

Ancient Adélie penguin colony revealed by snowmelt at Cape Irizar, Ross Sea, Antarctica

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ABSTRACT

The Ross Sea (Antarctica) is one of the most productive marine ecosystems in the Southern Ocean and supports nearly one million breeding pairs of Adélie penguins (*Pygoscelis adeliae*) annually. There also is a well-preserved record of abandoned penguin colonies that date from before the Last Glacial Maximum (>45,000 ¹⁴C yr B.P.) through the Holocene. Cape Irizar is a rocky cape located just south of the Drygalski Ice Tongue on the Scott Coast. In January 2016, several abandoned Adélie penguin sites and abundant surface remains of penguin bones, feathers, and carcasses that appeared to be fresh were being exposed by melting snow and were sampled for radiocarbon analysis. The results indicate the “fresh” remains are actually ancient and that three periods of occupation by Adélie penguins are represented beginning ca. 5000 calibrated calendar (cal.) yr B.P., with the last occupation ending by ca. 800 cal. yr B.P. The presence of fresh-appearing remains on the surface that are actually ancient in age suggests that only recently has snowmelt exposed previously frozen carcasses and other remains for the first time in ~800 yr, allowing them to decay and appear fresh. Recent warming trends and historical satellite imagery (Landsat) showing decreasing snow cover on the cape since 2013 support this hypothesis. Increased $\delta^{13}\text{C}$ values of penguin bone collagen further indicate a period of enhanced marine productivity during the penguin “optimum”, a warm period at 4000–2000 cal. yr B.P., perhaps related to an expansion of the Terra Nova Bay polynya with calving events of the Drygalski Ice Tongue.

INTRODUCTION

One consequence of global warming in recent decades has been the melting and retreat of glaciers, ice caps, and snowfields in polar and montane regions worldwide. In areas where mountain glaciers and snow have retreated, biological and archaeological remains are being re-exposed, including perishable and fossil remains (Dixon et al., 2005; Nesje et al., 2012; Alex, 2018). Here, I extend these discoveries to the Antarctic continent, where snowmelt in the Ross Sea region has exposed remnants of an ancient Adélie penguin (*Pygoscelis adeliae*) colony that has remained preserved under snow and ice for centuries. This site, located at Cape Irizar, Victoria Land, was investigated in January 2016 and appeared to represent a colony that was preserved intact at the time or shortly after it was abandoned. Thus, this locality is unique in that recently exposed “fresh” carcasses, bones, feathers, and guano of penguins are giving this site an appearance of a recently active colony. Here, this site is described with radiocarbon and stable carbon isotope ($\delta^{13}\text{C}$) analyses of surface

and subsurface penguin tissues that demonstrate a complex occupation history at Cape Irizar over the past ~5000 yr. Multiple occupations and abandonments of this cape by breeding penguins also provide insight on past sea and fast-ice conditions and marine productivity during a warm period at 4000–2000 calibrated calendar (cal.) yr B.P. known as the penguin “optimum” (Baroni and Orombelli, 1994; Emslie et al., 2007).

STUDY SITE

Cape Irizar (–75.55S, 162.95E; Fig. 1) is a rocky headland on the north side of Lamplugh Island, just south of the Drygalski Ice Tongue at the northern end of the Scott Coast, Victoria Land, Ross Sea. This cape was first sighted and named by Robert Falcon Scott in 1901–1904 and was first visited during Ernest Shackleton’s *Nimrod* expedition in 1907–1909 and again in 1911–1912 by Scott’s *Terra Nova* expedition. No mention was made then or subsequently of an active penguin colony at Cape Irizar on these first visits, though other active penguin colonies along the Victoria Land coast to the north

were reported. The closest active Adélie penguin colony to Cape Irizar today is at Inexpressible Island, 75 km to the north and on the opposite side of the Drygalski Ice Tongue (Fig. 1).

