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VOLCANISM OF HOT SPOTS ON THE RÉUNION AS THE EXAMPLE

*Dragan Radovanović *, Danica Srećković-Batoćanin**, AleksandarValjarević*[1]*
* Faculty of Natural Science and Mathematics, Department of Geography, Kosovska Mitrovica, Serbia
** University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

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Abstract: Réunion (French.: La Réunion, formerly: Īle Bourbon) is beside the Mauritius the largest and the youngest island on the Mascarene Plateau in the Indian Ocean. The island is of volcanic origin, formed through volcanic activity initiated by deeply settled "hot spot" inside the Earth's mantle. It was formed within the last 2,000,000 years from lava effusions whose volume is up to now nearly 75,000 km^3. Only 3% of its volume is emergent and the total height from the sea floor is 6,500 m. The island is about 40 km in width with about 800,000 inhabitants. The capital city is St Denis. The nature of the island is impressive: active volcano, mountains above 3,000 m in height and deep canyon, frequently exceeding 2,000 m in depth. Since 2010, about 40% of its area is announced a National park and a UNESCO World Heritage site.

Key words: La Réunion, Volcanism, Geology, Geophysics analysis

Introduction

Réunion is placed in the Indian Ocean, east from Madagascar and at approximately 150 km from Mauritius (Figure 1). The island has received the name yet in 1793, but very soon (in 1801) it was changed into the Īle Bonaparte. The original name was brought back after the French Revolution (1848) and the final broke of Burbons. Arab sailors discovered the island and named it Dina Morgabin (Western island). The early first Europeans were Portuguese that settled it in 1635 under the name Saint Apolonia. Soon it was occupied by the French who ruled from the Port Luis, the capital and the biggest city on Mauritius. Colonization started in the second half of the 17th century when the earliest 20 inhabitants settled it. Since that time the island is inhabited by French emigrants, Africans, etc. Ethnically diverse population is still very characteristic for this island. The importance of the island as the stopover on the way to India decreased with the opening of the Suez Channel in 1869. Réunion is administratively, since March 19th 1946, one of 26 overseas departments of France receiving the code 974 and being the integral part of the Republic of

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[1] Correspondence to: aleksandar.valjarevic@pr.ac.rs

France. It consists of four arrondissements divided into 49 cantons and 24 municipalities. It joined the European Union and is a part of the Euro zone.

