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Major eruption-induced changes to the McDonald Islands, southern Indian Ocean

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Abstract: The McDonald Islands (53°S, 73°E) originally comprised three small islands that lie on the Kerguelen Plateau, 44 km west of Heard Island. No volcanic activity was observed since their discovery in 1874 until 1997, when two passing ships recorded major changes and eruptive behaviour. A 2001 satellite image showed that the main island had doubled its area. This paper reports observations made from a cruise ship in November 2002, supplemented by a high-resolution satellite image acquired in March 2003. A new volcanic complex comprises lava domes, spines and flows, all assumed to be phonolitic, similar to the older volcanic rocks. The complex shows dormant volcanic activity, with numerous fumaroles, recent spine evolution and lava flows. Changes in relative sea level have connected Flat and McDonald Islands. A spit about 1km long with extensive shoals beyond, now extends eastward from McDonald Island and presents new hazards to shipping. Biological changes include colonization by king penguins (*Aptenodytes patagonica*), previously absent, and a large reduction in numbers of formerly widespread macaroni penguins (*Eudyptes chrysolophus chrysolophus*).

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Introduction

The McDonald Islands originally comprised McDonald Island, Flat Island, and Meyer Rock. They lie on the Kerguelen Plateau 44 km west of Heard Island. They were discovered in 1854 (Downes 2002), and were inspected and sketched from HMS *Challenger* in 1874 (Tizard *et al*. 1885). Only two landings have been reported – a reconnaissance of 45 minutes in 1971 (Budd 1972) and a visit of four days in 1980 (Veenstra & Manning 1982). In April 1986 a solo yachtsman anchored overnight in the eastern lee of the main island (Clark 1988) but did not report any signs of volcanic activity.

During the 1980 visit the islands were mapped by ground survey and aerial photography and a geological survey was made (Clarke 1982, Clarke *et al*. 1983). The resultant map was included in the 'Edition 3' map (NMP 85/072) of Heard and McDonald Islands (Australian Division of National Mapping 1986). A vertical air photograph taken in 1980 was reproduced in a 'Satellite Image' map (GIU 91/045) of Heard and McDonald Islands (Australian Antarctic Division 1991). A map of the islands as they were in 1980 was recently published (Australian Antarctic Division 2002).

Heard Island has experienced eruptions, lava flows, and fumarole activity at intervals from 1881 to the present on its summit and upper slopes (summarized in Quilty & Wheller 2000 and in the Global Volcanism Program 2004 website: http://www.volcano.si.edu/world/volcano.cfm?vnum=0304-01=&VErupt+Y&VSources=Y&VRep=Y&VWeekly=N&volpage=erupt accessed 29 March 2005). In contrast, on the McDonald Islands no volcanic activity or morphological changes were observed between 1874 and 1986.

In December 1992, a scientific party on Heard Island had evidence of a volcanic eruption somewhere offshore in the region, from their observation of pumice strandings on both sides of Elephant Spit and at Stephenson Lagoon (Green 1992) shortly after an earthquake, suggesting there had been a volcanic eruption somewhere in the region. Equivalent pumice was collected on Laurens Peninsula, Heard Island, and confirmed to have close geochemical affiliation with McDonald Island lavas (Collerson *et al*. 1998, Barling *et al*. 1994). Volcanic activity on McDonald Island was first observed in March and April 1997, and in most subsequent years. Details are given in Quilty & Wheller (2000) and in GVN 2004 website: http://www.volcano.si.edu/gvp/world/region03/indian_s/mcdonald/var.htm accessed 30 November 2004). All the observations after 1992 have been made from passing ships, and no landings were made. The reports emphasized emissions of steam or smoke from many sources at the northern end of McDonald Island, together with possible lava flows and rubble deposits, but they said little or nothing about changes in the shape or size of the island.

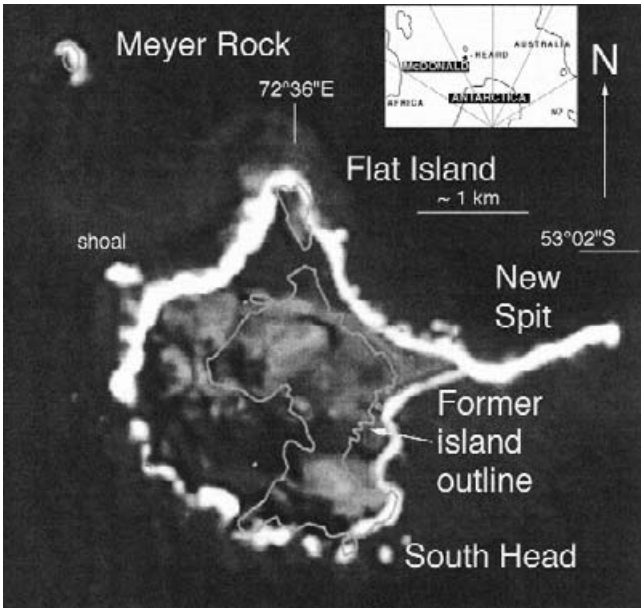

Fig. 1. McDonald Islands in November 2001 (satellite image) against the pre-eruption 1980 map (from www.aad.gov.au/default.asp?casid=5492 accessed 30 November 2004).

