OCEAN DRILLING PROGRAM

LEG 157 SCIENTIFIC PROSPECTUS

DRILLING INTO THE CLASTIC APRON OF GRAN CANARIA AND INTO THE MADEIRA ABYSSAL PLAIN

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

ABSTRACT

The Volcanic Island Clastic Apron Project (VICAP) entails a case history study of a coupled system, "oceanic island - volcaniclastic apron." The source area, Gran Canaria, one of the best studied volcanic islands, has a 15-m.y.-long record of chemically distinct volcanic stages. Drilling through the submarine feather edge of the shield stage will allow dating of the beginning of shield volcano growth. We expect abundant datable mineral phases from the Miocene, Pliocene, and Quaternary compositionally evolved volcanic phases on Gran Canaria and neighboring younger Tenerife. These will allow high-resolution calibration of several dating methods and reconstruction of the submarine and subaerial growth and destruction of both islands in detail from the volcaniclastic sediments. The seamount/island evolution as deduced from drilling, together with the volcanic, temporal, and compositional evolution of the subaerial part of the islands, will allow quantification of mass-transfer rates in the system: decompressing mantle diapir - island - peripheral sedimentary basin.

The Madeira Abyssal Plain (MAP) project is aimed at testing the hypothesis that ocean-basin sedimentation is controlled by sea-level changes which affect the stability of sediments on continental margins, including those on the flanks of volcanic islands. The products of mass-wasting events accumulate on the continental slope and on the abyssal plains, but the abyssal plain is the only place where a complete record can be obtained at one drill site. The combined VICAP-MAP project focuses on the development of the Canary Basin in terms of the history of volcanic activity in the Canary hotspot, the detailed evolution of large volcanic oceanic islands, growth of peripheral sedimentary basins (volcanic aprons), and the filling of the distal Madeira Abyssal Plain.

INTRODUCTION

VICAP

VICAP (Figs. 1 and 2) concerns the physical and chemical evolution of the confined system "asthenosphere - lithosphere - seamount - volcanic island - peripheral sedimentary basin" by drilling into the proximal, medial, and distal facies of a volcaniclastic apron. This apron consists of the seismically "chaotic" flank facies with velocities around 3.4-4 km/s and the basin facies characterized by widespread reflectors (Fig. 3), representing volcaniclastic sediments interfingering with biogenic and continent-derived clastic material. We aim to achieve a quantitative analysis of this confined "geo-system."

The basin facies contains large amounts of material representing the evolution of the entire complex island volcano (Figs. 4 and 5); most importantly, it includes material from the inaccessible submarine stage, representing >90% by volume of the volcanic edifice. The most distal sites on the Madeira Abyssal Plain will enable us to identify and date major volcanogenic turbidites from Canary Island sources, and hence large mass wasting and volcanic events in the Canary Island archipelago.

The project is designed as a case history study that will allow an assessment of the past volcanic, petrologic, and plate-tectonic environments of sedimentary basins adjacent to productive volcanic source areas, including marine volcaniclastic successions drilled in the DSDP/ODP programs.

Gran Canaria is unusually well exposed and well studied. The island has been volcanically active intermittently throughout the past 15 m.y. Igneous rocks, both mafic and evolved, show a large spectrum in chemical and mineralogical composition. Gran Canaria has experienced several stages of extreme magma differentiation, unique among volcanic islands, generating both frequent explosive rhyolitic, trachytic, and phonolitic fallout ashes and many ash-flow deposits. The distinct composition of individual ash flows, as well as other volcanic rocks, throughout the island's evolution will greatly facilitate stratigraphic subdivision in the cores. The evolved rocks contain significant amounts of K-rich mineral phases (feldspar and mica) - a prerequisite for high-resolution age studies. A major element of the program will be therefore high-precision single-crystal $^{40}Ar/^{39}Ar$ age dating with the aim of monitoring the island and basin evolution in time slices as short as 100,000 years.

The neighboring islands of Tenerife (volcanically active for less than ca. 8 m.y.; Ancochea et al., 1990), Fuerteventura (active for more than 20 m.y.; Le Bas et al., 1986), and Lanzarote also contribute to the sediments in the area (Fig. 6). They have not yet been studied in as great detail as Gran Canaria but also show wide and characteristic compositional variations.

MAP

MAP drilling (Fig. 1) is aimed at testing the hypothesis that ocean basin sedimentation is controlled by processes such as sea-level change and major volcanic events which affect the stability of sediments on continental margins including those on the flanks of volcanic islands. The products of mass-wasting events accumulate on the continental slope and on the abyssal plains, but the abyssal plain is the only place where a complete record can be obtained at one drill site. Seismic evidence suggests that the abyssal plain is a young feature, with the whole 350-m-thick turbidite sequence (20,000 km^3) having been deposited in just a few million years. The drilling on the Madeira Abyssal Plain will also allow mass balance calculations of sediment transported from the continental margins to the deep sea, including mass balances for volcanogenic sediments derived from Madeira and the Canary Islands. The history of volcanogenic turbidites will be closely tied to the history of the volcanic islands and should provide information on the initiation of hotspot activity, on phases of increased volcanic activity, and major island-flank collapse events.

The study of early diagenesis in sediments accumulating under non-steady-state conditions will also be advanced by study of these sediment sequences. The concept of a "progressive oxidation front" was first proposed following studies of the MAP turbidites (Wilson et al., 1985, 1986; Thomson et al., 1987). When the turbidite top is in diffusive contact with bottom waters following deposition, several elements redistribute themselves around the oxic/postoxic (or sub-oxic) boundary at the front. This results in layers of metal concentrations, with some metals persisting long after conditions have become reducing, and some metals disappearing quickly. We need to know more about the long-term persistence of these signatures to aid in interpreting paleo-redox conditions. The presence of multiple fronts will allow successively older signatures to be examined. The diagenesis and maturation of organic matter can also be examined in the turbidites, as well as in the clastic apron sites, by techniques such as Rock-Eval pyrolysis.

STUDY AREA - GRAN CANARIA

Submarine Growth Stages of the Canary Islands

The temporal evolution and regional age progression of Canary Island volcanism is based largely on the subaerially exposed rocks because the much greater volume of submarine volcanics is hidden at depth (Figs. 3 and 7). Fossils in sediments interfingered with volcaniclastics in the subaerially exposed Fuerteventura basal complex suggest that volcanism on the easternmost islands may have begun at 70-80 Ma (Le Bas et al., 1986). Detailed information about the submarine stages is badly needed to quantify models of the age progression in the archipelago. Hence drilling through the feather edge of the shield stage of Gran Canaria is one of the main goals of Leg 157.

Structure, composition, and evolution of the submarine part of the Canary Islands are largely unknown except for La Palma, where a 3.5-km-thick section of the uplifted submarine part is well exposed (Staudigel and Schmincke, 1984; Fig. 8). This section consists of a central plutonic complex, a sheeted dike swarm and abundant sills, a lower extrusive section (~650 m thick) made up almost exclusively of pillow lavas, and an upper extrusive section (~1150 m thick) made up of >50% pillow fragment breccias and several types of mass-flow deposits, many consisting of resedimented, shallow-water-derived, vesicular hyaloclastites. The hyaloclastites on La Palma are overlain by volcaniclastic debris flows which contain abundant tachylite and a wide variety of subaerial volcanic and subvolcanic rock fragments (ranging from microgabbro to trachyte).

Such debris flows form excellent seismic reflectors, and their volume south of Gran Canaria probably exceeds 50 km^3 (G. Wissmann, unpublished seismic data). In the Canary Basin north of Gran Canaria, the volcaniclastic island flank is well defined by reflection and refraction data (Banda et al., 1981). It has seismic P-wave velocities between 3.4 and 4.6 km/s extending out to a distance of 40 to 60 km off the coast and is underlain by a ~2.5 - 3 km thick pre-volcanic sediment layer characterized by lower velocities of 3.0 - 3.2 km/s.

Previous drilling has shown that both submarine and subaerial phases are reflected in the volcaniclastic sediments off Gran Canaria. At DSDP Site 397 (Fig. 1), less than 100 km south-southeast of Gran Canaria, hyaloclastite debris flows (V3, Fig. 4) are interpreted to represent material from the submarine stage of an island (probably Fuerteventura) transported for more than 100 km to the south and southwest (Schmincke and von Rad, 1979). The overlying alkali basalt-fragment rich debris flows (V1, V2, Fig. 4), consisting largely of tachylitic and highly vesicular clasts, are interpreted to represent the shallow-water and shield stages of emerging Gran Canaria, judging from their chemical and mineralogical composition. They form the bulk of the debris flows mapped seismically by Wissmann (1979) and thus are thought to reflect the rapid growth of an island during the shield stage (Fig. 4). A very large amount of clastic debris is generated during the transition period seamount/island by phreatomagmatic and magmatic explosive activity as well as erosion of freshly formed pyroclastic deposits (Fig. 5).

Younger ash layers at DSDP Sites 369 and 397 (Fig. 1) reflect later, differentiated, subaerial stages of an island (Fig. 9), such as the 14-13.5 Ma-rhyolite, 13.5-9.5-Ma trachyphonolitic, and the Pliocene phonolitic ash layers. The Pleistocene ash layers are probably derived from Tenerife.

The excellent stratigraphic control, coupled with detailed $^{40}Ar/^{39}Ar$ dating, of samples from drill cores into the volcanic apron around Gran Canaria will provide a unique opportunity to study the geochemical evolution of the early (submarine) stage of ocean island volcanism. Combined with the detailed geochemical studies on the subaerial portion of Gran Canaria (Figs. 10 and 11) (Schmincke 1987-94; Hoernle et al., 1991; Hoernle and Schmincke, 1993a, b, and references therein), the geochemical evolution of the submarine stage will serve to better understand the slow passage of the lithosphere over a broad area of mantle upwelling ("plume").

Geology of Gran Canaria

Gran Canaria (28°00'N, 15°35'W) is one of the inner islands of the Canarian archipelago in the central eastern Atlantic, some 100 km off the northwestern African passive continental margin. All subaerially exposed volcanic and intrusive rocks were emplaced within the last 15 m.y. (McDougall and Schmincke, 1976). The most recent dated eruption on Gran Canaria took place approximately 3,500 years ago (Schmincke, 1976). The island can thus be considered volcanically active, as testified by numerous prehistoric basanite scoria cones, maars, and lava flows. Three major magmatic/volcanic cycles have been distinguished on Gran Canaria, which have been further subdivided into several stages (Schmincke, 1976, 1982, 1987-94; Hoernle and Schmincke, 1993a and b) (Fig. 9).

