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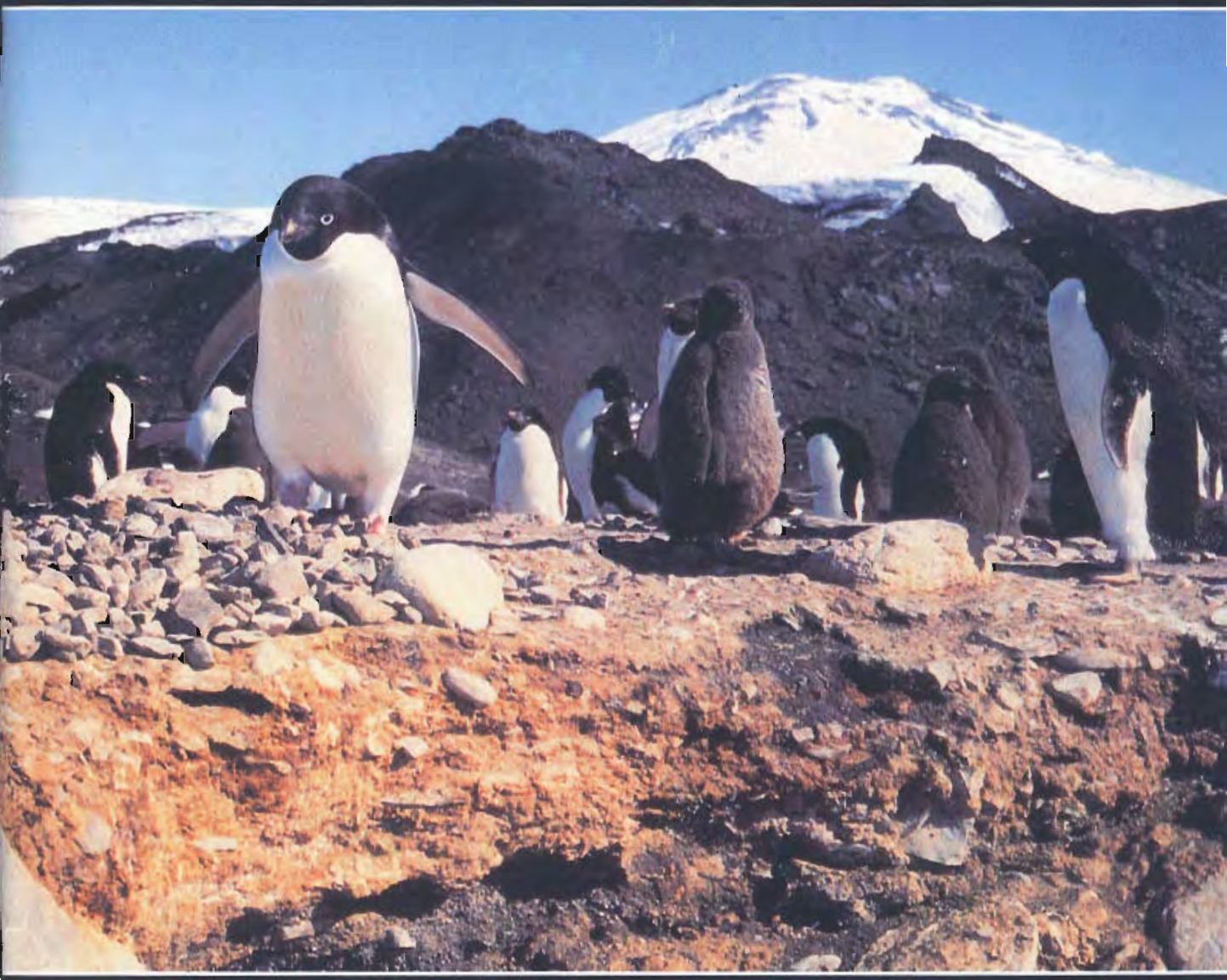