Lambert et al. (2002) and Lorenzini et al. (2009, 2014) reported seven radiocarbon ages on penguin guano from Cape Irizar ranging from ca. 4700 to 840 cal. yr B.P. Thus, the site was further investigated in 2016 to determine whether additional guano and ornithogenic soils were present so that further sampling could recover penguin remains. This visit resulted in the discovery of several small pebble concentrations (Adélie penguins construct their nests using pebbles; Ainley, 2002) that appeared quite old from the presence of dry, dusty ornithogenic soil. Moreover, there were also fresh remains of penguin carcasses, bones, and tissues scattered on the surface that appeared more modern in age (<5–10 yr old), though penguins cannot access this cape today from fast ice and cliffs along the shoreline. This unusual association of apparently recent and ancient remains was further investigated by excavating ancient pebble concentrations and collecting surface remains (mummies, bones, and feathers) from several locations nearby. Some of these surface remains were still being exposed by melting snow, while others had been exposed for some time and covered with lichens or algae.

That Cape Irizar is only revealing its penguin occupation record in recent decades is likely due to increased snow melt in the Ross Sea region over the past few decades. Temperature records combined with analyses of decadal variation in the Southern Annular Mode at McMurdo Station (–77.85S, 166.67E) since 1958 document a warming trend that has accelerated, with summer temperatures rising by ~0.5 °C per decade since the 1980s (Ainley et al., 2005; LaRue et al., 2013). Similar to Beaufort Island (Fig. 1; LaRue et al., 2013), satellite imagery dating from the 1980s to the present provides evidence for snowmelt increasingly exposing