The composition and age of the submarine part of the island are unknown. The subaerial Miocene Cycle started with the rapid formation (~0.5 Ma) of the exposed tholeiitic to mildly alkalic shield basalts. At 14 Ma, the basaltic shield phase was followed by a 0.5-m.y.-long volcanism of trachytic to rhyolitic ash flows (~15 cooling units). A large caldera (~20 km in diameter) was formed during the beginning of this phase. High-precision single-crystal $^{40}Ar/^{39}Ar$ dating has shown that the ash flows erupted at intervals of 0.03-0.04 m.y. (Bogaard et al., 1988). After the rhyolitic stage, >500 km^3 of silica-undersaturated nepheline trachyphonolitic ash flows, lava flows, and fallout tephra and rare basanite and nephelinite were erupted between ca. 13 and 9.5 Ma, followed by syenites and a large cone sheet swarm in the central caldera complex until ca. 8 Ma. Following a major nonvolcanic hiatus lasting approximately 3 m.y., the Pliocene cycle began with local nephelinites and basanites at ~5 Ma. The eruption rate increased 5 to 4 m.y. ago, and the lavas became systematically more SiO_2-saturated, ranging from basanites to alkali basalts to tholeiites. Between 4 and 3.4 Ma, alkali basalts, trachytes, basanites, and phonolites were intercalated with massive hauyne-phonolite breccia flows, fallout ashes, and pumice flows, intruded by trachytic and hauyne phonolite domes (Roque Nublo Group). Following a brief hiatus in volcanism, there was a resurgence in volcanism, during which only highly undersaturated, unusually voluminous mafic volcanics (melilite nephelinites to basanites, 3.2-1.7 Ma) were erupted. Quaternary volcanism occurred almost exclusively in the northern half of the island. The oldest dated Quaternary volcanics are 1-Ma nephelinites, whereas the more recent Quaternary volcanics are predominantly basanites, with rarer alkali basalt, tephrite, and hauyne phonolite.

In summary, important aspects of the volcanic and chemical evolution of Gran Canaria include

1) the striking differences in compositions of mafic rocks (tholeiites, alkali basalts, basanites, tephrites, nephelinites) erupted in temporally well-defined episodes over a period of ~15 m.y. (Fig. 10),

2) the very large volume of evolved magmas erupted between 14 and 13.5 Ma (silica-oversaturated trachytes and peralkaline rhyolites), 13 and 9.5 Ma (trachyphonolites), 4 and 3.4 Ma (trachytes through strongly silica-undersaturated hauyne phonolites), and ~1 Ma (hauyne phonolites), whose explosive eruptions generated excellent widespread ash beds,

3) the characterization of units or groups of units by their bulk rock and mineral chemical composition and mineral modes and their distinction from volcanic rocks derived from the other Canary Islands,

4) the systematic variation in isotopic compositions with bulk rock composition and age on Gran Canaria and other Canary Islands (rocks of roughly known age can thus be correlated with volcanic cycles of different islands), and

5) the abundant K-bearing phenocrysts (anorthoclase, sanidine, and, in the Fataga trachyphonolites, biotite) of the evolved lavas that allow precise single crystal dating.

STUDY AREA - MADEIRA ABYSSAL PLAIN

Background

The Madeira Abyssal Plain (MAP) lies in the deepest part of the Canary Basin at a water depth of 5400 m, and occupies an area of 400 km north-south by 200 km east-west (Fig. 12). The late Quaternary geological history of the MAP is known in greater detail than any other abyssal plain. During the last 730,000 years very large turbidity flows entered the MAP with a frequency apparently related to climate changes: they appear to have been initiated during periods of both rising and falling sea levels. Between these flows, sedimentation reverted to hemipelagic deposition, which alternated between carbonate-poor sediment during glacials and carbonate-rich during interglacials.

Lithology

Hemipelagic Sediments

The hemipelagic sediments alternate between clays and marly clays deposited during glacial intervals, and oozes and marly oozes deposited during interglacial conditions. The distinction between these sediment types is dictated by the water depth of the site, placing it above the carbonate compensation depth (CCD) during interglacials, but below the CCD during glacials, when bottom-water changes allow the spread of corrosive Antarctic Bottom Water into the area. This pelagic sediment sequence is clearly displayed in cores from the small hills which protrude above the plain; they show alternating marls and clays with some ooze layers. Each layer is at maximum a few tens of centimeters thick, with the clays usually being just a few centimeters thick. Average accumulation rates are between 0.3 and 1.5 cm/k.y. Sediments older than about 2 m.y. contain decreasing percentages of calcium carbonate, and sediments older than 3.5 Ma consist of continuous red clay, which is expected to extend to at least Cretaceous sediments or possibly to the basement (Weaver et al., 1986).

Turbidites

The turbidites form the thickest layers and have been studied in great detail (Fig. 13). Individual turbidites can be recognized by their mineralogical composition, microfossils, stratigraphic position and color. Individual flows have been designated by letter from A at the top down to turbidite Y which has an age of about 730,000 years (Weaver et al., 1989). They fall into three compositional groups related to distinct source areas.

Organic-rich turbidites derive from the upwelling cells off the northwest African margin and have two sources, one north and one south of the Canaries. They contain more than 0.3% organic carbon and 45%-60% $CaCO_3$ (de Lange et al., 1987). They are represented over most of the plain by very fine-grained sediment (Md 8-9 phi). The basal layers of these turbidites are commonly coarser, although in the west (distal) this usually means a slight coarsening of the basal few centimeters only. In the eastern part (more proximal) of the area, particularly adjacent to the break of slope at the foot of the continental rise, the basal layers, represented by sands, may be over 1 m thick (Weaver and Rothwell, 1987). The oxidation front mechanism discussed later results in bi-colored turbidite units, usually olive green below the relict oxidation front where the organic material remains, and pale green above where the organic material has been oxidized.

Volcanic turbidites have high TiO_2 contents (about 1.5% carbonate free), low organic carbon (<0.3%), and 50%-60% $CaCO_3$ (de Lange et al., 1987). They are fine grained over most of the plain, coarsening to the east and northeast. Their volcanic component is derived from the volcanic islands of the Canaries and/or Madeira. These turbidites are buff brown in color without well-developed relict oxidation fronts.

The white calcareous turbidites contain over 75% $CaCO_3$ and show chemical compositions more akin to the pelagic sediments of the area than to the other two groups (de Lange et al., 1987). They thicken to the west along the Cruiser fracture zone valley (Weaver et al., 1992) and are believed to derive from the Cruiser/Hyeres seamount chain.

Geological History

Stratigraphy

The lithofacies representing the glacials and interglacials, respectively, can be correlated with the oxygen isotope stage chronology, and several isotope stages have been identified micropaleontologically using nannofossils (Weaver, 1983) (Fig. 14). Weaver and Kuijpers (1983) used this bio-lithostratigraphy to show that the incoming turbidity currents did not erode the seabed, and that the turbidites entered the area with a frequency related to climate change. Sedimentation fits a regular pattern, with thick turbidites lying between the successive hemipelagic units (clays and oozes). Thus the turbidites were deposited both during the transitions from glacial to interglacial conditions and from interglacial to glacial conditions with a frequency of one turbidite every 20-40 k.y. Twelve of the last 18 isotope stage boundaries are represented by a turbidite from a single source, and two have turbidites from two sources (Fig. 15). Each of the four sources operated for a limited time period, supplying several turbidites before giving way to one of the other sources. The reasons for this may be related to recharge times or changes in accumulation rate in the source areas with time. The Canary Island source may have been activated during times of increased volcanic activity in the islands, and the marine record may therefore give the best constrained information on these active phases.

Deeper Structure

The longest cores so far recovered from the MAP represent about 730,000 years (Fig. 16). Four seismic units have been identified (Weaver et al., 1986; Searle, 1987) overlying a basement of Late Cretaceous age (80-100 Ma). The deepest unit (Unit D) is seismically transparent and only intermittently present and may represent a facies change within Unit C.

Unit C represents pelagic sediment, since it drapes over the underlying basement. We believe Unit C to represent red clay, since the area has lain below the CCD almost continuously throughout its history (Weaver et al., 1986), and cores into the local abyssal hills show red clay in sediments older than about 3 m.y. The upper two units (A and B) probably both represent turbidite sediments, the distinction being in the strength of the reflectors, which are much weaker in the lower Unit (B). The combined thickness of Unit A/B varies between 120 and 530 m, but averages about 350 m (Fig. 17).

Weaver et al. (1986) interpreted the evolution of the abyssal plain from core data and seismic stratigraphy. Seismic Unit C is about 200 m thick and would have required a long time for its deposition if it were all, or mainly, red clay. Turbidite Unit A/B fills the depressions in Unit C and levels off the seafloor to give the flat plain. Unit A/B has accumulated rapidly - at about 100 m/m.y. for the last 300,000 years calculated from piston cores, although we have a lesser rate of 50 m/m.y. from the ESOPE (Etude des Sediments Oceaniques par PEnetration) long cores for the last 730,000 years. These accumulation rates suggest that the abyssal plain could have formed in just a few million years. During the late Quaternary there was considerable erosion of the shelf and upper slope with massive slope failures, slides, and debris flows. The lateral equivalents of these slides and debris flows are found on the plain as turbidites.

For the volcanic turbidites, we know that recent turbidites derive from the westernmost islands of La Palma and Hierro, which are in their shield phase. It is possible that large-scale island erosion or flank collapse is limited to the shield phase or other rapid-growth phases. Thus both constructive and destructive phases in the evolution of volcanic islands may be apparent in the turbidite sequence for each successive island in the Canary chain.

Geochemistry

The Redox Status of the Sediments

Difficulties with the direct measurement of Eh in sediments have led to the adoption of a proxy geochemical convention for defining the redox status, based on the chemical species found in pore-water solution. This is feasible because the oxidation of organic carbon, the principal reductant buried in sediments, progresses with bacterial mediation using a sequence of electron acceptors in order of decreasing thermodynamic advantage. Thus oxygen is utilized first, followed by nitrate, manganese, and iron oxyhydroxides and sulfate in that order (Froelich et al., 1979).

These observations have led to the concept of a progressive oxidation front, which is formed as bottom-water oxygen diffuses down into the turbidite from the sediment/water interface after emplacement, oxidizing, as it does so, the organic carbon introduced with the turbidite (Wilson et al., 1985, 1986). Various redox-sensitive pore-water species show gradients into the front, which appears to be coincident with the color changes in both turbidites. The abrupt redoxcline implied across this front (Sorensen et al., 1987) is in contrast to the succession proposed by Froelich et al. (1979), which is often taken as the general case for deep-sea sediments.

