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NEW SURVEYS OF MACDONALD SEAMOUNT, SOUTHCENTRAL PACIFIC, FOLLOWING VOLCANOSEISMIC ACTIVITY, 1977-1983

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Abstract. Macdonald Volcano, located at the younger end of the Austral Islands chain and discovered in 1967 from teleseismic *T* waves, has been the site of intense volcanoseismic swarms from 1977 to January, 1984. Three new surveys of its summit, including by scuba divers, have revealed pinnacles reaching 27 m b.s.l., and a variety of fresh features, such as fractures and spatter cones. It is strongly suggested that the summit of the volcano swelled and the pinnacles grew since Johnson's last survey in 1975.

Introduction

Macdonald Seamount (28.99°S; 140.26°W) was discovered in May 1967 following a strong seismic swarm detected by hydrophones of the Hawaiian Institute of Geophysics Network [Norris and Johnson, 1969]. It was later identified and surveyed by a number of expeditions [Johnson, 1970; Johnson and Malahoff, 1971; Johnson, 1977; Johnson, 1980], the last three yielding a shallowest sounding at 49 m below sea level [b.s.l.]. Despite large scatter in K-Ar ages of individual islands in the chain, Macdonald is generally considered to be the active expression of a hotspot having generated the Cook and Austral Islands [Jarrard and Clague, 1977]. Preliminary petrological results show an undersaturated and alkaline chemistry, not significantly different from that of the other Austral Islands [Brousse and Richer de Forges, 1980]. Finally, magnetic surveying of the volcano has suggested the presence of a magmatic chamber [Johnson, 1980], but no crater was found during any of Johnson's expeditions.

Seismic Swarms

Over the past 6 years, a total of 12 seismic swarms at Macdonald were identified through detection of *T* waves by stations of the French Polynesia seismic network, described most recently by Okal et al. [1980]. (Strictly speaking, we do not detect *T* waves but rather seismic phases resulting from the conversion of acoustic energy at the receiving island shore; we call this a *T* wave record for simplicity.) The possibility of using sound waves to detect distant submarine eruptions was suggested by Ewing et al. [1946], and the first actual such report goes back to Dietz and Sheehy [1954]. Routine use of high magnifications (2×10^6 at 3 Hz) allows the regular monitoring of the area of Macdonald through detection at Polynesian stations, including Tubuai (1110 km); Rikitea, Gambier (838 km); Afareaitu, Moorea (1599 km); and Vaihoa, Rangiroa (1704 km); location of the more explosive events achieves a precision of ±5 km, leaving no doubt as to the origin of the observed seismic swarms. On the other hand, no earthquakes at Macdonald have ever been detected from conventional seismic waves; however, the level of detection in this remote area is about $M_L = 3.5$, and our experience in the Tahiti-Mehetia area [Talandier and Okal, 1984] shows that major seismic swarms emanating from volcanic areas can take place entirely below this level. Seismic tremors would not be detected either since they are known to rarely propagate over distances greater than 100 km.

Typical examples of *T* waves recorded from Macdonald have been given by Okal et al. [1980], to which the reader is referred. Their principal characteristic is the long duration of the wavetrain, reaching up to an hour, which cannot be explained by propagation effects. As such, the *T* waves could not be the only recorded phases of otherwise undetected earthquakes. We interpret them as generated by the acoustic pulse resulting from degassing (and possibly boiling of seawater) on the ocean floor during the extrusive phase of submarine eruptions. This mechanism is made possible by the shallow character of the source; in deeper situations (e.g., Mehetia and Teahitia in the immediate vicinity of Tahiti [Talandier and Okal, 1984]), the greater ambient pressure prevents the existence of a gas phase, and *T* waves are absent. Occasional impulsive arrivals (see Figure 5 of Okal et al. [1980]) correspond to explosive events accompanying the start of most (but not all) of the swarms.

Macdonald was discovered from a short-lived swarm on May 29, 1967, lasting only 4 hours [Norris and Johnson, 1969]. No activity was then detected until December 1977; since then 12 swarms have taken place; the detection capabilities of the Polynesian network have not improved since 1967, thus the quiescence of the volcano from 1967 to 1977 is real. The swarms' characteristics are summarized in Table 1. Talandier and Okal [1982] have described the first six swarms, covering the period 1977-81; the recent ones have in general been more intense. The March 1982 swarm starts as a progressive increase in the noise level, followed by puffs of stronger amplitude; few explosive sequences are observed. The June 1982 sequence features a sudden, explosive start followed by 19 impulsive sequences, lasting up to 80 seconds; sustained noise of variable intensity is continuous during the whole swarm. The March 1983 swarm starts slowly through a series of small explosions; it features a large number of explosive sequences (about 320) lasting up to 100 seconds, and accompanied by strong puffs of high amplitude noise; some of the latter last up to an hour. The May 1983 swarm starts slowly as an increase in the noise level, and shows very few explosive sequences; it consists mostly of noise, whose amplitude is strongly modulated, and which eventually dis-