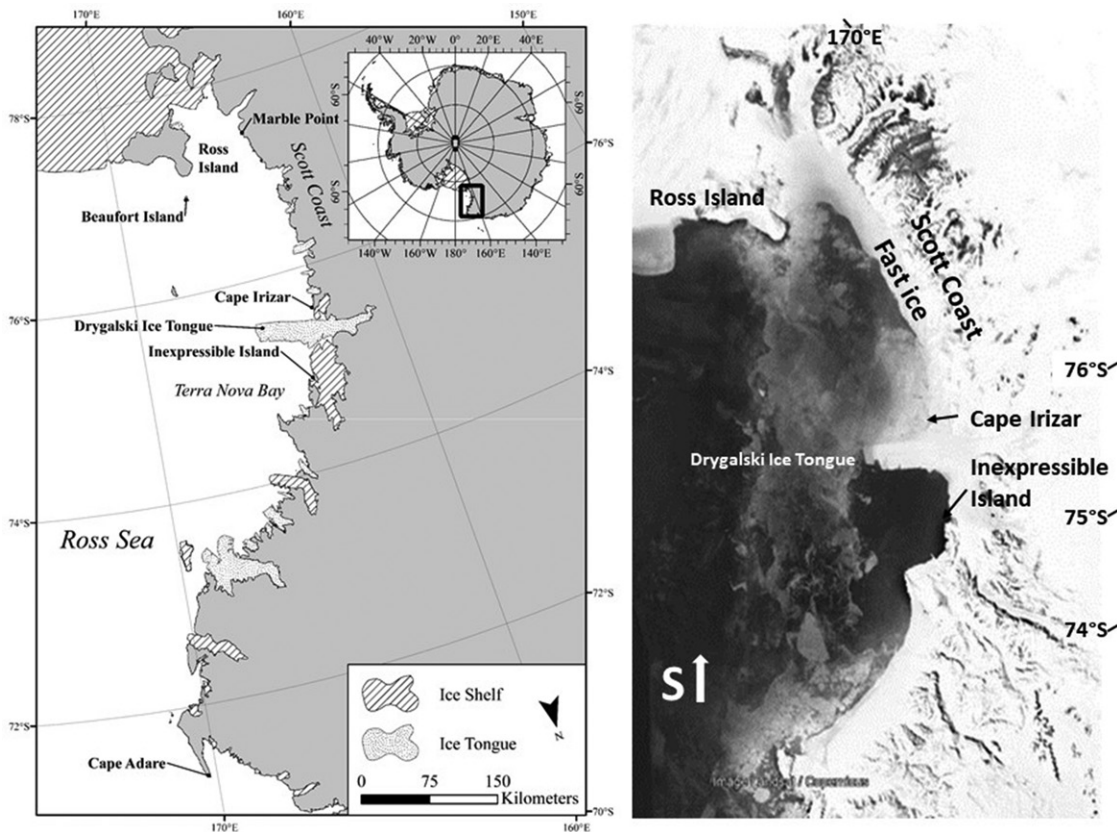


Figure 1. (Left) Map of the Ross Sea region (Antarctica) showing location of sites discussed in text. (Right) Satellite image showing extent of the fast ice on the Scott Coast and location of Cape Irizar to the south of the Drygalski Ice Tongue (Image data: Google™, Maxar Technologies [https://www.maxar.com/]).

the ground surface at Cape Irizar only within the past decade. Although high-resolution imagery is available only from 2017 onward, Landsat images taken on 30 December each year since 1984 indicate that the cape had remained consistently covered by snow until 2013, when a large area of exposed terrain (~0.5 km²) became more visible on the northeastern side (Fig. 2). These images also reveal increasing exposure of smaller areas of terrain on the eastern and southeastern sides of the cape. These data indicate that the penguin remains at Cape Irizar had been exposed from beneath the snow for only ~3 yr before 2016, although guano deposits were visible prior to this (Lambert et al., 2002), explaining the presence of actively decaying and “modern”-appearing bones and chick carcasses.

METHODS

Abandoned penguin sites were mapped and excavated following previously published methods (Emslie et al., 2011). At each sampling site, a 0.7 × 0.7 m or smaller test pit was excavated in the pebble concentration; one site was probed and sampled with a trowel. Surface pebbles were removed and placed on a tarp. Excavations proceeded in 5 cm levels to the bottom of ornithogenic soils, with all excavated sediments dry screened through two nested screens with mesh sizes of 0.64 and 0.32 cm², respectively. Organic remains were separated from the larger mesh screen in the field, and sediment from the 0.32 cm² screen was saved for additional analysis in the laboratory. Fol-

lowing excavations, the pits were backfilled and all surface pebbles were replaced. Surface remains of bone and feathers collected near these pebble concentrations were also collected.

Selected organic remains were submitted for radiocarbon analysis at the Woods Hole National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility (Woods Hole, Massachusetts, USA). These remains included seven bones, six eggshell fragments, three skin samples (two from surface mummies), and two feathers, for a total of 18 samples (Table 1). Bone collagen was also analyzed for $\delta^{13}\text{C}$ in 11 bones, including the seven used for radiocarbon analysis. All radiocarbon ages, including the seven guano dates reported by Lorenzini et al. (2014), were corrected and calibrated for the marine carbon reservoir effect using Calib 7.0.4 and the Marine13 database (Stuiver and Reimer, 1993; <http://calib.org/calib/>) using a regional correction $\Delta R = 750 \pm 50$ yr. Ages are reported as 2σ ranges in cal. yr B.P.

Four additional bones were analyzed for $\delta^{13}\text{C}$ at the University of North Carolina Wilmington (UNCW). One of these bones was of known age based on attached skin that was submitted for radiocarbon analysis (sample OS-128545; Table 1). The ages of the other three bones were estimated by taking the midpoint of the 2σ range of dated bones from the same stratigraphic level. Collagen was extracted following the methods of Sealy et al. (2014), with the addition of a 24 h lipid extraction with

2:1 chloroform:methanol solution (Liden et al., 1995). Bone samples were cleaned, crushed, and placed in glass vials for lipid extraction. After drying, 0.2 M HCl was added to the vials at room temperature. The acid was changed every other day until decalcification was complete. Bones were then rinsed three times in distilled water and freeze dried prior to isotope analysis. Each sample was weighed and loaded into tin cups and flash combusted in a Costech Elemental Analyzer (EA 4010) paired with a Thermo Electron Delta V Isotope Ratio Mass Spectrometer (EA-IRMS) at UNCW. Quality of preservation and accuracy of isotopic values was assessed by C:N ratios (DeNiro, 1985). Raw results were normalized on a two-point scale using enriched and depleted reference materials (USGS40 and USGS41a).

