37. SEISMIC STRATIGRAPHY AND VERTICAL TECTONICS OF THE EMPEROR SEAMOUNTS, DSDP LEG 55

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ABSTRACT

In terms of its geology and geomorphology, the southern and central Emperor Seamount chain varies from simple sharp-peaked volcanic seamounts to complex flat-topped, carbonate-capped guyots. Geologic maps for nine seamounts (Kōkō, Ōjin, Jingū, Nintoku, Yōmei, Suiko, "northern" Suiko, Seamount "B," and an unnamed seamount) were constructed from seismic reflection profile data. The seismic stratigraphy used consists of nine distinct acoustic units: (1) acoustic basement-volcanic rocks, (2) a well-layered sedimentary unit restricted to the adjacent sea floors, (3) shallow-water bank interior deposits, (4) reef or carbonate bank deposits, (5) terrace deposits, (6) shallow-water lagoonal sediments, (7) well-layered ponded sediments, (8) an acoustically transparent pelagic unit, and (9) slump or slope detritus. These units are defined using combinations of acoustical characteristics consisting of reflectability of the rocks (i.e., opaque or transparent), reflector type (i.e., amplitude, strong or weak), distortion (i.e., hyperbolics or side echoes), and lateral and vertical continuity reflection patterns which consist of contorted, parallel, and prograded reflectors. The seismic stratigraphic units are relatively thin, but represent a complex depositional history. Drilling on four guyots (Ōjin, Yōmei, Nintoku, and Suiko) during DSDP Leg 55 and on one guyot (Kōkō) during DSDP Leg 32 reveals shallow-water carbonate deposition on subsiding volcanic islands that supports the seismic reflection interpretations. The seismic profiles allow a relatively accurate determination of the depositional history of all those areas with seismic coverage.

The subsidence history of the seamounts of the southern Emperor chain is fairly simple. Many of the seamounts once stood above sea level as islands and slowly subsided beneath wave-base. Subtle differences in the seamount morphologies indicate that the rates of subsidence varied between seamounts. All but two seamounts (Yōmei and the unnamed seamount) have undergone complete wave planation and all of the guyots once stood as shallow-water carbonate banks or atolls. Many stages of atoll development are represented in the southern and central Emperor chain. These geomorphic stages vary from youthful to mature, and reflect the rate of subsidence or duration spent in the shallow-water environment. Jingū and the unnamed seamount are seamounts that spent little or no time in the subaerial or shallow-water environments. Yōmei represents a youthful to intermediate atoll stage (barrier reef stage of Darwin, 1842) with a volcanic island surrounded by a lagoon and fringing reefs. Nintoku Seamount and Seamount "B" also represent an intermediate atoll stage, but apparently did not develop lagoons, and existed as shallow-water carbonate banks or reef-flats that experienced relatively slow subsidence. Kōkō, Ōjin, Suiko and "northern Suiko" seamounts represent a mature atoll stage: all have well-developed lagoons, bank-interiors, and fringing reefs or carbonate banks, and experienced relatively slow subsidence.

INTRODUCTION

Seamounts in the southern and central Emperor Seamount chain have diverse geology, but an apparent simple vertical tectonic history. They range from sharp-pointed volcanic peaks to flat-topped guyots capped by carbonate buildups.[1] Most of the seamounts once stood above sea level as islands, and have since subsided to their present depth. The seamount morphology suggests a similar subsidence history for most seamounts along the chain. Geomorphic differences indicate, however, that rates of subsidence varied between seamounts. The development of seamount morphology is dependent on the interplay of the rate of subsidence and the rate of carbonate sedimentation, which is in large part a function of water temperature. Similar seamount morphology could result from slow subsidence in cool waters (i.e., slow carbonate sedimentation) or from more rapid subsidence in warm waters (i.e., rapid carbonate sedimentation). The main difference between the two would be in the total thickness of deposits accumulated in a

[1] *Carbonate buildup* is defined by Cook et al. (1972) "as a largely nongenetic term for any laterally restricted accumulation of carbonate sediment and/or carbonate skeletal framework that was deposited higher (at least on one side) than the level of adjacent sedimentation. It is used where more specific terms connoting the nature or origin of the accumulation are either unwarranted, unnecessary, or uncertain. The term is a general one."

given time. McKenzie, Bernoulli, and Schlanger (this volume) have shown that water temperatures during formation of the Emperor Seamounts were cooler during formation of Suiko Seamount (~65 m.y.B.P., Dalrymple, Lanphere, and Clague, this volume) and became progressively warmer until the formation of Kōkō Seamount (~48 m.y.B.P., Dalrymple, Lanphere, and Clague, this volume). This warming trend ended about 40 m.y. ago as Kammu Seamount formed in considerably cooler water than Kōkō Seamount. It is difficult to estimate the rate of carbonate sedimentation as a function of water temperature, so we have used the term *subsidence* to indicate the relative difference between true subsidence and carbonate buildup. Thus, the differing morphologies of the seamounts indicate differential subsidence along the chain. The varying thicknesses and types of sedimentary units capping the seamounts reflect differences of time that a seamount spent in a particular environment. For example, a small, sharp-peaked seamount surrounded by a narrow, wave-cut platform covered with a thin terrace deposit spent relatively little time in an emergent environment and rapidly subsided beneath wave-base. In contrast, a broad, flat-topped guyot with a thick, shallow-water carbonate cap probably remained in an emergent environment for a relatively long time and slowly subsided through wave-base. Warm water (greater than 25°C) favors development of the more productive Coral–Algal reef-building facies,[2] whereas cooler water (around 20°–22°C) favors the less productive Bryozoan–Algal facies (Schlanger and Konishi, 1975). Most major seamounts of the southern and central Emperor chain appear to have had a subaerial history, followed by wave planation, shallow-water carbonate bank sedimentation,[3] and carbonate deposition from the Bryozoan–Algal facies.

We have constructed geologic maps for nine seamounts (Kōkō, Ōjin, Jingū, Nintoku, Yōmei, Seamount "B," an unnamed seamount between Seamount "B" and Suiko, Suiko, and northern Suiko seamounts) of the southern and central Emperor chain. These maps are based principally on seismic stratigraphy developed from geophysical data collected during the pre-Leg 55 Site Survey (see Dalrymple, Greene, Ruppel, Bear, and Clague, this volume) and on geophysical and drill-hole data collected during DSDP Leg 55. Many of the seamounts have only one or two seismic profiles across them, but their morphology and symmetry allows for approximating lithologic boundaries in areas not covered by seismic reflection data. Thus, the geologic maps are generalized and speculative.

[2] *Reef.* "A reef in terms of ecologic principles is a product of the actively building and sediment binding, biotic constituents which, because of their potential wave-resistance have the ability to erect rigid, wave-resistant topographic structures." (Lowenstam, 1950).

[3] *Bank* follows the definition of Cook (1972) "for a deposit composed of skeletal or nonskeletal carbonate material that accumulated topographically higher than the adjacent seafloor, and in which reef growth in the sense of Lowenstam (1950) was essentially absent."

SEISMIC STRATIGRAPHY

Seismic stratigraphy for the Emperor Seamounts was interpreted from continuous seismic reflection data collected on several cruises in the vicinity of the seamounts. These data were collected mainly from Suiko Seamount in the north to Kōkō Guyot in the south, principally from latitude 45°N to latitude 35°N, and between longitude 170°E and 171°E (Figure 1). The profiles extend locally out across the flat ocean floor adjacent to the seamount chain. Therefore, the seismic stratigraphy discussed here covers both the deep ocean floor and the seamounts.

Acoustic characteristics used to describe stratigraphy are derived primarily from the interpretation of single-channel 160-kJ Sparker seismic reflection profiles collected by the U.S. Geological Survey's R/V *S. P. Lee* during the DSDP Leg 55 site survey of the Emperor Seamounts in 1976 (cruise LEE8-76-NP). These profiles are shown and discussed in detail by Dalrymple, Greene, Ruppel, Bear, and Clague (this volume). Ancillary acoustic criteria were obtained from air-gun seismic reflection data collected by the Hawaii Institute of Geo-

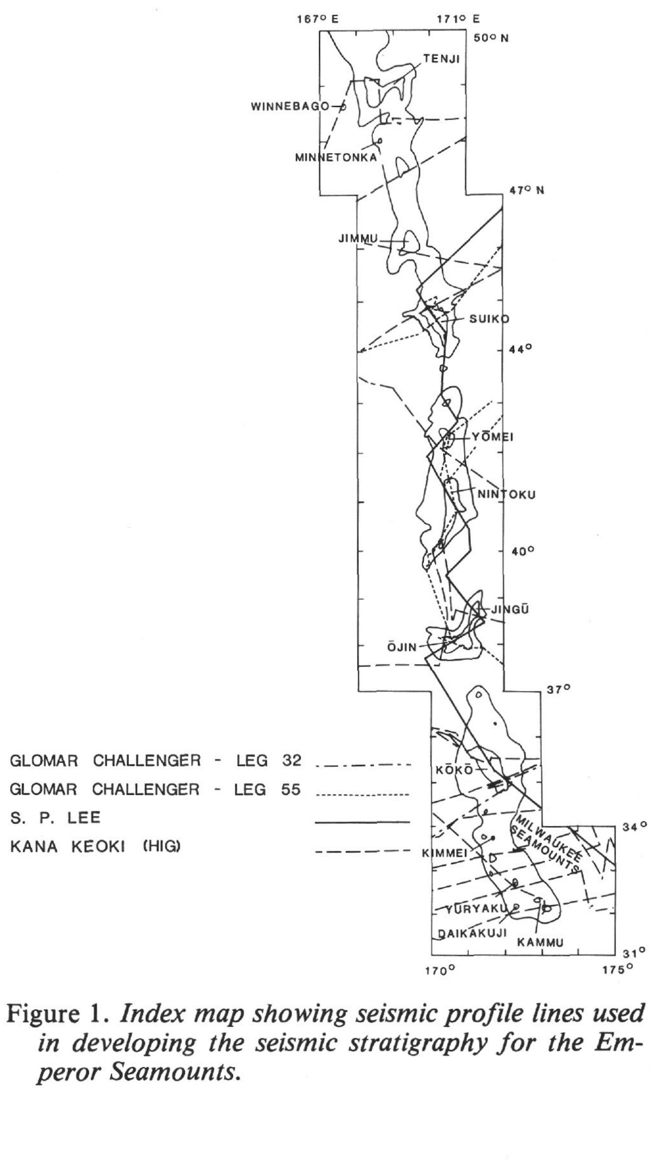


Figure 1. *Index map showing seismic profile lines used in developing the seismic stratigraphy for the Emperor Seamounts.*

physics' R/V *Kana Keoki* in 1977 (cruise KK770317-05) and from air-gun and 3.5-kHz seismic reflection records collected on the cruise of the *Glomar Challenger*.

Criteria used to distinguish geologic units in the seismic reflection profiles are based on seismic signal characteristics. These characteristics include the presence of consistently identifiable morphological, structural, and sedimentary features such as rounded mounds, truncated bedding or irregular acoustical surfaces (unconformities), sequences of prograded beds, cross-bedding, and parallel bedding. Line drawings are used to show the results of seismic interpretation of selected seismic profiles.

Strongly contrasting density, velocity, or structure between lithologic units within a stratigraphic section generally causes independent, distinct, acoustical signatures. Thus, igneous and metamorphic rocks or highly folded, well-lithified sedimentary rocks can be differentiated from well-bedded, consolidated to semi-consolidated sediments on the basis of characteristic seismic signatures. Correlation of such seismic units with rocks exposed on the sea floor and recovered from drill-holes leads to the development of a geological "seismic" stratigraphy that can be used to construct a geologic map.

Nine acoustic units have been identified in the seismic reflection profiles. Two of these units (acoustic basement and the acoustically transparent unit) are common to both the flat ocean floor and the seamounts. Three acoustic units are identified beneath the flat deep ocean floors: (1) acoustic basement, (2) a well-layered sedimentary unit, and (3) an acoustically transparent sedimentary unit. Eight acoustic units are identified on the seamounts: (1) acoustic basement, (2) shallow-water bank interior deposits, (3) reef or carbonate bank deposits, (4) terrace deposits, (5) shallow-water lagoonal sediment, (6) well-layered ponded sediment, (7) slumps and slope detritus, and (8) a transparent sedimentary unit. These units are discussed in detail in the following pages, starting with the stratigraphically lower or oldest(?) unit and ending with the highest or youngest unit.

Acoustic Characteristics

Flat, Deep Sea Floor

(1) Acoustic Basement (Tv, Figure 2)

Acoustic basement appears in the seismic profiles as a strong reflection containing many diffractions or hyperbolic reflections and beneath which no coherent reflectors are evident (Figure 2). The surface of the acoustic basement is commonly irregular, and is in unconformable contact with the overlying units. The acoustic basement correlates with volcanic rocks; these rocks are locally faulted and exposed on the peaks and flanks of seamounts that project above the sedimentary cover.

(2) Well-Layered Sedimentary Unit (Twb, Figure 2)

Unconformably overlying the irregular surface of the acoustic basement is a well-layered, strongly reflecting (high-amplitude) and rhythmically bedded unit characteristic of sedimentary rocks (Figure 2). This unit may be turbidites that grade away from the seamounts into well-consolidated and well-layered pelagic sedimentary deposits. Thickness of this unit is variable, and the maximum thickness (0.5 s) is generally found near the base of the seamounts. We interpret this unit to be the "opaque layer" described by Ewing et al. (1968). Also, the seismic reflection profiles collected along tracks across the deep ocean basins traversed by the *Glomar Challenger* in transit to and from the drill sites show this unit to be present beneath an acoustically transparent layer (Dalrymple et al., this volume). Locally, the unit is absent or is seen as an undisturbed pocket of sediment filling small basins in the acoustic basement. In other places the unit is disturbed or eroded and difficult to identify.

(3) Acoustically Transparent Sedimentary Unit (Tap, Figure 2)

Conformably or unconformably overlying the well-layered unit is an acoustically transparent unit that extends to the sea floor. This unit contains a few weak reflectors that are generally flat-lying when present (Figure 2). Seismic energy is only weakly reflected from the surface of this unit, and in some localities the surface is difficult to locate. We have interpreted this unit as pelagic sediment, and correlate it with the acoustically transparent unit described by Ewing et al. (1968). Thickness of the acoustically transparent unit is variable, ranging from 0.05 seconds to a maximum thickness of over 0.5 seconds on seismic reflection profiles we collected during transit to and from the drill sites (see Greene, this volume). The transit profiles of the *Glomar Challenger* to and from ports of call during Leg 55 show that this unit is present everywhere along our tracks and locally fills Holocene(?) structural basins.

Seamounts

(1) Acoustic Basement (Tv, Figure 3)

As with the acoustic basement beneath the flat, deep ocean floor, the acoustic basement of the Emperor Seamounts is characterized by strong reflections containing many diffractions or hyperbolic reflections beneath which no coherent reflectors occur (Figure 3). The surface of the acoustic basement of the seamounts varies from an undulating to a smooth, flat, or gently sloping surface. This surface is normally in unconformable contact with the overlying acoustic units. The acoustic basement reflection is from volcanic rocks that are essentially an upward extension of the volcanic rocks found beneath the flat, deep ocean floor.