Major morphological changes to McDonald Island were first recognized in 2002, when a satellite image acquired in November 2001 was compared with the 1980 aerial photographs (Manning 2002). The area of the islands had doubled from 1.13 to 2.45 km^2. The image showed that some prominent features had disappeared, and that Flat Island had become connected to McDonald Island. Figure 1 shows the satellite image of 2001, superimposed upon the outline of the 1980 map.

Unaware of the satellite imagery, three of the present authors independently recognized the massive volcanic changes to the shape and size of McDonald Island on 25 November 2002. They sailed within about 1 km of it, *en route* to Heard Island in the cruise ship *Akademik Sholkalski* (Heritage Expeditions, New Zealand). They returned the following day, in clear weather, for closer study and high-resolution digital photography of the eastern and northern aspects of the islands. The western and southern aspects could not be inspected because the ship's captain, wary of new hazards (as exemplified in the shoals east of the new spit), declined to circumnavigate the island. The Australian authorities could not give short-notice permission to land on McDonald, which is within the Heard–McDonald World Heritage area. Geoscience Australia obtained a further, high-resolution satellite image of McDonald Island taken in March 2003 (Fig. 4).

We here report the observed changes and offer a geological interpretation, based on our personal observations, our digital photographs, and the two satellite images.

Results and discussion

Pre-eruption status

Morphology: Figure 2 (reproduced with permission from Budd 1972) shows the main details of McDonald Island itself in 1971. A narrow isthmus divided the island into a steep southern hill (Maxwell Hill) rising to 212 m, and a sloping northern plateau (Samarang Hill) rising from 25 m in the south-east to 112 m in the north-west. Vertical cliffs mostly bounded both parts, and from the foot of the northern cliffs a low promontory extended to Macaroni Hill (51 m), beyond which a shallow strait of about 100 m separated Flat Island from McDonald Island. West of this promontory was a conspicuous blade of rock called The Needle (90 m).

Geology: Clarke (1982) described the McDonald Islands as consisting of the eroded products of phonolite volcanism. He reported that the plateau was laminated tuff whose east coast exposed phonolite dykes; Maxwell Hill was a phonolite dome; South Head, Macaroni Hill and Meyer Rock (an isolated pinnacle about 1 km north-west of Flat Island) were similar dome features; The Needle was a dyke; and Flat Island consisted of thin phonolite lava flows

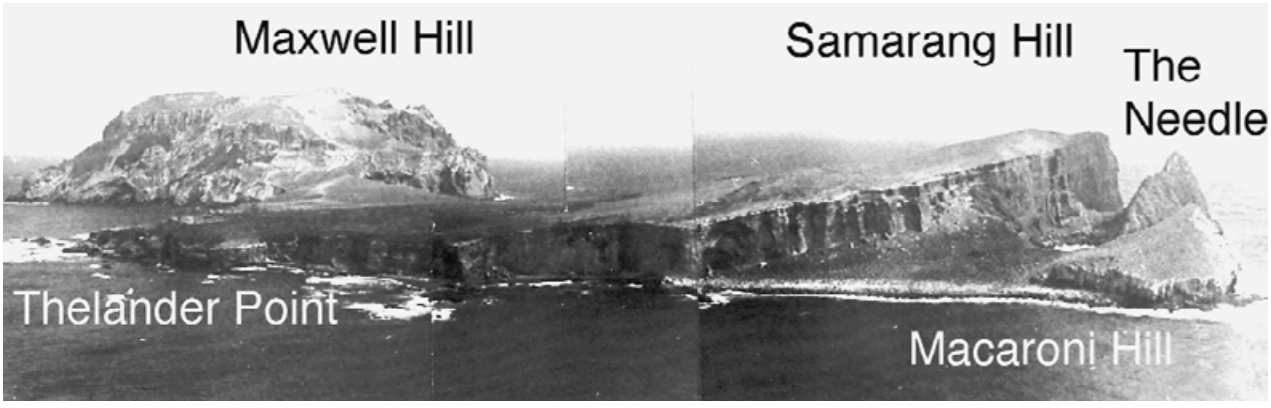

Fig. 2. A panorama of McDonald Island from the north-east in January 1971 (with permission, from Budd 1972).