Several redox-sensitive elements (Mn, Fe, P, Co, Cu, Ni, U, V, I, and Zn) redistribute about the progressive oxidation front when it is active (Fig. 18). Some of these redistribution profiles persist in buried turbidites, where the oxic depths achieved when the fronts were active can be recognized by color contrasts near the tops of individual units (Jarvis and Higgs, 1987). These color contrasts are therefore preserved in anoxic pore-water conditions experienced following emplacement of later turbidites.

LEG 157 SCIENTIFIC OBJECTIVES AND METHODOLOGY

Compositional Evolution of Mantle Sources and Magmas

A major objective during Leg 157 is the detailed determination of major element and trace element concentrations and isotopic ratios of bulk rocks and single components using analytical methods such as XRF and ICPMS as well as mass spectrometry. Microprobe, ion probe, and synchrotron microprobe analyses and microthermometry will be performed on selected glass and mineral separates and glass inclusions in phenocrysts. Volcanic clasts from various sources can be distinguished by chemical and mineralogical differences. The compositional database for Gran Canaria is unique, since it contains several thousand mineral, greater than one thousand rock, and greater than one hundred isotope ratios. Rocks from Tenerife are less extensively analyzed to date, but data from many current projects will be available by 1995. Volcanic rocks from Madeira and the Canary Islands can be unequivocally distinguished by major and trace elements as well as isotope ratios. Compositional analysis of large clasts and mineral phases should be complemented by analysis of glass and fluid inclusions.

The observed variations in the subaerial portion, making up only 5% of the volcano, are not representative of the entire volcano. The isotopic composition of the subaerial volcanics on Gran Canaria change significantly with age (Fig. 11), possibly reflecting greater influence of lithospheric/asthenospheric assimilation in the late stages of ocean island volcanism. If this is the case, then the voluminous submarine volcanics, formed when the volcano was directly above the plume, should more closely reflect the true isotopic composition of the plume.

Knowledge of the chemical and mineralogical composition and age of the submarine stage of Gran Canaria will allow us to more clearly characterize

1) the composition of different mantle reservoirs (i.e., plume, asthenosphere and lithosphere),

2) the generation of melts from these reservoirs, and

3) mixing of magmas/material from these reservoirs. Grain size and freshness of some clasts should be sufficient to obtain reliable radiogenic isotope ratios.

High-Resolution Stratigraphic, Compositional, Temporal, Structural, and Sedimentological Analysis

Single crystals can be dated by $^{40}Ar/^{39}Ar$ laser heating, yielding uncertainties lower than 1%, provided suitable material is available. This method will be extensively applied because of the abundance of K-feldspar and biotite-bearing highly evolved rhyolitic, trachytic, and phonolitic magmas especially on Gran Canaria (some 50 to 100 volcanic explosive events, such as ash flows and fallout layers, between 14 and 3.5 Ma, whose products are widespread in the sedimentary basins as shown by previous drilling at DSDP Sites 369 and 397. This will be complemented by dating of K-feldspar-bearing ash layers from Tenerife, expected to be abundant in the southwestern and possibly also northern apron in deposits younger than ~2 Ma. In the MAP sites, ash layers from the Azores volcanic islands are expected to occur, as well as datable material transported from the Canaries in sediment flows.

Seismic, biostratigraphic, and magnetostratigraphic analyses will also be employed. Widespread conspicuous seismic reflectors in marine sediments around the Canary Islands and volcanic islands in general are mostly volcaniclastic debris-flow sheets. South of the Canaries, DSDP Sites 369 and 397 on the West Sahara slope reach Lower Cretaceous sediments. In the north, DSDP Site 415 (Fig. 1) reaches rocks of late Albian age; whereas a Tithonian reflector can be traced from DSDP

Site 416 (Fig. 1). This seismic stratigraphy has been carried across the island chain into the sedimentary basins north and south of Gran Canaria based on data collected in 1991 and 1993.

High-resolution stratigraphy has been achieved for the late Quaternary Madeira Abyssal Plain sediments by dating pelagic layers between successive turbidites. Lower down in the MAP sequence the pelagic lithologies will be limited to red clay, and biostratigraphy therefore becomes more complicated. It is, however, possible to analyze calcareous nannofossils from the turbidites which were originally deposited well above the CCD, and, due to rapid burial, have had their carbonate preserved. They obviously contain a reworked mixture of nannofossils, but first-occurrence data (FAD's) will not be affected. The FAD of a species will simply occur in the first turbidite to be laid down after its appearance, and, since turbidites occur commonly on the plain, this age will be close to the true age of this datum.

Distinct units of volcaniclastic sediments will be correlated between holes and with the land record based on their age, composition, structure, and texture. Similarly, turbidites on the abyssal plain are expected to have distinctive compositional signatures, enabling them to be recognized in each drill site and related to their sources (Canary Islands, Madeira, NW African margin). Tephra layers will be geographically extensive and should make excellent marker horizons. Our published and unpublished data from DSDP Sites 369 and 397 indicate that clinopyroxenes and feldspar phenocrysts, and even most glass shards, are generally fresh in tephra layers as old as 14 Ma.

Volcanic Evolution of Gran Canaria Reconstructed from Apron Sediments

A major problem in dating the inception of oceanic intraplate volcanism is the fact that most of the volume occurs under water. We expect to be able to more precisely date the beginning of volcanism of Gran Canaria and the younger island of Tenerife, as well as that of the eastern Canaries, through drilling through the feather edge of the volcanic apron. These data will provide important constraints for calculating progression of volcanism across the island chain and therefore plate kinematics.

If the submarine portion of the volcano also represents multiple cycles of chemically distinct volcanism as on land, then the evolution of a Canary Volcano may be significantly different from the evolution of a Hawaiian volcano (Moore and Fiske, 1969; Watts and ten Brink, 1989; Moore et al., 1989). These differences may ultimately reflect differences in rates of plate motion and plume flux rate. The Hawaiian Islands, the end member for Pacific-type ocean island volcanoes, were formed on a very rapidly moving plate by a plume with an extremely high flux rate. The Canary Islands, a possible end member for Atlantic-type ocean islands, on the other hand, were formed on a very slowly moving plate by a very weak, possibly intermittent plume (Hoernle and Schmincke, 1993b).

The drilling strategy aims to identify many of the Miocene and Pliocene evolved ignimbrites and fallout ashes on Gran Canaria with their counterpart marine flow and fallout tephra layers, contributing to better volume calculations of magmatic events. We also expect to distinguish primary from secondary volcaniclastic fragments and deposits and thus be able to date and quantify erosional and volcanic episodes and compare the computed rates and volumes with those derived from the more accessible, but less complete, land record.

We expect a strong correlation between volcanic turbidite emplacement and active volcanic phases on the Canary Islands and Madeira. Some of our other work around the Canaries is aimed at determining whether single volcanic eruptions initiate mass wasting or whether material first accumulates on the island slopes until it becomes unstable. These volcanic-rich turbidites nevertheless seem to be tied to sea-level change, and there could be a link between climate (sea-level) change and volcanic activity as well as sea-level change and slope stability.

Paleobathymetry, Paleoenvironments, and Paleoceanography

The VICAP drill holes provide important perspectives for the reconstruction of paleobathymetry and paleoceanography of the eastern North Atlantic Ocean around the Canary Islands. It will be of particular importance to investigate the paleobathymetry of the volcaniclastic apron by means of 1) reconstructing the CCD and other dissolution interfaces, 2) analyzing in detail benthic foraminifers as qualitative depth indicators, and 3) comparing carbon isotope ratios in the shells of calcareous benthic organisms and planktonic surface-water-dwelling organisms (particularly the carbon isotopes of benthic organisms during periods of elevated carbon contributions in the course of volcanic-activity maxima).

Inferences on sea-level changes will allow us to separate local from global, tectonically related effects. The system of currents in the vicinity of the Canary Islands during the past 15 m.y. (stratigraphy of deep-water circulation) can be reconstructed, and the response of currents (direction, velocity, composition, temperature, stratification, etc.) to the evolution of the Canary Islands evaluated.

The youngest sediments will permit detailed studies of the Neogene sedimentary sequence with emphasis on the Messinian salinity crisis, which is developed in the Mediterranean but also seems to leave a trace in the isotope signals of the entire Atlantic.

Information on paleo-wind directions can be gained by reconstruction of depositional fans of Plinian fallout ashes. Late Tertiary and Quaternary climatic evolution in the Sahara and Sahel Zone may be deduced from silica dust fluxes.

Diagenesis

We want to quantify the long-term effects of sediment burial and diagenesis in a sequence of mixed volcanic, organic-poor and organic-rich sediments and assess 1) chemical fluxes between components, especially volcanic glass and pore solutions, 2) maturation of organic matter at elevated temperatures in the proximal facies near the hotter interior of an island as well as 3) during low-temperature diagenetic conditions away from the hotspot.

Long-term persistence of the record of oxidation fronts in the turbidites includes examination of metal relocations, particularly of uranium (Colley and Thomson, 1990; Jarvis and Higgs, 1987). The more mobile redox active elements, such as iron and manganese, migrate away after conditions become reducing, so that the interpretation of paleo-redox conditions requires an understanding of elements which do not remobilize and thus are expected to provide persistent signatures. We will evaluate the stability of such signatures in sediments older than the 700-ka examples studied to date (Colley and Thomson, 1990).

Buried organic carbon appears to undergo only very slow oxidation, once oxygen and nitrate are exhausted. Extrapolations from existing pore-water data (30-m cores) suggest that pore water sulfate is not consumed until a depth of about 100 m below the sediment/water interface is reached.

Such a gradient length limits the potential sulfate supply and sulfide formation. The pore-water concentrations of ammonium and phosphate ions, however, both increase linearly with depth over 30 m, suggesting that organic remineralization may be active at greater depth.

We will assess in detail chemical fluxes between components, especially volcanic glass and pore solutions, focusing on volcaniclastic units differing in composition (e.g., basaltic - rhyolitic - phonolitic) interlayered with biogenic sediments. How will the composition of pore solutions reflect the strongly contrasting major and trace composition of the volcaniclastics?

The timing of hydrothermal and low-temperature circulation and the mass budget of element exchanges related to the submarine growth stage of Gran Canaria will be investigated by determination of diagenetic gradients, authigenic phases, and alteration of volcanic glass along radial profiles. The glassy nature of volcaniclastic debris makes it an especially sensitive indicator of diagenetic processes.