(2) Shallow-Water Bank-Interior Deposits (Ts, Figure 4)

In many places on the Emperor Seamounts, the seismic reflection profiles show strong, parallel, flat-lying reflectors that directly overlie the acoustic basement. This unit occurs mainly within the interior of the seamounts (Figure 4), but can occur at or close to the margin of a seamount (Figure 2). It is often difficult to distinguish these reflectors from the volcanic rocks, especially where the seamount is shallow and the bubble pulse

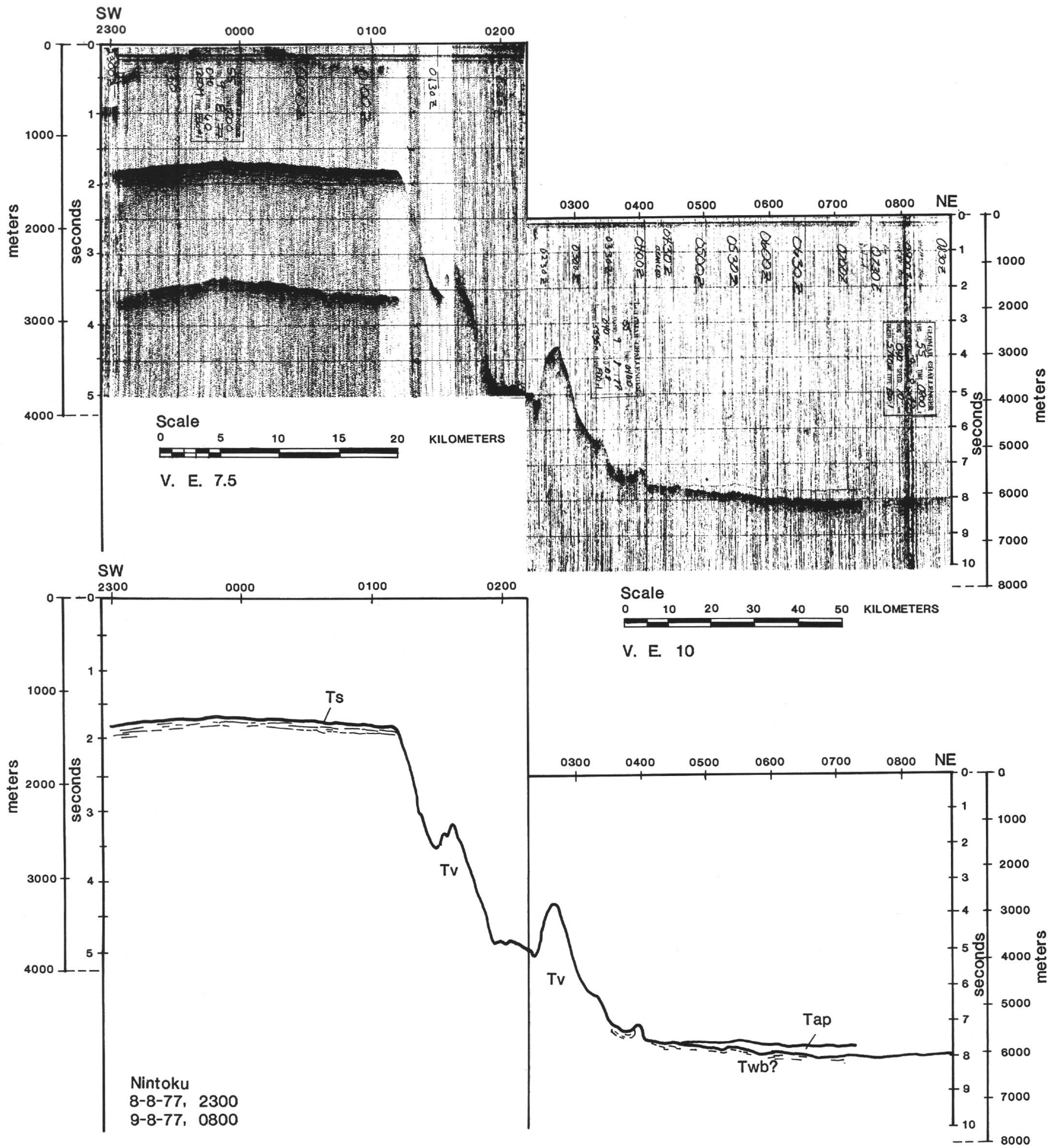


Figure 2. *Air-gun seismic reflection profile collected by the* Glomar Challenger, *showing the acoustic basement* (Tv), *well-layered sedimentary unit* (Twb), *and the acoustically transparent (pelagic) sedimentary unit* (Tap) *on the flat sea floor adjacent to Nintoku Seamount. Symbols defined in Figure 14 caption.*

interferes with legitimate reflections. However, we determined the existence of this unit from examination of seismic profiles across previously drilled Kōkō Guyot, which has a thick cover of layered sediment overlying a distinct volcanic surface (Figure 4). We interpret this unit to be a shallow-water carbonate bank deposit, principally on the basis of its laterally continuous, planar, well-layered nature and its stratigraphic and morphologic position (Figure 4). It is a layered unit suggestive of well-lithified sediment lying upon a flat to irregular,

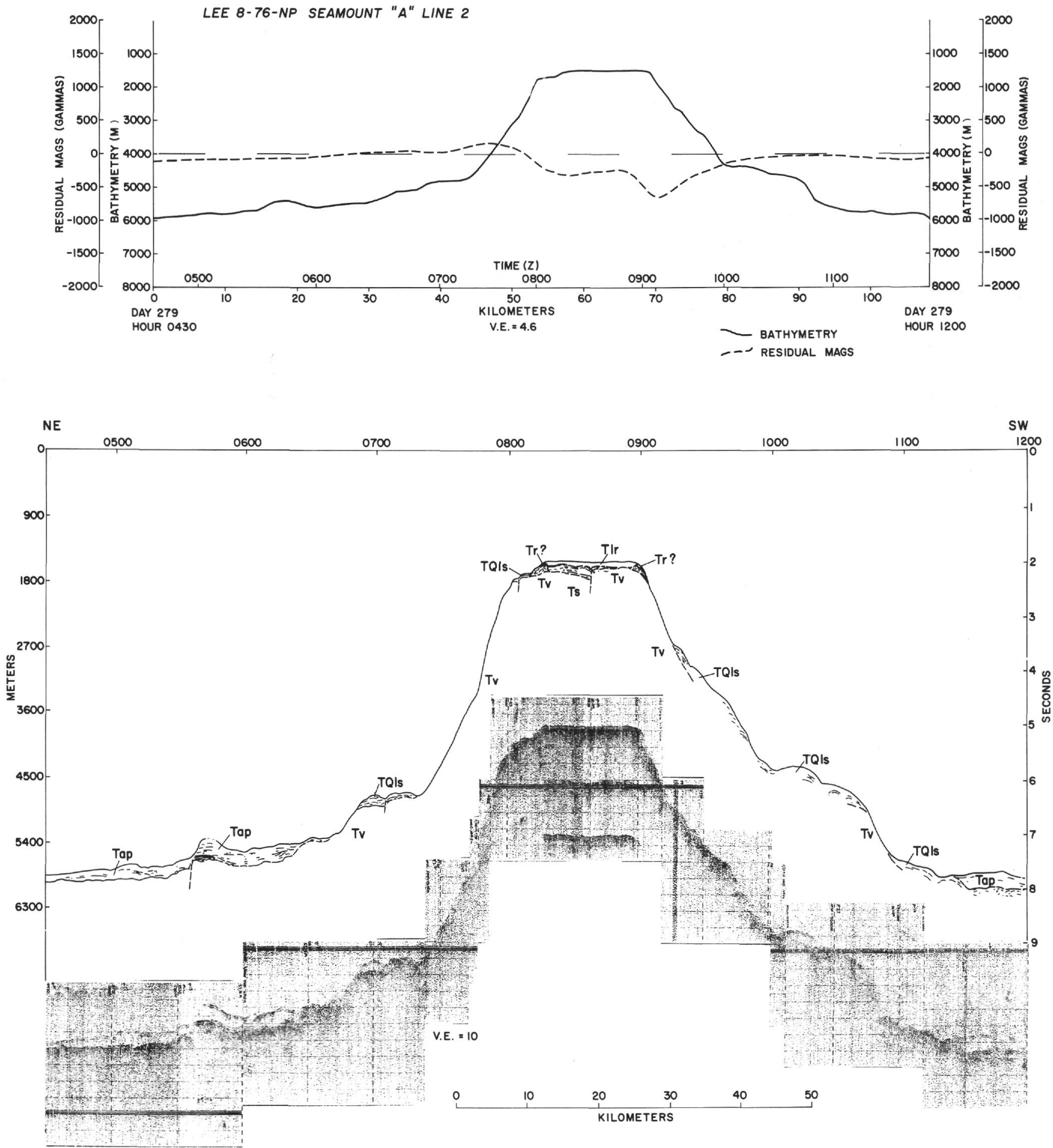


Figure 3. *Sparker seismic reflection profile across "northern Suiko" Seamount, collected aboard the* S.P. Lee. *Volcanic rocks are the acoustic basement. Symbols defined in Figure 14 caption.*

wave-cut volcanic platform. The unit is generally no more than 0.3 second thick, and occurs near the highest elevations of the seamount, sometimes laterally bounded by units interpreted to be fringing reefs or other more laterally restricted and topographically distinct shallow-water carbonate bank deposits (Figures 3 and 5).

Drilling on Kōkō Guyot by the *Glomar Challenger* (Leg 32, Sites 308 and 309, Larson and Moberly, et al., 1975) recovered coralline algae diagnostic of a coralline shallow-water reef-flat environment from this acoustic unit. This unit also correlates with limestone nodules and calcareous sand and silty mud found between 19 and 28.5 meters sub-bottom on Ōjin Seamount (Hole 430A) and with bank-like assemblages of carbonate sand and sandy mud, containing algal nodules and calcarenite, found at a depth of 52.5 to 163.5 meters on

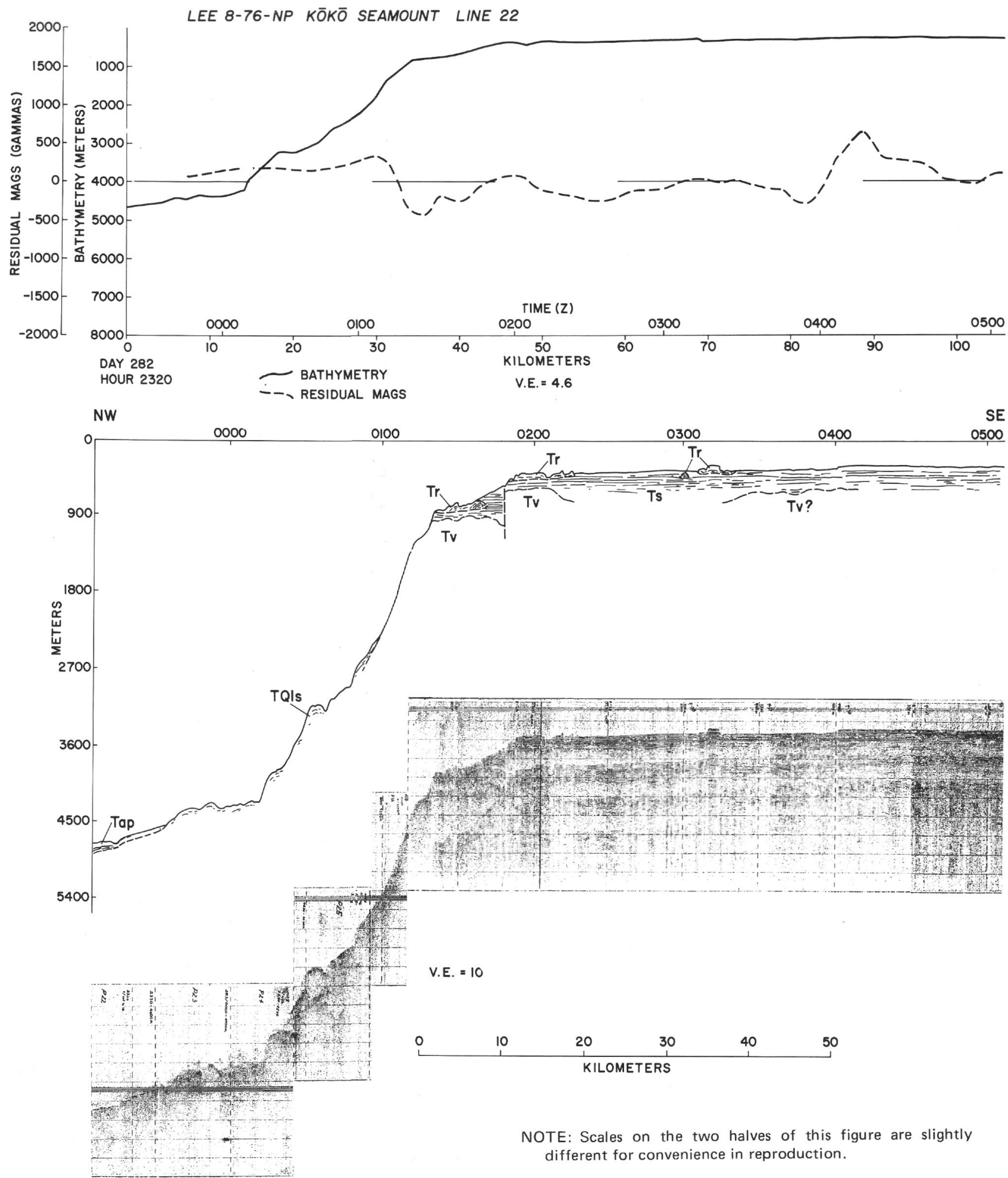


Figure 4. Lee *Sparker profile across Kōkō Guyot, showing well-layered shallow-water bank deposits. Symbols defined in Figure 14 caption.*

Suiko Seamount (Hole 433A). These rocks indicate typical shallow-water carbonate environments.

(3) Reef or Carbonate Banks (Tr, Figures 4, 5, and 6)

Reefs or carbonate banks are identified principally by geomorphology. These features are generally restricted to the fringes of the guyots, and consist of rounded to cone-shaped mounds or square-shaped topographic highs with botryoidal surfaces (Figures 4, 5, and 6). Acoustically, these reefs or banks are characterized by strong reflection surfaces (a high acoustic impedance contrast). They are often associated with hyperbolic and internally contorted to discontinuous reflections that result from either the irregular surface topography or

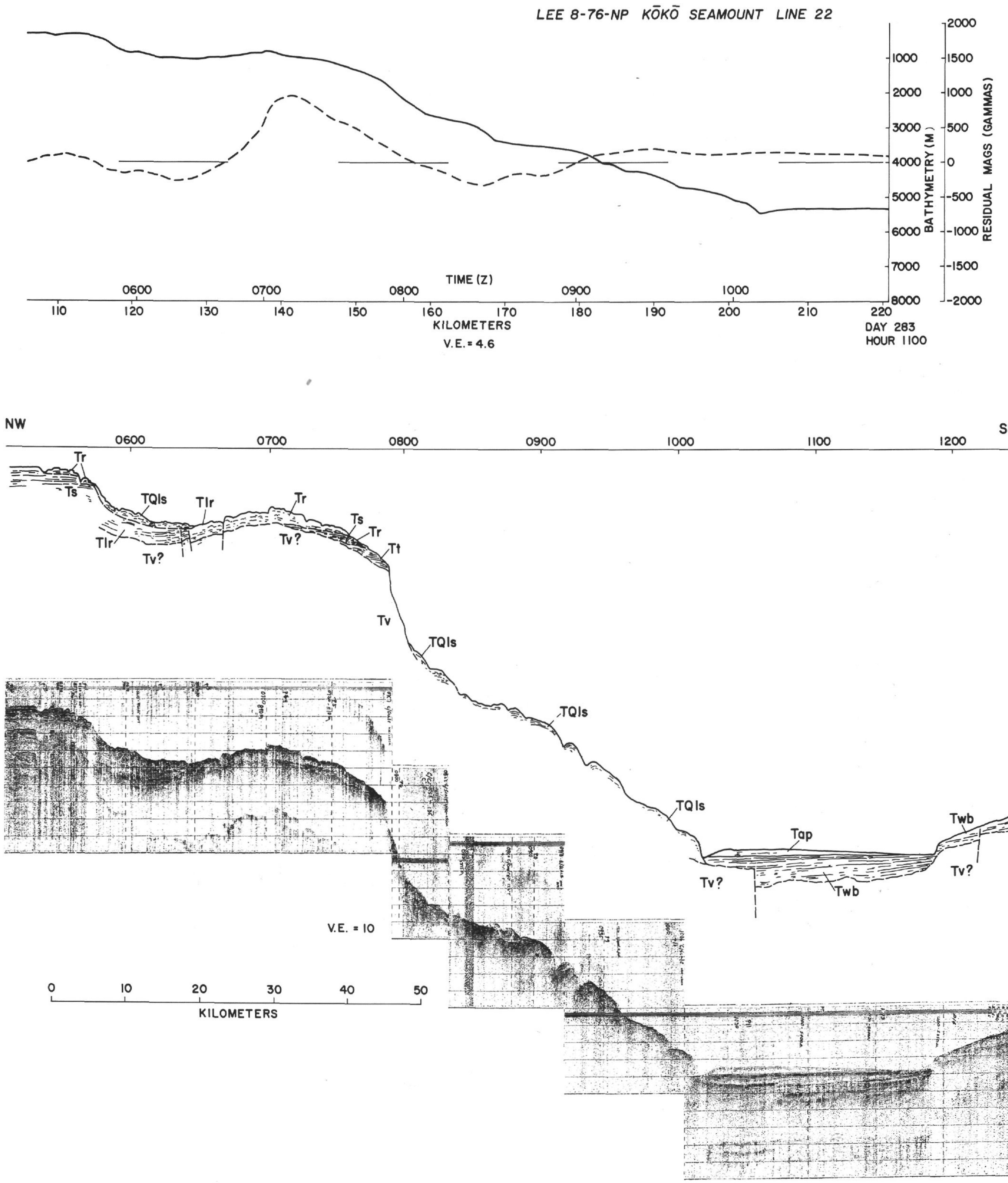


Figure 4. *(Continued)*.

the variable density and irregular internal structure. Poorly layered and discontinuous flat-lying reflectors often occur beneath the base of these features. The reefs or banks attain a maximum thickness of nearly 0.25 second. In some cases we cannot distinguish acoustically between volcanic knobs and the reef or bank structures. Several buried rounded mounds identified in the seismic reflection profiles may represent extinct reefs or banks that have been covered with sedimentary deposits (Figure 7). Davies et al. (1972) describe abundant lower Ter-