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TABLE 1. Summary of Volcanoseismic Swarms at Macdonald Seamount

Date	Origin Time	Duration	Characteristics
29 May 1967	03:22	4 hours	Weak; Macdonald discovered
11 Dec 1977	02:30	5 days	Strong; explosive sequences
30 Sep 1979	12:46	5 hours	Intermediate; short-lived; intense explosions
12 Feb 1980	23:30	12 hours	Intermediate; sustained noise; few explosions
10 Nov 1980	11:09	21 hours	Strong; many explosive sequences
24 Dec 1980	16:10	13 hours	Intermediate; explosions
15 Feb 1981	16:11	13 hours	Intermediate; few explosions
01 Mar 1982	22:07	11 hours	Intermediate; few explosions
05 Jun 1982	04:18	43 hours	Strong; explosive sequences
14 Mar 1983	17:37	9 days	Long and strong; large number of explosions
17 May 1983	05:15	4.5 days	Intermediate; few explosions
27 Oct 1983	14:12	15 hours	Weak swarm, but strong explosive sequences
24 Dec 1983	21:10	9.5 days	Very strong; longest swarm; no explosions

appears through slow decay. The October 1983 swarm is a short-lived series of 22 explosive sequences lasting up to 10 minutes, accompanied only by low-amplitude noise. Finally, the December 1983 swarm is the longest and most intense sequence ever recorded at Macdonald; its main characteristics are the absence of explosive events, and sporadic noise occurring in puffs, becoming less and less frequent towards the end of the swarm, and finally dying out; a quasi-continuous noise level is recorded during Christmas Day.

Figure 1 summarizes the history of activity detected at Macdonald volcano since 1977. Clearly, the level of activity has picked up sharply in 1983. The total duration of the swarm activity reported here (33 days over 7 years) remains low when compared to other hawaiian-type volcanoes (e.g., Kilauea, Loihi [Klein, 1982], or even Teahitia near Tahiti [Talandier and Okal, 1984]). It should be emphasized however, that extrusion taking place on the southern flank of the seamount would probably go undetected by our stations to the north; activity concentrated inside a crater could also inhibit the development of oceanwide *T* waves; in addition, activity at a weak level, following or preceding swarms, could also go undetected.

The evolution observed in the last few months, from swarms featuring explosive sequences to the latest swarm consisting exclusively of sustained noise with no explosions, is reminiscent of the pattern observed at other volcanic sites, of a general "mellowing" of the seismic signature of the events once the final fountaining phases of the extrusion have been reached. Examples would be the development of low-frequency tremor at Poás, Guatemala [Guendel, 1981] and the 1983 volcano-seismic swarm at Teahitia Seamount, in the Tahiti-Mehetia area [Talandier and Okal, 1984]. The intensity and characteristics of the December 1983 swarm at Macdonald suggest that an intense phase of volcanic extrusion was by then taking place. In conclusion, seismic detection of acoustic waves from Macdonald Seamount show that this volcano has been intensely active in the past few years, and especially so in 1983.

New surveys of Macdonald Seamount

On-site surveys of Macdonald Seamount have included 5 expeditions by R.H. Johnson on *Havaiki, Argo,* and *Kawamee* between 1969 and 1975, and more recently 3 visits by French ships: the Navy patrol-ship *La Paimpolaise* on June 7, 1981, the Research Vessel *Marara* on January 21, 1982 and the Navy escort-ship *Enseigne de Vaisseau Henry* on July 30, 1983. Johnson's surveys identified a shallow pinnacle topping at 49 m b.s.l., which was explored by scuba divers during the 1975 expedition. The cumulative time spent at the site by Johnson's expeditions (5 days) was longer than that of the three more recent surveys. However, as of December 1975, the shallowest sounding found was still 49 m.