Provenance, Frequency, Volume Calculations of Transported Sediments: 3-D Modeling of Basin Evolution

Much of the volcanic sediment transferred from the submarine flanks of volcanic islands (and sediments from continental margins) into adjacent basins, and thence to the abyssal plain, will be transported by slumps, slides, debris flows and turbidites. One of the key questions centers around the relative volume fraction of proximal debris flows, and distal turbidites, both originating from the same event. We know from previous studies that debris flows are common around the Canary Islands, whilst the MAP is composed of distal turbidites. Thus we have a unique opportunity to combine data on proximal and distal flows to determine sediment budgets for the whole basin.

To determine sediment budgets for material transferred from the submarine and subaerial stages of the Canary Islands by volcanic processes and erosion, as well as for filling of the abyssal plain, it will be necessary to (a) drill the different facies areas of the apron on the two contrasting sedimentary basins north and south of Gran Canaria as well as the abyssal plain, (b) identify the volcanic-rich turbidites and their source areas, (c) obtain a nannofossil stratigraphy from the turbidites, (d) radiometrically date their volcanic minerals, and (e) estimate the area covered by individual flows from seismic data as was done for several recent turbidites by Weaver and Rothwell (1987).

Isopach maps for each sedimentary unit through the last 300,000 years have allowed us to calculate the volumes of material in each flow, showing that the largest turbidites have volumes on the order of 190 km^3 (Weaver and Rothwell, 1987). A consistent pattern has emerged, with turbidites thickening either to the east or the west and being fairly constant from north to south. Since we know the boundaries of the plain, back in time through our dense seismic grid, we will be able to extrapolate from the measured thicknesses of each turbidite in each of the three drill sites. Identification of the same turbidite in different cores is based upon the fact that each one usually has its own microfossil and geochemical signature.

The proposed drilling operation and available seismic data will provide an excellent database for 3-D modeling of the clastic aprons of Gran Canaria and Tenerife and the whole Canary Basin. The limited size of the clastic apron, the high-resolution stratigraphy from detailed pre-site surveys, and the drilling, together with identification of sediment geometry from seismic surveys, and point source of sediment fluxes, will facilitate the development of a model. The main topic is the reconstruction of the system, i.e., sediment source, dispersion, and fill, the history of deposition of the clastic apron, continental margin, and abyssal plain. From these data it will be possible to calculate the transport of components such as organic carbon.

Model development will include 1) a database of all available data with spatial and time coordinates, 2) end-member modeling of various sedimentological, geochemical, and petrological parameters to specify sediment-source relations within the stratigraphic framework, 3) a time series approach based on the recovered material to analyze and correlate series of volcanic and sedimentary events with emphasis on the major volcanic input-pulses (volcanic cycles) building up the volcaniclastic apron, 4) areal and volume modeling of the different stratigraphic units (cycles) including seismic results using geostatistics and other volume-modeling techniques, and 5) a reconstruction of the apron-building history compared to the Gran Canaria deroofing, and calculation of the sediment budget by stacking of single stratigraphic units to reconstruct the spatial evolution of the volcaniclastic apron in an overlay model. Numerical simulation of volcaniclastic dispersion and deposition from the central volcanic area will be based on volcanological parameters (eruption styles, eruption intensities, etc.) and comparison to the reconstruction.

Response of the Lithosphere to Loading and Heating during Magmatic Activity and Enhanced Levels of Stress Associated with Temporal Changes in Plate Dynamics

The bathymetry around oceanic intraplate volcanic complexes is determined by 1) the density-, thickness-, and age-dependent static equilibrium of underlying oceanic basement, 2) subsidence by loading with the volcanic edifices and their volcaniclastic aprons (e.g., Watts and ten Brink, 1989), 3) subsidence by loading with continent-derived sediments, and 4) uplift by reheating of the lithosphere due to thermal anomalies in the mantle associated with intraplate volcanism or by dynamic uplift. In the case of the Canary Islands, the relative scale of these effects is a matter of ongoing debate. The zone of intraplate deformation offers the prospect of making quantitative progress in the study of lithospheric response to enhanced levels of stress associated with temporal changes in plate dynamics.

Identification of marker beds enables volumetric interpretations and reconstruction of the three-dimensional structure of the volcaniclastic apron, which in turn allows deduction of the spatial and temporal response of the lithosphere/mantle system (intraplate deformation and mechanics of flexure) to gravitational loading. The sediment aprons around the islands preserve direct and indirect evidence of volcano growth and vertical movements. VICAP-MAP will study the interplay of vertical loading and in-plane stresses using high-resolution data on the temporal evolution of the area. For this purpose, the flexural behavior of the lithosphere using depth-dependent rheologies and variations in stress level associated with this particular tectonic setting will be modeled using state-of-the-art numerical modeling techniques.

DRILLING PLAN/STRATEGY

Locations and descriptions of the proposed MAP and VICAP sites are given in Table 1 and shown in Figures 12 and 2, respectively.

Madeira Abyssal Plain Sites (MAP)

The MAP sites, proposed sites MAP-1, MAP-3, and MAP-4, will focus on the far distal facies of Canary Islands volcaniclastic sediments intercalated with detritus derived from Madeira, the Atlantis-Meteor seamount complex, and the West African continental slope.

Proposed site MAP-1 has been chosen in an area where all the seismic reflector units are well developed. The site also lies in a fracture zone valley which, throughout its history, has had a connection through to the continental rise to the east. Thus, as far as we can tell, there has never been an obstruction to turbidity-current flow. This ensures that the base of each seismic unit should be datable at its oldest point (particularly important where units may onlap onto basement highs). This site, therefore, provides the best opportunity to ascertain the relationship of turbidite input to sea-level change and Canary Island development. MAP-1 is located 25 km to the west-southwest of the site of a 34-m-long giant piston core, MD10, which contains a complete turbidite sequence through the last 690 k.y. (isotope stages 1 to 17) including turbidites A to U. The average accumulation rate of the sediments recovered in this giant piston core is 50 m/m.y. Proposed site MAP-3 will be located proximally near the base of the Lower Continental Rise, at a water depth of 5430 m, and will encounter turbidites with silty and sandy bases. Experience suggests that, in this area, no more than 30% of each turbidite will be coarse, and thus we hope to achieve good recovery. The site has been chosen to identify one of two possible entry routes for turbidites into the abyssal plain (one from the south and one from the north) by examination of the thickness and coarseness of basal layers of each turbidite.

Proposed site MAP-4 is located to the north of the central basin (5440 m water depth) in an area where additional small turbidites are common. It will provide information on the thickness of both large and small turbidites.

Seismic units on the abyssal plain are well known. Units C and D probably represent pelagic clay with an average of 200-m thickness and an average accumulation rate in excess of 2.2 m/m.y. The top two units (A and B) are both regarded as turbidites. Unit B is about 225 m thick and less well stratified with fewer reflectors than Unit A, which averages about 125 m in thickness and is strongly laminated. Searle (1987) showed that Units A and B are conformable, while Unit A/B is unconformable on the underlying Unit C.

We will drill beyond the base of the turbidite sequence, identified on the seismic profiles, in one site so as to identify the earlier sediment types and look for isolated turbidites which may be related to early development of the Canary Islands.

Drilling of three sites will allow calculations to be made of volumes of individual sediment flows which can be used to determine sediment budgets for the whole Canary Basin. This set of sites would allow the first mapping of the buildup of an ocean basin on a layer by layer basis, thus providing the information for calculating the volumes of sediment transported to the deep ocean per unit time. The extensive knowledge of the area already obtained will allow precise estimates of the volumes of individual turbidite flows from just the three sites. When this is combined with estimates of the amount of material deposited as debris flows on the continental rise, calculations of sediment budgets for the whole Canary Basin can be made.

Northern Sites (VICAP)

We propose to drill two sites north and northeast of Gran Canaria. Proposed site VICAP-1a, and back-up proposed site VICAP-1, are located in the North Canary Basin and will be drilled to a depth of approximately 1000 mbsf in an attempt to drill through the feather edge of the basaltic shield stage and the younger volcaniclastic deposits north of Gran Canaria. Proposed site VICAP-2a, and backup proposed site VICAP-2, are located on the outermost edge of the massive island flank, i.e., the "seismic apron.". VICAP-2a will be drilled to a depth of approximately 600 mbsf to test the validity of dating initiation of the shield by the stratigraphic position of the base of the apron.

The basin sediments north of Gran Canaria are expected to reflect volcanic, erosional and sedimentation processes that differed significantly from those south of Gran Canaria. At proposed site VICAP-1a, we hope to penetrate the lowermost part of the Gran Canaria shield stage as well as part of the Fuerteventura shield aprons. These data will show if the age of volcanism in the eastern Canary islands is compatible with a hotspot location at 20 to 30 Ma and an age progression of volcanism from northeast to southwest as proposed by Holik et al. (1991). While the deposits from the submarine stage of Gran Canaria may, or may not, differ in composition and type from those in the south, the younger volcaniclastic deposits should reflect a volcanic and erosional evolution that differs appreciably from that in the south. We expect sufficient fallout layers and distal submarine equivalents of ash flows to date the deposits by single crystal laser heating because ash flows were also erupted from the northern ring fissures of the Miocene caldera but in lesser amounts. Phonolitic deposits from the Fataga Group (~13-10 Ma) should dominate. We also expect much more erosional detritus generated during the largest nonvolcanic period in the island's history between ~9 and 5 Ma. By far the largest difference should show up in the Pliocene to Holocene deposits. Primary and eroded products from the >100 km^3 Roque Nublo Stratovolcano (comparable to present-day Tenerife in size but not in composition) ash flows, lavas, debris flows, and lahars were largely channeled to the north and northeast, the thick Las Palmas clastic fan on land indicating the huge volume of these deposits. Ash layers from the Roque Nublo phase of volcanic activity (~5 - 3.5 Ma) should be abundant at the northern sites. Detritus from eroded basanitic to nephelinitic flows should dominate the volcaniclastic deposits from the last 2 m.y., probably interspersed with some fallout tephra layers from Tenerife. We do not expect thick volcaniclastic apron deposits from Tenerife at these sites, however.

Southern Sites (VICAP)

We propose to drill two holes southeast and southwest of Gran Canaria in the South Canary Basin. Proposed site VICAP-4 is located south-southeast of Gran Canaria. This site will be drilled to a depth of approximately 600 mbsf to determine the thickness of the volcaniclastic deposits (i.e., the medial facies). DSDP Site 397, located farther south, will be used as a reference site for the distal facies. An attempt will be made to verify the correlation of DSDP Site 397 stratigraphy with the MCS M16-4 and M 24 records in the deep part of the South Canary Basin well away from the continental slope. Proposed site VICAP-7 is located southwest of Gran Canaria. This site will be drilled to an approximate depth of 700 mbsf in an attempt to identify and determine the thickness of the Gran Canaria shield stage and the younger Gran Canaria and Tenerife deposits (the medial facies).