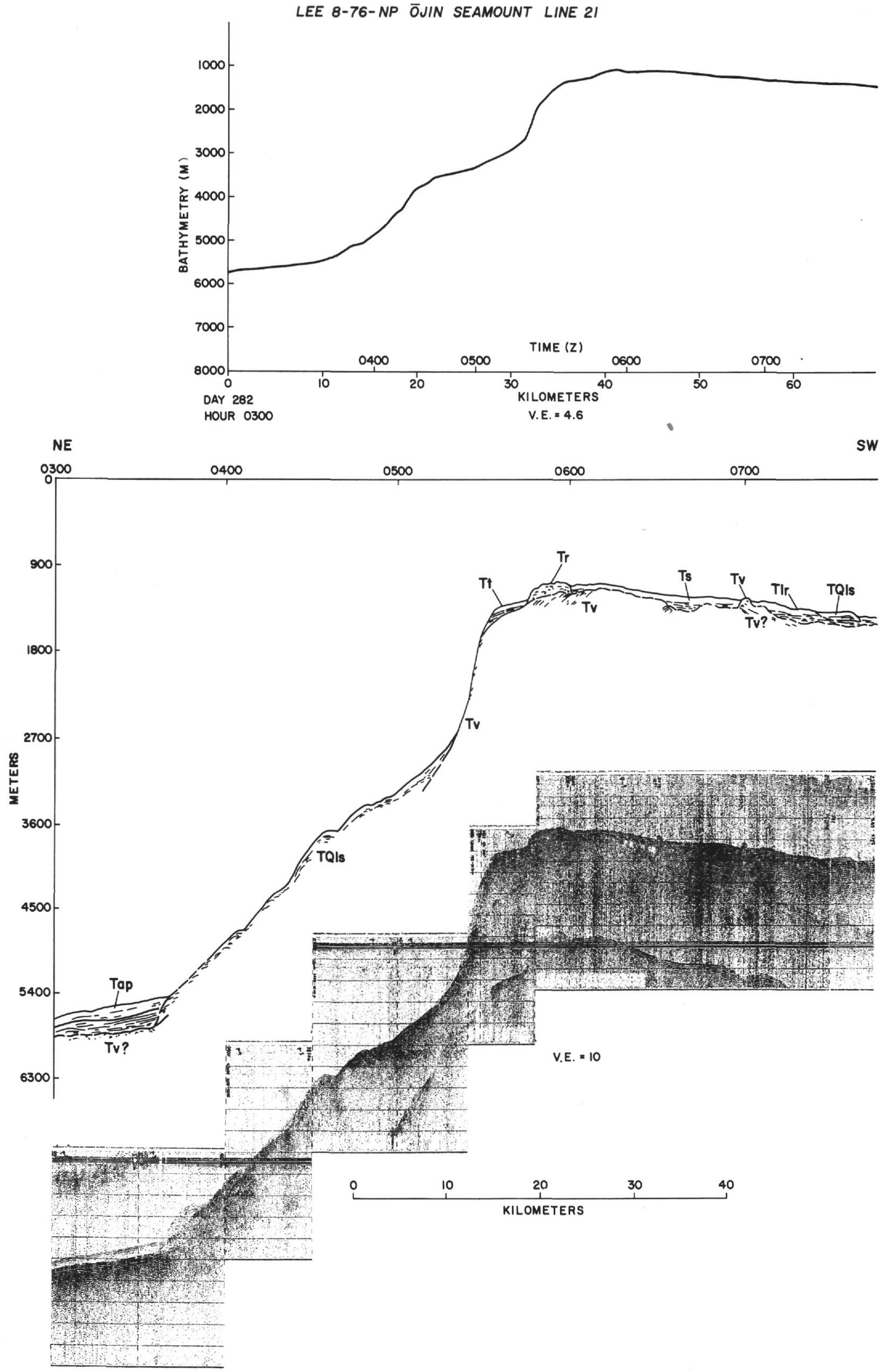


Figure 5. Lee *Sparker profile across Ōjin Seamount, showing reef or carbonate bank deposit. Symbols defined in Figure 14 caption.*

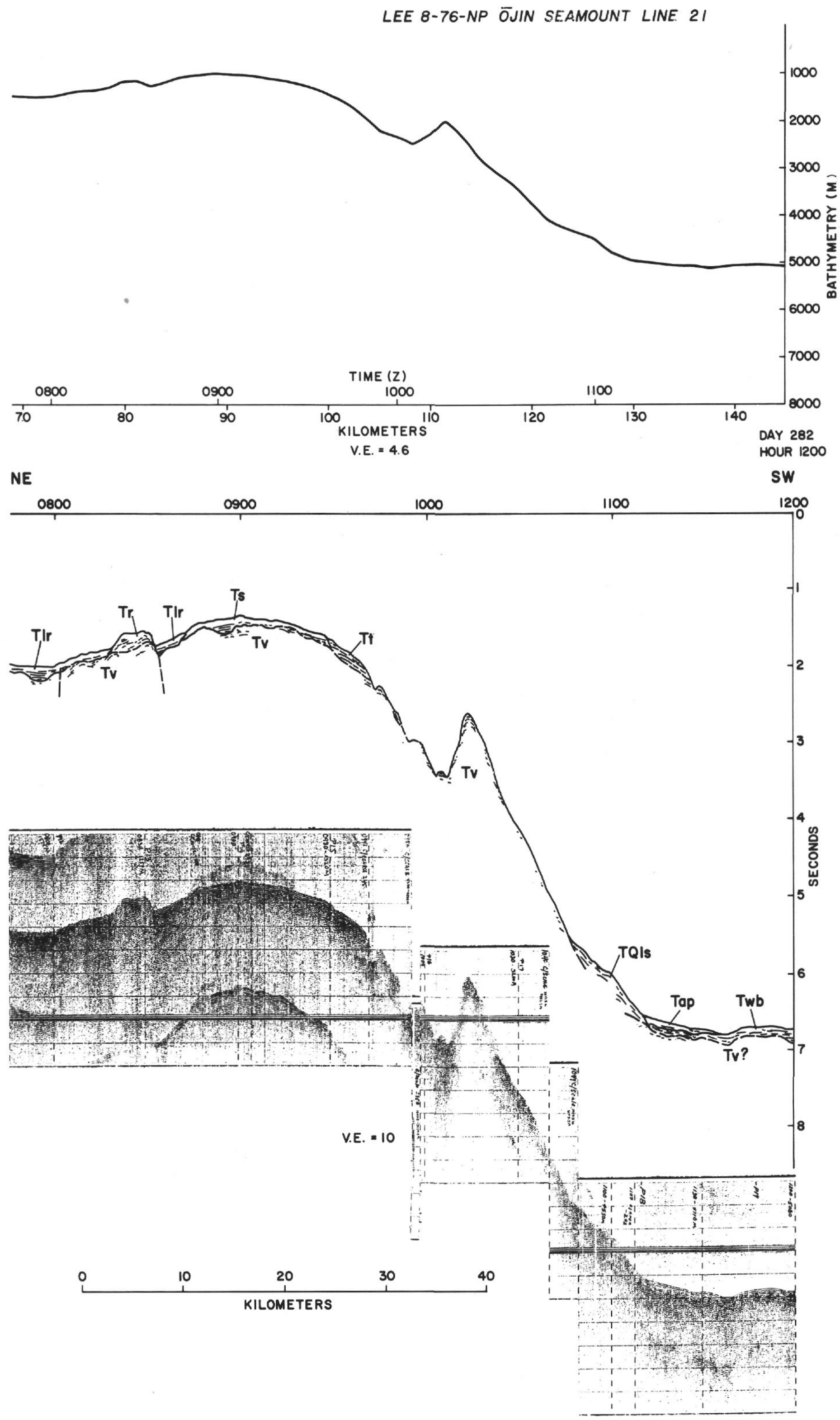


Figure 5. *(Continued).*

tiary hermatypic corals typical of a reef environment that were dredged from Kōkō Guyot.

No reef or bank was drilled on Leg 55, but at Site 433, drilling penetrated lagoonal deposits that were laid down near a seismically defined buried reef or carbonate bank. No coralgal or corralline material was recovered, so we assume that the nearby carbonate buildup is made up of a bryzoan-algal carbonate assemblage rath-

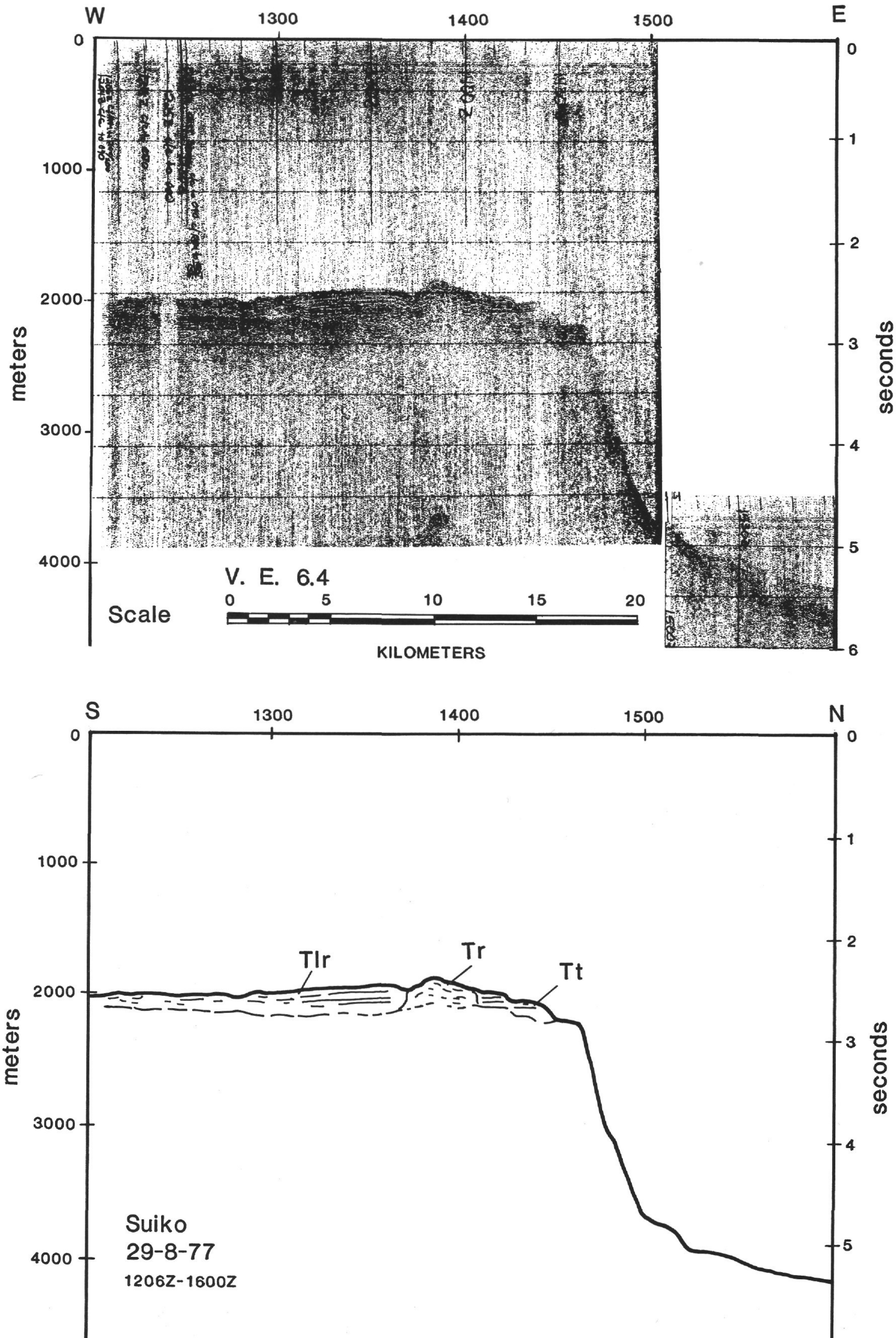


Figure 6. Glomar Challenger *air-gun profile across Suiko Seamount, showing reef or carbonate bank deposit. Symbols defined in Figure 14 caption.*

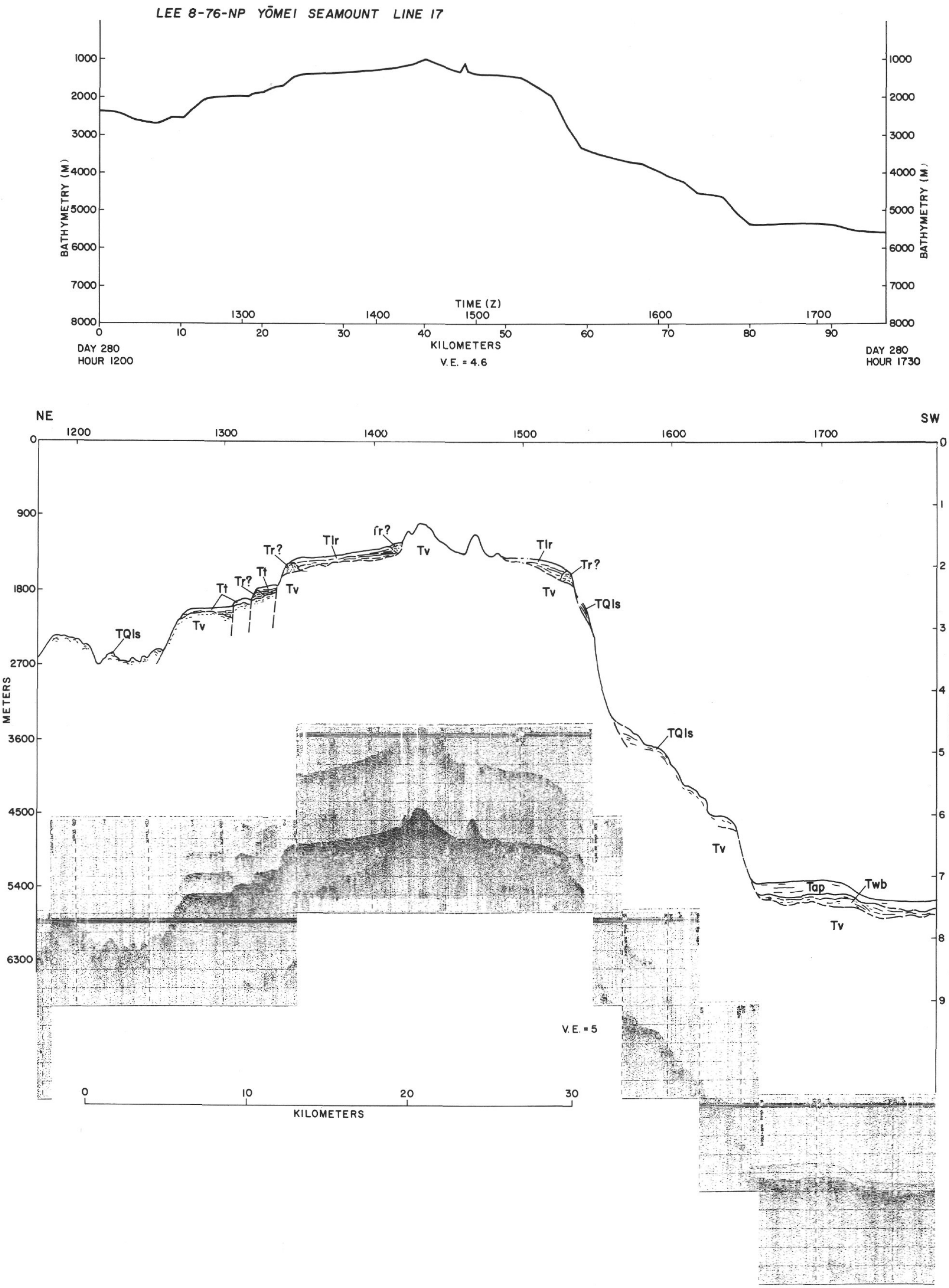


Figure 7. Lee *Sparker profile across Yōmei Seamount, showing buried reefs or banks and terrace deposits. Symbols defined in Figure 14 caption.*

er than a coral–algal assemblage (McKenzie, Bernoulli, and Schlanger, this volume).

(4) Terrace Deposits (Tt, Figure 7)

Many flat-lying to gently dipping, continuous, progradational acoustic reflectors found on the distal, upper surfaces of the seamounts are interpreted as depositional terrace deposits. These constructional features are situated primarily seaward of annular reef or bank deposits, and commonly have prograding sedimentary structure (Figure 3). Not all seamounts on the chain have fringing reefs or banks, and the terraces then slope gently away from a central reef, bank, or drowned volcanic island (Figure 7). Locally, these deposits, especially near their distal edges, range from 0.10 to nearly 0.30 seconds in thickness.