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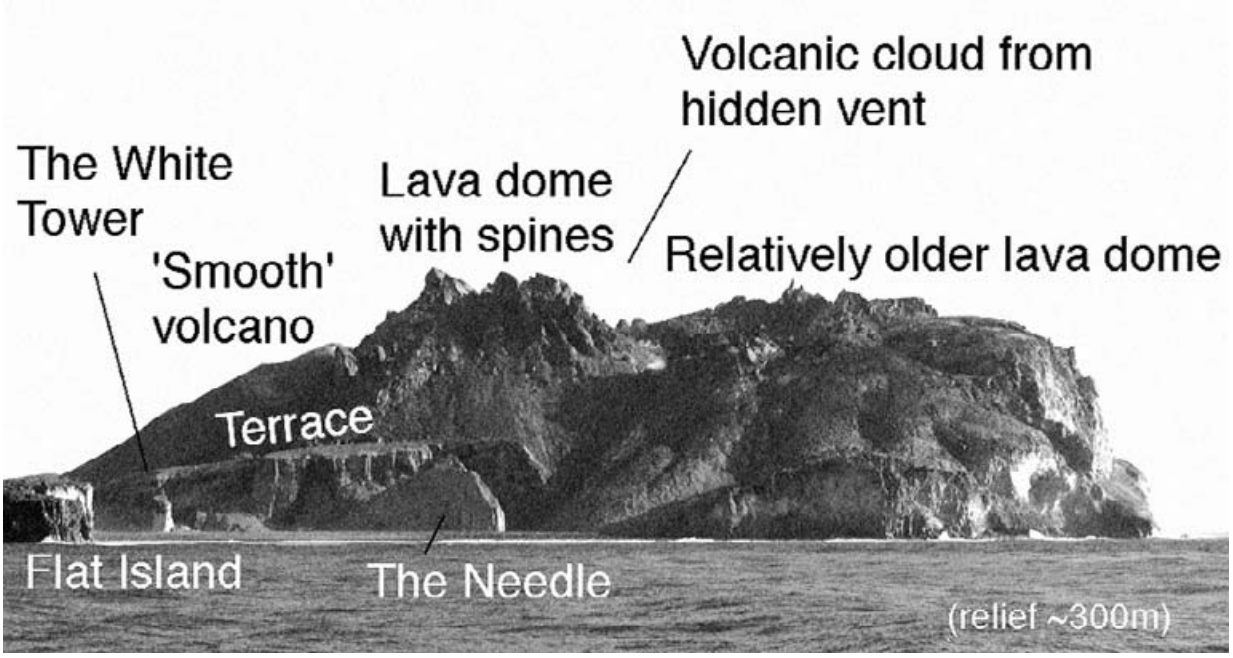

Fig. 3. A photograph of McDonald Island from the north in November 2002 (Stephenson, photo 332).

overlying a massive volcanic basement. Clarke *et al*. (1983) reported abundant limestone inclusions in the lavas, a few chert clasts, but no basalt clasts; and they also reported K–Ar determinations of *c.* 36–79 ka. Aerial photography (Australian Antarctic Division 1991) shows that bedded pyroclastic rocks, dipping gently south**,** underlie the extensive main island plateau. J.G. Jones (in Budd 1972) suggested that The Needle might mark the fissure where a vent for these volcanic rocks lies. These geological details indicated an eroded, presumed extinct, volcano built on a pelagic sediment basement, consistent with the geology of the Kerguelen Plateau and with the young oceanic-island volcanoes of Heard and McDonald developed on it (Quilty & Wheller 2000).

Biology: As with similar places on Heard Island, in 1971 and 1980 (Budd 1972, Johnstone 1982) most of McDonald Island was covered by tussock grass (*Poa cookii*), Azorella (*Azorella selago*), and Kerguelen cabbage (*Pringlea antiscorbutica*). Bird species included extensive colonies of macaroni penguins (*Eudyptes chrysolophus chrysolophus*) on McDonald Island and the southern half of Flat Island. On the plateau of McDonald Island were 800–900 breeding pairs of southern giant petrels (*Macronectes giganteus*), dense colonies of diving petrels (presumably *Pelecanoides georgicus*), skuas (*Stercorarius skua lonnbergi*), and sheathbills (*Chionis minor*). Black-browed albatross (*Diomedea melanophris*) bred on the cliffs of Maxwell Hill and on Meyer Rock. No king penguins (*Aptenodytes patagonica*) were seen on either visit. On the narrow beaches under the eastern cliffs of the plateau were 50–100 breeding fur seals (*Arctocephalus tropicalis gazella*) and a few elephant seals (*Mirounga leoninas*).