Proposed site VICAP-5 (backup site) will be drilled to a depth of approximately 300 mbsf and will penetrate the volcaniclastic deposits (proximal facies) south of Gran Canaria. The site is located at the continuation of a large on-land canyon. By drilling this site, we aim to determine the sedimentation rates for a major drainage system that has operated since the Miocene shield stage (~14 Ma). Proposed backup site VICAP-8 is located southwest of Gran Canaria and directly south of Tenerife. This site will be drilled to an approximate depth of 1300 mbsf and furthers the primary objective at proposed site VICAP-7, identifying and establishing the thickness of the Gran Canaria shield stage and the younger Gran Canaria and Tenerife deposits.

These sites should provide a fairly complete sequence of volcaniclastic deposits derived from the submarine and southern subaerial volcanic stages, especially many submarine equivalents of the abundant voluminous ash flows that entered the sea along the paleocoastline of the island between ~14 and 10 Ma, as well as younger fallout layers. The seismic lines available show a clear separation of an upper and lower group of sediments, interpreted as the main boundary between the bulk of the submarine growth stage of the Gran Canaria volcaniclastic apron, overlain by younger volcaniclastic Gran Canaria apron deposits (subaerial stages?) and the much younger Tenerife volcaniclastic apron, distinguishable by age and composition from those derived from Gran Canaria. The excellent recovery of Miocene and younger fallout ash layers at ODP Sites 369 and 397, southeast of Gran Canaria, makes us confident that many ash layers will be recovered. Proposed site VICAP-4 is an important link to correlate information from Site 397, drilled on DSDP Leg 47A, to the more proximal sites of Leg 157. Abundant fallout tephra (ash) layers and distal submarine extensions of ash flows that entered the sea at the southwestern coast of Tenerife during the past 2 m.y. should dominate the uppermost part of the sections, because the sites are downwind from the island.

Cross-Channel Sites (VICAP)

One second priority site may be drilled to establish a correlation between North and South Canary Basin across the channel separating Gran Canaria from Fuerteventura (proposed site VICAP-3). VICAP-3 will be drilled to a depth of approximately 700 mbsf through a sediment pocket unconformably overlying irregular volcanic relief (extension of Fuerteventura?) in an attempt to correlate North to South Canary Basin stratigraphy across channel.

Logging Strategy

The standard three tool strings, Quad-Combination, Geochemical, and Formation Microscanner, have been selected for Leg 157 holes drilled over 400 mbsf. In holes less than 400 mbsf, logging will occur where it assists in meeting the scientific objectives of the site (primary site MAP-3 and alternate site VICAP-5). The tools are described briefly below; more information on the tools exists in the ODP Wireline Logging Manual, published by Lamont-Doherty Earth Observatory of Columbia University.

Quad Combination Tool String: This will be the first logging tool string to be run in the hole, measuring formation velocity, resistivity, density, and natural gamma-ray activity in a single logging pass. Sonic velocity data are combined with density measurements to calculate an impedance log and generate synthetic seismograms. These wavelet logs are used to directly tie the seismic information to the logs and core data. The density and resistivity logs are valuable for lithologic information on the hole. This tool string also provides continuous physical property measurements of density and porosity at half-foot (0.1524 m) intervals with or at 1-in. (.025-m) and 2-in. (.05-m) measurements of density and porosity, respectively, when logged in the "high-resolution" logging mode.

Geochemical Tool String: The geochemical tool string measures relative concentrations of Si, Ca, Fe, S, H, and Cl and wet weight percentages of K, U, Th, and Al on the ship. Later shore-based processing produces dry weight percentages of these elements along with Gd and Ti. These chemical logs provide lithologic information from the hole. Matrix inversion programs are available at the shore-based log analysis centers for more detailed processing. Continuous chemical measurements from this tool are made every 0.1524 m. This tool is planned for all logged sites in this leg. The preliminary results of this tool will be reviewed after logging the first VICAP site (VICAP-1A), and a decision will be made whether or not this tool contributes to the scientific objectives of all remaining VICAP sites.

Formation Microscanner: The FMS provides oriented, two-dimensional, high-resolution images of the variations in microresistivity around the borehole wall. The string also includes a general-purpose inclinometer tool (GPIT) which measures the declination and inclination components of the Earth's magnetic field vector and allows for the orientation of the microresistivity measurements. The FMS can be used for the following applications: correlation of coring and logging depth, orientation of cores and location of the cored sections when recovery is less than 100%, mapping of sedimentary structures and interpretation of depositional environments, and providing very high-resolution resistivity measurements (3 mm) which can be transformed into high-resolution porosity and density measurements.

Due to the nature of the lithology to be encountered on this leg, calculated logging times include the use of the Sidewall Entry Sub (SES). The decision of whether or not to use this tool will be made on board the ship based on consolidation of sediments, possibility of swelling clays, occurrence of hard ledges, and general weather conditions. The use of this tool adds an additional 10 to 15 hours of logging time, but significantly reduces the risk of not obtaining logs throughout the hole, and tool loss.

Sampling Strategy

Sediment diagenesis studies of organic-rich turbidites require a dedicated sampling program. Where relict oxidation fronts are detected, 75-cm-long u-channel sampling will be required (10 examples will be studied from MAP sites). Investigation of the longevity of uranium concentrations near oxidation fronts requires closely spaced sampling through 30-cm-long intervals in at least three specific examples at the MAP sites.

Pore-water analysis is required for all MAP and VICAP sites at a frequency of one sample per core for the first 10 cores, one sample in every second core from core 10 to 200 m, and one sample in every third core from 200 m to the base of the hole.

Frequent sampling for pore water is also required at specific locations dependent on lithologies drilled, e.g., tephra layers or compositionally distinct volcaniclastic units. These will need to be selected on board and sampled after splitting of the core liner but before splitting of the core.

Up to 12 half-round samples at each VICAP site may be taken for integrated geochemical and petrological analyses (i.e., thin sections, XRF, single crystal dating, and stable and radiogenic isotope analyses). In addition, high-resolution sampling exclusively for single crystal dating will be done.

REFERENCES

Ancochea, E., Fuster, J.M., Ibarrola, E., Cendrero, A., Coello, J., Hernan, F., Cantagrel, J.M., and Jamond, C., 1990. Volcanic evolution of the island of Tenerife (Canary Islands) in the light of new K-Ar data. *J. Volcanol. Geotherm. Res.*, 44:231-249.

Banda, E., Dañobeitia, J.J., Surinach, E., and Ansorge, J., 1981. Features of crustal structure under the Canary Islands. *Earth Planet. Sci. Lett.*, 55:11-24.

Bogaard, Pvd., Schmincke, H.-U., Freundt, A., Hall, Ch., and York, D., 1988. Eruption ages and magma supply rates during the Miocene evolution of Gran Canaria: single crystal ^{40}Ar/^{39}Ar laser ages. *Naturwissenschaften*, 75:616-617.

Colley, S., and Thomson, J., 1990. Diffusion of U-series radionuclides at depth in deep-sea sediments. *Nature,* 346:260-263.

de Lange, G., Jarvis, I., and Kuijpers, A., 1987. Geochemical characteristics and provenance of late Quaternary sediments from the Madeira Abyssal Plain. *In* Weaver, P.P.E., and Thomson, J. (Eds.), *Geology and Geochemistry of Abyssal Plains*. Spec. Publ. Geol. Soc. London, 31:147-166.

Froelich, P.N., Klinkhammer, G.P., Bender, M.L., Heath, G.R., Cullin, D., Dauphin, P., Hammond, D., Hartman, B., and Maynard, V., 1979. Early oxidation of organic matter in pelagic sediments of the eastern equatorial Atlantic: suboxic diagenesis. *Geochim. Cosmochim. Acta*, 43:1075-1090.

Hoernle, K., and Schmincke, H.-U., 1993a. The petrology of the tholeiites through melilite nephelinites on Gran Canaria, Canary Islands: Crystal fractionation, accumulation, and depths of melting. *J. Petrol.*, 34:573-578.

Hoernle, K.A., and Schmincke, H.-U., 1993b. The role of partial melting in the 15 Ma geochemical evolution of Gran Canaria: A blob model for the Canary Hotspot. *J. Petrol.,* 34:599-626.

Hoernle, K.A., Tilton, G., and Schmincke, H.-U., 1991. The Sr-Nd-Pb isotopic evolution of Gran Canaria: Evidence for shallow enriched mantle beneath the Canary Islands. *Earth Planet. Sci. Lett.*, 106:44-63.

Holik, J.S., Rabinowitz, P.D., and Austin, J.A., 1991. Effects of Canary Hot Spot volcanism on structure of oceanic crust off Morocco. *J. Geophys. Res.*, 96, B7:12,039-12,067.

Jarvis, I., and Higgs, N.C., 1987. Trace-element mobility during early digenesis in distal turbidites: late Quaternary of the Madeira Abyssal Plain, N. Atlantic. *In* Weaver, P.P.E., and Thomson, J. (Eds.), *Geology and Geochemistry of Abyssal Plains*. Spec. Publ. Geol. Soc. London, 31:179-214.

Le Bas, M.J., Rex, D.C., and Stillman, C.J., 1986. The early magmatic chronology of Fuerteventura, Canary Islands. *Geol. Mag*., 123 (3):287-298.

McDougall, I., and Schmincke, H.-U., 1976. Geochronology of Gran Canaria, Canary Islands: Age of shield-building volcanism and other magmatic phases. *Bull. Volcanol.*, 40:1-21.

Moore, J.G., Clague, D.A., Holcomb, R.T., Lipman, P.W., Normark, W.R., and Torresan, M.E., 1989. Prodigious submarine landslides on the Hawaiian Ridge. *J. Geophys. Res.,* 94:17,465-17,484.

Moore, J.G., and Fiske, R.S., 1969. Volcanic substructure inferred from dredge samples and ocean-bottom photographs, Hawaii. *Geol. Soc. Am. Bull.*, 80:1191-1202.

Schmincke, H.-U., 1976. Geology of the Canary Islands. *In* Kunkel, G. (Ed.), *Biogeography and Ecology in the Canary Islands*: the Hague (W. Junk), 67-184.

Schmincke, H.-U., 1982. Volcanic and chemical evolution off the Canary Islands. *In* von Rad, U., et al. (Eds.), *Geology of the Northwest African Continental Margin*: Berlin, Heidelberg, New York (Springer Verlag), 273-306.