In 1981, *La Paimpolaise* reported a 27 m sounding; however, this ship has rather poor navigation systems. In 1982, the satellite-navigating *Marara* mapped the summit of the seamount as a plateau extending approxi-

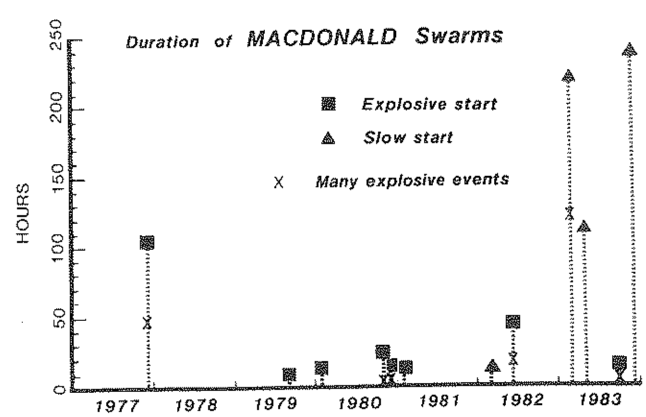

Fig. 1. History of the duration of seismic swarms at Macdonald Seamount. The period 1967-1977 was totally quiet.

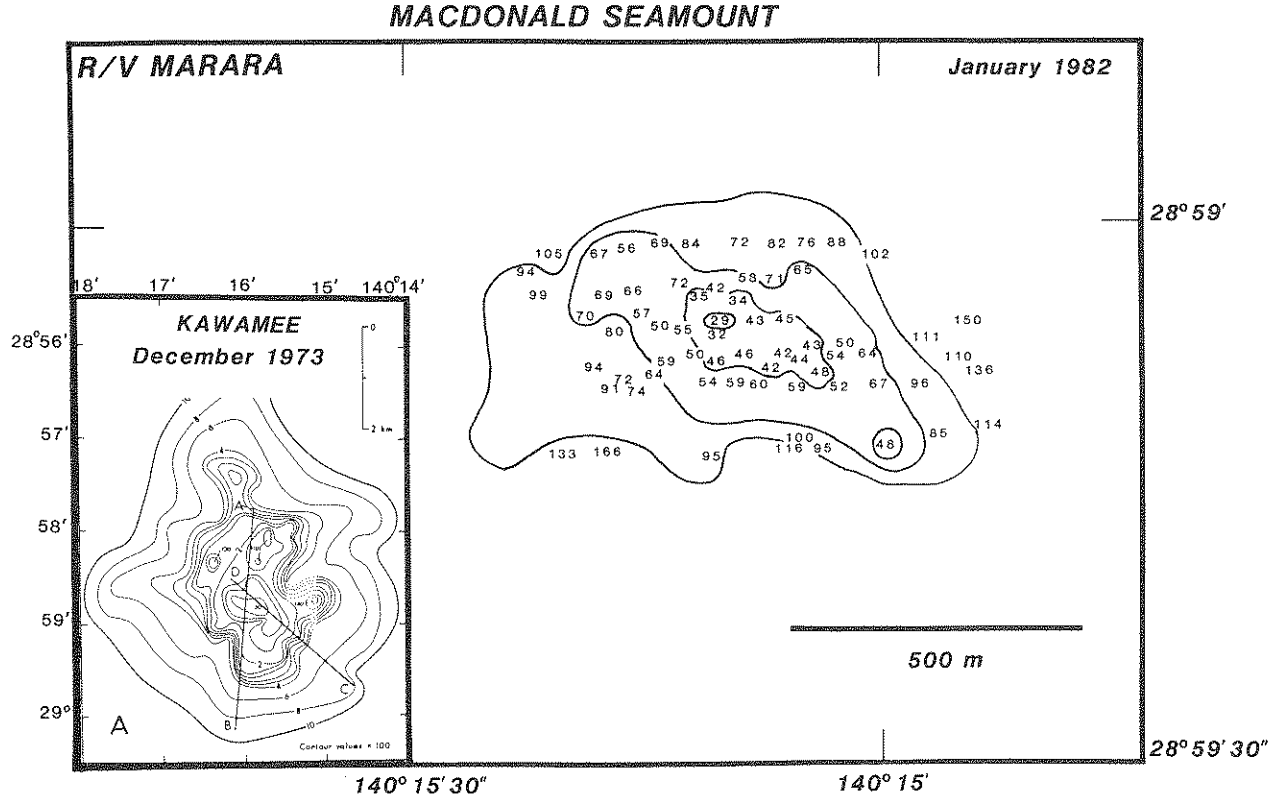

Fig. 2. Bathymetric survey of the summit of Macdonald volcano by *Marara*, January 1982. Coordinates are obtained from the ship's satellite navigation system. The inset at lower left is a reproduction of *Kawamee*'s 1973 survey [Johnson, 1980].