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# GEOLOGY

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**COVER:** Penguin nest on ornithogenic soil at Edmonson Point, Wood Bay, Antarctica. Considerable information about deglaciation following the last glacial maximum has come from the remains of marine birds along the Antarctic coast. Ornithogenic soils are common, and they show that most of the coastal ice-free areas have been used as penguin rookeries. At abandoned sites a layer of well-sorted pebbles, used by the penguins to build nests, hide relict ornithogenic soils, which provide datable remains such as bones, feathers, egg fragments, and guano. Dates from several sites document the occupation of rookeries during the past 11 ka. See "Abandoned penguin rookeries as Holocene paleoclimatic indicators in Antarctica" by Carlo Baroni and Giuseppe Orombelli, p. 23.



*(continued on next page)*

Geology

# Abandoned penguin rookeries as Holocene paleoclimatic indicators in Antarctica

Carlo Baroni and Giuseppe Orombelli

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**Notes**

# Abandoned penguin rookeries as Holocene paleoclimatic indicators in Antarctica

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## ABSTRACT

**Penguins are sensitive indicators of the Antarctic climate and of the environmental parameters that limit their presence and distribution. Paleoenvironmental data, obtained from the study of abandoned penguin rookeries (*Pygoscelis adeliae*) along the Victoria Land coast in Antarctica, indicate a $^{14}C$ date of 11–13 ka for the oldest abandoned rookery and supply new information about the timing of glacier retreat in southern Victoria Land after the last glacial maximum. The continuous presence of the Adélie penguins is documented from 7 ka. According to our data, the limiting factors that control the presence of penguins along the coast of Victoria Land changed during the Holocene. Whereas several colonies were occupied for very long periods, other sites were used for more or less extended periods and then abandoned. The greatest diffusion of rookeries occurred between 3 and 4 ka, a period of particularly favorable environmental conditions that has never been repeated. It was followed by a sudden decrease in the number of penguin rookeries shortly after 3 ka. This event has been attributed to an increase of the sea-ice extension and may have been correlated to a worldwide phase of climate change near the Subboreal-Subatlantic boundary. A minor phase of penguin reoccupation occurred locally in the eighth to fourteenth centuries (A.D.). Because the presence and number of penguins reflect the state of health of the Antarctic marine ecosystem, it is important to evaluate the variations in their distribution in the past, in the absence of human-induced changes.**

## INTRODUCTION

During the austral summer, more than a million couples of Adélie penguins, almost half the world population of this species, make their nests in the Ross Sea region, Antarctica (Taylor et al., 1990). They occupy 26 rookeries between Cape Adare and Ross Island where (at Cape Royds) the southernmost colony of penguins in the world is located (Fig. 1). The total number of penguins present in the area comes to almost five million if we include those penguins that have not yet reached sexual maturity. Censuses have shown an increase in the number of nesting couples over the past 10–20 yr; this may be due to climatic and environmental modifications. The currently occupied rookeries are concentrated into two main areas: one along the coast of northern Victoria Land, between Cape Adare and Coulman Island, and the other on the southernmost islands of the Ross Sea (Franklin, Beaufort, and Ross islands). A third, less colonized area is the Terra Nova Bay region.

Among all the *Pygoscelis* penguins, the Adélies are considered the most resistant to extreme environmental conditions. They nest in the ice-free zones of the coastal area in large colonies. They instinctively return to the same rookeries where they were hatched, showing a strong homing ability. The location of the colonies is determined by the following factors: ice-free coastal areas that are suitable for nesting, access to the sea, the absence of persistent fast ice, the availability of food, the relative absence of predators (Stonehouse, 1975; Müller Schwarze, 1984). Penguins have been known to travel hundreds of kilometres, walking and tobogganing on the sea ice to reach their rookeries. However, there seems to be a negative relation between the distance of the colonies from the edge of the sea ice in October when nesting activity starts and the size of the colony (Sparks and Soper, 1987). Availability of food (krill and, to a lesser extent, small fishes and squids), sea-ice, and climatic conditions are the main limiting factors. According to Taylor et al. (1990), a decrease in the population trend of six Ross Sea Adélie penguin rookeries shows correlation with late breaking out of sea ice and with negative December mean temperature anomalies. They also suggest that the impressive increase of Adélie penguins in the Ross Sea since 1982 is a consequence of the recent warming trend in Antarctica and the southern ocean and of the concurrent decrease of the sea-ice extent (Jacka, 1990) that augmented the availability of food, improved the nesting success, and reduced mortality.