Schmincke, H.-U., 1987-1994. *Geology and Geological Field Guide of Gran Canaria*, editions 1-6: Kiel (Pluto Press).

Schmincke, H.-U., and von Rad, U., 1979. Neogene evolution of Canary Island volcanism inferred from ash layers and volcaniclastic sandstones of DSDP Site 397 (Leg 47A). *In* von Rad, U., Ryan, W.B.F., et al., *Init. Repts. DSDP*, 47, Part 1: Washington (U.S. Govt. Printing Office), 703-725.

Searle, R.C., 1987. Regional setting and geophysical characterization of the Great Meteor East area in the Madeira Abyssal Plain. *In* Weaver, P.P.E., and Thomson, J. (Eds.), *Geology and Geochemistry of Abyssal Plains*. Spec. Publ. Geol. Soc. London, 31:49-70.

Sorensen, J., Jorgensen, K.S., Colley, S., Hydes, D.J., Thomson, J., and Wilson, T.R.S., 1987. Depth localization of denitrification in a deep sea sediment from the Madeira Abyssal Plain. *Limnol. Oceanogr*., 32:758-762.

Staudigel, H., and Schmincke, H.-U., 1984. The Pliocene seamount series of La Palma/Canary Islands. *J. Geophys. Res.*, 89:11,195-11,215.

Thomson, J., Colley, S., Higgs, N.C., Hydes, D.J., Wilson, T.R.S., and Sorensen, J., 1987. Geochemical oxidation fronts in NE Atlantic distal turbidites and their effects in the sedimentary record. *In* Weaver, P.P.E., and Thomson, J. (Eds.), *Geology and Geochemistry of Abyssal Plains*. Spec. Publ. Geol. Soc. London., 31:167-177.

Watts, A.B., and ten Brink, U.S., 1989. Crustal structure, flexure, and subsidence history of the Hawaiian Islands. *J. Geophys. Res.*, 94:10,473-10,500.

Weaver, P.P.E., 1983. An integrated stratigraphy of the upper Quaternary of the King's Trough Flank area, NE Atlantic. *Oceanol. Acta*, 6:451-456.

Weaver, P.P.E., and Kuijpers, A., 1983. Climatic control of turbidite deposition on the Madeira Abyssal Plain. *Nature*, 306:360-363.

Weaver, P.P.E., and Rothwell, R.G., 1987. Sedimentation on the Madeira Abyssal Plain over the last 300,000 years. *In* Weaver, P.P.E., and Thomson, J. (Eds.), *Geology and Geochemistry of Abyssal Plains*. Spec. Publ. Geol. Soc. London, 31:71-86.

Weaver, P.P.E., Rothwell, R.G., Ebbing, J., Gunn, D., and Hunter, P.M., 1992. Correlation, frequency of emplacement and source directions of megaturbidites on the Madeira Abyssal Plain. *Mar. Geol.*, 109:1-20.

Weaver, P.P.E., Searle, R.C., and Kuijpers, A., 1986. Turbidite deposition and the origin of the Madeira Abyssal Plain. *In* Summerhayes, C.P., and Shackleton, N.J. (Eds.), *North Atlantic Palaeoceanography*. Spec. Publ. Geol. Soc. London, 21:131-143.

Weaver, P.P.E., Thomson, J., and Jarvis, I., 1989. The geology and geochemistry of the Madeira Abyssal Plain sediments: a review. *In* Freeman, T. (Ed.), *Advances in Underwater Technology, Ocean Science and Offshore Engineering - Disposal of Radioactive Waste in Seabed Sediments*: London (Graham and Trotman), 18:51-78.

Wilson, T.R.S., Thomson, J., Colley, S., Hydes, D.J., Higgs, N.C., and Sorensen, J., 1985. Early organic diagenesis: the significance of progressive subsurface oxidation fronts in pelagic sediments. *Geochim. Cosmochim. Acta*, 49:811-822.

Wilson, T.R.S., Thomson, J., Hydes, D.J., Colley, S., Culkin, F., and Sorensen, J., 1986. Oxidation fronts in pelagic sediments: diagenetic formation of metal-rich layers. *Science*, 232:972-975.

Wissmann, G., 1979. Cape Bojador slope, an example for potential pitfalls in seismic interpretation without the information of outer margin drilling. *In* von Rad, U., Ryan, W.B.F., et al., *Init. Repts. DSDP*, 47:Washington (U.S. Govt. Printing Office), 491-500.

TABLE 1
Time Estimates - Leg 157

Site	Latitude	Longitude	Water Depth (meters)	Sediment Cored (mbsf)	Basement Cored (mbsf)	Total Depth (mbsf)	Operating Time (days)	Logging Time (days)	Total On Site (days)	Transit Time (days)
PRIORITY 1 SITES										
Barbados Port Call (Leg 157 begins 29 July 1994)										
										6.7
MAP-1	31°09'N	25°26'W	5440	500	0	500	4.9	1.9	6.8	
										0.2
MAP-4	31°59'N	25°02'W	5440	300	0	300	3.2	0.0	3.2	
										0.3
MAP-3	30°47'N	24°24'W	5430	300	0	300	3.3	1.7	5.0	
									15.0	
										2.1
VICAP-1a	28°39'N	15°09'W	3560	1050	0	1050	9.5	2.2	11.7	
										0.1
VICAP-2a	28°27'N	15°34'W	3515	570	10	580	5.0	1.8	6.8	
										0.3
VICAP-4	27°18'N	15°13'W	2860	500	0	600	3.4	1.6	5.0	
										0.2
VICAP-7	27°27'N	16°23'W	3560	700	0	700	5.4	1.9	7.3	
									30.8	
Las Palmas Port Call (Leg 157 ends 24 September 1994)										0.3
					TOTAL DAYS	56	34.7	11.1	45.8	10.2
PRIORITY 2 SITES										
MAP-2	31°56'N	24°05'W	5430	300	0	300	3.2	0.0	3.2	n/a
VICAP-3	28°02'N	14°59'W	1540	700	0	700	4.3	1.7	6.0	n/a
VICAP-5	27°40'N	15°41'W	340	300	0	300	1.1	1.2	2.3	n/a
VICAP-8	27°16'N	16°42'W	3620	1300	0	1300	12.9	2.4	15.3	n/a
VICAP-1	28°44'N	15°04'W	3560	1000	0	1000	8.8	2.2	11.0	n/a
VICAP-2	28°34'N	15°33'W	3580	800	0	800	6.9	2.0	8.9	n/a

FIGURES

Figure 1. Location of VICAP and MAP study areas and DSDP drill sites. Isobaths in kilometers. (After Searle, 1987).

Figure 2. Map of the central Canary Islands with locations of the proposed first- and second-priority VICAP drill sites.

Figure 3. Schematic drawing of ocean island and its clastic apron. The volume of the clastic apron may exceed the volume of the island itself. The volcanic apron consists of the "seismically chaotic" flanks of the island, consisting dominantly of hard volcanic rocks including pillow lavas, pillow breccias, debris-flow deposits, and slump blocks, and the basin facies, characterized by widespread reflectors representing volcaniclastic mass-flow deposits (debris flows, turbidites) and ash fallout layers. From Schmincke (1987-1994).

Figure 4. Three schematic growth stages of a volcanic ocean island as reflected in three main types of submarine volcaniclastic rocks drilled at DSDP Site 397 (Leg 47A) ~100 km south-southeast of Gran Canaria. From Schmincke (1982).

Figure 5. General scheme of volcanic ocean island evolution showing temporal variations in magma production rate, topography, and deposits formed. From Schmincke (1987-1994).

Figure 6. Age progression of shield phases in the Canary Islands. Age data of the shields are not well constrained for most islands. Note the large number of magmatic phases on most islands. Nearly all islands have been active in historic and prehistoric times. From Schmincke (1994).

Figure 7. Schematic diagram of Gran Canaria and Tenerife shield volcanoes and volcaniclastic sediments in the volcanic apron. From Schmincke (1994).

Figure 8. Schematic representation of the submarine series on La Palma. From Staudigel and Schmincke (1984).

Figure 9. Volume-eruption rate relationship of major magmatic phases during the Miocene, Pliocene, and Quaternary (Q) volcanic cycles on Gran Canaria. Stratigraphic names are given on the right. From Hoernle and Schmincke (1993a).

Figure 10. Mg-number and total alkalis for mafic lavas from the Gran Canaria shield and later stages. From Hoernle and Schmincke (1993a).

Figure 11. Sr- and Pb-isotope variations with age of Gran Canaria volcanic rocks, and magma production rates derived from eruption rates with a correction for volume loss due to crystal fractionation. From Hoernle et al. (1991).

Figure 12. Bathymetric map of the Madeira Abyssal Plain based on numerous PDR records and interpretation of GLORIA sidescan sonar. Positions of drill sites marked.

Figure 13. Correlation of cores along a north-south transect across the Madeira Abyssal Plain. Note dominance of the sequence by fine-grained turbidites and lateral continuity of major turbidite units. Turbidites are letter coded from the top.

Figure 14. Late Quaternary stratigraphy based on calcareous nannofossils. Upper figure shows combination of FAD and LAD data with acme intervals. Lower figure shows correlation of abyssal plain cores. Note similar abundances of species in the same turbidite from different cores.

Figure 15. Frequency of turbidite input to the Madeira Abyssal Plain related to the oxygen isotope stratigraphy. Timing of each turbidite shown by arrow; arrow length related to the turbidite composition: short arrows = organic-rich turbidites; medium-length arrows = volcanic-rich turbidites; long arrows = calcareous turbidites. Note that many turbidites were emplaced at oxygen isotope stage boundaries. Volumes of turbidites have been estimated from isopach maps of each flow.

Figure 16. Lithological log of giant piston core from near proposed site MAP-1. Turbidites are letter coded from the top. Pelagic layers are assigned to oxygen isotope stages - numbers to right. (After Weaver et al., 1992).

Figure 17. Isopach map of seismic unit A/B derived from seismic profile data. This unit represents the turbidite fill of the abyssal plain. Contours in meters.

Figure 18. Metal relocations around fossil oxidation fronts in two separate turbidites (E and F) (after Jarvis and Higgs, 1987).

