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KŌKO SEAMOUNT: A MAJOR GUYOT AT THE SOUTHERN END OF THE EMPEROR SEAMOUNTS

T. A. DAVIES[1], P. WILDE[2] and D. A. CLAGUE[1]

[1] *Scripps Institution of Oceanography, La Jolla, Calif. (U.S.A.)*

[2] *Institute of Marine Resources, University of California, Berkeley, Calif. (U.S.A.)*

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ABSTRACT

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Kōko seamount is an exceptionally large guyot situated at 35° 30′N, 171°45′E, at the southern end of the Emperor seamount chain. An accurate survey of Kōko seamount and two successful dredge hauls from near its summit were made by R/V "Thomas Washington" in August 1971. The dredge hauls included samples of a wide variety of unusual igneous rocks and coral reef debris. The significance of the occurrence of coral reef debris capping a guyot which is now both too deep and too far north for active reef growth is discussed briefly.

INTRODUCTION

The Emperor seamounts, first described and named by Dietz (1954), effectively separate eastern and western parts of the North Pacific Ocean, north of the Hawaiian ridge. They extend almost due south along 170°E for some 1300 miles from the neighborhood of Komandorski Island at the western end of the Aleutian chain to a point approximately 32°N, 173°E (Fig.1). The southern end of the Emperor chain is bounded by what may be the westward extension of the Mendocino fracture zone (Hayes and Pitman, 1970). In general the Emperor seamounts are not well known, although some investigations have been carried out on Suiko seamount (Tomoda, 1968).

In August 1971, on Leg 7 of the Scripps Institution of Oceanography's "Aries" Expedition, R/V "Thomas Washington" made bathymetric, magnetic and seismic reflection (airgun) surveys, and several dredge hauls in the region of the southern Emperor seamounts (Davies et al., 1971). While engaged in this work, a hitherto unnamed guyot was charted, centered at approximately 35°20′N, 171°30′E. This guyot was not shown on Dietz's original chart of the Emperor seamounts, although he did suggest that there might be more shoal areas in the region than were then known (Dietz, 1954). Chase and his colleagues, in preparing their recent chart of the North Pacific, used additional

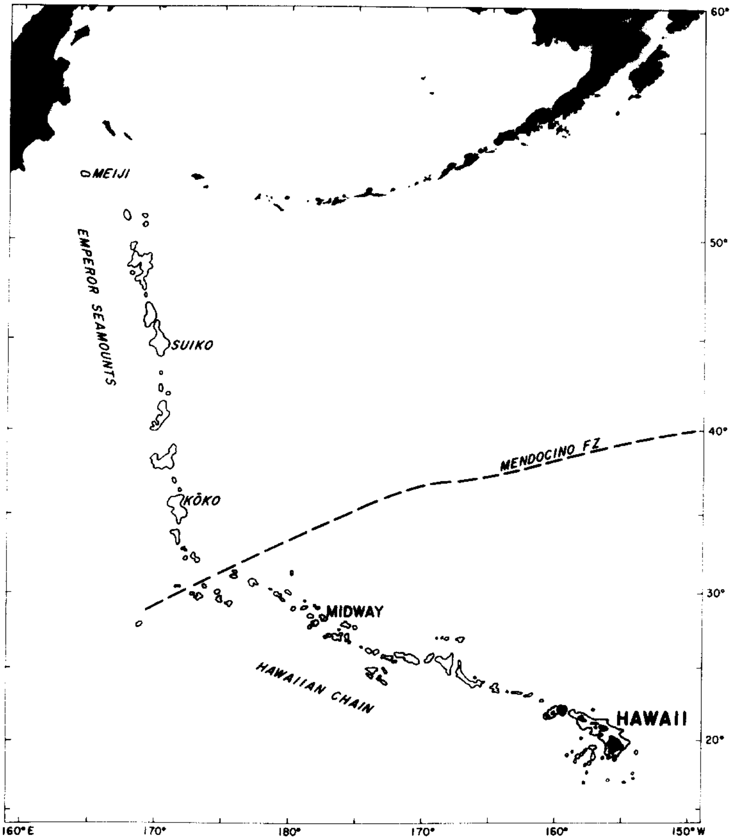

Fig. 1. Location of Kōko seamount within the Hawaiian–Emperor chain.

bathymetric data, consisting of east–west tracks and spot soundings, from the U.S. Hydrographic Office and from Scripps' "Lusiad" expedition, to add four seamounts between the originally charted Ojin and Kinmei seamounts (Chase et al., 1970). The southern pair of seamounts added by Chase and his associates have now been shown to be a single large guyot. This guyot is of interest because of its remarkable size and the wide variety of rock types which were sampled in the dredges.