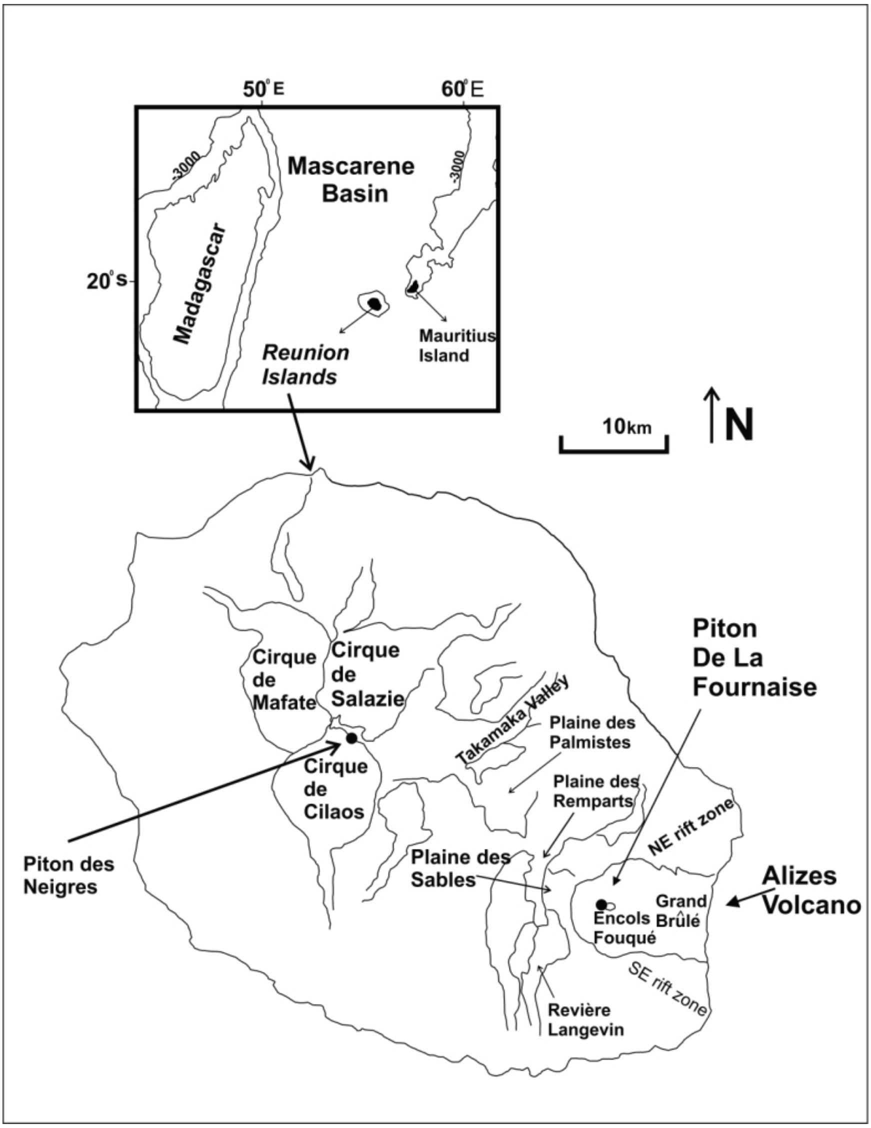

Figure 1. Geographic position of the Réunion island (small picture above) and the main relief forms on it. Redrawn from Moreira and Kurz (2001) by Valjareviċ A.

Although it is accessible by roads with more than 400 curves there are still places that could be reached only on foot or by helicopter. The island recorded the highest precipitation on the Earth for 24 hours, receiving 1,869 mm rainfall between March 15th and 16th in 1952. Réunion also has the world record of precipitation in 72 hours — 3,929 mm. This record achieved the Commerson crater in March 2007 during the Gamede cyclone.

Intraplate, hot-spot volcanism

The Réunion Island is located in the southernmost part of the Mascarene Plateau, a very complex oceanic domain that was formed by the Indian Ocean floor spreading since the end of the Cretaceous to the Paleocene. It is approximately 800 km distant from Madagascar. The origin of the island is related to the activity of a hot spot — a deeply seated, long-lasting zone of volcanic activity in the mantle. The same hot spot is responsible for the Deccan Traps and about 500,000 km^2 of flood basalts that erupted at the end of Cretaceous period (Richards, Duncan, & Courtillot, 1989). Afterwards (62 Ma ago) plate motion on south-west created a chain of islands in which Mauritius and Réunion are located (Duncan, Backman, & Peterson, 1989). Model of creation of volcanic islands and plateaus by the source of magma in the mantle (hot-spot/mantle plume) and the overriding oceanic plate suggested Wilson (1963), trying to explain the occurring volcanic activity far from the plate boundaries or mid-ocean rifts. The sources of magma are “drops”, plume, which derived by partial melting of deep and non-depleted Earth's mantle. Being of less density, these “drops” rise like salt domes across the mantle, protrude the ocean crust and erupt on the ocean floor. This led to the formation of the ocean islands or plateaus (Figure 2). A number of hot spots is pretty notorious, but is most probably about 40–50 (Richards et al. 1988; Sleep 1990). Hot spots occur within the continental plate, too (e.g. Yellowstone Park). The aerial connection between the hot spots and zones with low velocities of seismic waves has been proved. The documented seismic anomaly beneath the South Pacific and Africa reflects to the existence of mantle plume of 1,000 to 2,000 km in diameter. According to seismic data beneath Island is a mantle plume on shallow depth, whereas beneath the Hawaiian Islands it is much deeper. The origin, position and the size of ocean islands depend on the velocity of the overriding plate: slow motion produces larger amounts of lava and results in large, lonely islands with thick crust, like Island. In contrast, a rapid motion led to smaller amounts of erupted lava and a chain of smaller islands. Geochemical studies of these lavas are very important offering data about the deep asthenosphere region in the Earth’s mantle and the age of the ocean lithosphere. A chain of volcanoes above a hot-spot, as well as a chain of volcanic islands uses to be formed in the same direction with the plate motion. Thereby, the oldest, pretty ago extinct volcano is far away from the hot-spot. Hot-spots follow the direction of the plate above and any change in the direction of plate motion, most probably due to changes in spreading velocity, led to different direction of volcanoes, i.e. volcanic island's chain (Morgan, 1972). The Réunion hot-spot may be followed practically as much as 5,000 km (Bonneville, Barriot, & Bayer, 1988). The island itself lies in almost 350 km wide zone, which is bordered by two transform faults: Mauritius and the Machanoro-Vilshow fracture zone. At present is it inactive spreading center as the hot-spot activity was stopped when a new rift between India and the Réunion hot-spot has been opened; actually, a proximity of a triple junction (points where the three mid-ocean ridges in the Indian Ocean meet together): South-western Indian ridge, Central and the South-east Indian ridges. The opening of the Indian Ocean, third in size on the planet, started with the separation of Africa from Antarctic and Australia. The Indian Ocean got its present look and size 36 Ma before when the India definitely joined to Asia. The motion of the Indian plate was really fast (about 15 cm per year). Traces of that motion remained recorded in the two long submarine lineaments–Chagos–Laccadive plateau and the Ninety East ridge. In contrast to mid-ocean ridges (three of them), in the Indian Ocean is the only one deep trench — Java–Sunda trench. The Australian and Indian plates are still independent and subducting beneath the Eurasian plate.