RESULTS

Two pebble concentrations (sites 1 and 2) were excavated, and three others (sites 3–5) were located and mapped (Fig. 2); no other sites were located. All sites were shallow, with only ~10–15 cm depth to the ornithogenic soils. Site 1 (0.7 × 0.7 m test pit) was excavated in two levels before reaching the bottom of the soil. Site 2 was shallower with only one level excavated. Site 3 was sampled by probing to depths of as much as 10 cm to recover datable organic remains (bones, eggshell). Two intact Adélie penguin chick mummies were collected from the surface at sites

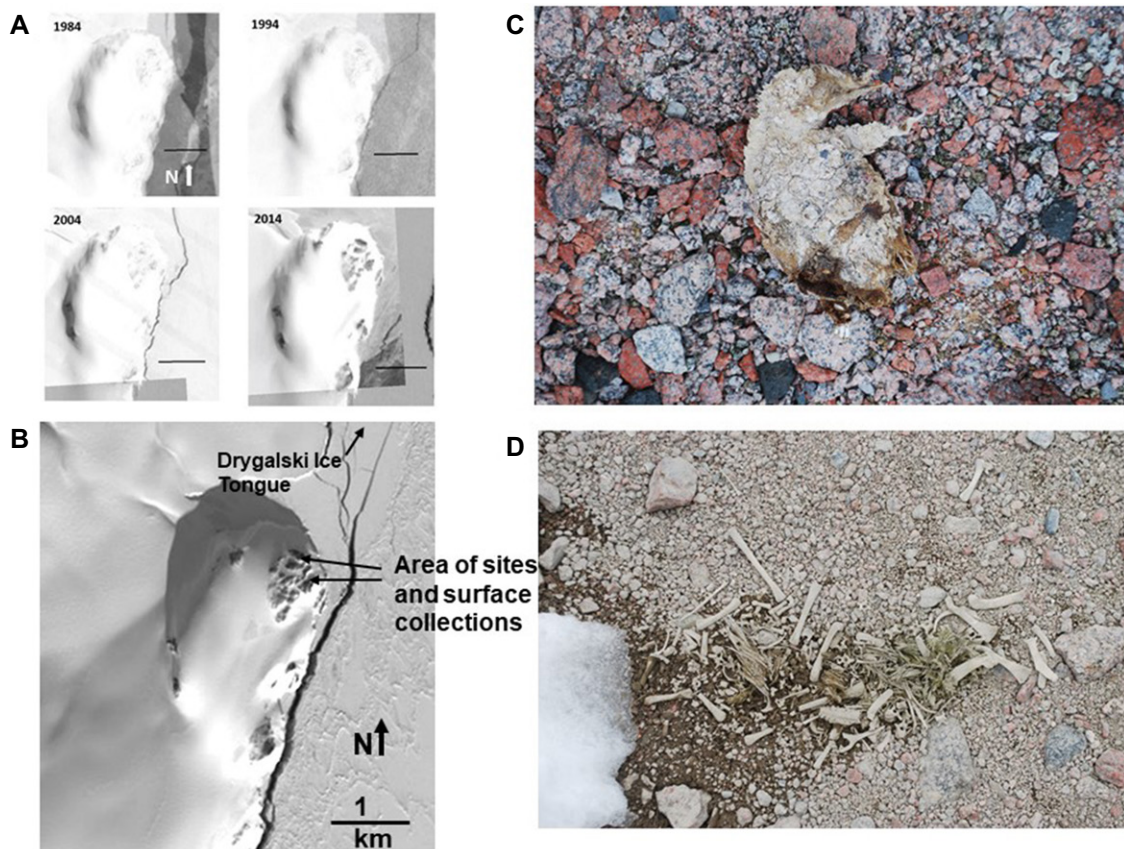


Figure 2. (A) Satellite images of Cape Irizar, Ross Sea, Antarctica, taken in January every 10 years since 1984, indicating the gradual exposure of surface from snow melt (Image data: Google™, Landsat/Copernicus, U.S. Geological Survey, and Maxar Technologies; scale bar = 1 km in each photo). (B) Current view of Cape Irizar showing location of sampling conducted in 2016. (C) Mummy of Adélie penguin chick (total length ~20 cm) on the surface of site 5 that has been radiocarbon dated at ca. 800 calibrated calendar yr B.P. (D) Recently decayed chick carcass (each bone ranges from 5 to 10 cm in length) near the melting snow line at Cape Irizar in 2016.