Post-eruption status in November 2002

Morphology: The general appearance in 2002 was very similar to that of April 1997 (Dr R. Williams, personal photographs). All the volcano-building eruptions had occurred from a new volcanic complex south and west of

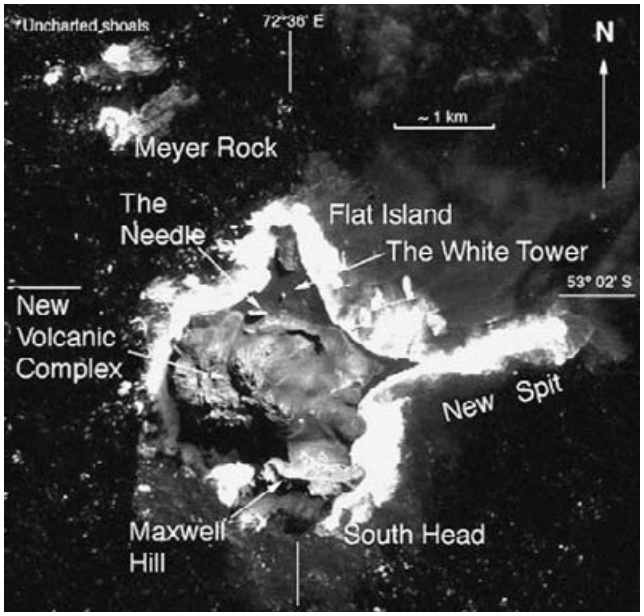

Fig. 4. A high-resolution satellite image made in March 2003: Digital Globe Imagery - pan and colour merged (Geoscience Australia).

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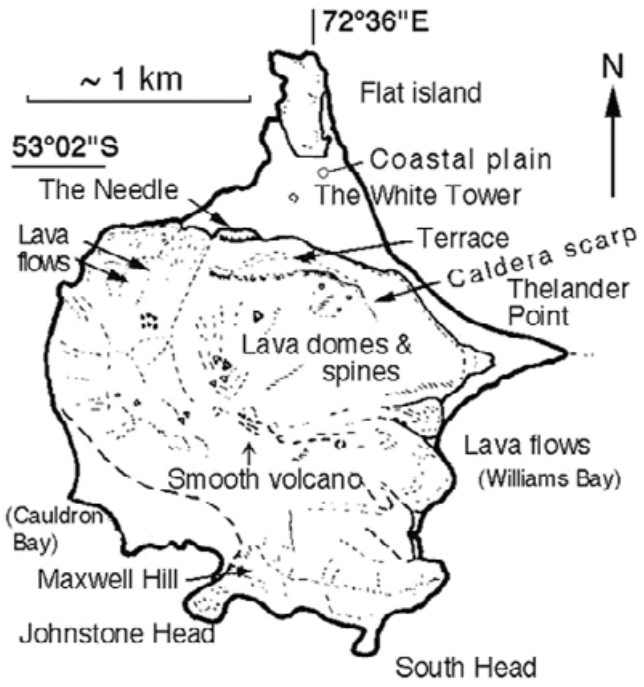

Fig. 5. Interpretation diagram for Fig. 4, showing lava domes, spines and lava flows.

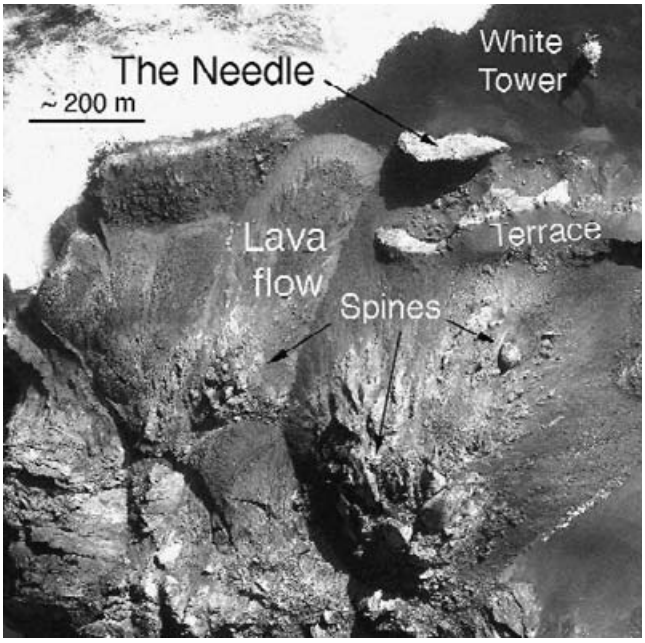

Fig. 6. An enlargement of part of the March 2003 satellite image with details of the main volcanic complex, south of The Needle.

The Needle (Figs 3, 4 & 5). This area had been the western part of the Samarang Hill plateau and the adjacent sea to the west. Whereas the eruptions had not changed either Maxwell Hill or obliterated the northern cliffs of the Samarang Hill plateau, McDonald Island had extended considerably to the west by lava eruption. The former channel between Macaroni Hill and Flat Island no longer existed and beaches had been formed south of Flat Island and around Thelander Point. There was now a coastal plain connecting Flat Island with McDonald. These coastal changes appeared to be consistent with a change in relative sea level and uplift of the island by perhaps 5 m. Thelander Point had been extended eastwards with a long offshore spit, with skerries and shoals beyond its eastern extremity (Fig. 4).