Volcanism on the Réunion

The island displays a shape of flattened cone, having in diameter 200 to 240 km in its base. Its height from the ocean floor is about 6,500 m. Only a minor part of this volcanic edifice appears above the sea-level, something about 3% of its volume (Malengreau, Lénat, & Froger, 1999). Numerous seamounts protruding sediments on the ocean floor, which are related to transform faults or a series of parallel ridges, are detected in the vicinity of the island (Lénat, Boivin, Deniel, Gillot, & Bachèlery, 2009).

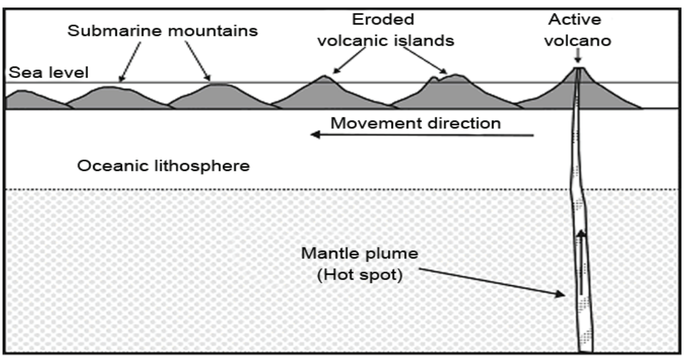

Figure 2. Simplified model of the hot spot influence on relief of the Earth

Seamounts are younger than the ocean crust and some of them are probably older than Réunion where, according to some estimation, a volcanism started a 9,000,000 years ago (Lénat et al., 2009). The island is, sensu stricto, composed of two volcanic massifs: Piton de la Fournaise and Piton des Neiges. Piton de la Fournaise (Furnace Peak) is located in the southeastern part of the island and represents one of the most active world volcanoes. It is active over 500,000 years and has erupted more than 150 times since 1640 when recording started (Gillot & Nativel, 1989). Today its activity is expressed by 0.4 km^3 annually which is the average for larger hot spots. The cone is 2,631 m high with a caldera on top, approximately 8 km in diameter. Eruptions are like those on Hawaiian Islands: basalt lava erupts either like fountains from aside cracks or as lava flows (Figure 3a). The last notable eruption was in April 2007 when volcano erupted 3,000,000 of $m^3$of lava daily. A part of caldera sank down for 330 m, and the volume of released area after collapse is 120,000,000 m^3.