Terrace deposits, as identified from seismic reflection profiles, were drilled at Sites 431 and 432 on Yōmei and Nintoku Seamounts. At both sites sediment recovery was poor. However, a small amount of rounded pebbles, including some granitic in composition, and iron–manganese gravel, zeolitic sand, sponge spicules, and calcareous foraminifers recovered at Yōmei (Hole 431) suggest that the sedimentary unit is a marine terrace deposit covered with ice-rafted material and an iron–manganese pavement (see McKenzie, Bernoulli, and Schlanger and Karpoff, Peterschmitt, and Hoffert, this volume). On Nintoku (Site 432), conglomerate and sand from this unit contains bryozoans, gastropods, echinoid spines, calcareous algae, and serpulids. This assemblage suggests a shallow-marine skeletal biota indicative of a shallow-water carbonate environment and typical of proximal depositional terraces. The coarse-grained and conglomeratic sandstone layers penetrated in Hole 432 have lithologic and biogenic components that are partially graded, suggesting downslope transport of sediment; such grading is often characteristic of the basal part of marine terraces.

(5) Shallow-Water Lagoonal Sediment (Tlr, Figure 8)

We interpret acoustically well-layered (rhythmetically bedded) continuous to discontinuous reflectors, which vary locally from seismic opacity to transparency, to be shallow-water lagoonal sediment. These deposits are generally restricted to dish-shaped depressions bounded by laterally restricted features resembling carbonate reefs or banks, reef flats, or volcanic peaks (drowned islands). The flat-lying reflectors commonly lap onto the sides of the depressions to form buttress unconformities (Figure 8). These deposits occur only on the guyots, and generally are well developed only on the larger guyots with depressed centers, such as those found on Suiko and Ōjin Seamounts. The thickest unit filling a lagoon-like position on the Emperor Chain occurs on the north side of Suiko Seamount, where the deposits are nearly 0.75 second thick.

Lagoonal deposits identified from seismic reflection profiles were drilled on Ōjin (Site 43) and Suiko (Site 433) during DSDP Leg 55. On Ōjin Seamount, the drill of Hole 430A penetrated 47.5 meters of calcareous mud and sand containing benthic foraminifers, ostracodes, and calcareous algae typical of shallow-water shelf lagoon environments. On Suiko Seamount, Hole 433A penetrated 52.5 meters of pelagic oozes with a basal altered tuffaceous mud, and 113.5 meters of carbonate sand, sandy mud with algal nodules, and calcarenite. This calcareous sediment contains a biota composed of benthic foraminifers, coralline algae, bryozoans, and ostracodes typical of a warm shallow-water habitat (Butt, this volume).

(6) Ponded Sediment (Tps, Figure 9)

Ponded sediment on the Emperor Seamounts is generally characterized acoustically by well-layered continuous reflectors concentrated in basement or bedrock depressions along the seamount flanks or in saddles between seamounts. These deposits are the result of downslope transport of bank and/or reef and volcanic erosional detritus that is blocked from further downslope travel by topographic highs or depressions (Figure 9). Seismic reflection profiles collected across the Emperor Seamounts by the R/V *S.P. Lee* and the *Glomar Challenger* show localized ponded deposits on the lower flanks of Ōjin, Nintoku, and Suiko Seamounts. In places these deposits are nearly 0.5 second thick.

(7) Slumps and Slope Detritus (TQls, Figures 3 and 5)

The lower flanks of the seamounts in the Emperor chain commonly have extensive concentrations of sediment packages with irregular and distorted internal reflectors that we interpret to be slump materials and slope detritus (Payton, 1977). Acoustically these deposits are locally transparent to opaque, and consist of many hyperbolic reflectors caused by hummocky topography (Figures 3 and 5). We believe these deposits are the result of rapid downslope transport of eroded carbonate and volcanic detritus that accumulated along the outer edge of the seamounts' tops. Although the base of the slumps are not well defined, it appears that these deposits are over 0.5 second thick at the base of most of the seamounts. On Suiko and Ōjin Seamounts, rotated slump blocks are present in the interior parts of the carbonate buildup where carbonate sediment accumulated on a gently sloping surface (Figure 5). These mass transport features generally range from 0.1 second to nearly 0.35 second in thickness.

(8) Acoustically Transparent Sedimentary Unit (Tap, Figure 10)

Localized acoustically transparent units are present in depressions on the tops and flanks of the Emperor Seamounts (Figure 10). Few or no internal reflectors occur within this unit, and often the upper surface, which is the sea floor, is non-distinguishable. On Suiko Seamount, the graben basin in which Hole 433 was drilled contains an upper cover of acoustically transparent sediments identified in the *Lee* 3.5-kHz profiles. However, 3.5-kHz seismic reflection profiles collected at 2 to 3 knots by the *Glomar Challenger* on Leg 55 show this upper cover to have many strong and repetitively bedded reflectors (Figures 11, 12, and 13). Drilling of this unit disclosed non-stratified pelagic ooze. Similar seismic characteristics are described by Mullins et al. (1978). Drilling rates varied during penetration of this unit, indicating either a difference in compaction or diagenesis that was disturbed by drilling and thus not visually observed in the core.

GEOLOGY AND VERTICAL TECTONIC HISTORY

Except for two seamounts (Yōmei and the unnamed seamount between Seamount "B" and Suiko), the seamounts we mapped appear to be drowned atolls that have undergone complete wave planation (Plate 1, in pocket). The guyots remained in a shallow-water environment long enough to form carbonate banks and reefs, and locally to accumulate hundreds of meters of other types of shallow-water carbonate material (McKenzie, Bernoulli, and Schlanger, this volume). In the seismic reflection profiles, we can identify distinct atoll morphologic features, such as seaward (marginal) reefs or carbonate banks, bank interior flats, depressed lagoon-like features, islands, interior, laterally restricted carbonate bank and/or reef buildups, carbonate knolls, and patch reefs. Drilling results of Leg 55 shows the presence of shallow-water carbonate sediment on four of the Emperor Seamounts: Ōjin, Yōmei, Nintoku, and Suiko. Therefore, our geologic maps show the guyots of the southern chain to be atolls. These atolls differ in shape and maturity. The diversification in morphology represents different atoll-building stages, influenced by vertical tectonics. In the following section, we discuss the geology of the seamounts and the influence of vertical tectonics on the development of stratigraphy and morphology.

Kōkō Guyot

Kōkō Guyot is a large, very flat-topped seamount with a thick, well-bedded shallow-water carbonate cap (Larson, Moberly, et al., 1975; Dalrymple, Greene, Ruppel, Bear, and Clague, this volume). The flat top of the seamount covers an area of over 5800 km^2, and is elongated northwest–southeast (Plate 1 of Clague et al., in pocket). This edifice most certainly comprises several volcanoes, but we are unable to distinguish any independent volcanoes in the subsurface, because erosion of the volcanic rocks apparently has been so complete and the carbonate cap is too thick (Figure 4). Seismic reflection profiles do show an irregular acoustic basement surface that domes upward at the southeastern edge of the guyot, which is probably a remnant volcanic center. This dome is capped with well-developed reef or dissected carbonate bank sediment that acts as a southwestern buttress to thick, well-layered lagoonal deposits. The reef and/or bank and lagoonal deposits are faulted, suggesting that tectonic activity continued during or after deposition of the carbonates.

Kōkō Guyot, as shown on the geologic map, was an extensive, mature carbonate bank or atoll (Figure 14). It was a relatively broad linear carbonate buildup with a nearly circular lagoon and fringing reefs or banks restricted to its southeastern edge. The more interior parts of the buildup covered an area of about 5200 km^2, and contained many patch reefs and/or laterally restricted banks or knolls. The lagoon and its associated surrounding discontinuous fringing carbonate reefs and/or banks occupied an area over 650 km^2. Depositional terraces are developed nearby, probably all around the guyot, but are absent along the northern edge.

Sites 308 and 309 of DSDP Leg 32 are on Kōkō Guyot. At Site 308, the *Glomar Challenger* drilled into an altered volcanic silt and biogenic volcanic sandstone indicative of shallow water. The presence of bryozoans, coral, and oöliths suggests a warm-water carbonate environment (Larson, Moberly, et al., 1975). At Site 309, a small amount of unconsolidated foraminifer-bearing biogenic carbonate sand was recovered. The presence of coral and mollusk fragments also suggests a warm-water carbonate environment.

The thick bank interior deposits (200 m or more thick), thick lagoonal deposits (200 m or more thick), and thick fringing reef and/or bank features (nearly 150 m thick), suggest that Kōkō Guyot remained in warm, shallow-water environments for some time, perhaps longer than any of the other seamounts within the southern Emperor chain. Alternatively, its development may have occurred in warmer waters where carbonate sedimentation was quite rapid. Before extensive carbonate sedimentation, complete wave planation of the volcanic surface took place. Gradual subsidence through wave-base allowed for the steady accumulation of carbonate sediment within the interior of the carbonate buildup, with a major lagoon forming in a structural depression near the southeastern edge of the bank. This lagoon and the fringing banks and reefs formed Kōkō atoll. Continued wave attack on Kōkō atoll and bank developed carbonate detritus that formed the broad, extensive terrace deposit or fore-reef talus that nearly surround the guyot.

Kōkō appears to have remained in a near-emergent environment long enough for complete wave planation and thick shallow-water carbonates to accumulate. It subsided through wave-base at a rate that allowed carbonate deposition to keep up with subsidence.

Once carbonate sedimentation ceased, the seamount slipped rapidly below wave-base: most of the original carbonate relief appears to be unmodified by erosion. The top of Kōkō Guyot lies at a depth of 337 meters, and did not tilt during its descent, as indicated by the marginal or seaward reef or carbonate bank deposits, on the north and south sides, which lie at equal depths of 785 meters.

Ōjin Seamount

Ōjin Seamount is a flat-topped, east–west elongated guyot capped with shallow-water carbonates and terrace deposits (Clague, Dalrymple, Greene, Wald, Kono, and Kroenke, this volume). Its flat top covers an area of approximately 2000 km^2 (Plate 1 of Clague, et al., in pocket). Seismic reflection profiles indicate that this guyot consists of at least two well-eroded volcanic cones, one on the east and one on the west, overlain by thin-bedded shallow-water carbonate buildup (Figure 5). The volcanoes of Ōjin were eroded nearly flat by wave planation, as indicated by the relatively flat yet gently undul-

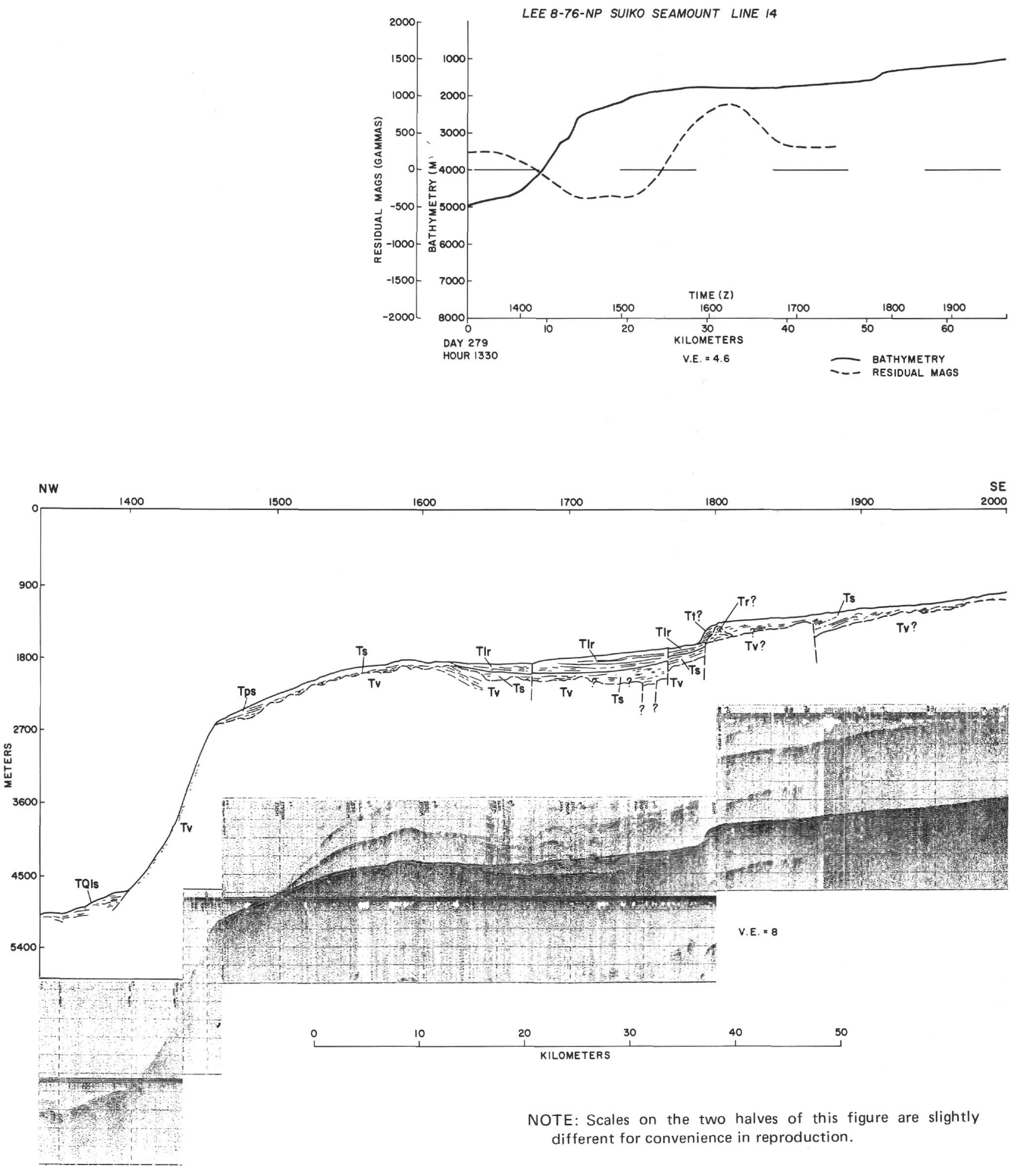
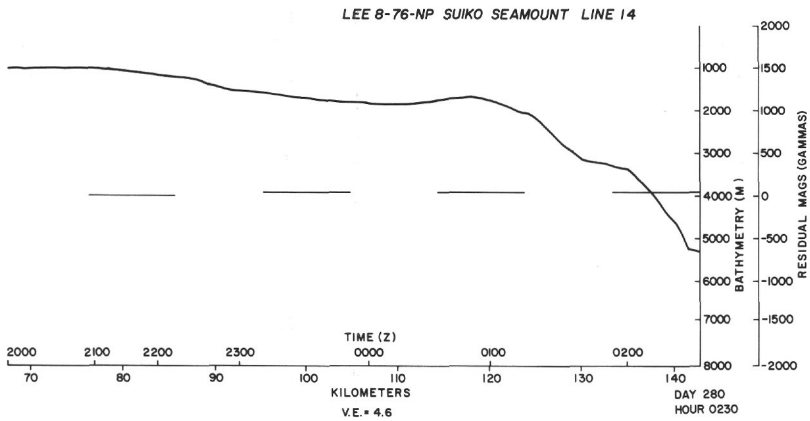


Figure 8. Lee *Sparker air-gun profile across Suiko Seamount, showing lagoonal sediment. Symbols defined in Figure 14 caption.*