The present population of penguins has recolonized the coastal areas of Victoria Land, which had been abandoned during the last glacial maximum, when the Ross Sea embayment was occupied by an expanded Antarctic ice sheet with its grounding line at ~100 km from the edge of the continental shelf (Denton et al., 1989; Anderson et al., 1992). The recession of the marine-based ice sheet began after 17 ka and was completed in the early Holocene (Stuiver et al., 1981; Orombelli et al., 1991). The grounding line was already south of Terra Nova Bay before 10,824 ±640 yr B.P. (Krissek, 1988), and south of Ross Island before 7750 ±90 yr B.P. (Kellogg et al., 1990). Deglaciation was accompanied by marine ingression and by the glacio-isostatic uplift of the coastal areas, leading to the formation of Holocene raised beaches.

## ABANDONED PENGUIN ROOKERIES

Much information regarding the deglaciation following the last glacial maximum has come from the remains of marine birds, traces of which attest to their presence along the coast of Victoria Land.

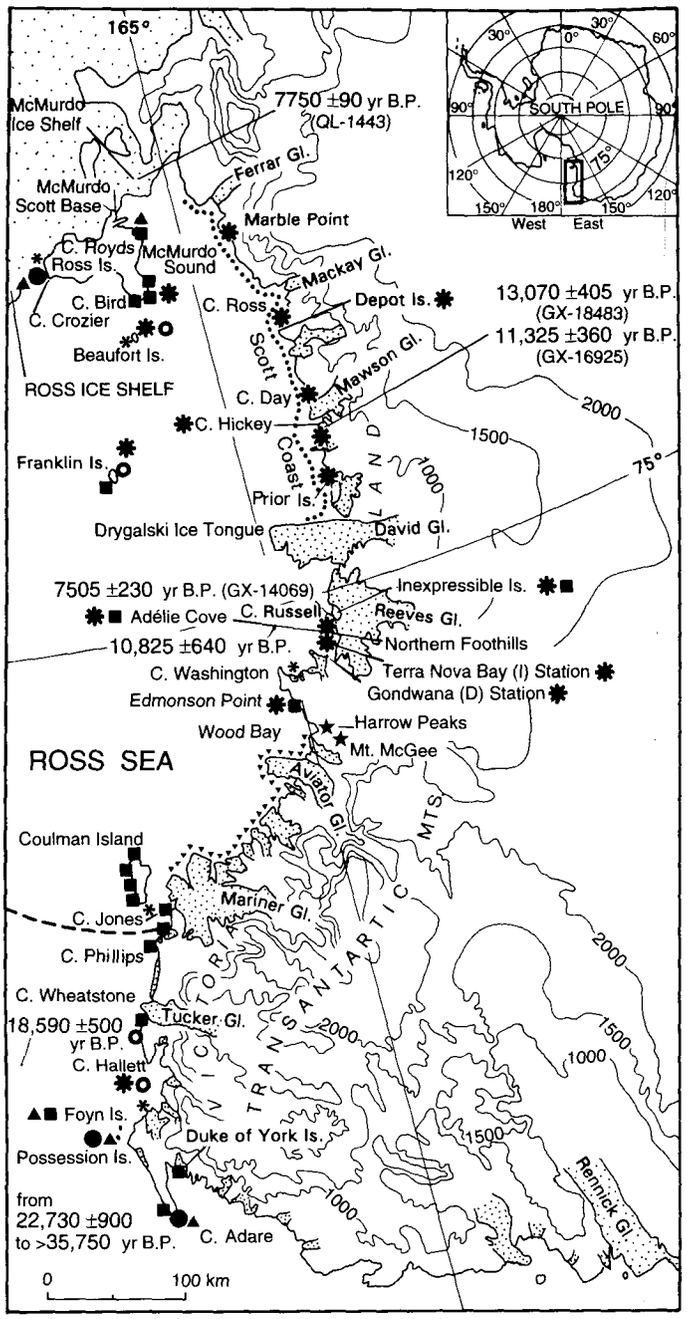


**Figure 1. Distribution of present and abandoned penguin rookeries along Victoria Land coast. Adélie penguin rookery size distributions (after Taylor et al., 1990): square—<50,000 pairs; open circle—50,000 to 100,000 pairs; solid circle—>100,000 pairs. Small asterisk—Emperor penguin rookery; large asterisk—abandoned Adélie penguin rookery; star—abandoned snow petrel nesting site; triangle—ornithogenic soil not yet dated. Toothed line indicates section of coast without present penguin rookeries and with no evidence of abandoned nesting sites. Dotted line indicates section of coast without present penguin rookeries but with evidence of several abandoned nesting sites. Dashed line shows presumed position of grounding line of marine-based Antarctic ice sheet during last glacial maximum. C.—cape; Gl.—glacier. Contours in metres above sea level. For most significant $^{14}C$ dates (yr B.P.) for retreat of grounding line, see Krissek (1988), Reid (1989), Kellogg et al. (1990), Baroni and Orombelli (1991), and Taviani et al. (1993). Adélie penguin rookeries are mainly concentrated at two ends of Victoria Land between Cape Adare and Coulman Island, and