Extinct volcano, Piton des Neiges, known as the Snow Peak, is the highest point on the island. Actually it represents the eroded volcanic cone of a volcano that extinct 20,000 years ago. Three deep canyons: Salazie, Cilaos and Mafate, represent relics of destroyed volcanic cones (Figure 3b). The canyon Salazie is the largest and mostly green, with over 100 waterfalls and the Le Voile de la Mariée as the most attractive one. Piton des Neiges is on the northwest and occupies nearly 2/3 of the island area. The oldest products of it are olivine rich basalts, erupted 2,080,000 million years ago (McDougall, 1971). Later eruptions (before 330,000 years) are alkali basalts (Gillot and Nativel, 1989; Deniel et al.,1992).

Figure 3a. Basalt lava erupts like fountain from aside cracks. *Photo courtesy,* Radovanović D.

Figure 3b. Main and a parasite crater. *Photo courtesy,* Radovanović D.

Recent geophysical studies (Malengreau, 1995) reflected on the presence of third volcanic centre, Alizés volcano, in the Grand Brûlé region (see Figure 1). It was active, probably, in the same time as Piton de Neiges, and these two may represent two main volcanic centers. On their remnants generated Piton de la Fournaise.

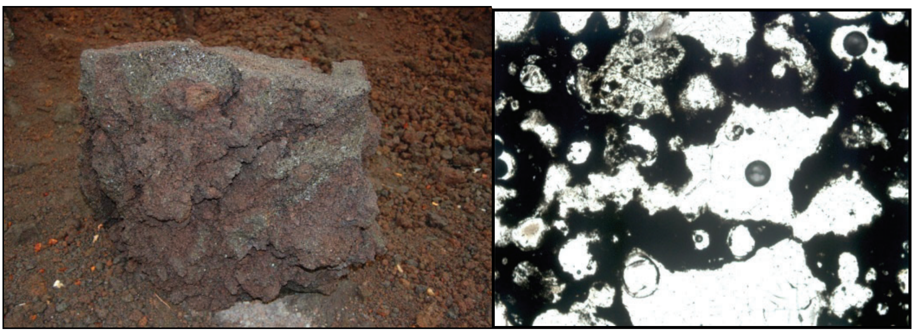

Figure 4. Réunion basalt — macroscopic and microscopic images (length of microphotograph — 3 mm; crossed nicols).

Volcanic products are shield basalts, which regarding composition correspond to picrite basalts. These high-magnesium and iron-rich rocks are also known as oceanites (Lacroix, 1923). Typical representatives are rocks from the Hawaiian volcanoes. Rocks may form on different ways: crystallization of primitive picrite melts that are slightly modified peridotite of the upper mantle; accumulation of the early-formed olivine from picrite melts or from “normal” basic magma. The olivine inherits the composition of the parent magma (Krishnamurthy, Gopalan, & Macdougall, 2000). According to IUGS (International United Geological Society) classification, the volcanic rocks on Réunion correspond to picrite basalts with nearly 30% vol. of olivine (Le Bas, 1999). They contain >12% MgO, <52% SiO_2 and occasionally >3% Na_2O + K_2O. The high Fe/Mn (>65) ratio is a result of the mantle plumes activity and interaction of mantle and crust. Basalts from Réunion are rust-red rocks of vesicular structure and porphyritic to glassy texture (Figure 4). Phenocrysts of olivine and plagioclase are hardly recognized and rare. The groundmass is glassy with vesicles of different shape and size. Vesicles formed when the water and gasses from magma (lava) migrate during the eruption and drop of pressure.

Methodology

A few samples were optically analyzed using petrographic polarized microscope for transmitted light Leica DMLSP, which is connected with camera Leica DFC290 HD over program LAS V4 and by the Scanning Electron microscope (SEM-EDS), type JEOL JSM-6460 with EDS detector at the Faculty of Mining and Geology in Belgrade. The X-ray diffraction analyses (XRD) were performed at the Technical Faculty in Kosovska Mitrovica. The first kind of analyses required classic way of sample preparation — grinding by the equipment KNUTH-ROTOR (Struers), and polished with addition of diamond paste using DP-U3 (Struers). Afterwards, samples were cleaned with alcohol and covered with thin layer (15–25 nm) of electro-conductive substance (carbon) using equipment LEICA EM SC2005.