As all of the Emperor seamounts have been named after Japanese emperors, we propose that this seamount be named Kōko seamount.

The purpose of this contribution is to present a brief description of Kōko seamount. More detailed accounts of the igneous and sedimentary rocks from the dredge hauls are in preparation and will be presented in future papers.

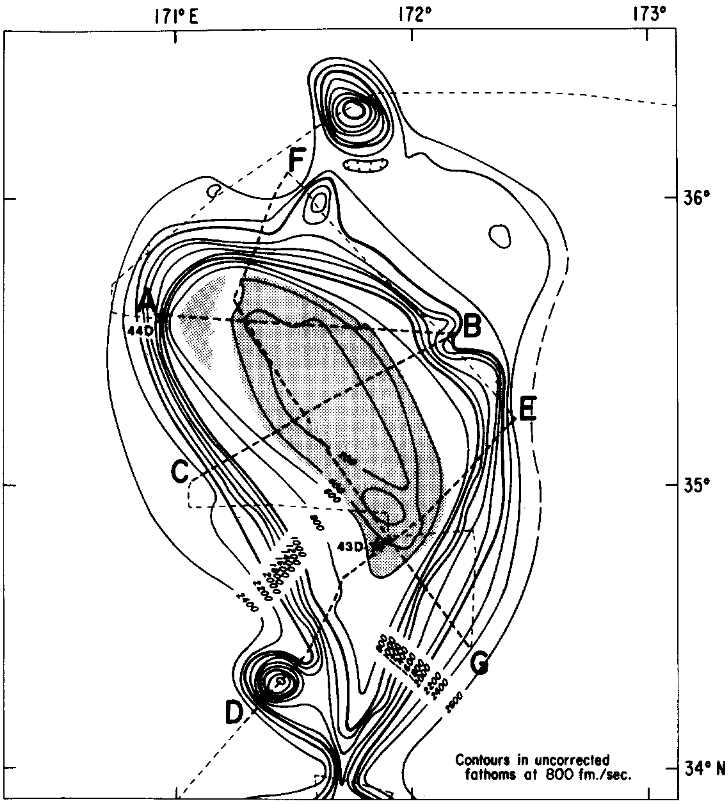

Fig.2. Bathymetry of Kōko seamount. Broken lines show survey tracks of R/V "Thomas Washington" (August, 1971) upon which contouring is largely based. Lettered tracks refer to seismic profiles in Fig.3 and 4. Stars show positions of dredge hauls. Shaded area shows approximate extent of the coral reef capping the guyot.

BATHYMETRY

Fig.2 shows the bathymetry of Kōko seamount, based largely on surveys conducted by the "Thomas Washington" in August 1971. These surveys were controlled by precise satellite navigation giving an overall accuracy in positioning of ± 0.1 n mile. Some earlier ships' tracks across the region have been used also in compiling the chart.

As will be seen from Fig.2, Kōko seamount rises from a regional depth of about 2600 fathoms to within 135 fathoms of the surface. Broadly elliptical in shape and aligned in a north northwest–south southeast direction, it is clearly a guyot and is extremely large. At its base, roughly the 2000–2200 fathom level, Kōko seamount measures 120 n mile by 60 n mile and the flat summit plateau, less than 200 fathom in depth, measures some 50 n mile by 13 n mile. The sides of the guyot are smooth and steep (gradient 1 to 8), rising from abyssal depths to a marked break in slope at a depth of 600–1000 fathoms.