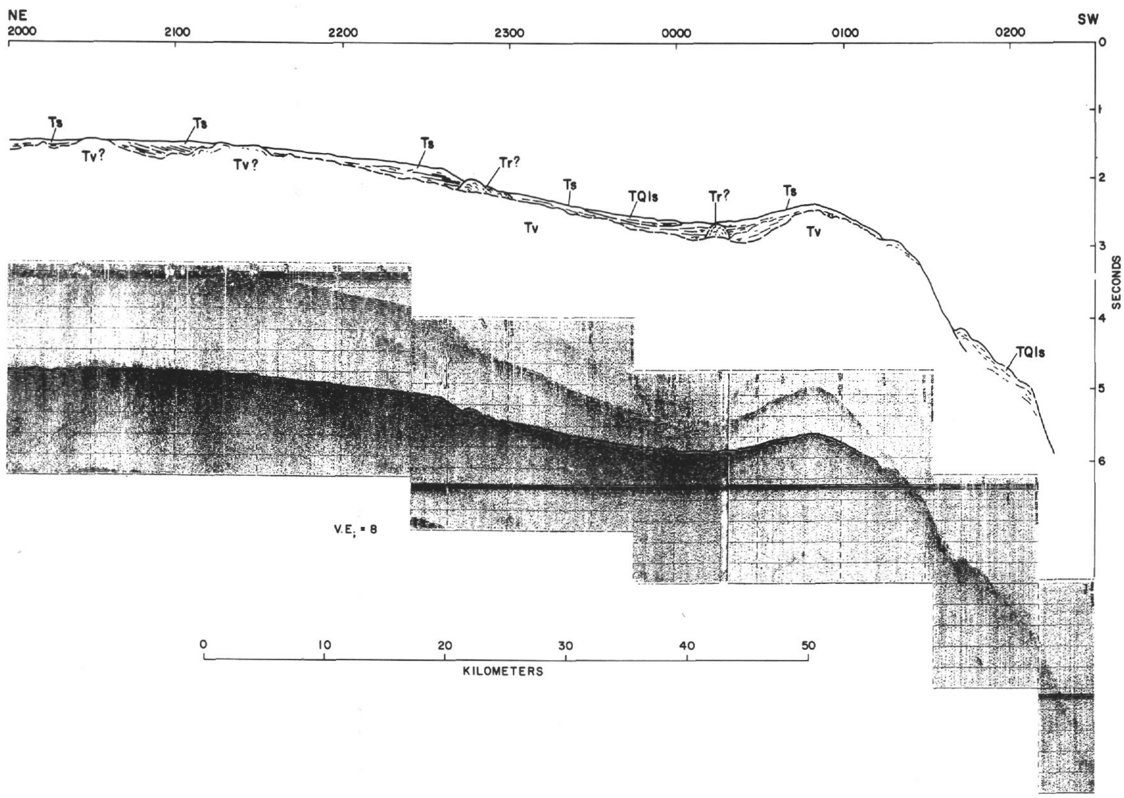


Figure 8. *(Continued).*

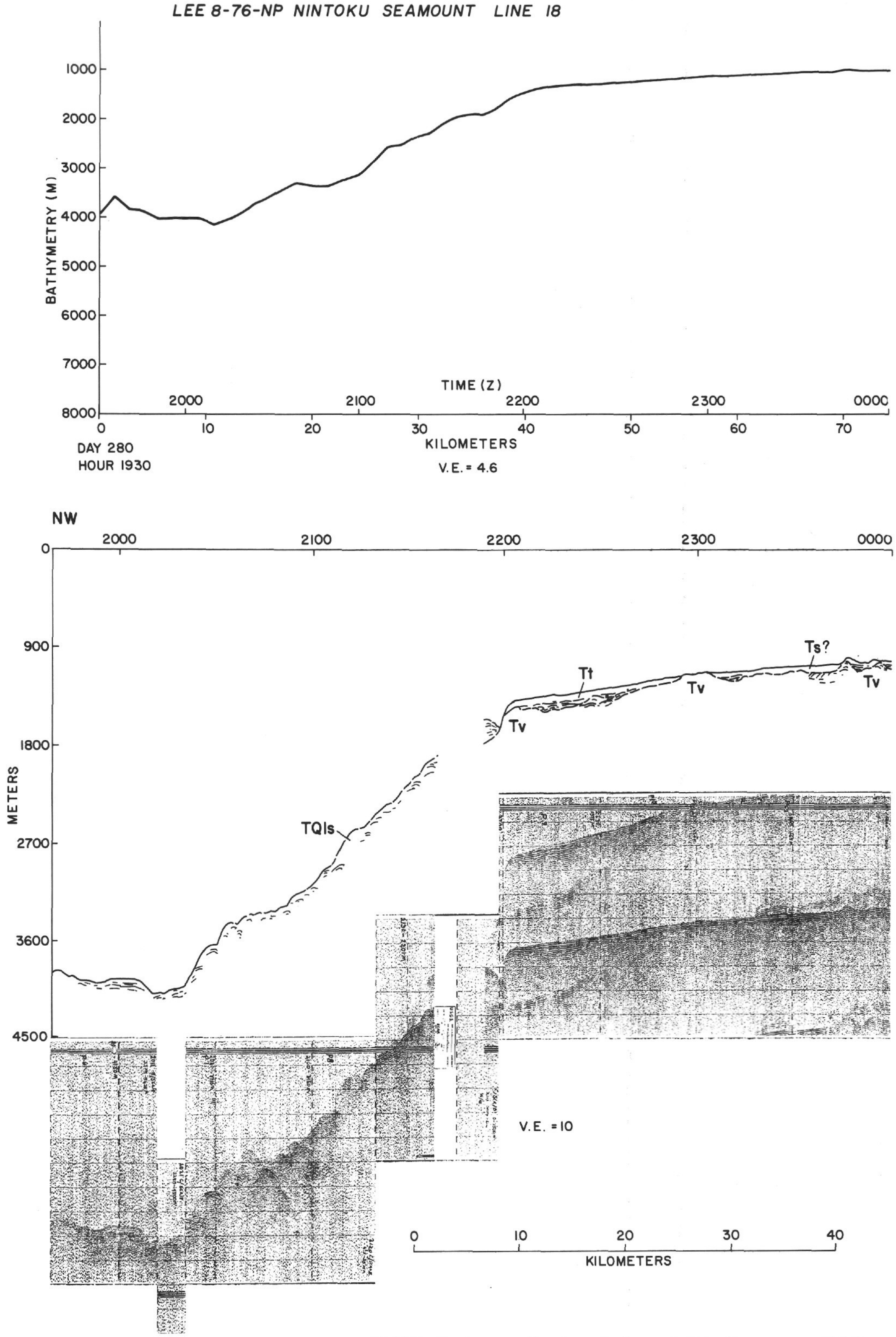
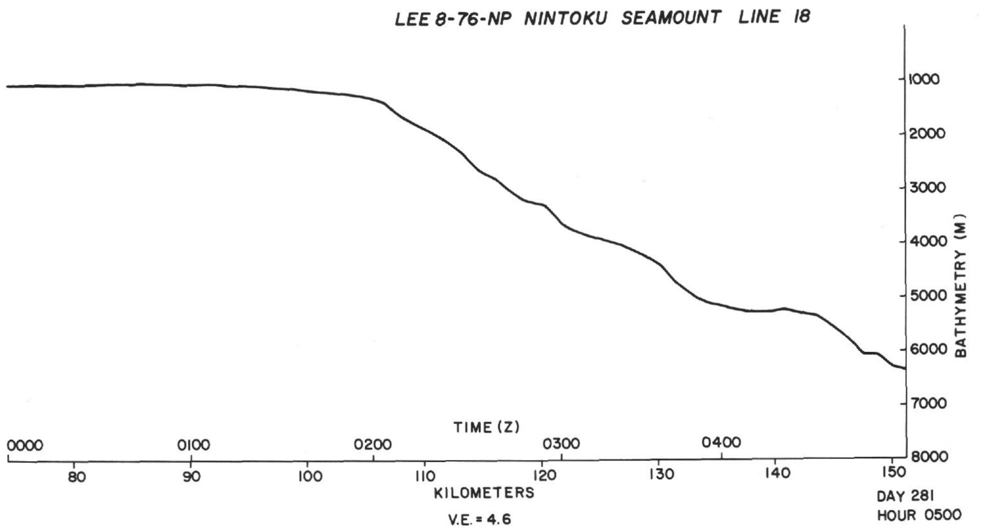


Figure 9. Lee *Sparker profile across Nintoku Seamount, showing ponded sediment. Symbols are defined in Figure 14 caption.*



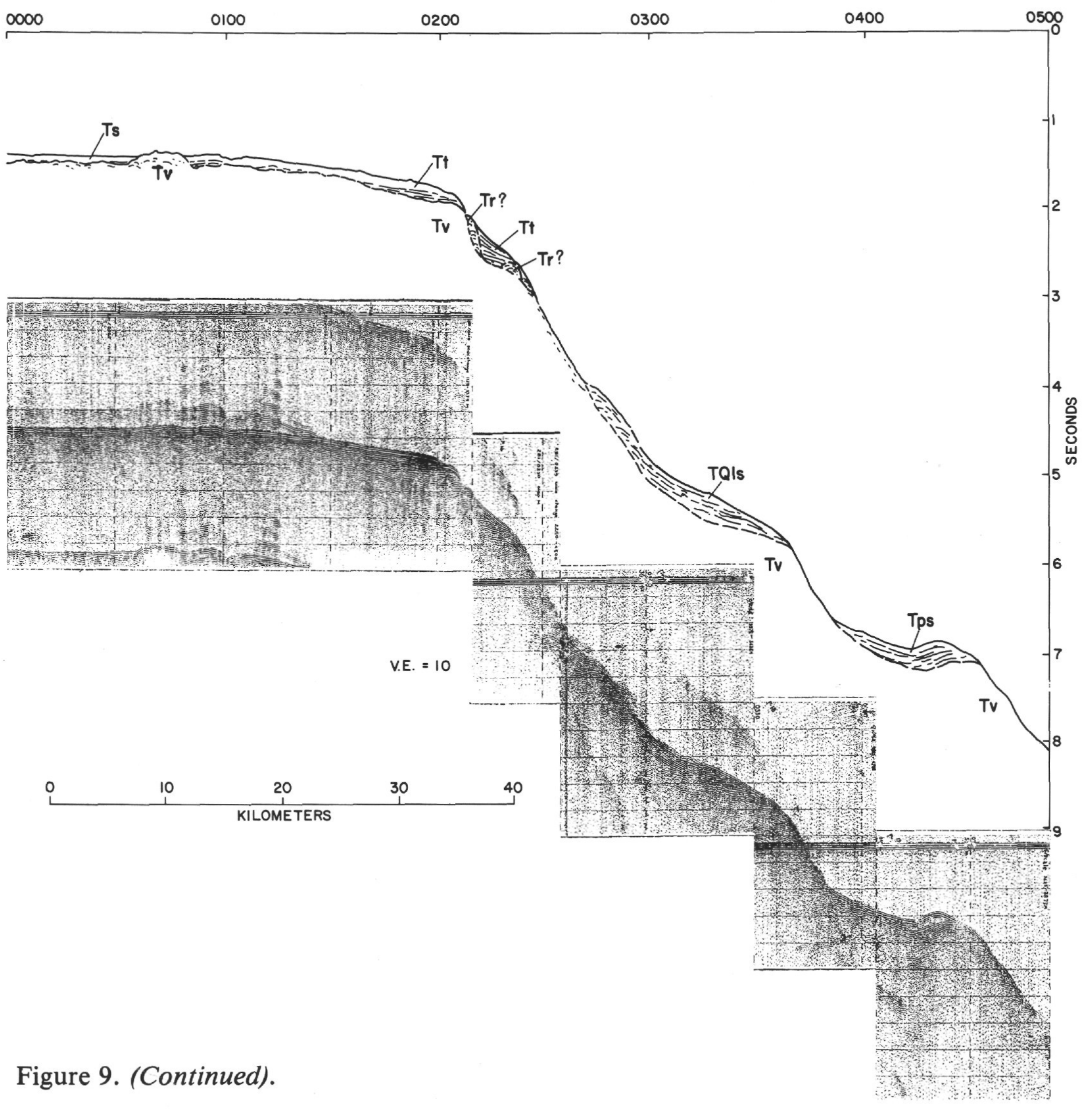


Figure 9. *(Continued).*

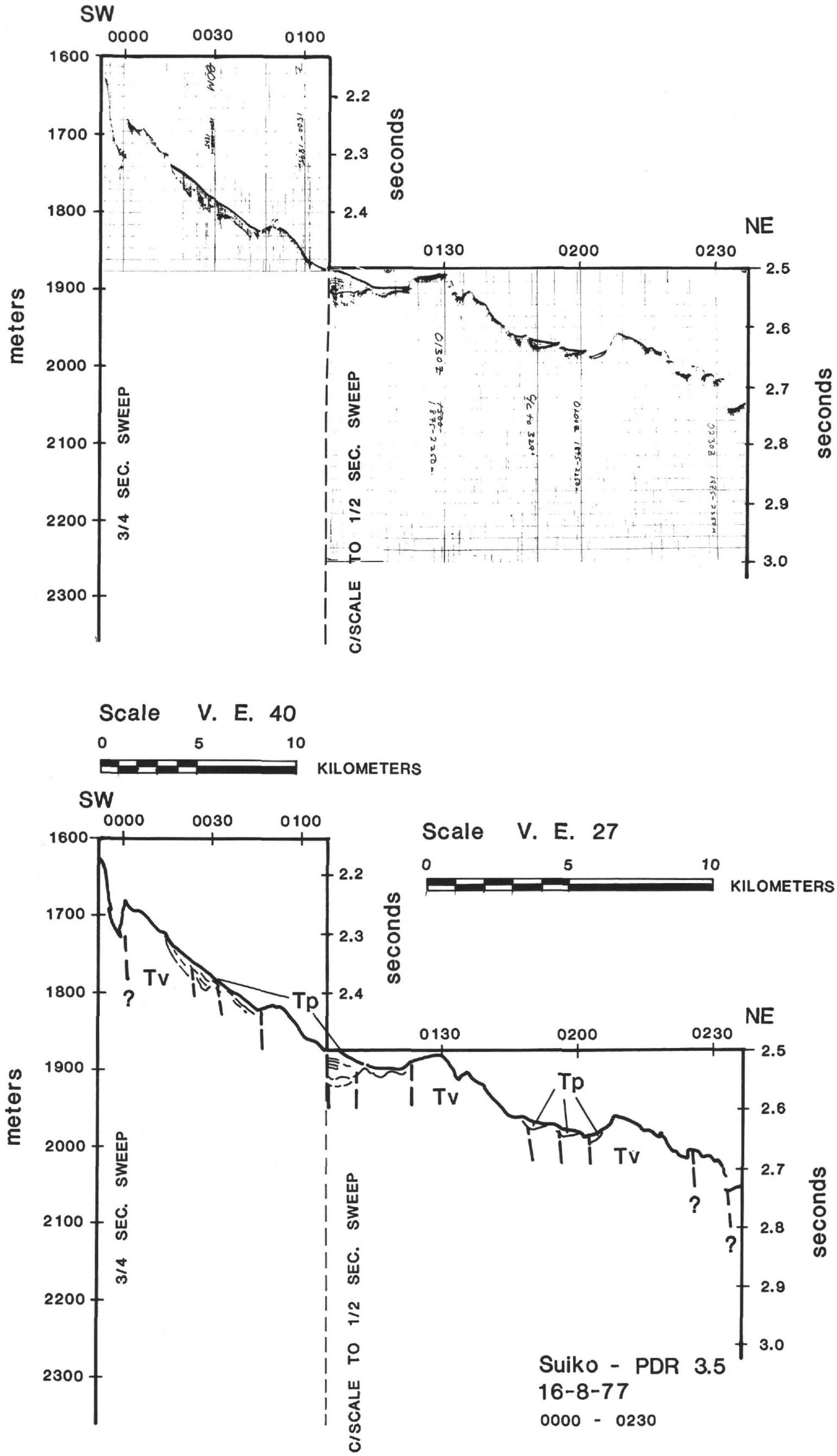


Figure 10. Glomar Challenger *3.5-kHz profile across Site 433 on Suiko Seamount, showing "bedded" pelagic sediment. Symbols are defined in Figure 14 caption.*

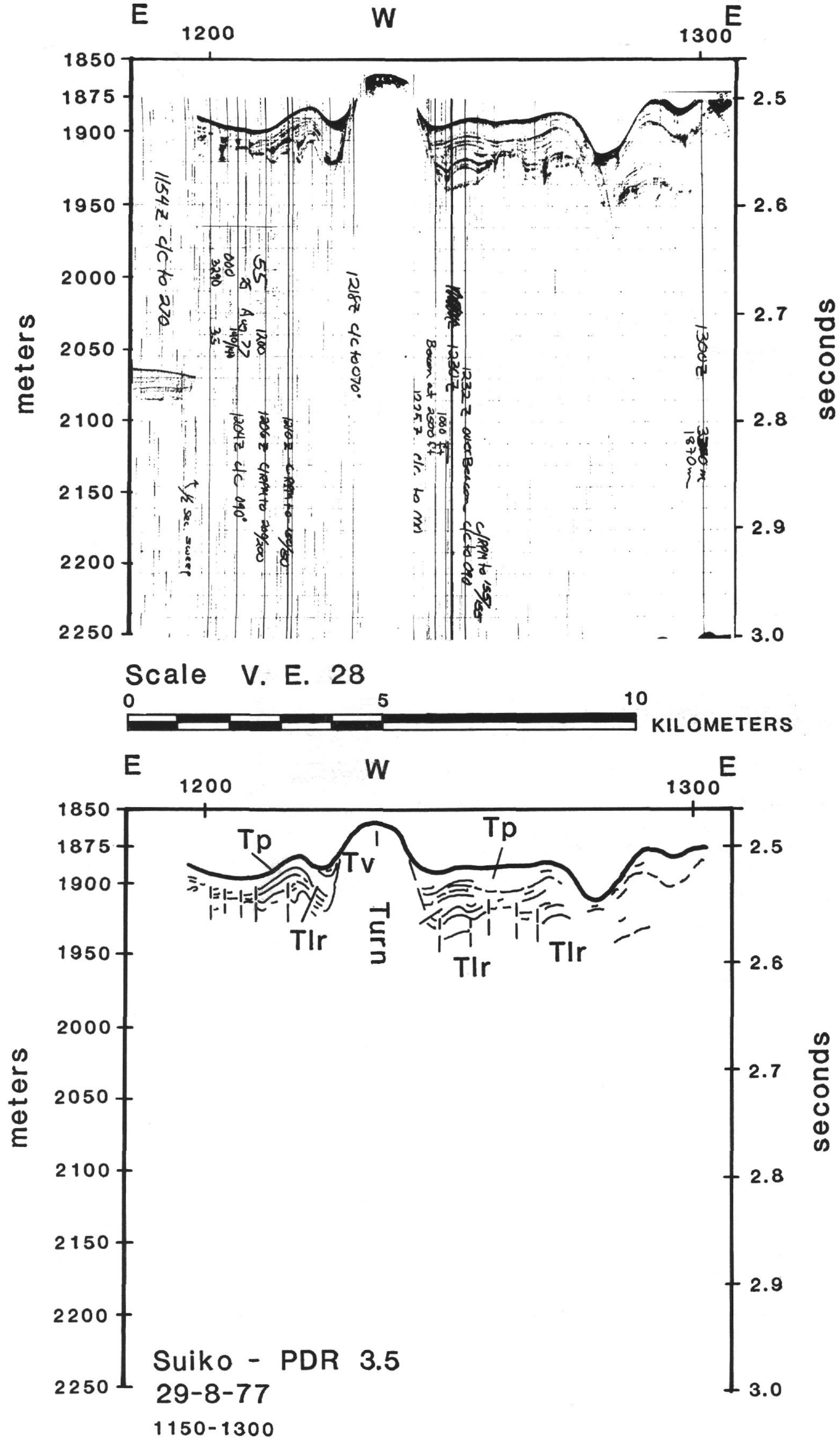


Figure 11. Glomar Challenger *3.5-kHz profile across Suiko Seamount, showing ponded pelagic sediment. Symbols are defined in Figure 14 caption.*