X-ray difraction analyses were done by D2 PHASER (Brucker). The equipment is supplied by dynamic scintillation detector and ceramic roentgen Cu tube (KFL-Cu-2K) with step 2θ from 5 to 75. These analyses required samples to be milled and powdered. Conditions during the analyses were the following: step 0.02 for 10s. Identification of detected mineral phases were based on obtained difractograms and the peak intensities using the software package Topas 4.2 with additional application of data from the ICCD base PDF-2 Release 2013.

Obtained results

According to results obtained by the SEM-EDS analyses, which are presented in the Table 1, four mineral phases were identified: feldspar (basic plagioclase), olivine, clinopyroxene and chrome spinel (Figure 5). Content of elements (weight %) in mineral phases are detected in the basalt from Réunion (Table 1).

Table 1. Contents of the elements (%) in the basalt from the Réunion

phases	O	Na	Mg	Al	Si	K	Ca	Ti	Cr	Fe
Pyroxene	44.8	3.92	5.95	5.98	25.48	0.24	11.53	0.38	0.26	1.46
	46.22	3.97	6.63	6.53	23.52	0.21	10.98	0.48	0.32	1.14
	45.98	3.73	5.83	5.41	24.81	0.07	11.72	0.29	0.42	1.74
	44.99	4.07	5.82	5.82	25.3	0.53	11.93	0.18	0.13	1.23
	46.01	3.53	5.64	6.87	23.99	0.38	11.73	0.18	0.15	1.52
Feldspar	45.87	0.19		19.23	20.73		13.98			
	45.55	0.41		19.87	20.03		14.14			
	44.83	0.38		20.33	19.99		14.47			
	46.01	0.78		19.52	19.97		13.72			
	46.15	0.42		20.52	19.32		13.59			
Olivine	43.78		28.99		19.38					7.85
	44.43		28.71		19.42					7.44
	44.92		28.53		18.73					7.82
	44.18		28.93		19.08					7.81
	42.97		29.71		19.43					7.89
Chromite	35.87		5.49	9.94				0.32	32.28	16.1
	33.87		5.38	10.43				0.72	33.14	16.46
	34.01		6.01	10.09				0.52	32.39	16.98
	35.02		6.32	10.63				0.34	32.51	15.18
	33.72		6.72	9.52				0.42	32.95	16.67

Source of data: analyzed sample of one piece of basalt stone directly binged from the Réunion

Plagioclase is basic, commonly anorthite with very low sodium (albite) component (from 0.95 to maximally 5.68 %). The absence of potassium in plagioclase clearly indicates the origin from oceanic environment, i.e. continental shield basalts are tholeiites with relatively high K_2O in comparison to mid-ocean ridge basalts and display chemistry similar to basalts from ocean islands. Olivine with the given amounts of Fe and Mg considers hyalosiderite. Olivine is actually the most abundant mineral in analyzed samples (9.70%). Clinopyroxene occurs in weakly developed, needle-shaped crystals (crystal nucleus). It corresponds to alkali pyroxene, aegirine (Deer, Howie, & Zussman, 1992).

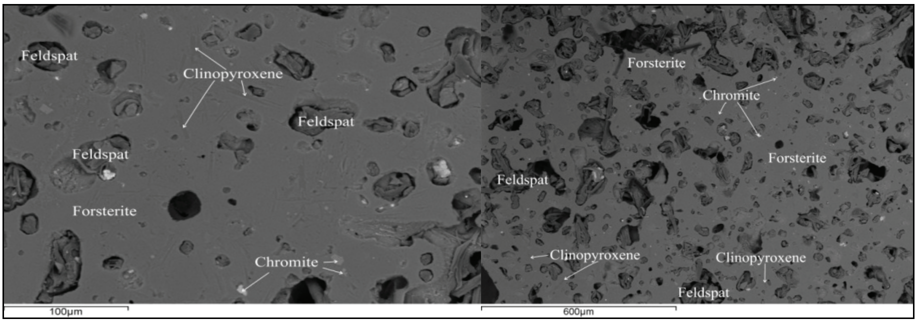

Figure 5. SEM image of recognized phases.