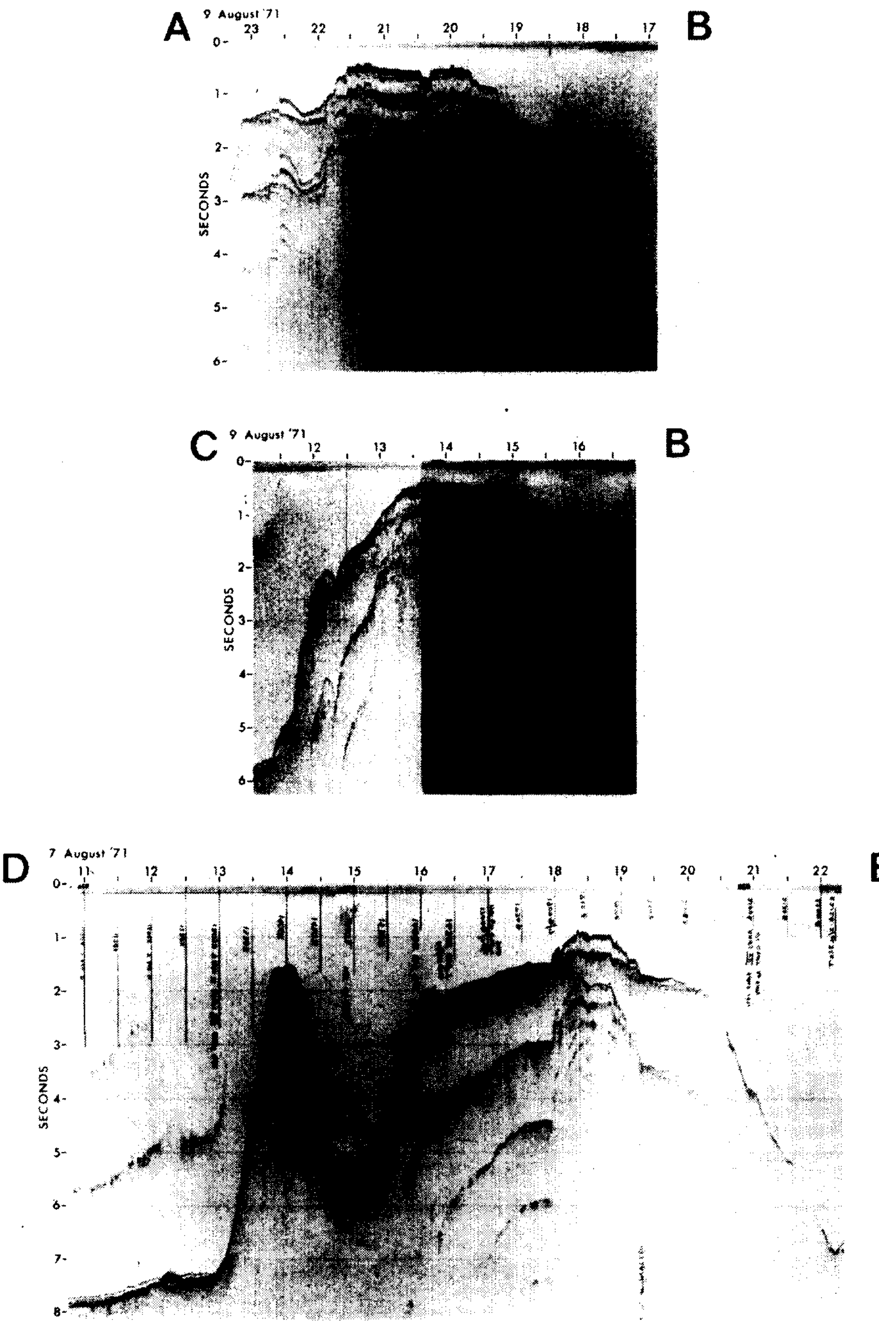

Fig.3. Seismic reflection profiles across Kōko seamount. Letters refer to tracks on Fig.2. All profiles were run at a constant speed of 9 knots.

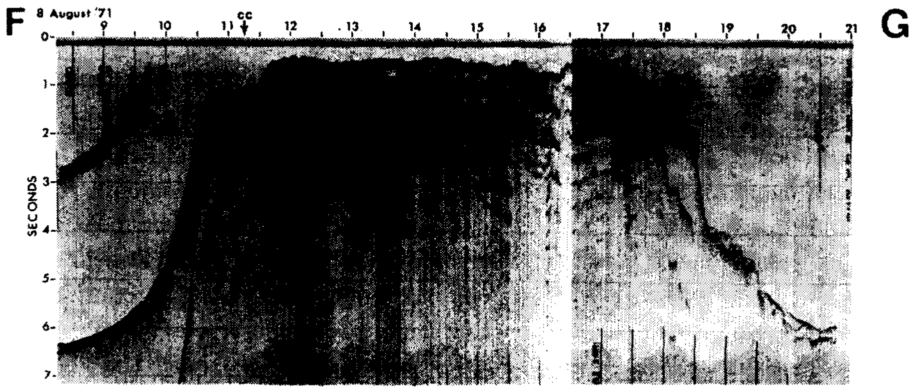

Fig.4. Seismic reflection profile along the length of Kōko seamount. Letters refer to track on Fig.2. Profile run at a constant speed of 9 knots.