A localized event had removed Macaroni Hill, except for the small remnant that we here call 'The White Tower'. This event did not appear to have affected the adjacent Needle or Flat Island, nor was any local volcanic construction apparent. North and west of Thelander Point, the sea had eroded the coastal plain to form a new line of low cliffs and terraces behind a sandy beach. At Thelander Point the cliffs gave way to sandy slopes, and the beach curved away to the east in a low ridge, from which the new spit and its shoals extended eastward for over a kilometre.

The new satellite image shows that south of the new volcanic complex, the isthmus connection with the Maxwell Hill peninsula had been widened, covering the series of coves originally present in the former Williams Bay to the east. Cauldron Bay on the west had also largely disappeared with formation of a broad beach (Fig. 5). The erupted lavas have extended the north-west side of the volcano, to almost reach an offshore shoal (Fig. 1), mapped originally a kilometre west of The Needle. This shoal, about 200 m across, was now only about 40 m from the north-west coast.

In November 2002, there was intermittent release of volcanic clouds from a hidden source south of the main volcano rim (Fig. 3). These clouds were limited in amount and were being carried away eastwards towards Heard Island as an array, marching down wind. This phenomenon was also well displayed in the full Heard–McDonald 2001 satellite image, website:www.aad.gov.au/default.asp?casid=5492 (accessed 30 November 2004). The 2001 satellite image (and to a lesser extent, the 2003 image) shows lighter-coloured water surrounding the island and extending towards Meyer Rock (Fig. 1). This is interpreted to be due to suspended material of uncertain nature and origin. It is not obviously being swept eastwards next to the spit, by the presumed prevailing east-flowing current.

The 2003 satellite image (Fig. 4) shows two previously unreported shoal areas north and north-west of Meyer Rock. These are about 65 m from Meyer Rock and about 10 m (NW shoal) and 20 m (N shoal) across. With the major changes to the north coast of McDonald Island and the new spit extending east from Thelander Point, these are new shipping hazards.

Geology: McDonald Island now consists of a high volcano complex, which is presumably all phonolite (Fig. 4). The 2001 satellite image (Fig. 1) indicated a main volcano with the appearance of a large irregular central crater, but the

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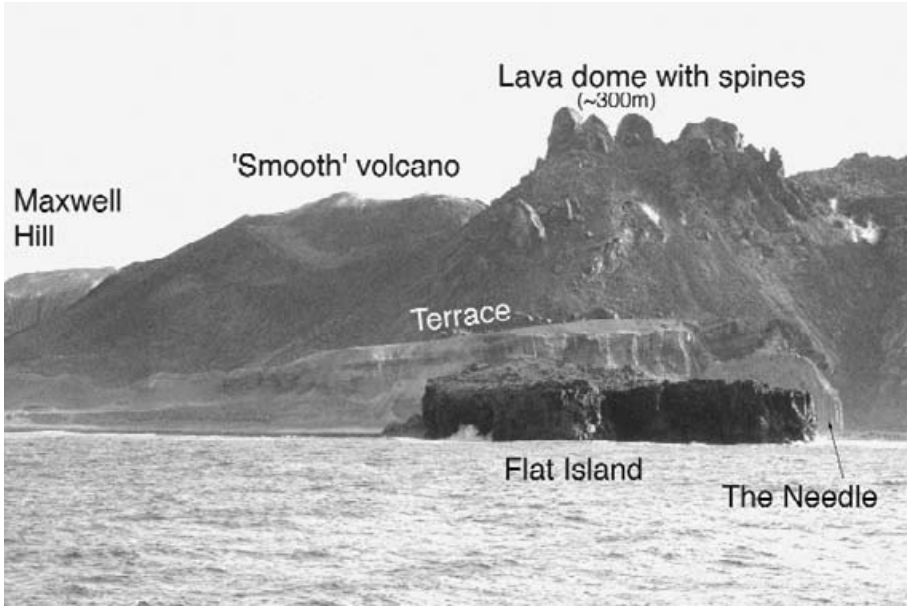

Fig. 7. McDonald Island from the north, November 2002. Vertical relief about 300 m. (P. Hansbro, photo 38).

higher resolution 2003 image suggests this feature is a shadow artifact. The summit region of the volcano is comprised of several lava domes with spines (interpretative diagram, Fig. 5). Lava domes are extrusions of steep-sided dome-shaped viscous lava (e.g. Williams & McBirney 1979). Spines are smaller columns of solid lava, which are thrust up, piston-like, from near the top of some lava domes. Details of some of the lava domes and spines are shown in Figs 6–9. Some of the spines must have generated relatively early, such as the one in Fig. 8, because it appears to be largely unchanged on photographs since 1997. The details of some other domes and spines appear to have been actively changing since 2000 (such as the major one in Fig. 7).