Spinel is chromian. The abundance of detected mineral phases, using the XRD analyses obtained data, is given in the Table 2 and Figure 6. In fact, the XRD analyses confirmed results obtained by optical studies. In the same table parameters of crystal lattice are presented, those obtained experimentally and with theoretical values. Their comparison revealed some higher values of lattice parameter and crystal volume in basalt from volcano Piton de la Fournaise than values in the literature (Angel**,** Carpenter, & Finger, 1990; Yu, 1997; Dimitrieva, Bokii, & Ashikhmina, 1991; Nestola et al., 2007). Additionally, crystal system, space groups and the Pearson symbols for each of the identified phase are given in the table.

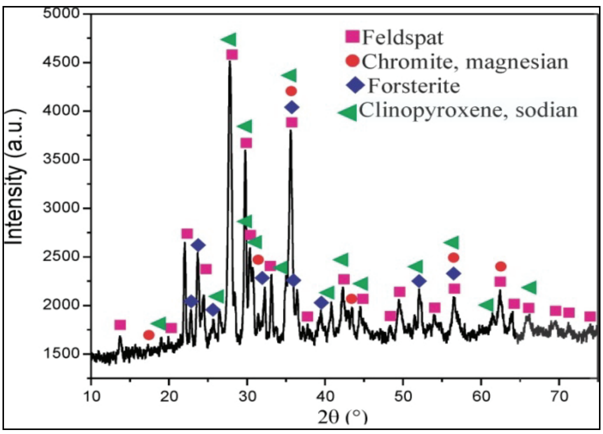

Figure 6. Diffractogram for the analyzed sample

Table 2. Results of XRD sample analysis from Réunion (Piton de la Fournaise)

Lattice parameters		Phase			
		Feldspat	Olivine	Chromite, magnesian	Clinopyroxene
Crystal sistem		Triclinic	Orthorhombic	Cubic	Monoclinic
Space group		$I\bar{1}$	Pbnm	$Fd\bar{3}mZ$	C12/c1
Pearson symbol		aP52	oP28	cF56	mC40
phase% in sample		54.17%	9.70%	4.74%	31.39%
a (Å)	Exp.	8.17234(5)	4.781650(2)	8.41669(9)	9.758561(8)
	Ref.	8.176 [1]	4.758[2]	8.4 [3]	9.6035 [4]
b (Å)	Exp.	12.88154(7)	10.23274(3)		8.905036(4)
	Ref.	12.867 [1]	10.217 [2]		8.7793 [4]
c (Å)	Exp.	14.20497(1)	6.0008(3)		5.2703(1)
	Ref.	14.170 [1]	5.987 [2]		5.2546 [4]
α (°)	Exp.	93.2484(5)			
	Ref.	93.22 [1]			
β (°)	Exp.	116.093(7)			106.592(8)
	Ref.	115.83 [1]			106.625 [4]
γ (°)	Exp.	90.3094(3)			
	Ref.	91.19 [1]			
V ($Å^3$)	Exp.	1,340.0501(0)	293.6174(5)	596.2458(6)	438.920(9)
	Ref.	1337.94 [1]	291.04 [2]	592.7 [3]	424.51 [4]

Source of data: Results of XRD analysis sponsored by authors.

Conclusion

Products of volcanic activity at the Réunion Island are shield basalts, vesicular in texture and glassy texture. In composition they correspond to picrite (earlier) and alkali basalts (later volcanic products). Rocks are generally high-magnesium and iron-rich. The studied samples contain olivine, basic plagioclase (anorthite) and sodium pyroxene. Accessory constituent is chrome spinel. Intensive erosion disabled more precise location of the studied samples, but their mineral composition reflect on products derived during later phases of volcanic activity.

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