mately 100 × 150 m, at depths ranging from 34 to 50 m b.s.l. A pinnacle rising to 29 m, with an elliptical shape, about 30 × 50 m, was recognized at the NW end of the plateau (see Figure 2), and charted at 28°59′5″S and 140°15′10″W with a horizontal precision estimated at 200 m [Villiers and Corlay, 1982]. On a larger scale the general bathymetry of the area charted by *Marara* is in good agreement with *Kawamee*'s 1973 and 1975 surveys; however a comparison of the results of the two surveys (Figure 2 and Figure 4 of Johnson [1980]) shows fundamental differences. First, the absolute location of the summital plateau is moved approximately 500 m to ESE; this figure is approximately twice the precision claimed by the *Marara*'s navigation system and may not be significant. More importantly, the summital plateau extending about 150 m at an average depth of 40 m (with many soundings shallower than 49 m) is absent from *Kawamee*'s survey. While the pinnacle reported by Johnson may correspond to the 48 m sounding at the SE end of the plateau on Figure 2, it is extremely unlikely that Johnson's repeated surveys would have consistently overestimated the depth to the summital plateau by a factor of 2. It is also unlikely that he would have missed an existing 29 m pinnacle, given the density of tracks in the immediate vicinity of the summit [Johnson, 1974]. In addition, the echogram profiles taken across the structure (Figure 3 of Johnson [1980]) are incompatible with *Marara*'s chart. We are thus led to propose that the pinnacle at 29 m did not exist at the time of Johnson's last survey, in 1975, and similarly, that the summital plateau rose significantly between 1975 and 1982.

In 1983, *E. V. Henry* confirmed the presence of the pinnacle, with a 27 m sounding. A team of scuba divers explored the central part of the summital plateau at an average depth of 40 m. They identified a fissure with fresh walls, and spatter cones made of scoriated lava, on either side of this rift, about 3 m in diameter and 6 m tall (see Figure 3). These are not covered with algae,

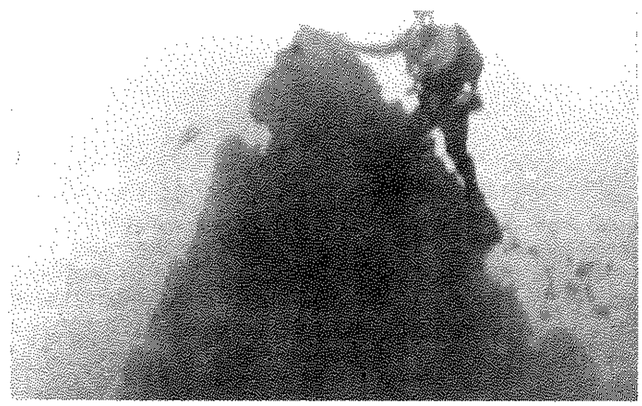

Fig. 3. Photograph of spatter cone on summital plateau taken by divers from *E. V. Henry* in July, 1983, at depth of 40 m.

and their summits do not exhibit a cavity. It is probable that they were created by lava ejected from the nearby fissure. No such formations were described by the scuba divers on the 1975 expedition. On the basis of algae cover and the absence of glass from lavas dredged on the pinnacle and summital plateau, Johnson [1977] and Brousse and Richer de Forges [1980] have suggested that both formed in the Pleistocene above sea level and were later sunk by a combination of erosion and eustatic sea rise. This is clearly impossible for the fresh spatter cones observed in 1983. Divers from *E.V. Henry* also sighted the central pinnacle at 27 m depth, which could be a very large spatter cone, or the site of an incipient or future crater in the doming stage (J.-L. Cheminée, pers. comm., 1983).

In addition, *E.V. Henry* reported a discoloration spot located approximately 2 km East (leeward) of the summit, oriented NNW-SSE and about 700 m long; its presence, 75 days after the May 1983 seismic swarm suggests the continued occurrence of hydrothermal activity. According to the *Kawamee* map, soundings in the area of the discoloration spot are about 1100 m, a somewhat large value to account for surface observation. These waters, leeward of the shallower seamount, may have been carried away by winds and currents. A similar geometry has been reported for discolorations at Monowai Seamount in the Tonga-Kermadec group [Davey, 1980].

Conclusion

The combination of seismic detection and new exploration of Macdonald Seamount shows: (i) intense volcanoseismic activity during 1977-1983, picking up significantly during the past few months; (ii) highly probable swelling and upwelling of the summital plateau, as well as of the central pinnacle, now reaching only 27 m b.s.l.; (iii) fresh fissuring, and spatter cones, probably due to violent ejections; (iv) occurrence of hydrothermalism during quiescence of the volcano, as well as absence of explosive phenomena at the start of the more recent swarms, both suggesting the permanence of surficial magmatic activity; (v) possible formation of a dome or crater at the location of the central pinnacle.

At this stage, it would be impossible not to speculate about a possible emergence of Macdonald Island in the future. The evolution evidenced by discrepancies between the various surveys taken at 7 years' interval would suggest that emergence could occur within the next few decades. A detailed study of the edifice is however warranted before a more specific conclusion can be reached.

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