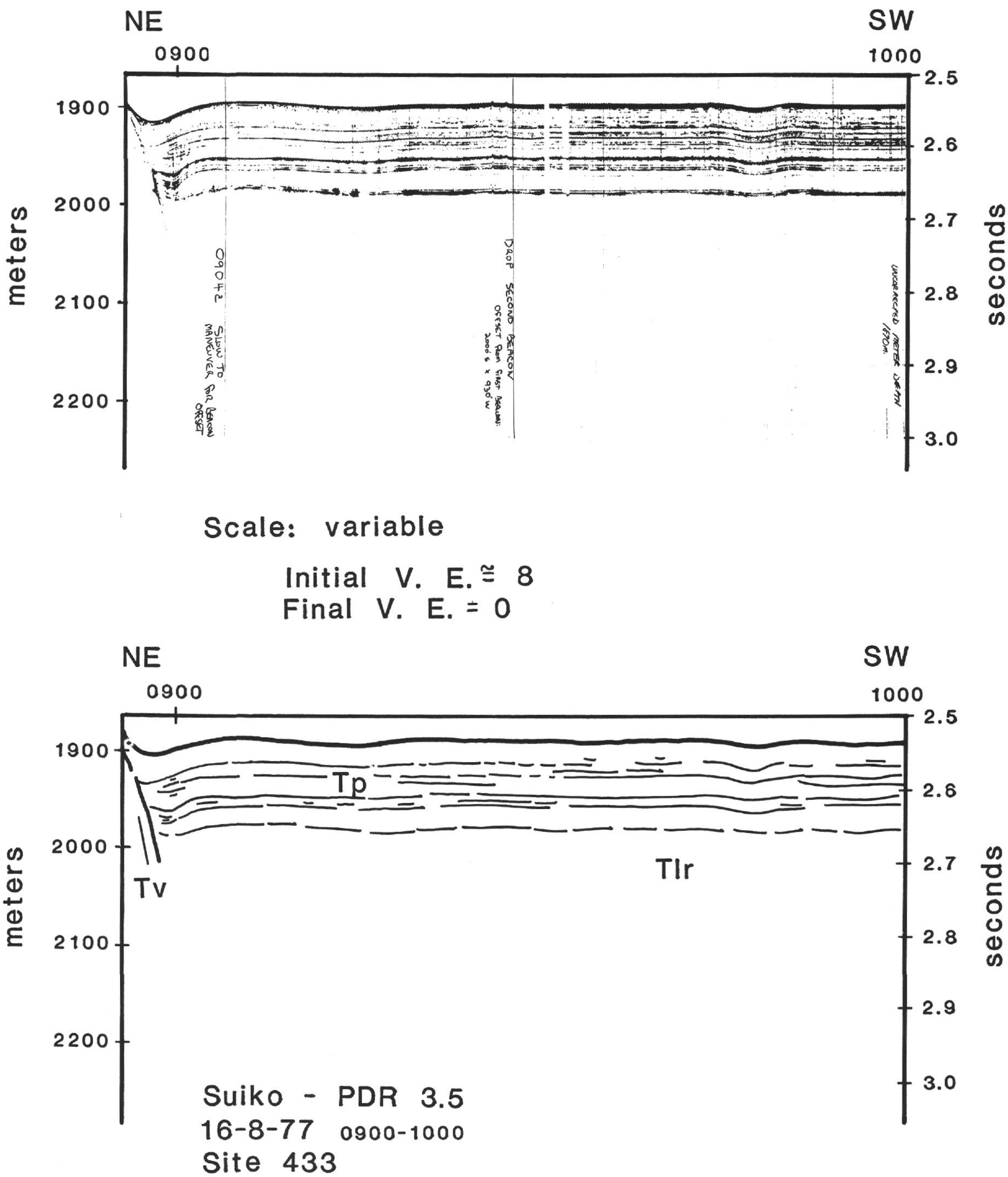


Figure 12. Glomar Challenger *3.5-kHz profile across Suiko Seamount, showing ponded pelagic sediment. Symbols are defined in Figure 14 caption.*

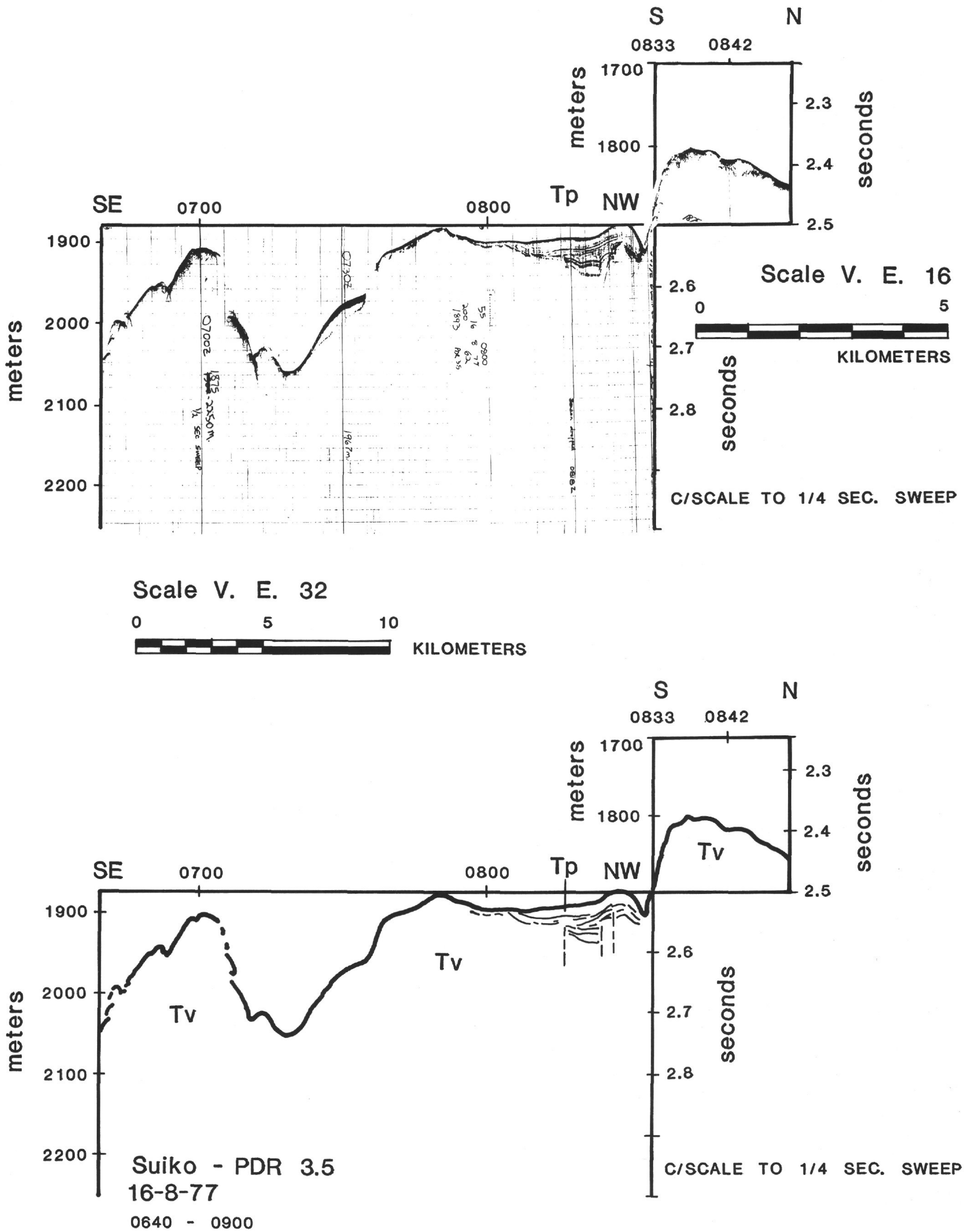


Figure 13. Glomar Challenger *3.5-kHz profile across Suiko Seamount, showing pelagic sediment. Symbols are defined in Figure 14 caption.*

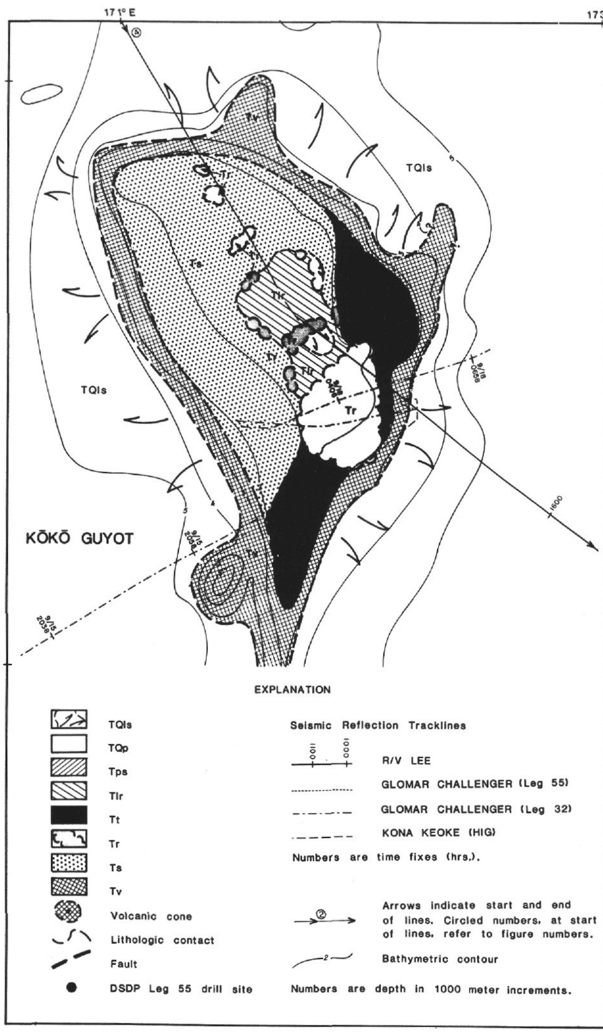


Figure 14. *Idealized geologic map of Kōkō Guyot.* Tv, *Tertiary volcanics (acoustic basement);* Twb, *Tertiary well-layered sedimentary unit;* Ts, *Tertiary shallow-water bank interior deposits;* Tr, *Tertiary reef or carbonate bank deposit;* Tt, *Tertiary marine terrace deposit;* T/r, *Tertiary shallow-water lagoonal sediments;* Tps, *Tertiary ponded sediment;* Tap, *Tertiary pelagic sediment (acoustically transparent layer);* TQls, *Tertiary and Quaternary slumps and slope detritus.*

ating surface of the acoustic basement (see Dalrymple, Greene, Ruppel, Bear, and Clague, this volume). In a depression between the two volcanoes, eroded detritus from the volcanic rocks and later carbonate detritus and shallow-water carbonate sediment accumulated to a thickness of 235 meters.

Ōjin Seamount, before its subsidence below wave-base, was in a mature atoll stage. It was a linear atoll with broad, expansive flats, fringing reefs or carbonate banks, and a central lagoon (Figure 15). The interior flats were separated by the central lagoon and its fringing reefs. On the eastern side of the guyot, a buildup interior covered an area of over 650 km², and was

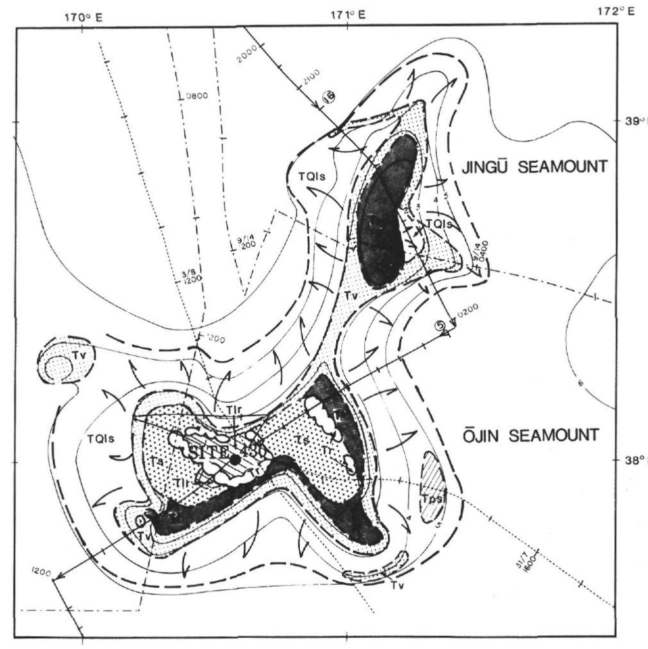


Figure 15. *Idealized geologic map of Ōjin and Jingū seamounts. Symbols are defined in Figure 14 caption.*

bounded on the east by patchy seaward reefs or carbonate banks. The buildup interior on the east side of Ōjin covered an area of over 550 km². The central lagoon extended over an area of 3.5 km² and was nearly surrounded by non-continuous fringing reefs or carbonate banks. Depositional terraces were well developed and restricted to the south and east edges of this guyot.

DSDP Site 430 is in the central lagoon of Ōjin Seamount. At that site we drilled through nearly 60 meters of pelagic and shallow-water carbonate sediment consisting of oöliths, algal nodules, and nodular limestone (McKenzie, Benoulli, and Schlanger, this volume). The drill bottomed in volcanic rocks consisting of vesicular basalts indicative of subaerial eruption. Oxidized soil zones recovered in cores from Ōjin Seamount (Site 430) also indicate that this guyot spent some time in a subaerial environment.

Ōjin appears to have first subsided slowly through wave-base. Extensive interior carbonate bank deposits developed upon the resulting erosional surface, along with associated fringing reefs or carbonate banks. Gradual buildup of the circular discontinuous reefs or banks within the center of the seamount gradually isolated the central lagoon. Southward and eastward transport of eroded volcanic and carbonate debris led to deposition of prograded terrace deposits that reached a thickness of about 170 meters.

