within the range of $100 \text{ m} < h \leq 500 \text{ m}$, 17.2% elevation h occurs within the range of $500 \text{ m} < h \leq 1500 \text{ m}$ and 0.6% elevation h occur within the range of $1500 \text{ m} < h \leq 4000 \text{ m}$. The Island of Borneo is characterized by 82.2% of low elevation areas (500 m and lower), encompassing the ridges, channels, plateaus, hinterlands and along the coastal zones. The remaining 17.8% of high elevation areas (500 m and higher) include the elevated zones of the Central Range Region, the Muller and the Schwaner mountains as well as Mount Niut area, the Mangkaliat Headland and the Meratus-Bobaris Zone.

The images map of the free-air gravity of Borneo, Figure 1(b), demonstrates the level of gravity anomalies which ranges from about -50 mGal to +300 mGal. Throughout Borneo the average elevation is approximately 248.27 m and the average level of free-air gravity is about +43.91 mGal. The near-zero elevation free-air gravity averages at about 34.49 mGal, Figure 1(d). The presence of the 40 km thick mantle plume at the depth of 160 km[10] have necessitated the Moho level to be situated at about 25.2 km. This suggests that Borneo is experiencing uplift. Moreover, in the Central Range Region where elevation ranges from 500 m to 3000 m and averages at about 806 m, the free-air gravity averages at about +71.4 mGal, indicating a higher rate of uplift.

Areas with low to intermediate levels of altitudes (near sea level to about +300 m) are characterised by free-air gravity which ranges from about +10 mGal to +30 mGal. The elevated zone of the Central Range Region (CRR) is characterized by free-air gravity anomalies which ranges from about +40 mGal to +160 mGal and higher. In the Mangkaliat Headland in the east, with the maximum altitude of about 100 m, the free-air gravity reaches up to about +100 mGal. To the south-east, within the Meratus-Bobaris Zone where elevation ranges from about 200 m to 1000 m, the free-air gravity varies from about +60 mGal to +110 mGal.

The Bouguer gravity images map of Borneo is shown in Figure 1(c). Throughout the island, Bouguer gravity varies from about -100 mGal to +150 mGal. The SW-NE striking pattern of low level Bouguer gravity which ranges from about 0 mGal down to -100 mGal (dark blue to grey colours) is interpreted as to represent the existence of the mantle-plume structure. Elsewhere in the central southwest and to the southeast parts of the island, low level Bouguer gravity (dark blue colour) are interpreted as to represent sedimentary basins potential for hosting hydrocarbon deposits. Total thickness of sedimentary sequence reaches to about 8 km in the southeast corner of the island. A moderate to high level Bouguer gravity (yellow to red colours) characterized most of the central west, central south and eastern parts of the island. These are interpreted as to represent denser ophiolites close to surface or a high level of the Mohorovičić discontinuity, results from the oblique compressional tectonics in these parts of the region. The plot of the near-zero elevation against free-air gravity is shown in Figure 1(d).

The radial power spectrum depth analysis of Bouguer gravity grid, Figure 1(e), exhibits three distinctive clusters of depth to the lithological boundaries. The depth to the top of the mantle plume $d_1$ = 158.9 km, the depth to the Mohorovičić discontinuity $d_2$ = 23.8 km and the depth to the top of the granitic crust $d_3$ = 7.9 km. The lithospheric scale gravity model of the mantle-plume structure, Figure 1(f), was explored using the depth constraints obtained from the radial power spectrum analysis. Figure 1(g) shows the map of the depth to the mantle-plume structure. The structure is approximately elliptical in shape, orienting SW-NE at the central north of the island, the Central Range Region, 600 km long, 300 km wide and 40 km thick.

Figure 2(a) and 2(b) show the images of topography and free-air gravity of the Central Range Region of Borneo. At a cut-off elevation of 400 m, the mean value of elevation is 0.806 km and the mean value of free-air gravity is +71.4 mGal. Figure 2(c) demonstrates the evaluation of the isostatic status of the Central Range Region through the computation of the gravity effects of the crustal and lithospheric columns beneath the region. Figure 2(c.1) shows the crustal and lithospheric column of a tectonically-tranquil region where mean values of topographic elevation and free-air gravity are both 0 m and 0 mGal. The crust is composed of granitic rocks of a standard thickness of 30 km and an average density of 2.67 ton/m$^3$, overlying directly the upper mantle with an average density of 3.07 ton/m$^3$. Figure 2(c.2) shows the present-day crustal and lithospheric column without the existence of the mantle plume at depth and both the crust and the topography are composed of granitic rocks. With a mean value of topographic elevation of 0.806 km and the mean value of free-air gravity 0 mGal, in this setting, the compensated level of the crustal root is at 36.2 km below sea level. With free-air graviry of +71.4 mGal, the compensated level of the crustal root is at 30.65 km below sea level, Figure 2(c.3). However, the present of the mantle plume beneath Borneo requires higher anti root of the granitic crust in order the system to try achieving the isostatic equilibrium. In this case, with free-air gravity of +71.4 mGal, the compensated level of the crustal root is at 21.47 km below sea level, shown in Figure 2(c.4). Figure 2(c.5) demonstrates the crustal and lithospheric column with the mantle plume at 160 km below sea level, with an average density of 2.87 ton/m$^3$. The top most of the column is topography with an average elevation of 0.806 km and with an average density of 2.07 ton/m$^3$. The second layer is the lower crust with a total thickness of 4 km[2] and average density of 2.27 ton/m$^3$. Under this condition, the top of the crust is at 15.7 km and the thickness of the crust is 11.7 km. This implies the removal and the exposure of the 14.3 km thick of the crustal rocks, followed by further processes at surface *i.e.* erosion, weathering and transports of the detrital materials. These materials are believed to contain economic ore deposits.

Figure 2(c,6) shows the simplified diagram of the Present Day Crustal and Lithospheric Column of the Central Range Region of Borneo. Figure 2(c.7) shows the approximate geometry of the mantle-plume structure at 160 km below sea level. Figure 2(d) illustrates a model of topography and the transport pathways of materials from the Central Range Region to the entire low areas of Borneo.

## Conclusions and recommendation

Results of the analysis of topography and gravity data set in this study evidently demonstrates the status of the isostacy of the Borneo Island and more specifically the Central Range Region. The region is isostatically disequilibrium, characterized by high level crustal anti root of about 15.7 km deep. The computed thickness of the present-day granitic crust is about 11.7 km and along with the assumed thickness of upper crust of about 4 km and the mean elevation of topography of 0.806 km, the system suggest that approximately 14.3 km crust has been removed, uplifted and exposed at surface. The exposed crust is susceptible to weathering, erosion and alteration to detrital materials are believed to contain valuable ore deposits.

A better quantification on the rate of the uplift may be achieved by making a systematic measurement throughout the island, employing the GPS surveys and age dating. Pioneering works at the field sites are highly recommended for the purpose of examining the rock samples as well the detrital materials.

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