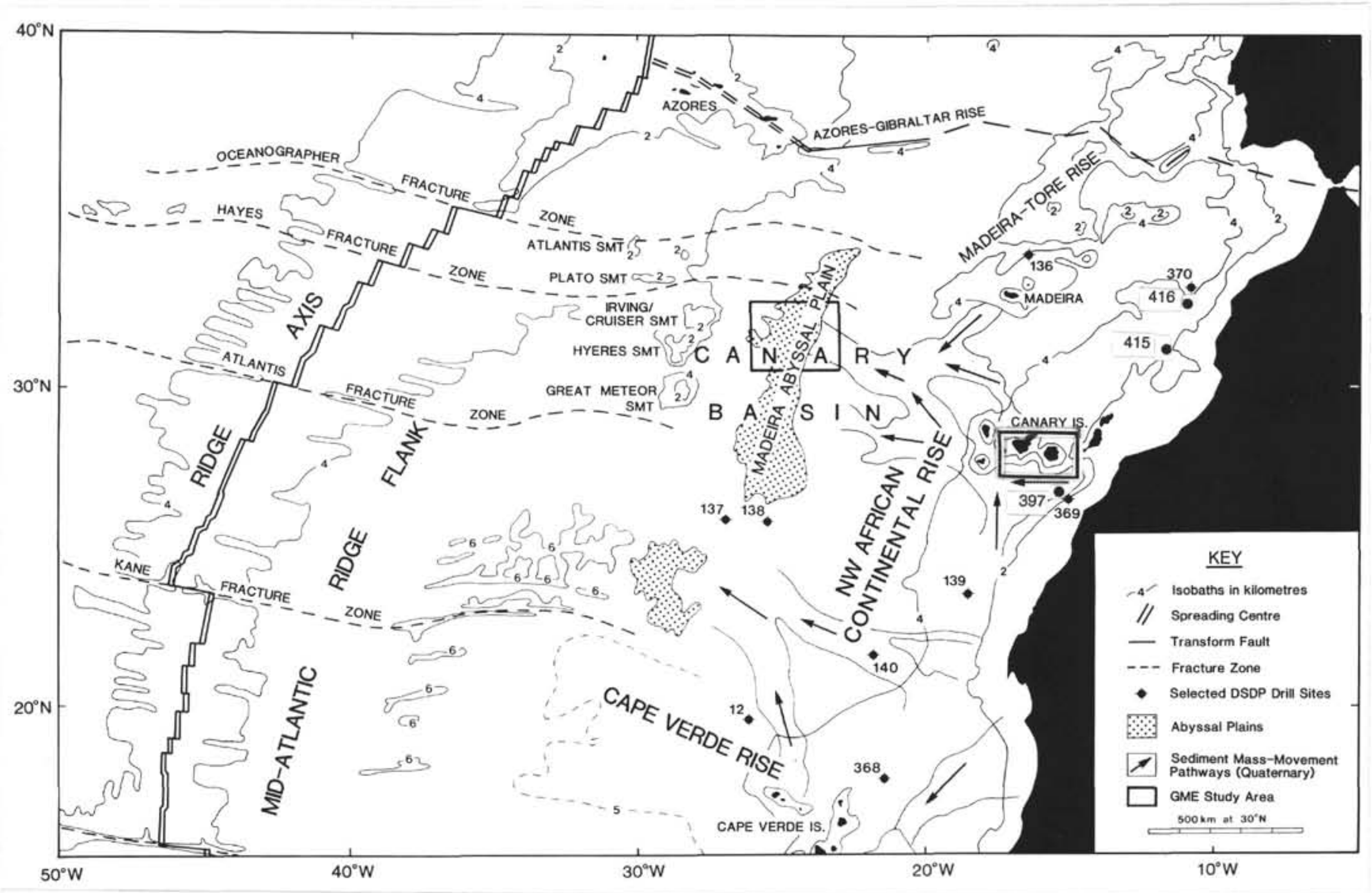

40°N
30°N
20°N
50°W
40°W
30°W
20°W
10°W
AZORES
AZORES-GIBRALTAR RISE
OCEANOGRAPHER
FRACTURE
ZONE
HAYES
FRACTURE
ZONE
ATLANTIS SMT
PLATO SMT
IRVING/
CRUISER SMT
HYERES SMT
GREAT METEOR
SMT
ATLANTIS
FRACTURE
ZONE
KANE
FRACTURE
ZONE
MID-ATLANTIC
RIDGE
AXIS
RIDGE
FLANK
CANARY
BASIN
MADEIRA ABYSSAL PLAIN
MADEIRA-TORE RISE
MADEIRA
136
370
416
415
CANARY IS.
397
369
NW AFRICAN
CONTINENTAL RISE
137
138
139
140
12
368
CAPE VERDE RISE
CAPE VERDE IS.
KEY
Isobaths in kilometres
Spreading Centre
Transform Fault
Fracture Zone
Selected DSDP Drill Sites
Abyssal Plains
Sediment Mass-Movement Pathways (Quaternary)
GME Study Area
500 km at 30°N

Figure 1

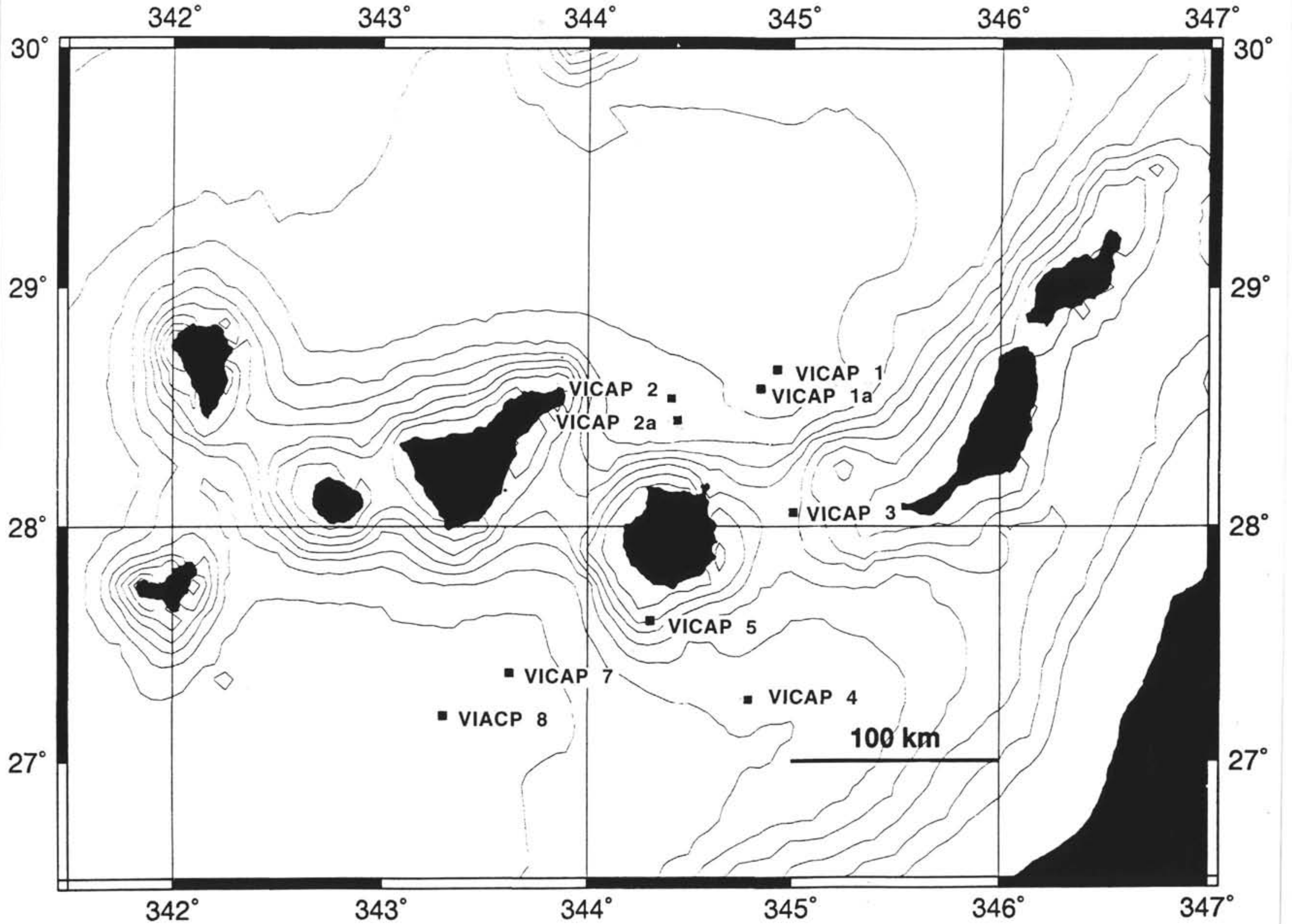

342°
343°
344°
345°
346°
347°
30°
29°
28°
27°
VICAP 1
VICAP 1a
VICAP 2
VICAP 2a
VICAP 3
VICAP 5
VICAP 7
VICAP 4
VIACP 8
100 km