on southernmost islands of Ross Sea. Third, less colonized area, is found in Terra Nova Bay region. Present population of penguins has recolonized coastal areas of Victoria Land, which had been abandoned during last glacial maximum, when Ross Sea embayment was occupied by marine-based ice sheet. Scott Coast has been particularly sensitive to environmental factors that limit presence of penguins, particularly variations of extent and persistence of fast ice.**

Ornithogenic soils are common and testify to the fact that most of the coastal ice-free areas had been used as penguin rookeries. These sites are scattered along the coastal belt but are concentrated on Holocene raised beaches, marine terraces, and surrounding areas. The abandoned sites in present-day rookeries or those in areas no longer occupied are still easily identifiable because of the presence of a thin layer of well-sorted pebbles, which were collected by the penguins to build their nests. The relative age of the abandoned pebbly nesting sites can be evaluated on the basis of the amount of lichen cover on the pebbles and by the development of periglacial deformation. These pebbly patches hide relict ornithogenic soils, which are differentiated into distinct horizons of various depth (Ugolini, 1972). These soils provide datable organic remains such as bones, feathers, fragments of eggs, and guano. From several sites, a series of superimposed dates (up to four) was obtained. These sequences document the duration and continuity of the occupation of the rookeries (Baroni and Orombelli, 1991).

Sixty-one $^{14}C$ dates ranging from 13,070 ±405 yr B.P. (GX-18483) to the present were obtained; 14 other dates were taken from the literature (Fig. 2; Table 1). Another 15 $^{14}C$ dates ranging from 9080 ±100 yr B.P. (TO-2659) to the present were supplied by abandoned nesting sites of snow petrels.

Abandoned penguin nesting sites were found in the vicinity of several currently occupied colonies (Cape Royds, Inexpressible Island, Northern Foothills, and Edmonson Point). However, many other abandoned sites were identified in localities not currently occupied by penguins, particularly in the section of coast between Terra Nova Bay and McMurdo Sound (Fig. 1).