Almost the entire lower parts of the former Samarang Hill plateau have either been destroyed, or smothered by the new volcano complex. A remnant of the original plateau still flanks the volcano on the north and north-east as a terrace with bedded volcanic materials, bordered by cliffs which appear to be unchanged (Fig. 7). The adjacent white blade of The Needle (Figs 4, 6 & 7) also appears to be unchanged. The terrace cliffs have a disposition close to the original. Further east towards the former Thelander Point, the plateau edge continues, forming a lower line of cliffs and terraces. South of Thelander Point the cliffs give way to sloping ground. The original Thelander Point can still be recognized on the satellite image (Fig. 4).

Lava domes. The volcanic complex is comprised of several lava domes (Figs 5 & 6) about 300 m high, and a smooth

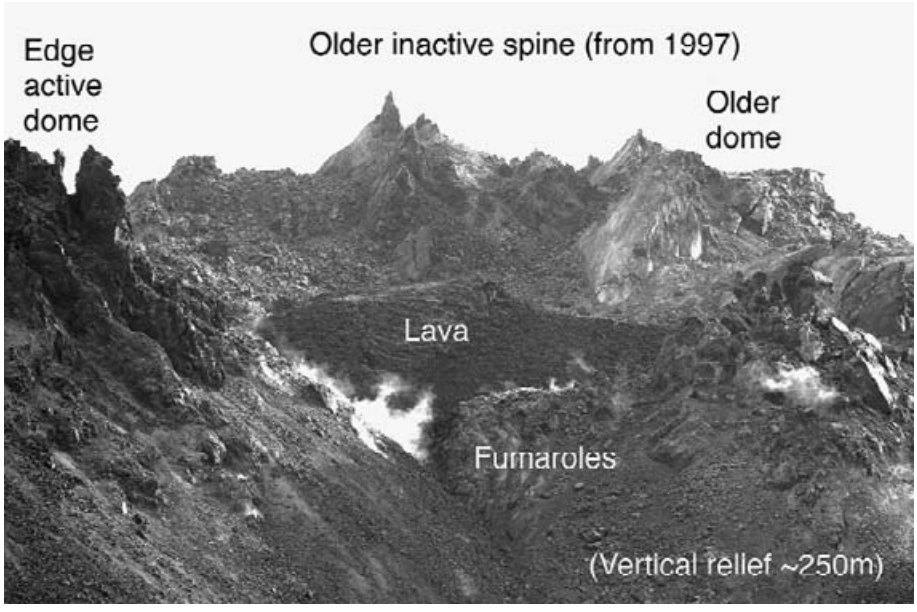

Fig. 8. The west edge of the active lava dome shown in Fig. 7. (P. Hansbro, photo 29).

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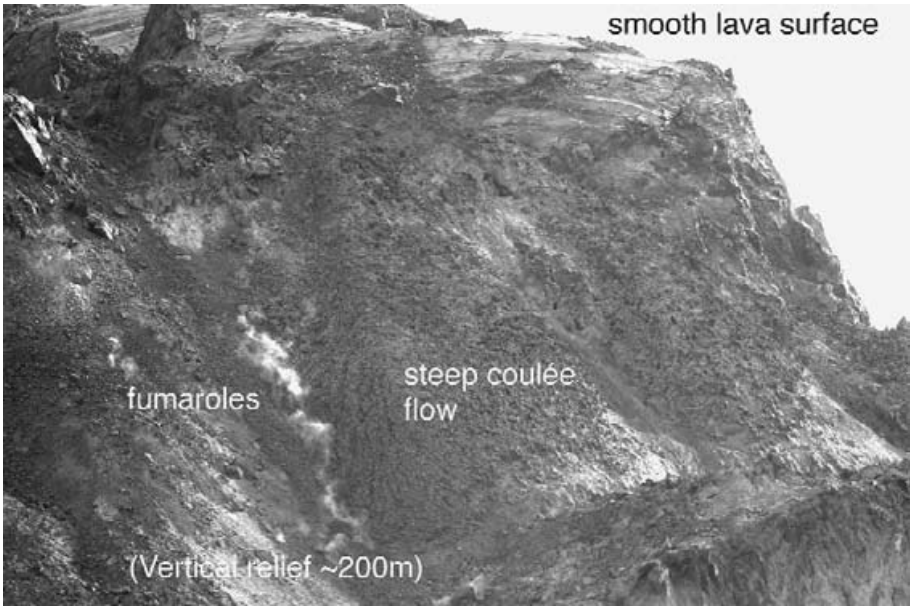

Fig. 9. Steep lava slopes north of the older dome shown in Fig. 8. (P. Hansbro, photo 30).

profiled volcano to the south-east, evident on Figs 7 & 10. Some of the lava domes are believed to have active dramatic spines (Fig. 7) with scree slopes. At times during the 2002 cruise, numerous fumarole emissions occurred on the steep northern slopes. More vigorous and widespread gas emissions are apparent in the still and video photographs taken by R. Williams in 1997**.**

Lava flows**.** A smooth-profiled volcano around 200 m high was observed on photographs in 1997 and 2002**,** east of the main volcanic complex and south of Thelander Point. In 2002 an indistinct lava flow from it extended to the coast. The 2003 satellite image shows this to be a recent lava flow (Fig. 10). It is also present on the 2001 satellite image. The smooth-profiled volcano contrasts with the main, rocky volcanic complex to the west. The smooth slopes could reflect fine ash cover, although there are also rocky areas. On its west side, this volcano has a well-delineated fault (?) boundary, trending north-east.