The amount of time the atoll spent in a shallow-water setting is unknown. The relatively thin bank-like material suggests that the time was short relative to the time Kōkō spent in shallow water — equal to Suiko's time and longer than that of the other seamounts mapped. Subsidence from the shallow-water environment apparently was quite rapid once it started, as suggested by

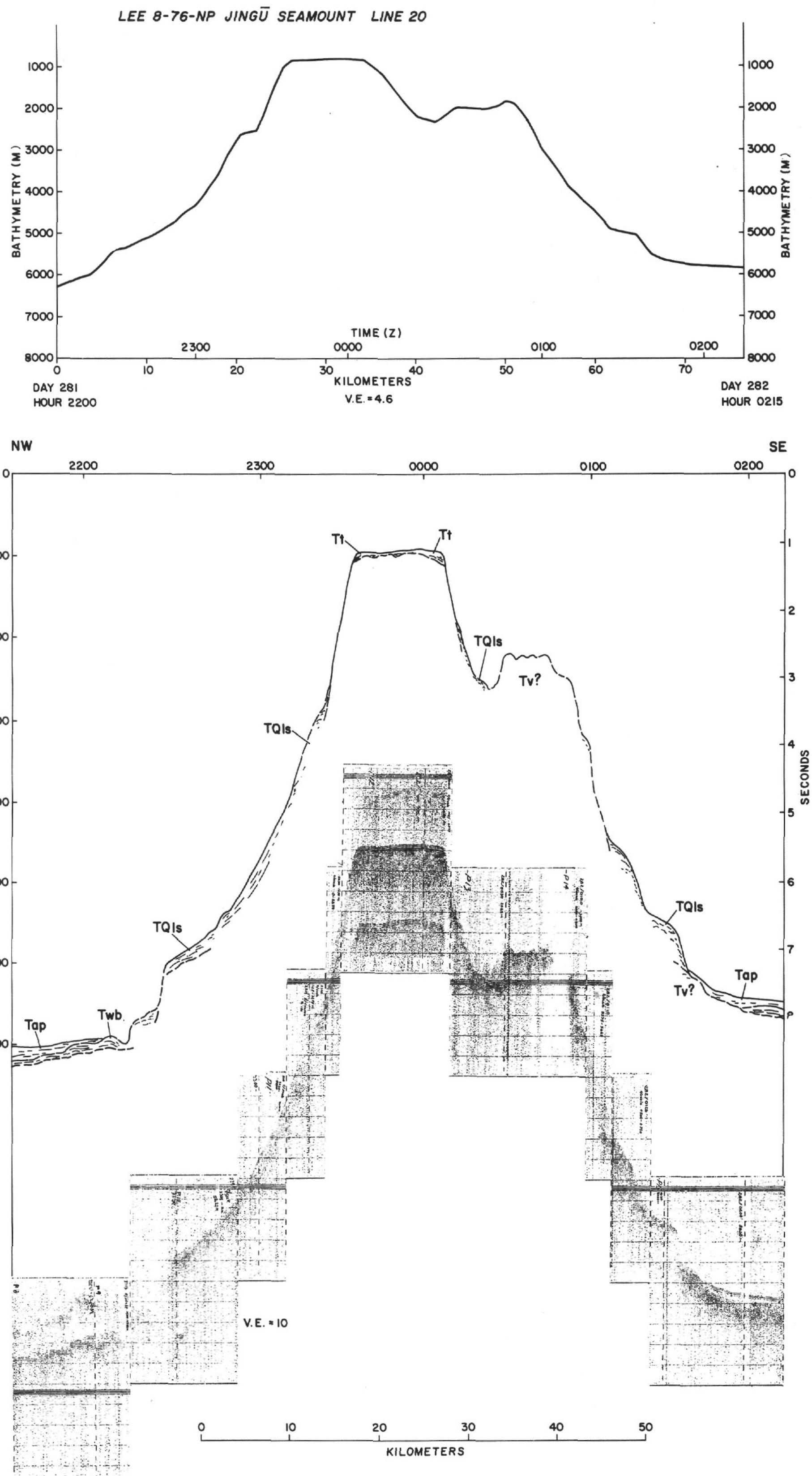


Figure 16. Lee *Sparker profile across Jingū Seamount, showing thin-bedded sedimentary deposits overlying an undulating acoustic basement. Symbols defined in Figure 14 caption.*

the sharp and unmodified relief of the carbonate morphology.

Ōjin atoll subsided to its present depth of 1575 meters. It is tilted slightly to the northwest; the guyot's upper northwest edge is approximately 55 meters deeper than its southwest edge.

Drilling results from Site 430 indicate that younger sediments were deposited at greater depths, suggesting that shallow-water carbonate deposition was not keeping pace with subsidence. The shallow-water stage did not last long at Ōjin, and the carbonate buildup had ceased to develop by the late Paleocene or early Eocene, probably as the result of continued subsidence (Hagn, Butt, and Malz, this volume).

Jingū Seamount

Immediately north of Ōjin Seamount, and connected to Ōjin by a narrow volcanic ridge, lies Jingū Seamount. Jingū is a flat-topped, north-south elongated guyot of simple morphology and geology. Its flat top is 200 meters shallower than Ōjin, and covers an area of nearly 1300 km^2 (Plate 1 of Clague et al., in pocket). Seismic reflection profiles show a steep flanked seamount with a thin layer of bedded sedimentary deposits overlying a flat yet gently undulating acoustic basement (Figure 16). There is no evidence in the seismic reflection profiles of shallow-water carbonate disposits such as reefs or banks. Therefore, we infer that the sedimentary cover is a terrace deposit composed of volcanic detritus.

Jingū Seamount appears to consist of one main volcanic cone that has undergone complete planation; associated with this volcano are one or two smaller, non-eroded ancillary cones. The guyot either stood above sea level as an island or approached sea level during its volcanic up-building and then remained at wave-base long enough to be completely flattened. Unlike most of the other seamounts within the southern Emperor Chain, Jingū either did not remain in shallow water long enough for shallow-water carbonate deposits to develop extensively, or wave erosion removed carbonate deposits and flattened relief after carbonate development ceased. We suggest that the guyot subsided rapidly out of wave-base, with a level descent (the guyot's edges lie at equal depths of 860 m) to its present depth of 845 meters. The guyot apparently never reached a mature atoll stage; its shallow-water history was probably short, so it did not advance beyond a youthful atoll maturity.

Nintoku Seamount

The guyot of Nintoku is one of the southern Emperor chain's larger, linear seamounts. It is gently domed and elongated in a north-south direction; its top covers an area of about 3400 km^2 (Plate 1 of Clague et al., in pocket). Seismic reflection profiles show Nintoku to have a generally flat acoustic basement (volcanic rocks) with local irregularities and covered with a thin (less than 200 m thick) sedimentary cover (Figure 9). The edifice is most probably composed of several large volcanic cones, but these are not distinguishable in the same seismic reflection profiles.

Nintoku Seamount was in an intermediate atoll stage (no lagoon, but fringing reefs and banks and extensive carbonate bank interior started to develop) before subsidence out of wave-base (Figure 17). Extensive carbonate bank interior covering an area of over 1950 km^2 made up the central part of this atoll or shallow-water bank. Remnant volcanic peaks pierce the shallow-water bank interior deposits. Extensive depositional terraces built outward from the atoll or bank proper. Partially buried, discontinuous, fringing reefs or carbonate banks appear to have buttressed and locally ponded the terrace deposits. These reefs or banks are restricted to the distal edge of the terrace deposits, and may represent an earlier stage in the guyot's history, a pre-submergence stage when initial carbonate sedimentation started on wave-eroded platforms and the fringing reefs or banks were established.

Site 432 of DSDP Leg 55 is on the north side of Nintoku Seamount in the terrace deposits (Figure 17). We recovered sparse samples of fossiliferous volcanic sand, sandstone, and calcareous conglomerate characteristic of detrital beach and proximal terrace deposits. These deposits were derived from a warm, shallow-water environment, and indicate a nearby source of shallow-water carbonate material (McKenzie, Bernoulli, and Schlanger, this volume). Lateritic soil recovered from Site 432 suggests that Nintoku once stood above the sea as an island (Karpoff, this volume).

Nintoku Seamount apparently long remained in a subaerial and shallow-water environment prior to carbonate accumulation. The island of Nintoku underwent extensive subaerial erosion and complete wave planation, as indicated by the extensive and well developed wave-cut platform. Buried fringing reefs and banks suggest that there were at least two episodes of rapid subsidence, one after these carbonates developed and the final one when the seamount as a whole subsided beneath wave-base. Generally, subsidence as a whole through wave-base was either so slow that carbonate relief produced by reefs and carbonate banks was eroded after the guyot passed out of the carbonate growth environment, or so rapid that the reefs or banks never did develop. Carbonate sedimentation had ceased by late Paleocene time, according to the fossil evidence in the cores from Site 432 (Butt, this volume).

Yōmei Seamount

Directly north of Nintoku Seamount lies the seamount of Yōmei. Yōmei is a relatively small feature compared with Kōkō, Nintoku, and Suiko; its top covers an area of about 2000 km^2, equal with Ōjin's top surface area (Plate 1 of Clague et al., in pocket). Yōmei is nearly circular in plan with a linear volcanic ridge extending to the southwest. Seismic reflection profiles show this seamount to consist of two central volcanic peaks surrounded by flat, wave-cut platforms (Figure 7). Upon the wave-cut platforms lies a thin (less than 100 m) cover of shallow-water carbonate deposits (Dalrymple, Greene, Ruppel, Bear, and Clague, this volume). (See the idealized map, Figure 18.) Patchily distri-

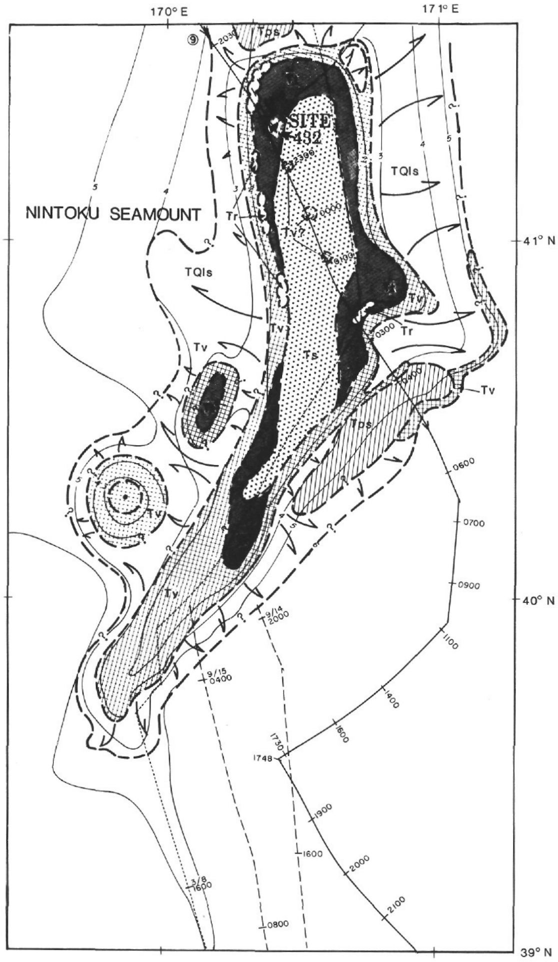


Figure 17. *Idealized geologic map of Nintoku Seamount. Symbols defined in Figure 14 caption.*

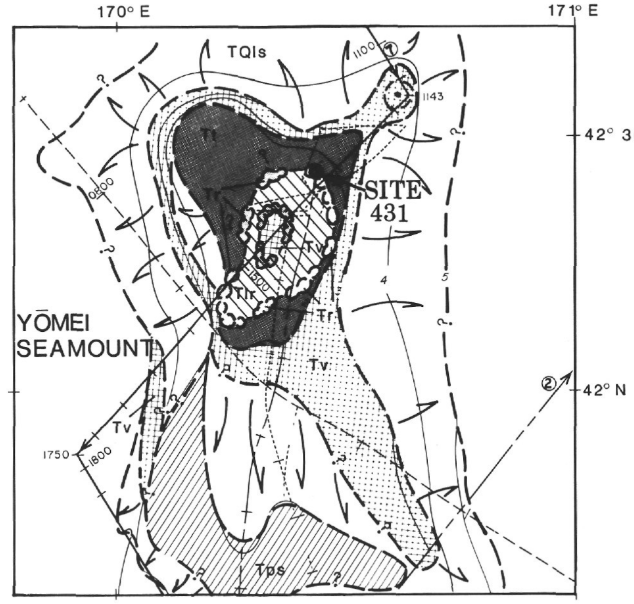


Figure 18. *Idealized map of Yōmei Seamount. Symbols defined in Figure 14 caption.*

buted fringing reefs or carbonate banks are located along the contact between the central volcanic peaks and lagoonal deposits, and barrier (?) reefs are located locally along the outer rim of the lagoonal deposits (Figure 7). Terrace deposits extend outward from the barrier reefs or outer carbonate banks. On the northeast margin of the seamount, terrace deposits and the underlying volcanic rocks are downdropped along normal faults.

Yōmei Seamount was in a youthful stage of atoll development just before its subsidence beneath wave-base (Figure 18). A small island with two prominent volcanic peaks stood in the center of a lagoon that covered an area of about 200 km^2. Small discontinuous fringing reefs or carbonate banks existed along the fringes of the island, and barrier reef development was active along the outer perimeter of the lagoon. Extensive terrace deposits nearly surrounded the atoll. These deposits resulted from the progradation of erosional volcanic and carbonate detritus derived from the atoll.

At Site 431, we drilled into terrace deposits on one of the downdropped fault blocks located along the northwestern side of Yōmei Seamount. Although drill stem problems prevented us from drilling through the sedimentary cover, we were able to recover a small amount of iron-manganese coated gravel and zeolitic sandy gravel indicative of depositional terrace deposits. The oldest sediment recovered is carbonate sand containing Eocene microfossils.

Subsidence of the island of Yōmei was slow at first. It remained in shallow water long enough to form an extensive depositional terrace, barrier reefs or outer carbonate banks, and a circular lagoon surrounding a volcanic island of steep relief. Wave planation of the volcanic edifice was not complete. An intermediate atoll stage (barrier reef stage of Darwin, 1842) apparently was well established before an episode of rapid subsidence beneath wave-base. Because complete erosion of the volcanic peaks and full development of the atoll did not take place, we think that the rate of subsidence out of wave-base was high. During its descent, the seamount was subjected to tectonic stresses that produced the block faulting on its northwestern side. During this subsidence, the seamount tilted to the southwest: its southwestern edge lies 180 meters deeper than its northeastern edge. Yōmei has subsided to its present depth of 980 meters.

Seamount "B"

Seamount "B" is situated directly north of Yōmei Seamount, and is a nearly circular seamount of simple geology and morphology. It is one of the smaller seamounts of the central Emperor chain, and has an upper, gently domed surface area of approximately 480 km^2 (Plate 1 of Clague, et al., in pocket). It is neither a sharp-peaked seamount nor a true guyot, but is intermediate between the two, and stands as a rounded carbonate-capped seamount. Seismic reflection profiles show Seamount "B" to be a single volcanic ediface modified by erosion. A thick, well-layered, progradational sedimentary cover overlies this domed volcanic surface (Figure 19). These sediments appear to be depositional ter-

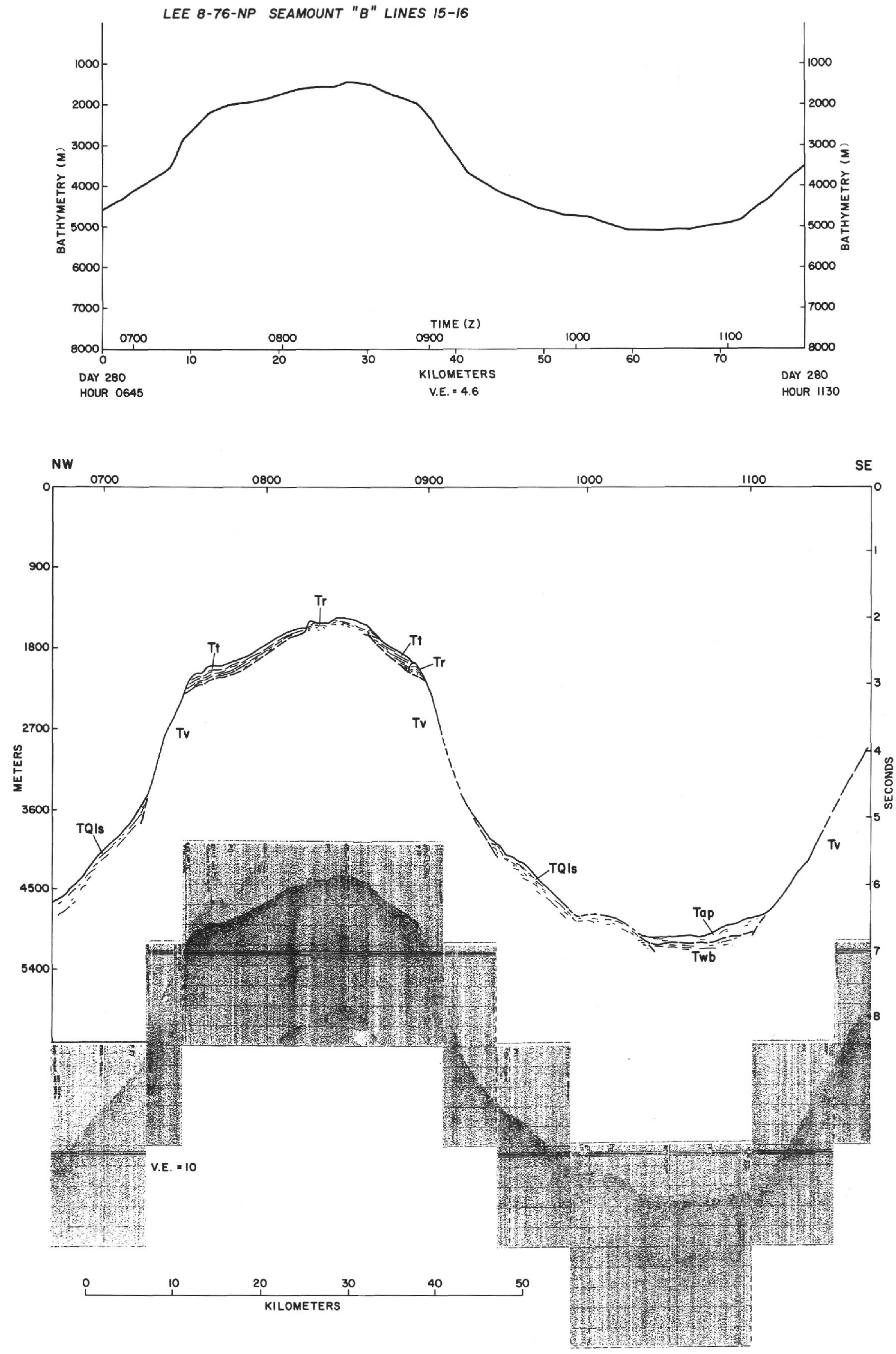


Figure 19. Lee *Sparker profile across Seamount "B", showing carbonate cap and terrace deposits overlying a domed volcanic surface. Symbols defined in Figure 14 caption.*

race deposits that surround a central reef or carbonate bank (Dalrymple, Greene, Ruppel, Bear, and Clague, this volume). Near the seamount's edge, these terrace deposits are over 150 meters thick. Fringing reefs or shallow-water carbonate banks are buried along the distal edge of the terrace deposits, and may locally have ponded these deposits.

