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

Jacques Talandier and Emile A. Okal

1Laboratoire de Géophysique, Papeete, Tahiti
2Northwestern University, Evanston, Illinois

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 [Jarard 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 x 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_s = 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 explosive phase of submarine eruptions. This mechanism is made possible by the shallow character of the source; in deeper situations (e.g., Tahitian 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-
TABLE 1. Summary of Volcanoseismic Swarms at Macdonald Seamount

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

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, Loihhi [Klein, 1982], or even Teahiti 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 fountain phases of the extrusion have been reached. Examples would be the development of low-frequency tremor at Poas, Guatemala [Guendel, 1981] and the 1983 volcanoseismic swarm at Teahiti Seamount, in the Tahiti-Meheta 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-

![Duration of MACDONALD Swarms](image)

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 by 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 by 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,
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 subca 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 Kawamea 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 discolations 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 hydrotermalism 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 evidence 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.

Acknowledgments. We thank all the participants in the Macdonald surveys aboard La Paimpolaise, Marara, and E.V. Henry, in particular the divers on the 1983 expedition. Discussion of preliminary interpretations of summital structures with J.-L. Cheminée is acknowledged, as well as preprint exchanges with R.H. Johnson. This research is supported by Commissariat à l'Energie Atomique.

References


Guedel, F., Estudio preliminar de las seísmicas sísmicas del volcán Poás, I., Bol. Vulcanol., 11, 5-9, 1981.


Johnson, R.H., Seamounts in the Austral Islands Region, National Geographic Society Research Reports, 2, 389-405, 1980.


(Received March 3, 1984; Accepted March 26, 1984)