4 and 5 (Fig. 2). Surface remains were collected at five other locations.

The 25 radiocarbon dates indicate an initial occupation of Cape Irizar by breeding Adélie penguins at 5135–4815 cal. yr B.P. (Table 1).

Dates from sites 2 and 3 as well as some surface remains further indicate that the first occupation period lasted from ca. 5135 to 2750 cal. yr B.P. A second occupation is evident from site 1 and some surface remains from 2340 to 1375 cal. yr

B.P. A third and final occupation is indicated by dates on the two surface mummies and subsurface guano at 1100–685 cal. yr B.P.

Eleven (11) bones with known or estimated radiocarbon ages provided $\delta^{13}\text{C}$ values that are ~1‰–2‰ higher during the period from 3000 to 2000 cal. yr B.P. compared to samples that date outside this period. These latter values decrease abruptly by ca. 2100 cal. yr B.P.; one low value also occurs at ca. 5000 cal. yr B.P. (Fig. 3).

Holocene Occupation History at Cape Irizar

The earliest radiocarbon dates on Adélie penguin remains from Cape Irizar place its initial occupation prior to the penguin “optimum” at ca. 5000 cal. yr B.P. (Fig. 3) and lasting for >2000 yr. After a period of abandonment of ~500 yr, a second occupation began at ca. 2300 cal. yr B.P. near the end of the penguin “optimum” (Fig. 3). This occupation lasted ~1000 yr when again there is a gap in the chronology until ca. 1100 cal. yr B.P. The third and final occupation followed from ca. 1100 to 685 cal. yr B.P. when again the cape was abandoned and remains so today. Although this complex occupation history could change with additional radiocarbon dates (other sites with different ages may yet be preserved under the existing snow cover), the tight clustering of dates from each of sites 1–3 (Table 1) as well as the correspondence between guano and tissue

TABLE 1. CAPE IRIZAR RADIOCARBON DATES AND $\delta^{13}\text{C}$ VALUES

NOSAMS sample no.	Provenience	Material	Uncorrected ^{14}C age (yr B.P.)	Calibrated 2 σ range (cal. yr B.P.)	$\delta^{13}\text{C}$ (‰)
GX-23276*	—	Guano	5310 ± 60	4855–4530	—
GX-23275*	—	Guano	4520 ± 65	3920–3485	—
GX-20577*	—	Guano	4945 ± 175	4790–3820	—
GX-20576*	—	Guano	4325 ± 85	3715–3220	—
OS-53463*	—	Guano	4110 ± 30	3365–3050	—
OS-53464*	—	Guano	2160 ± 25	1100–820	—
OS-62106*	—	Guano	2080 ± 35	1005–725	—
OS-125903	Site 1, level 1	Eggshell	2710 ± 20	1660–1375	—
OS-152181	Site 1, level 1	Left coracoid	3300 ± 20	2340–2080	-20.2
OS-125864	Site 1, level 2	Eggshell	2970 ± 20	1960–1685	—
OS-152182	Site 1, level 2	Phalange	3270 ± 20	2320–2040	-19.5
OS-125866	Site 2, level 1	Eggshell	4410 ± 20	3710–3420	—
OS-125896	Site 2, level 1	Eggshell	4390 ± 25	3685–3395	—
OS-151738	Site 2, level 1	Feather	4760 ± 25	4190–3855	—
OS-125972	Site 3, level 1	Eggshell	4640 ± 20	4030–3690	—
OS-125971	Site 3, level 2	Eggshell	4640 ± 20	4030–3690	—
OS-152183	Site 3, level 2	Left femur	5460 ± 25	5135–4815	-22.6
OS-125730	Site 4, surface	Skin from mummy	2000 ± 20	905–685	—
OS-125729	Site 5, surface	Skin from mummy	2050 ± 15	945–720	—
OS-152179	Surface	Right humerus	3230 ± 20	2290–1990	-20.2
OS-152180	Surface	Right femur	2980 ± 20	1970–1695	-22.3
OS-125727	Surface	Tail feather	2710 ± 20	1660–1375	—
OS-129769	Surface	Left femur	3190 ± 25	2270–1940	-20.0
OS-129770	Surface	Right femur	3860 ± 30	3045–2750	-19.3
OS-128545	Surface	Skin from foot	3950 ± 20	3180–2850	—
OS-128545	Surface	Phalange from foot	3950 ± 20	3180–2850	-20.1
**	Site 1, level 1	Left humerus	3300 ± 20	2340–2080	-20.8
**	Site 1, level 1	Scapula	3300 ± 20	2340–2080	-20.7
**	Site 1, level 2	Tarsometatarsus	3270 ± 20	2320–2040	-21.9