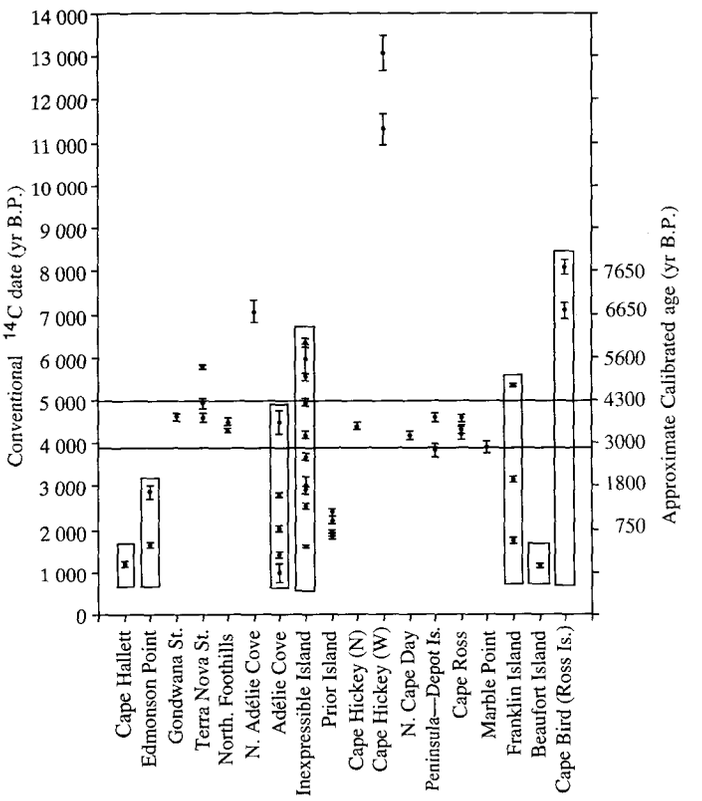


**Figure 2. Localities and age distribution of abandoned penguin nesting sites in Victoria Land. Vertical rectangles indicate present-day occupied rookeries. Horizontal lines bracket period of particularly widespread penguin diffusion in Ross Sea. Oldest abandoned penguin rookery is located near Cape Hickey. Continuous presence of penguins is documented from 7 ka.**

The oldest abandoned rookery was located near Cape Hickey (north of Mawson Glacier), where a 35-cm-thick ornithogenic soil was found above the marine limit (>40 m above sea level [asl]). $^{14}C$ dates of 11,035 ±360 (GX-16925) and 13,070 ±405 yr B.P. (GX-18483) suggest that the glaciers in this area had already retreated during late glacial time to positions similar to those of the present. Thus, at that time, environmental conditions might have allowed penguins access even there.

On the basis of the $^{14}C$ dates so far obtained, we can verify that several rookeries have been occupied continuously for long periods of time. This indicates that favorable conditions for penguin life have endured in the area. From 7 ka to the present, the continuous presence of penguins has been documented. At Cape Bird (Ross Island), two $^{14}C$ dates, 8080 ±160 (NZ-5990) and 7070 ±180 yr B.P. (NZ-5590; Speir and Cowling, 1984; Heine and Speir, 1989), indicate the ancient nature of this still-occupied rookery even if more recent dates are not available. The most characteristic example of the endurance of penguin occupation is represented by the colony on Inexpressible Island, which has been occupied continuously since at least 6335 ±110 yr B.P. (GX-13615) to the present. Other sites occupied for long periods are those on Franklin Island and Adélie Cove (Northern Foothills), which have been occupied since as early as 5340 ±50 yr B.P. (QL-141; Stuiver et al., 1981) and 4490 ±280 yr B.P. (NZ-6906A; Whitehouse et al., 1989), respectively. Sites of continuous penguin occupation in the past that are not currently colonized are Terra Nova Bay Station (Northern Foothills, 5770 ±60 [GX-12760] to 4585 ±105 [GX-15494] yr B.P.) and Prior Island (2385 ±80 [GX-16928] to 1845 ±75 [GX-16933] yr B.P.). Before the environment changed, these areas had favorable conditions for settlement.