In general the break in slope is at about 800 fathoms but is shallower at the northwestern end of the guyot.

Between the break in slope and the summit plateau the bathymetry is more complex. The summit plateau is bounded everywhere by cliffs and steep slopes which fall to depths of 400 to 600 fathoms. On the eastern and southern sides of the summit plateau is a terrace, 4 to 12 n mile in width, sloping gently outwards and falling from a depth of 500 fathoms at the base of the summit plateau to a depth of 800 fathoms at the outer break in slope. On the northern side the rough bottom falls away from the summit plateau in a steeper, but more or less uniform, slope to the outer break in slope which here varies from 500 to 1000 fathoms in depth. On the northwestern side of the summit plateau is another terrace, flatter than the southern terrace, and measuring up to 15 n mile across. It falls from a depth of 400 fathoms at the base of the summit plateau to about 600 fathoms at the break in slope. Between the northern and southern terraces, on the western side of the guyot, the upper slopes appear to fall away steeply but uniformly to the break in slope. These morphological features are clearly shown in the profiles in Fig. 3 and 4.

GEOLOGY AND STRUCTURE

Two dredge hauls were made on Kōko seamount (Fig.2). The deeper haul (44D), from the northwestern side of the guyot, produced samples of fresh, angular basalt, and coarse volcanic breccia. The shallower haul (43D) was taken from the southern end of the summit plateau and produced an interesting assortment of rock types, ranging from reef limestones to cobbles of diabase, mugearite, trachyte and nepheline phonolite (Clague and Greenslate, 1972). Reef-building corals and algae only flourish in depths less than about 30 fathoms, although they can survive down to about 85 fathoms. Hence it is apparent that at one time the guyot, if it was not an island, rose at least to within a few fathoms of the ocean surface. Concurrent with and subsequent to the development of the reef limestone cap it has subsided to its present depth.

The seismic reflection profiles (Fig.3 and 4) show some of the internal structure of the guyot. The limestone cap and the underlying basement volcanics can be distinguished clearly. The top of the basement can be traced as a shadowy reflector extending right across the guyot on all the profiles. However, because of the shallow water depth, the basement reflection is obscured by multiple reflections from the hard surface of the overlying limestone. The surface of the basement is irregular but generally smooth. It appears to arch upward abruptly under the limestone cap from its outcrop on the flanks. However, this apparent upward arching is due simply to the effect of the increase in acoustic velocity in the limestone cap relative to that through seawater. As a result, reflections which pass through the limestone and return from the basement have a shorter travel time than reflections whose direct path to basement is through the water column only. The actual configuration and depth of the basement surface cannot be determined from the records without a knowledge of the acoustic velocities in the overlying limestone. At Bikini and Kwajalein velocities in the limestone cap range from 2.1 to 3.35 km/sec (Raitt, 1954). If we make the assumption that the velocity in the limestone on Kōko seamount is about 3.0 km/sec, or about twice the velocity in seawater, then the upward arch of the basement beneath the limestone effectively disappears and it is clear that the basement surface, while broadly domed, is fairly smooth.

On all of the profiles the limestone cap shows as a thick (0.3–0.4 sec), acoustically transparent, central mass overlying the shadowy upper surface of the volcanics. There is a suggestion that the limestone cap may be in two layers with a very thin (0.1 sec) and discontinuous upper layer overlying the main mass (for example 2100 h on profile *AB*), although the reverberation of the bubble pulse obscures much of the detail of the upper 0.25 sec of the record. Either side of the central mass of limestone at the southern end (profile *DE*) are thinner transparent layers extending out to the break in slope and the outcrop of the volcanics. The surface of the volcanics under this region dips gently outwards. On some profiles the thin transparent layers are subhorizontal but on others they dip steeply outwards, away from the central mass.