*Dates reported by Lambert et al. (2002) and Lorenzini et al. (2014). Dashes indicate no data available. NOSAMS—National Ocean Sciences Accelerator Mass Spectrometry facility, Woods Hole Oceanographic Institution.

**Age estimated based on associated bone dated from the same level reported above.

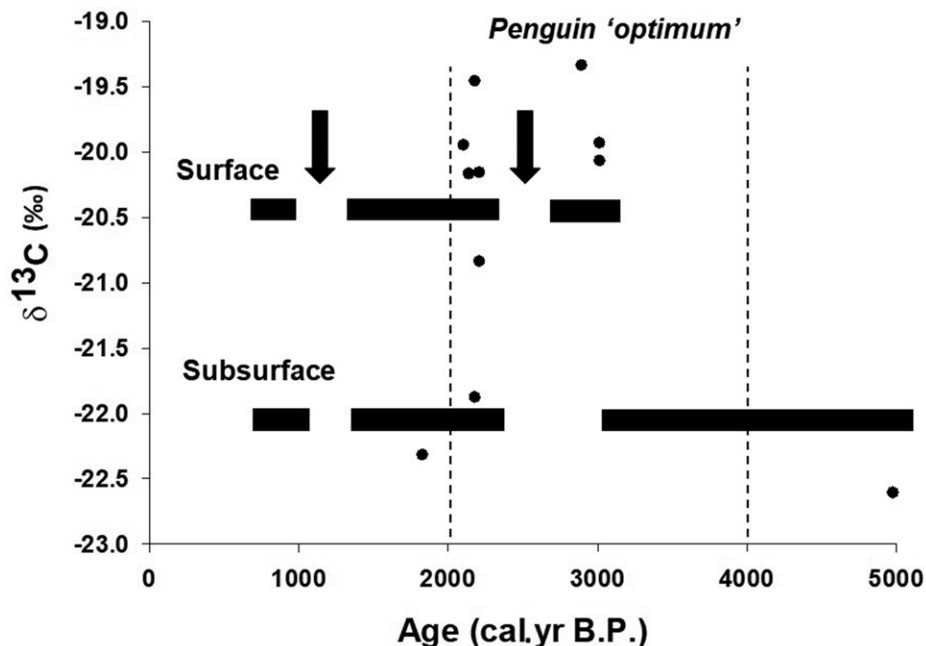


Figure 3. Ranges of 25 radiocarbon dates (2σ , in calibrated calendar [cal.] yr B.P.) on the subsurface (including guano dates from Lorenzini et al. [2014]) and surface Adélie penguin bones and feathers at Cape Irizar, Antarctica, indicating three occupation periods before, during, and after the penguin “optimum” (4000–2000 cal. yr B.P.; between vertical dashed lines). Bold arrows indicate two potential gaps, or periods of abandonment, over the past ~2500 yr. Collagen $\delta^{13}\text{C}$ values (solid circles) from 11 penguin chick bones from Cape Irizar show the highest values falling within the penguin “optimum”.

dates suggest that additional dates would not change these interpretations.