## DISCUSSION AND CONCLUSIONS

The distribution of $^{14}C$ dates shows several significant concentrations within narrow intervals followed by some very significant gaps (Fig. 2). In particular, a large number of $^{14}C$ dates (25) and of sites occupied (ten) can be noted in the interval between 3905 ±145 (GX-16924) and 4930 ±85 (GX-12758) yr B.P. This interval represents a time of major diffusion of penguins in southern Victoria Land. During this "penguin optimum," about ten rookeries existed along the coast from Wood Bay to Cape Ross, whereas only three are inhabited at present. Some abrupt change followed this "penguin optimum" and may account for the abandonment of seven rookeries, which have never been reoccupied. The $^{14}C$ dates of penguin remains are affected by a large error due to the reservoir effect and need a calibration, as discussed previously (Baroni and Orombelli, 1991). When the $^{14}C$ dates indicated above are calibrated (Stuiver and Braziunas, 1993), the "penguin optimum" roughly correlates to a warm phase recorded in the Dome C ice core between ~3 and 4 ka (Lorius et al., 1979). The abrupt end of the "penguin optimum" must have occurred immediately after 3 ka. It may be correlated to the climatic change that occurred near the Subboreal-Subatlantic limit when a generalized phase of glacial advance was recorded in both the Northern and Southern Hemispheres (Grove, 1990; Clapperton, 1990). Correlation with other Holocene paleoclimatic data from Antarctica and southern high-latitude regions is difficult because of the scarcity of available data, often conditioned by local peculiarity and very tenuous chronological control (Clapperton and Sugden, 1988).

Along the Victoria Land coast, the Prior Island rookery was occupied between 2385 ±80 (GX-16928) and 1845 ±75 (GX-16933) yr B.P. Calibration of these dates indicates that the rookery was occupied between the eighth and fourteenth centuries A.D., an interval comprising the Medieval Warm Period, and it was later aban-