Notice the small basement outcrop on the western edge of the reef on profile *DE*. This presumably represents a late stage dyke and is a likely source for the volcanic cobbles found with the reef debris in dredge 43D.

At the northern end of the guyot (profile *AB*) the structure is more complex (Fig.3 and 4). Here the areas on either side of the central reef mass have been down-faulted to produce a steep, broken slope on the eastern side and a broad uneven terrace on the west. As the irregularities in the reef surface are considerably greater than those in the surface of the underlying volcanics it seems reasonable to suggest that the down-faulting predates the formation of the reef and that the irregularities in the surface of the reef reflect differential rates of development.

One further point to note is that the base of the main reef body has an essentially constant depth of about 500 fathoms on the western side and 600 fathoms on the eastern side. This depth does not coincide with the break in slope which varies considerably in depth, but is everywhere deeper than the foot of the main reef mass.

DISCUSSION

Comparison with similar features

Table I lists the surface areas of true oceanic islands, atolls and other large guyots compared with Kōko seamount. As shown, Kōko seamount is certainly one of the largest, if not the largest, guyot known and also one of the shallowest. It compares in size with the largest atolls and with the larger composite island volcanoes such as Hawaii and Isabella.

Table II summarises our knowledge of the thickness of the carbonate cap on several atolls in the Pacific Ocean. In this regard also Kōko seamount is comparable with other atolls.

TABLE I

Areas of major oceanic islands, atolls, and guyots

Feature	Area (sq. miles)	sq. km	Reference
Guyots			
Kōko seamount			
200 fathom contour	564	1935	Fig.2, this paper
400 fathom contour	1080	3704	Fig.2, this paper
1000 fathom contour	3150	10805	Fig.2, this paper
Meteor seamount			
200 fathom contour	560	1921	Pratt (1963)
Hess guyot			
1000 fathom contour	ca. 100	3430	Hamilton (1956)
Horizon guyot			
1000 fathom contour	ca. 800	2744	Menard (1964)
Atolls			
Kwajalein	902	3094	Carter (1956)
Truk	860	2950	Freeman (1951)
Bermuda pedestal	315	1080	Pratt (1963)
Volcanic high islands	(at sea level)		
Hawaii	4030	13823	Freeman (1951)
Espiritu Santo	1500	5145	Freeman (1951)
Isabella (Galapagos)	1725	5917	Freeman (1951)
Savaii (Western Samoa)	703	2411	Freeman (1951)
Guam	215	737	Freeman (1951)

TABLE II

Thickness of carbonate cap on Pacific atolls

	Thickness (m)	Technique
Eniwetok	1400	drilled*
Bikini	1300	seismic refraction*
Kwajalein	1000	seismic refraction*
Funafuti	900	seismic refraction*
Kōko seamount	600	seismic reflection

*From Menard (1964)

Significance of the carbonate cap

The present location of Kōko seamount is about 3° north of the limit for active reef growth and at the extreme northern limit for reef corals (35° 10′) reported by Hamilton (1956). Furthermore the present shoal depth of 135 fathoms and the mean February sea surface temperature of 15°C (Sverdrup et al., 1942, Charts II, III) preclude active reef growth. Hamilton (1956) proposed 85 fathoms and 18.5°C as extreme conditions for reef growth. Optimum conditions for reef growth are 15 fathoms and 25°C. Consequently the occurrence of a coral reef capping Kōko seamount leads to some interesting speculations.

Clearly the guyot has subsided relative to sea level about 120 fathoms since the last active reef growth and about 700 fathoms since the planation of the volcano which forms the base of the carbonate cap. Cessation of active carbonate reef growth could be caused by either the water depth increasing (due to subsidence or eustatic rise of sea level) at a rate greater than the reef could build, or by an overall lowering of the surface seawater temperature, or by some other environmental factor.

Pleistocene history

The only way in which depth could have become the limiting factor on reef growth would be if the water depth had suddenly increased after the reef had been established. This leads to the suggestion that cessation of active reef growth might be a result of the post-Glacial eustatic rise of sea level. Eustatic lowerings of sea level during the Pleistocene are postulated to be a maximum of 72 fathoms (Milliman and Emery, 1968) to 87.5 fathoms (Donn et al., 1962) which indicate that even without allowing for subsidence the guyot could have been within about 50 fathoms of sea level during glacial maxima. Bloom (1970) has calculated the maximum rate of subsidence in the high islands and atolls of the Caroline Islands is about 1 fathom per 1000 years. Assuming this rate as a constant and allowing for eustatic changes in sea level one concludes that the water depth over Kōko seamount was optimum for active coral reef growth no later than 60,000–70,000 years B.P. and that the reef on the guyot is less than 1 million years old. Obviously the guyot has subsided previously at least 400 fathoms with carbonate sedimentation keeping pace with subsidence, even at this high rate of subsidence.