The satellite image also shows several other lava flows on the island (Figs 6 & 9). Figure 9 shows steep slopes north-west of the dome in Fig. 7, interpreted as relatively earlier lava flows. These steep flows have coulée features (cf. e.g. Cas & Wright 1987).

To confirm the full nature of the smooth-profiled volcano field examination is required. The conspicuous contrast of this cone with the other eruptive centres of the volcanic complex involves an absence of lava domes and spines. On balance, the limited details observed suggest a lava cone built up from successive felsic lava flows, rather than a

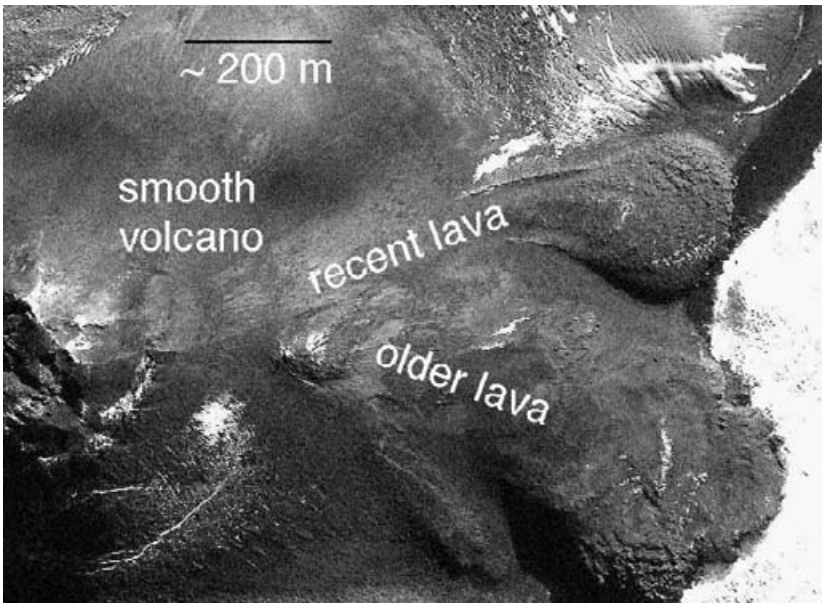

Fig. 10. An enlargement of part of the 2003 satellite image, showing the young lava flow near Thelander Point.

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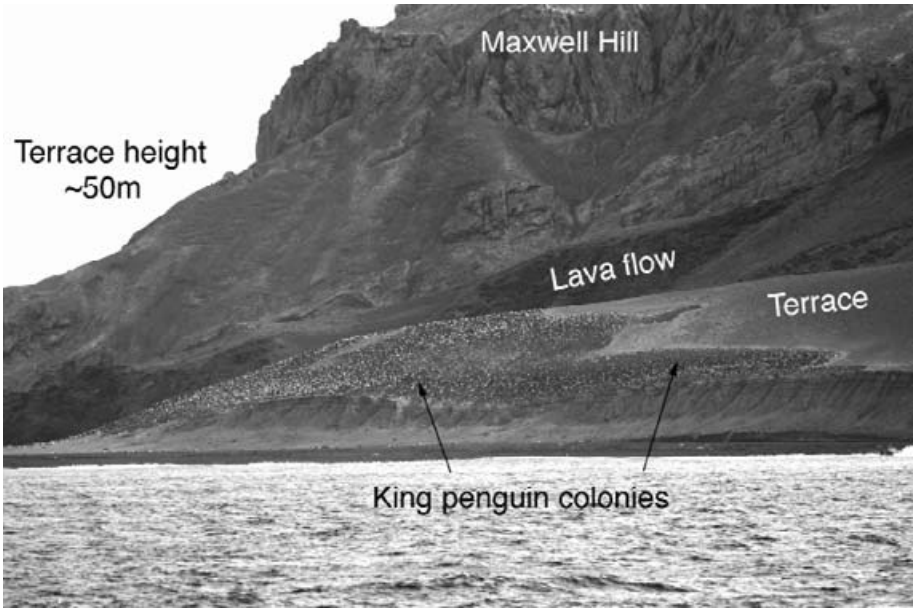

Fig. 11. King Penguin colonies on the terrace slopes west of Thelander Point. (P. Hansbro, photo 24).

pyroclastic cone - there are no concave slopes to its summit, no crater, and no indications of coarse tephra.