TABLE 1. $^{14}C$ DATES FROM PENGUIN NESTING SITES

| Locality* | Lab. no. | $^{14}C$ date (yr B.P.) | Material† |
|---|---|---|---|
| Cape Hallett (1) | R 384 NZ | 1210 ±70 | p.r. |
| Edmonson Point (2) | GX-13601 | 1650 ±70 | p.g. |
| Edmonson Point | GX-14076 | 2870 ±155 | p.g. |
| Gondwana St. (2, 3) | GX-13620 | 4615 ±85 | p.g. |
| Terra Nova St. | GX-15494 | 4585 ±105 | p.g. |
| Terra Nova St. | GX-15495 | 4915 ±115 | p.g. |
| Terra Nova St. (2, 3) | GX-12760 | 5770 ±60 | p.g. |
| Icarus C., North. Foothills (2) | GX-12754 | 4290 ±50 | p.r. |
| Icarus C., North. Foothills (2, 3) | GX-12755 | 4495 ±135 | p.bs. |
| Icarus C., North. Foothills (2, 3) | GX-13619 | 4495 ±95 | p.g. |
| N. Adélie C., North. Foothills (2, 3) | GX-13621 | 6855 ±195 | p.g. |
| N. Adélie C., North. Foothills (2) | GX-13622 | 6860 ±110 | p.g. |
| N. Adélie C., North. Foothills (2, 3) | GX-14098 | 7065 ±250 | p.g. |
| Adélie Cove, North. Foothills | GX-15493 | 930 ±260 | p.bs. |
| Adélie Cove, North. Foothills (2) | GX-12747 | 980 ±220 | p.bs. |
| Adélie Cove, North. Foothills (2) | GX-12749 | 1030 ±95 | p.bs. |
| Adélie Cove, North. Foothills (2) | GX-13602 | 1410 ±70 | p.g. |
| Adélie Cove, North. Foothills (2) | GX-15492 | 1480 ±175 | p.g. |
| Adélie Cove, North. Foothills (2) | GX-12748 | 1560 ±290 | p.bs. |
| Adélie Cove, North. Foothills | GX-15491 | 1687 ±175 | p.g. |
| Adélie Cove, North. Foothills (4) | NZ-6919A | 1782 ±76 | p.b. |
| Adélie Cove, North. Foothills (4) | NZ-6920A | 1857 ±68 | p.b. |
| Adélie Cove, North. Foothills (2) | GX-12750 | 2015 ±75 | p.r. |
| Adélie Cove, North. Foothills (4) | NZ-6997A | 2420 ±80 | p.b. |
| Adélie Cove, North. Foothills (4) | NZ-7035A | 2780 ±45 | p.b. |
| Adélie Cove, North. Foothills (4) | NZ-6906A | 4490 ±280 | p.b. |
| Inexpressible Island (4) | NZ-6963A | 1610 ±43 | p.r. |
| Inexpressible Island (4) | NZ-7037A | 2530 ±60 | p.r. |
| Inexpressible Island (2) | GX-13607 | 2900 ±90 | p.g. |
| Inexpressible Island (2, 3) | GX-13613 | 3010 ±220 | p.g. |
| Inexpressible Island (2, 3) | GX-13616 | 3340 ±85 | p.g. |
| Inexpressible Island (2, 3) | GX-13617 | 3675 ±90 | p.g. |
| Inexpressible Island (2, 3) | GX-12757 | 4190 ±80 | p.r. |
| Inexpressible Island (2, 3) | GX-12758 | 4930 ±85 | p.g. |
| Inexpressible Island (2, 3) | GX-13609 | 5315 ±100 | p.r. |
| Inexpressible Island (2, 3) | GX-13608 | 5360 ±90 | p.r. |
| Inexpressible Island (2) | GX-12756 | 5385 ±85 | p.r. |
| Inexpressible Island (2, 3) | GX-13610 | 5440 ±85 | p.r. |
| Inexpressible Island (2, 3) | GX-13611 | 5530 ±100 | p.g. |
| Inexpressible Island (2) | GX-13606 | 5575 ±185 | p.g. |
| Inexpressible Island (2, 3) | GX-13614 | 5945 ±340 | p.g. |
| Inexpressible Island (2) | GX-13618 | 6225 ±105 | p.g. |
| Inexpressible Island (2, 3) | GX-13612 | 6235 ±110 | p.g. |
| Inexpressible Island (2, 3) | GX-13615 | 6335 ±110 | p.g. |
| Prior Island | GX-16933 | 1845 ±75 | p.g. |
| Prior Island | GX-16932 | 1860 ±75 | p.g. |
| Prior Island | GX-16931 | 1910 ±75 | p.g. |
| Prior Island | GX-16930 | 2105 ±75 | p.g. |
| Prior Island | GX-16929 | 2205 ±75 | p.g. |
| Prior Island | GX-16928 | 2385 ±80 | p.g. |
| Cape Hickey N. | GX-16967 | 4365 ±90 | p.g. |
| Cape Hickey N. | GX-16966 | 4395 ±90 | p.g. |
| Cape Hickey W. | GX-16925 | 11,325 ±360 | p.g. |
| Cape Hickey W. | GX-18483 | 13,070 ±405 | p.g. |
| N. Cape Day | GX-16923 | 4180 ±90 | p.g. |
| N. Cape Day | GX-16910 | 4230 ±85 | p.g. |
| Peninsula—Depot Island | GX-16915 | 3825 ±150 | p.g. |
| Peninsula—Depot Island | GX-16916 | 3990 ±100 | p.g. |
| Peninsula—Depot Island | GX-16917 | 4580 ±100 | p.g. |
| Cape Ross | GX-16914 | 4220 ±160 | p.g. |
| Cape Ross | GX-16920 | 4255 ±155 | p.g. |
| Cape Ross | GX-16918 | 4310 ±155 | p.g. |
| Cape Ross | GX-16911 | 4315 ±90 | p.g. |
| Cape Ross | GX-16912 | 4465 ±90 | p.g. |
| Cape Ross | GX-16921 | 4555 ±90 | p.g. |
| Cape Ross | GX-16913 | 4570 ±90 | p.g. |
| Cape Ross | GX-16919 | 4735 ±165 | p.g. |
| Cape Ross | GX-16922 | 4780 ±160 | p.g. |
| Marble Point | GX-16924 | 3905 ±145 | p.g. |
| Franklin Island (5) | QL-170 | 1750 ±70 | p.r. |
| Franklin Island (5) | QL-169 | 3150 ±80 | p.r. |
| Franklin Island (5) | QL-141 | 5340 ±50 | p.r. |
| Beaufort Island (6) | NZ-? | 1150 ±45 | p.b. |
| Cape Bird (Ross Island) (7) | NZ-5590 | 7070 ±180 | p.r. |
| Cape Bird (Ross Island) (8) | NZ-5990 | 8080 ±160 | p.b. |