The last two occupations of Cape Irizar are unusual because this cape is now the only known site on the Scott Coast to have remained occupied by breeding penguins, and then reoccupied, during and after the penguin “optimum” that ended at 2000 cal. yr B.P. (Baroni and Orombelli, 1994; Emslie et al., 2007). Notably, the last occupation of Cape Irizar at ca. 1100 cal. yr B.P. overlaps with the Medieval Warm Period (A.D. 800–1300) and ended at the onset of the Little Ice Age at A.D. 1300, when average summer surface temperatures were as much as -2°C colder than present in the Ross Sea (Bertler et al., 2011; Rhodes et al., 2012). Thus, this colder period is likely when the cape and remnants of the active penguin colony at the time became permanently covered by ice and snow until recent warming trends began to expose it. These last two periods of occupation further indicate that localized marine conditions were allowing reoccupation here after the penguin “optimum” ended and not on the rest of the Scott Coast to the south.

The three apparent periods of occupation and abandonment probably were caused by changes in sea-ice conditions and presence or absence of fast ice blocking beach access by penguins to Cape Irizar (see Emmerson and Southwell [2008], Lescroëel et al. [2014], and Mezgec et al. [2017] for the effects of fast ice on penguin breeding sites), though periods

of snow accumulation that covered suitable nesting areas during the austral summer from changes in precipitation and wind patterns also may be involved. One hypothesis for the multiple episodes of occupation and abandonment at Cape Irizar is that changes in the size and thickness of the Drygalski Ice Tongue over time have influenced oceanographic conditions in the Drygalski Trough just south of the tongue, where Cape Irizar is located. This ice tongue has undergone two major calving events, as well as breakage from collision with an iceberg, since the beginning of the 20th century (Stevens et al., 2017). Fast ice south of the tongue, which can persist there well into the summer, currently discourages penguin access to beaches along the entire Scott Coast, which has not been occupied by breeding penguins since the end of the penguin “optimum” at 2000 cal. yr B.P. (Emslie et al., 2003, 2007), though guano dates from Dunlop and Prior Islands near the coast suggest occupation may have occurred there at ca. 1200–650 cal. yr B.P. (see Lorenzini et al., 2014). However, the north edge of the ice tongue also forms the southern boundary of the Terra Nova Bay polynya, while the south edge faces the northward-moving Victoria Land Coastal Current, and calving of the ice tongue would likely result in an expansion of the polynya’s open waters southward to Cape Irizar (van Woert et al., 2001; Stevens et al., 2017), thereby allowing penguin access to this cape for breeding.

Currently, the Ross Sea and its associated polynyas have the highest marine productivity in the Southern Ocean (Ainley, 2002; Smith et al., 2014). An expansion of these polynyas in the past would have increased primary productivity and chlorophyll *a* concentrations (Arrigo and van Dijken, 2003). The $\delta^{13}\text{C}$ results on bone collagen, while limited, support this hypothesis. The isotope values from chick bone collagen represent a relatively short interval during the austral summer, when the chicks were being fed by their parents while foraging in the local environment. The higher values in carbon isotopes during the penguin “optimum” are in accordance with a period of increased primary productivity (Fig. 3). While only 11 bones were available to analyze for $\delta^{13}\text{C}$, this hypothesis is testable with recovery of additional bone samples in the future.

CONCLUSIONS

The complex occupation history at Cape Irizar has resulted in a jumble of penguin remains of different ages on the surface and subsurface. Some of these remains appear fresh after being recently exposed from beneath melting snow and ice, while other remains are older in their exposure and covered with lichens. The ornithogenic soils and remains from the earliest occupations also are exposed on the surface, and these multiple occupations and abandonments help explain the broad range of radiocarbon dates obtained at this site. Past calving events of the Drygalski Ice Tongue and changes in the size of the Terra Nova Bay polynya provide the best explanation for why Cape Irizar is the only known site on the Scott Coast with this episodic occupation history. As warming trends continue in Antarctica and the Ross Sea, additional snow- and ice-covered sites may become evident and add to the dynamic record of penguin occupation and abandonment over millennia with climate change.

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