Spit and shoals**.** The other major change evident at McDonald on both of the satellite images, and on the 2002 cruise, is the long, new spit from the new coastal extension of Thelander Point, which continues to the east in a chain of skerries and shoals on which the sea breaks heavily. This long spit may be forming by sediment drift. It is unclear whether these features were present in 1997. There are small differences in the two satellite images indicating some spit migration (Figs 1 & 4).

Biology: The new volcanoes have buried the habitat of all the birds that previously occupied the plateau and isthmus of McDonald Island. The extensive colonies of macaroni penguins on the north-eastern slopes and summit of Maxwell Hill appeared to be unchanged, and new colonies covered terraces on the debris cliffs of the east coast. Flat Island, however, was seen to be deserted.

King penguins (*Aptendoytes patagonica*), which have been rapidly recolonizing Heard Island since the late 1950s (Budd 2000), were not seen on the McDonald Islands in either 1971 or 1980 – possibly because the steepness of the rocky coast had prevented them from gaining access to suitable habitat. In November 2002, however, photographs indicate large colonies of some thousands of King penguins with large chicks - many of them grouped in separate crèches - behind and to the north of Thelander Point (Fig. 11), access from the sea being now facilitated by the drifts of volcanic debris. Small groups of adult king penguins were visible among the elephant seals on the nearby beaches, and on their way up to the crèches. No fur seals were seen on shore, although groups of several dozen were seen swimming near the ship.

Changes between 1997 and 2002

We have set out to compare photographic evidence recorded from passing vessels from 1997. The video and photographs obtained by R. Williams in 1997 have been particularly useful as they demonstrate that the major changes observed during our 2002 visit and on the 2003 satellite image had already taken place by 1997. One of Williams's photographs featured on the website: www.volcano.si.edu/gvp/world/volcano.cfm?vnum=0304-011 (accessed 30 November 2004) shows the 'White Tower' remnant of the former Macaroni Hill, as well as gases venting from the rubble slope over the island's new volcanoes. Williams's photographs also show that Flat Island was already connected with McDonald Island in 1977.

The general appearance of McDonald Island in 2002 was similar to that of 1997, although the profiles of the spines on some of the lava domes indicate noteworthy changes. However, there have only been relatively minor changes to the main volcanic complex, apart from active flows from the smooth volcano and evolution of local domes and spines.

Eruption characteristics

The circumstances can only be surmised, because no landings have been made since 1980. It is remarkable that Macaroni Hill, which was recorded in 1971 and 1980 as a round isolated hill around 50 m high, has largely vanished, leaving only the lower 'White Tower' feature estimated to be about 10 m high (A.G. Bomford, personal communication 2003). This tower has near-vertical column features, analogous with those evident on Fig. 2 and similar to those on The Needle. The style of the eruption, which largely destroyed Macaroni Hill, but did not construct any recognized feature, is not clear. Macaroni Hill was either

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destroyed by explosive activity, or by collapse. We have not been able to recognize either an explosive crater or evidence of collapse.

The relationship between the old terrace and the adjacent edge of the big volcano now immediately south and west of it (Figs 4 & 5) can only be surmised from the satellite images. The shadow details indicate a narrow arcuate depression between the two. It may be that a major eruption stage occurred in the new volcano and destroyed some of its central features, producing a scarp feature across an earlier-stage western dome, and across the older terrace. This might have produced a small explosion caldera about 1 km in diameter, and the later volcano might have built up inside this, involving growth of the lava domes. Without field evidence, the size of the eruptions that changed McDonald is conjectural. The physiographic changes suggest only modest erupted volumes (< 1 km^3). Rafts of pumice were transported down-drift to reach the Heard coastline, but McDonald pumice has not been reported elsewhere. The pumice might have reached the sea in pyroclastic ash flows from the lava domes, or been broadcast more widely.

Research recommendations

The new volcanic complex in the McDonald Island group should be monitored regularly, to record evolving change, using high-resolution satellite images.

Field investigations are urgent. They should document all volcanic details, the geological products, and the status of the wildlife systems.

Changes in the surrounding waters are unsurveyed and are critically relevant as shipping hazards.

Acknowledgements

An army of interested observers shared the unveiling of McDonald with us. Among those particularly active in reviewing the fresh digital photos as we continued our cruise were Tony Bomford, Margaret Bradshaw, and the Downes family. The 1997 photographic records provided by Dick Williams and by Kevin Kiernan for summer 2000/01, gave critical evidence. Tony Bomford produced a sketch map with formline contours of McDonald Island as seen on 25–26 November 2002(www.aad.gov.au/default.asp?casid =5492, accessed 30 November 2004).

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