Reef growth is also temperature dependent, however. Sea surface temperatures calculated from $^{18}O/^{16}O$ ratios in foraminifera from the North Atlantic at 34°N (Emiliani and Flint, 1963) show what those authors interpreted as a 4°C increase in surface temperature during glacial minima and a 5°C decrease in sea surface temperature during glacial maxima, with respect to present-day sea surface temperatures. Both Olausson (1965) and Dansgaard and Tauber (1969) have pointed out that in fact the variation observed in the $^{18}O/^{16}O$ ratio is actually caused for the most part by "the amount of continental ice in excess or deficit over the amount present today" (Dansgaard and Tauber, 1969). Thus, during the Pleistocene, isotopic variations do not reflect directly changes in sea water temperatures. The present sea surface temperature at 35°N latitude is too low for active growth of reef corals. This suggests that cessation of reef growth is not connected with the post-Glacial rise of sea level, that the reef itself is of pre-Pleistocene age and that Bloom's figure for rate of subsidence is much too high for that of Kōko seamount.

Pre-Pleistocene history

In considering a pre-Pleistocene history for Kōko seamount we will take into account the possible effects of sea-floor spreading. It seems likely that growth of the reef ceased either due to sudden cooling of the sea surface waters, or due to movement of the seamount northwards into cooler waters as a result of sea-floor spreading, or some combination of these effects.

If we assume geographically fixed isotherms of tropical waters in the Cenozoic, Kōko seamount must be moved at least 3° to the south before active reef growth can commence. The recent analysis of Jackson et al. (1972), based on Wilson's hypothesis that the Hawaiian–Emperor chain developed from a single hot-spot (Wilson, 1963), suggests that Kōko seamount formed about 30 m.y. ago (Late Oligocene) and that active reef growth ceased when the seamount passed the under 18.5°C isotherm into cooler water 5–6 m.y. ago (Late Miocene).

If we accept 30 m.y. as the age of the basement surface and assume the seamount to have subsided 700 fathoms since its formation we can calculate a rate of subsidence of 23 fathoms/m.y., a considerably lower figure than that of Bloom (1970). This rate, taken in conjunction with the fact that the top of the guyot is 120 fathoms below the optimum depth for reef growth, suggests that reef growth ceased at 5–6 m.y. ago. This is in agreement with the age derived from the geometrical argument in the preceding paragraph and lends credence to our tacit assumption that subsidence is relatively uniform.

Unfortunately, the age of 5–6 million years is not corroborated by a preliminary maximum age of Lower Tertiary for the hermatypic corals dredged from Kōko seamount (J. W. Durham, pers. communication, 1972). This suggests either that the isotherms are not fixed or that the rate of movement postulated by the Jackson et al. (1972) model is too high, or some combination of these effects.

Considering temperature alone, it seems unlikely that the range of sea surface temperatures over Kōko seamount has remained unchanged throughout the Cenozoic. Arrhenius (1952) has shown that the deep-sea belt of carbonate ooze in the central Pacific has contracted since pre-Pleistocene times, which implies warmer temperatures during the Tertiary. Furthermore, $^{18}O/^{16}O$ ratios in cores from Deep Sea Drilling Project Site 47 (32°26.9'N; 157°42.7'E) show an increase in temperature relative to the Pleistocene of about 2°C in the Pliocene and 10°C in the Paleocene (Douglas and Savin, 1971). This is in general agreement with Durham's (1950) data on the position of February marine isotherms along the Pacific coast during the Cenozoic.

The problem is further complicated when we examine in detail the changing geometry through time of the Hawaiian–Emperor chain. It is beyond the scope of this paper, which describes chiefly the physical features of Kōko seamount, to analyse the complex interaction of the history of sea surface temperatures in the Pacific with refinements of various sea floor spreading models proposed for this area. A more extensive discussion of this problem will be presented in a forthcoming paper.

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