*References: 1—Harrington and McGellar (1958), 2—Baroni et al. (1991), 3—Baroni and Orombelli (1991), 4—Whitehouse et al. (1989), 5—Stuiver et al. (1981), 6—Harrington (1960), 7—Speir and Cowling (1984), 8—Heine and Speir (1989).

†P.r. = penguin remains; g. = guano; b. = bone; bs. = bones.

doned. However, elsewhere along the Victoria Land coast, other rookeries have continued to be settled to the present.

As already noted, the present-day rookeries are mainly concentrated at the two ends of Victoria Land. To a lesser extent the penguins have colonized the zone of Terra Nova Bay, which is characterized by an important permanent polynya. The abandoned rookeries, however, are principally located between Terra Nova Bay and McMurdo Sound. This section of coast has been particularly sensitive to environmental factors that limit the presence of penguins. One of these factors seems to be variations in the extent and persistence of the fast ice, which is mainly controlled by the summer temperature. The presence and extension of the ice tongues are also very important because they can dam the fast ice and prevent its breaking up even during the summer. However, the absence or the retreat of the ice tongues contributes to disintegration and drifting of the sea ice. Among the floating glaciers of Victoria Land, the Drygalski ice tongue is the most prominent. It penetrates into the Ross Sea for >80 km, damming the northward drifting of the sea ice (Frezzotti, 1993). Located in the middle of the Victoria Land coast, this huge ice tongue separates two very different marine coastal sectors: to the north the open water of the persistent polynya off Terra Nova Bay and to the south an almost continuous belt of sea ice facing the Scott Coast. Along the same coast, penguins have been present during the Holocene, but not continuously. This fact indicates environmental variations—changes in the extent of sea-ice cover caused by summer temperature variations and/or fluctuations of the Drygalski ice tongue. The widespread penguin rookeries along the Scott Coast between 4 and 3 ka indicate the presence of summer open waters close to the shore and the possible reduction or total disappearance of the Drygalski ice tongue. Similar environmental conditions could have occurred for a shorter period during the Middle Ages.

The spatial and temporal distribution of penguin rookeries along the Victoria Land coast is not random but shows a strong coherence, thus requiring a forcing cause—climatic and environmental changes. In particular, changes of sea-ice area and persistence are considered a major factor influencing the present and past distribution of penguin rookeries. Ornithogenic soils offer new possibilities for studying the changes that have affected climate, marine conditions, and floating glaciers during the Holocene in Antarctica. They may also contribute to the evaluation of variations of the Antarctic marine ecosystem in the absence of human-induced modifications.

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*Reviewer's comment*

Geoscientists have to be innovative, and this is a good lesson.
Jonathan Overpeck