Seamount "B" did not develop into an atoll, and probably existed initially as an island and then as a shallow-water carbonate bank (Figure 20). The map shows a central carbonate buildup covering an area of over 60 km^2, surrounded by extensive terrace deposits covering an area of over 400 km^2. Fringing reefs or shallow-water carbonate banks are shown sparsely distributed along the eastern edge of the terrace deposits.

Island "B" underwent moderate subaerial erosion and a small amount of wave planation along its circumference. However, no well-developed wave-cut platforms developed before the carbonate buildup was initiated. Fringing reefs or banks were poorly established when early subsidence dropped the fringes of the seamount beneath wave-base and the carbonate growth environment. This initial rapid subsidence caused only a short drop in elevation, and the crest remained in shallow water. The seamount remained stable long enough to develop an extensive reef or carbonate bank and to form depositional terraces composed of detrital volcanic and carbonate material. Because the topographic relief of the crestal reef or bank is sharp and apparently unmodified by erosion, we believe the final episode of subsidence beneath wave-base was rapid. This shallow-water carbonate buildup subsided to a present depth of 1520 meters and remained fairly level during this descent: edges of the seamounts top are of nearly equal depth.

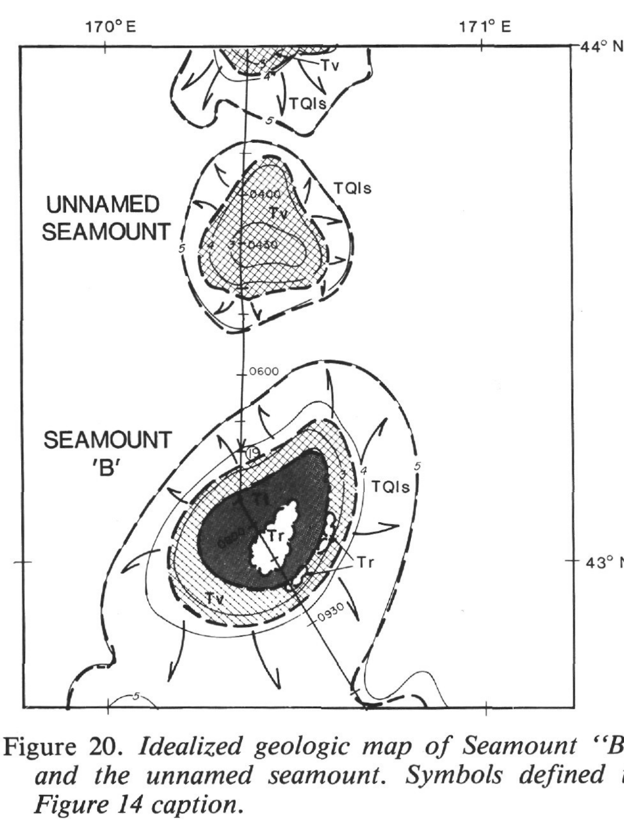


Figure 20. *Idealized geologic map of Seamount "B" and the unnamed seamount. Symbols defined in Figure 14 caption.*

Unnamed Seamount

Between Seamount "B" and Suiko Seamount lies a sharp peaked seamount of very simple geology and morphology (Figure 20). This seamount is a single volcanic cone that probably did not reach sea level during its upbuilding and therefore did not undergo wave-planation or subaerial erosion. If its crest reached shallow water, it did not remain long before its descent to its present depth. No evidence of carbonate sedimentation is apparent in the seismic reflection profiles.

Suiko Seamount

Suiko Seamount is perhaps one of the most morphologically and geologically complex guyots in the southern and central Emperor Seamount chain. It is a large, flat-topped to gently domed volcanic platform, elongated north-south and capped by shallow-water carbonate bank-interior sediment, lagoonal deposits, fringing reefs or carbonate banks, and depositional terrace deposits; its top covers an area of over 3250 km^2 (Plate 1 of Clague et al., in pocket). Seismic reflection profiles show an irregular centrally located, wave-cut volcanic platform overlain with extensive bank interior material that varies in thickness from less than 30 meters near the crest, where volcanic rocks crop out, to nearly 200 meters near the perimeter of the buildup (Figure 6). North and south of this central carbonate buildup, structural depressions are filled with flat-lying, well-bedded, lagoonal and pelagic sediments that reach a thickness of over 500 meters (Figure 21). The volcanic surface and overlying sediment in the northern lagoon is displaced along several normal faults. Partially buried discontinuous fringing reefs or carbonate banks are locally concentrated along the distal edges of the lagoons. This edifice appears to consist of at least three volcanoes: a large central one and two smaller ones north and south of it.

The geologic map of Suiko Seamount indicates that a very mature atoll existed before the seamounts subsided beneath wave-base (Figure 22). The central buildup interior covers an area of over 950 km^2, and a smaller bank flat located on the north side of the guyot covers an area of about 300 km^2. Lagoonal deposits nearly surround the central carbonate buildup, but are cut off by the buildup interior deposits along the eastern and western side of the guyot. Both the southern and northern lagoons are about 650 km^2 in area. The central depression of the northern lagoon is filled with acoustically transparent pelagic sediment. Patchily distributed fringing reefs or carbonate banks that buttress bank-interior and lagoonal deposits are present around the perimeter of the guyot. A narrow band of depositional terrace deposits are restricted to the eastern edge of the guyot.

Site 433 of DSDP Leg 55 is in the northern lagoon, and drilling there penetrated 110 meters of Paleocene carbonate sand and sandy mud with algal nodules above basalt. Although no coral reef detritus was found in the cores, the presence of shallow-water carbonate sediment indicates that a shallow basin existed adjacent to areas where carbonate generation was active. The faunal as-

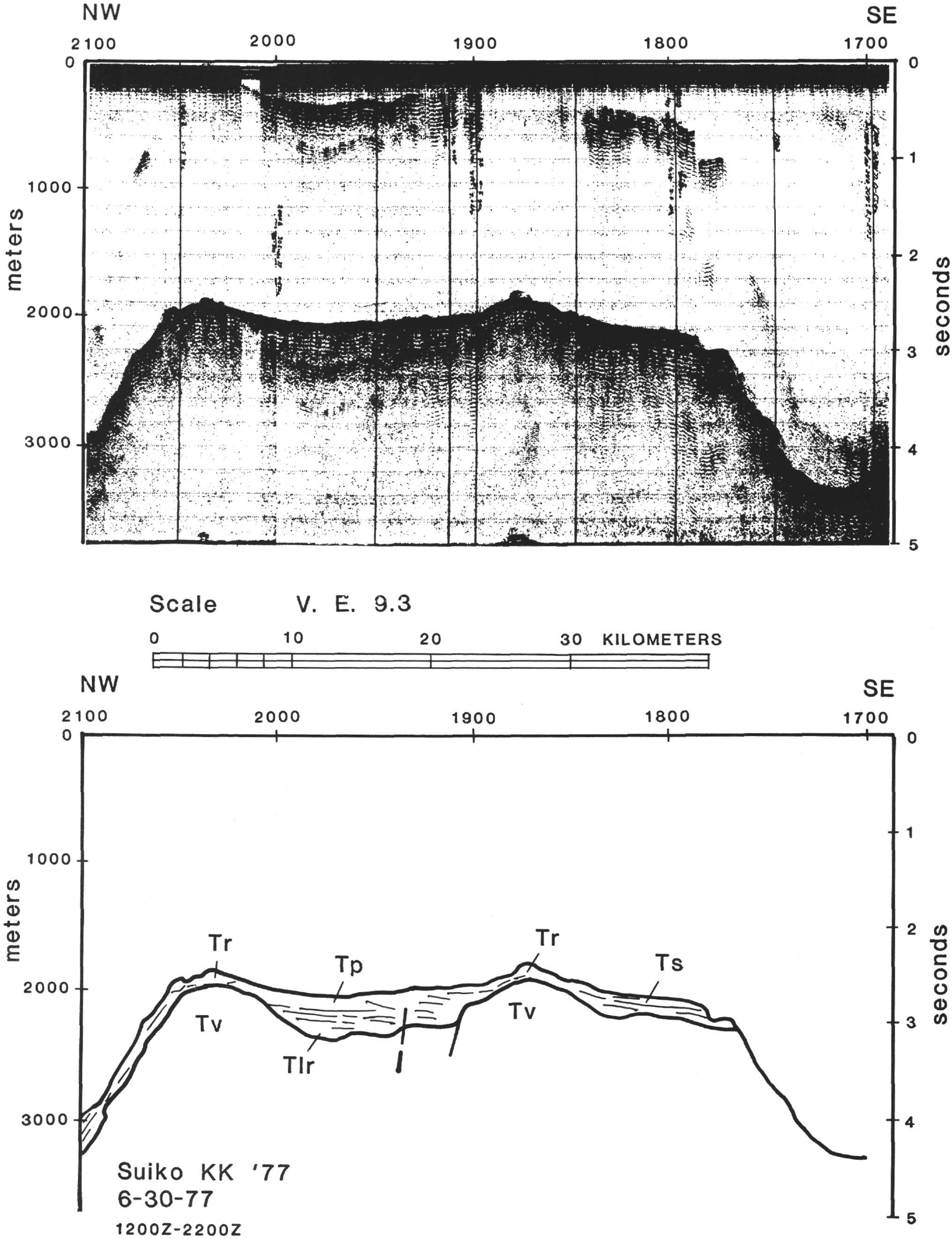


Figure 21. Kana Keoki *air-gun seismic profile across Suiko Seamount, showing flat-lying, well-bedded sediment filling in a large structural depression. Symbols defined in Figure 14 caption.*

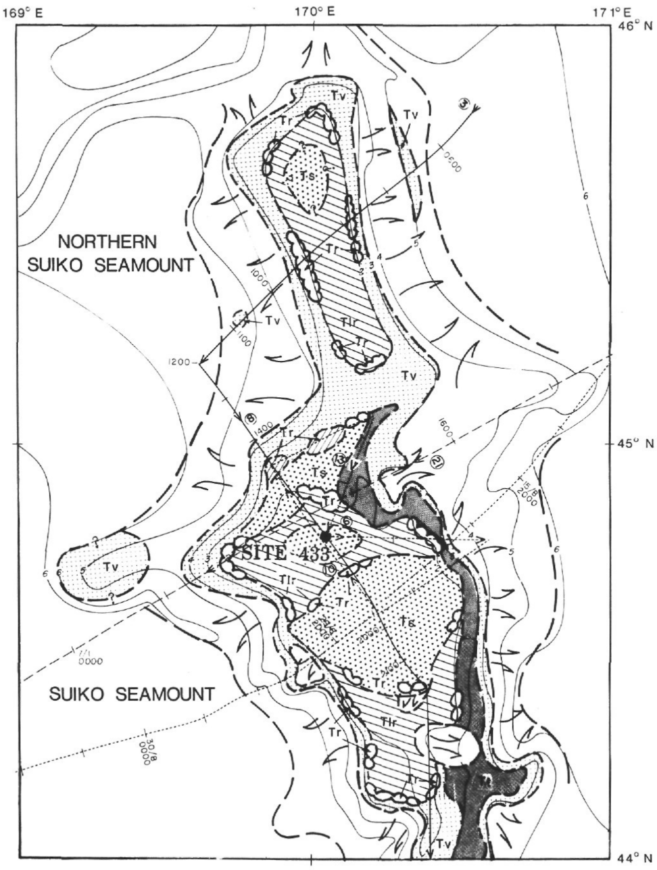


Figure 22. *Idealized geologic map of Suiko and "northern Suiko" seamounts. Symbols defined in Figure 14 caption.*

semblages in this carbonate sediment indicate that a variety of shallow conditions existed within the lagoon (Hagn, Butt, and Malz, this volume; Butt, this volume). The fauna indicate that carbonate deposition took place in water depths between 5 and 30 meters, and that the energy environment within the lagoon varied locally from high or moderate to low. The persistence of these assemblages throughout the 110 meters of carbonate sediment shows that the environment persisted for several million years (Butt, this volume) as the carbonate accumulation, which proceeded at about 1.8 cm/1000 years, kept pace with subsidence of the guyot. The sediment immediately above basalt is Paleocene, and the youngest (upper Paleocene) shallow-water sediment occurs at a sub-bottom depth of about 52 meters (Takayama, this volume; Butt, this volume; Hagn, Butt, and Malz, this volume).

Suiko Seamount once stood above the sea as an island, as indicated by oxidized vesicular basalt and lateritic soils drilled at Site 433. Subaerial erosion and wave-planation eroded the volcanic rocks and filled the intervening valley between the volcanic cones with sediment. Initial subsidence was slow as almost complete wave-planation took place. Carbonate generation started on the smaller northern and southern cones. The structural depressions separating the ancillary cones from the island proper developed into lagoons and started receiving detrital carbonate eroded from the surrounding bank-interior. A very youthful atoll stage developed. Fringing reefs or carbonate banks began to build up along the outer margins of the lagoons. As the island continued to subside, these distal bank-interior and fringing reefs or banks could not keep up with subsidence, and new fringing reefs or banks were established along the perimeter of the island. The lagoon along the north side was dropped down along faults, but continued to receive eroded detritus from the island. Continued slow subsidence allowed for complete planation of the island and development of an extensive bank interior. At this time Suiko stood as a shallow-water carbonate buildup. The poorly developed carbonate relief and thin cover of shallow-water carbonate deposits suggest that the guyot passed rapidly through the shallow-water environment. It subsided to its present depth of 1068 meters. The north edge of the guyot is about 125 meters deeper than the south edge, suggesting that the guyot tilted to the north during its descent. Tectonic activity continued long after the guyot slid beneath wave-base. The youngest shallow-water carbonate sediments and the overlying pelagic deposits are disrupted by faulting (Figure 12). Site 433 is in a graben that reflects tensional stress beneath the shallow-water lagoonal deposits. The folding and growth faulting indicate that this tectonic activity within the graben basin continued at least through the late Pliocene. Most of the reef or bank sediment has been down-dropped in the central part of the graben. The pelagic sediment is only faulted at its base, but the upper part of this sediment is folded in a manner that could only occur by tectonic warping and not by sedimentary draping.

"Northern Suiko" Seamount

"Northern Suiko" is a flat-topped, northwest-southeast elongated guyot located immediately north of Suiko Seamount on the northward continuation of the volcanic ridge that supports Suiko. The linear flat top of "Northern Suiko" is covered by a well-bedded, flat-lying sedimentary unit identified as lagoonal deposits (Dalrymple, Greene, Ruppel, Bear, and Clague, this volume). Its flat top covers an area of about 1135 km^2 (Plate 1 of Clague et al., in pocket). Seismic reflection profiles suggest that this guyot consists of several volcanoes, distributed along the northwest-southeast-oriented ridge, that were eroded to a flat surface by wave planation. In the central part of the guyot, a normal fault, downdropped on the northeast, formed a small structural basin that has accumulated over 225 meters of sediment (Figure 3). Small fringing reefs or carbonate banks bound this sediment at the edge of the guyot's top.

As with Suiko Seamount, "Northern Suiko" was a very mature atoll before subsidence beneath wave base (Figure 22). The guyot was not as extensive as Suiko, but still a fairly large lagoon, covering an area of nearly 800 km^2, developed. At the northern end of the lagoon a reef- or bank-flat covering an area of about 335 km^2 appears to cap an eroded volcanic dome. Patchy, discontinuous fringing reefs or carbonate banks surround the lagoon.

The history of subsidence of "Northern Suiko" guyot was probably similar to that of Suiko. The island remained at or near sea level long enough to be completely eroded and to develop shallow-water carbonates. Initial slow subsidence allowed the island to develop into a mature atoll with a central carbonate bank or flat and distal, patchily distributed fringing reefs or carbonate banks. Subsequent removal from the shallow-water environment was rapid: carbonate relief is poor and shallow-water carbonate deposits are thin. Deposition of pelagic and ice-rafted glacial-marine sediment also smoothed its topographic relief.

Post-erosional and post-depositional tectonics have gently disrupted shallow-water carbonate deposits. The fault identified in the seismic reflection profile across the central part of "northern Suiko" appears to be a growth fault that extends into the lagoonal deposits but does not offset the guyot's surface.

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