Figure 2

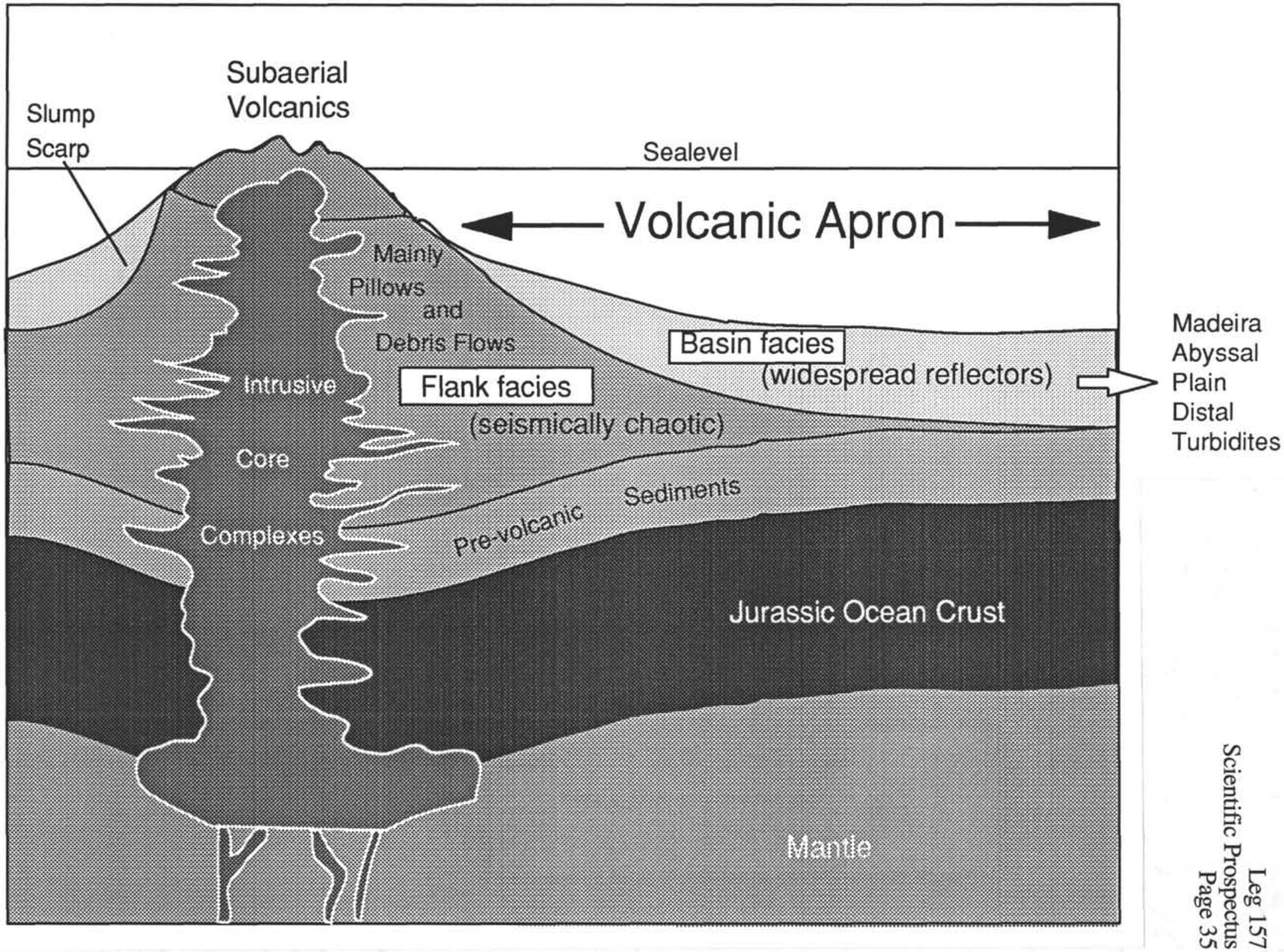

Subaerial Volcanics
Slump Scarp
Sealevel
Volcanic Apron
Mainly Pillows and Debris Flows
Intrusive Core Complexes
Flank facies
(seismically chaotic)
Basin facies
(widespread reflectors)
Madeira Abyssal Plain Distal Turbidites
Pre-volcanic Sediments
Jurassic Ocean Crust
Mantle

Figure 3

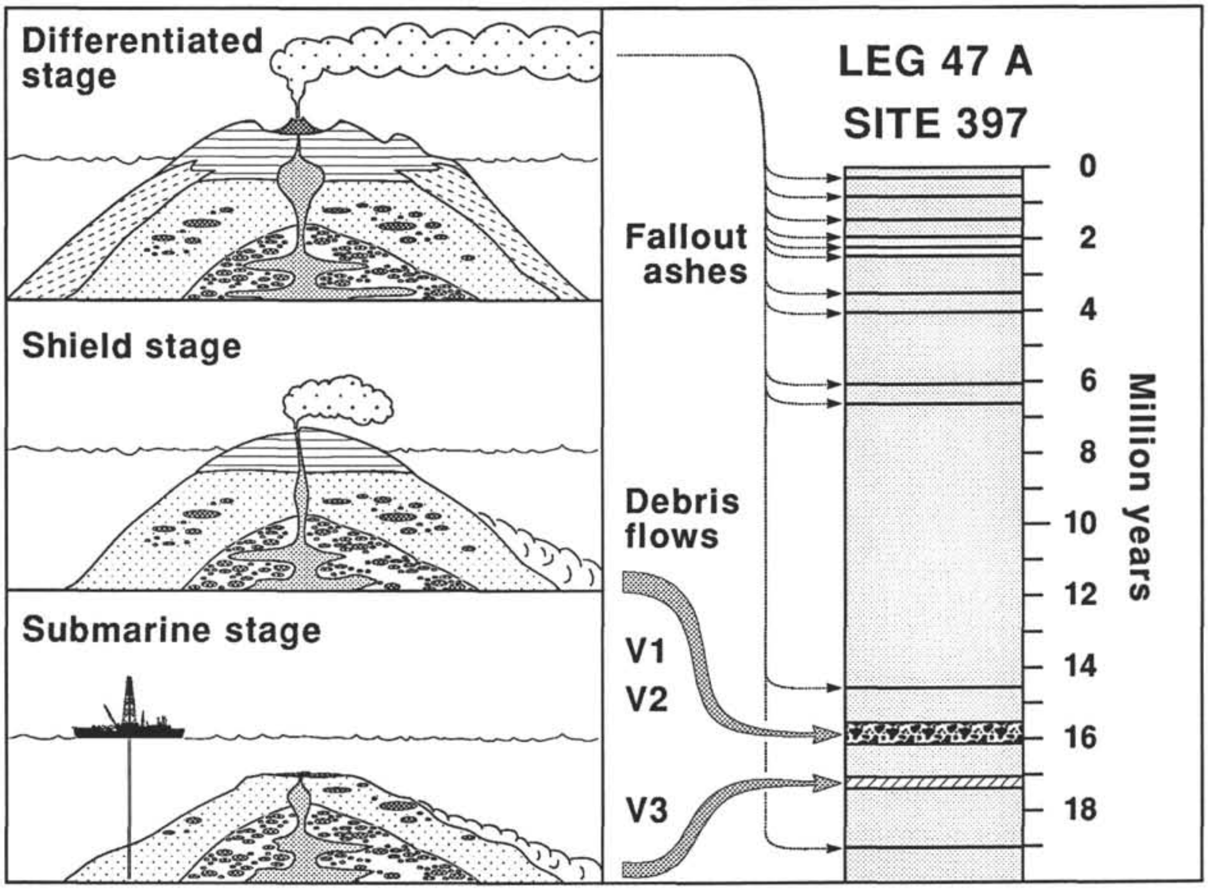

Differentiated stage
Shield stage
Submarine stage
Fallout ashes
Debris flows
V1
V2
V3
LEG 47 A
SITE 397
0
2
4
6
8
10
12
14
16
18
Million years

Figure 4

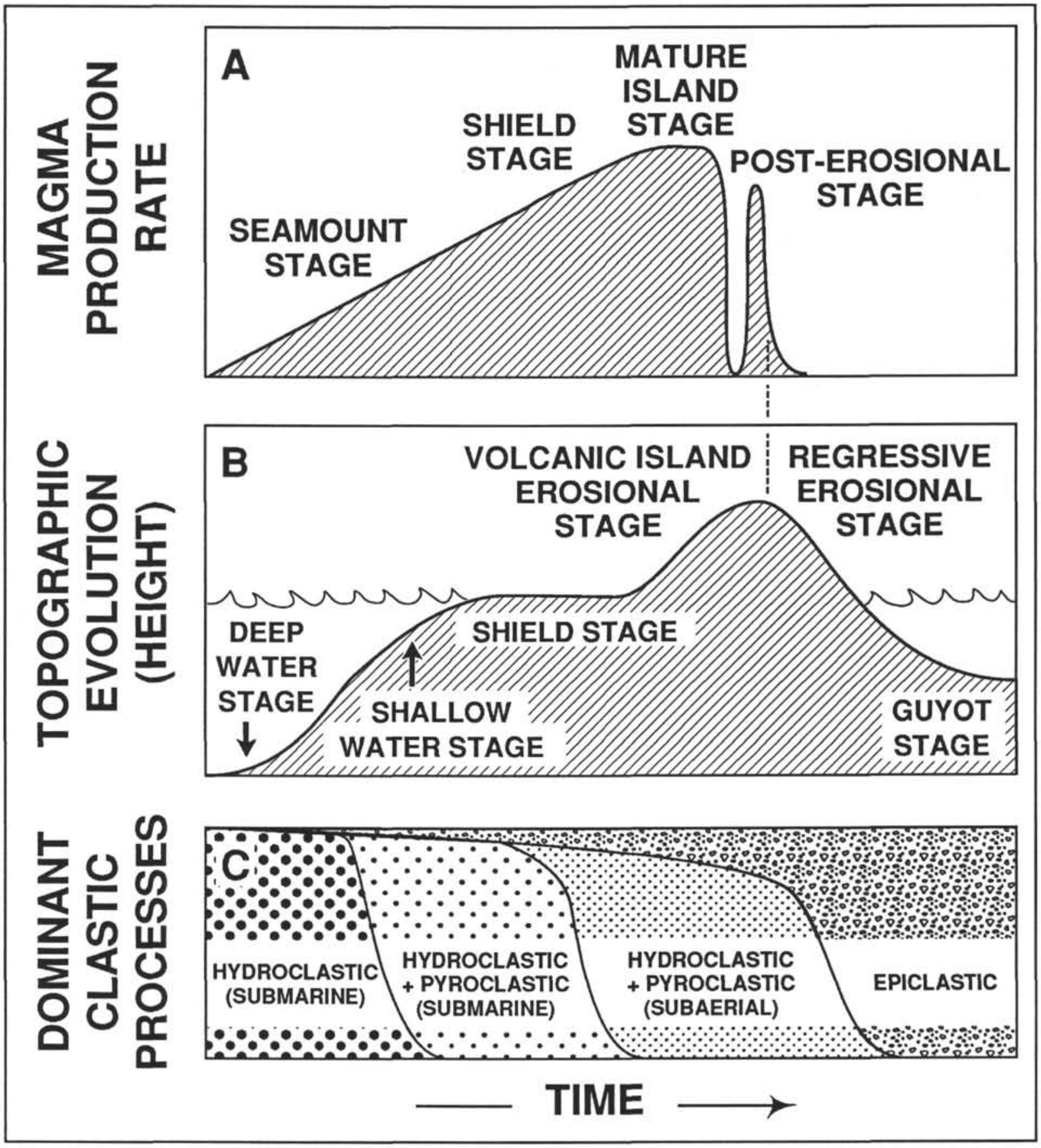

MAGMA PRODUCTION RATE
A
SEAMOUNT STAGE
SHIELD STAGE
MATURE ISLAND STAGE
POST-EROSIONAL STAGE
TOPOGRAPHIC EVOLUTION (HEIGHT)
B
VOLCANIC ISLAND EROSIONAL STAGE
REGRESSIVE EROSIONAL STAGE
DEEP WATER STAGE
SHIELD STAGE
SHALLOW WATER STAGE
GUYOT STAGE
DOMINANT CLASTIC PROCESSES
C
HYDROCLASTIC (SUBMARINE)
HYDROCLASTIC + PYROCLASTIC (SUBMARINE)
HYDROCLASTIC + PYROCLASTIC (SUBAERIAL)
EPICLASTIC
TIME

Figure 5

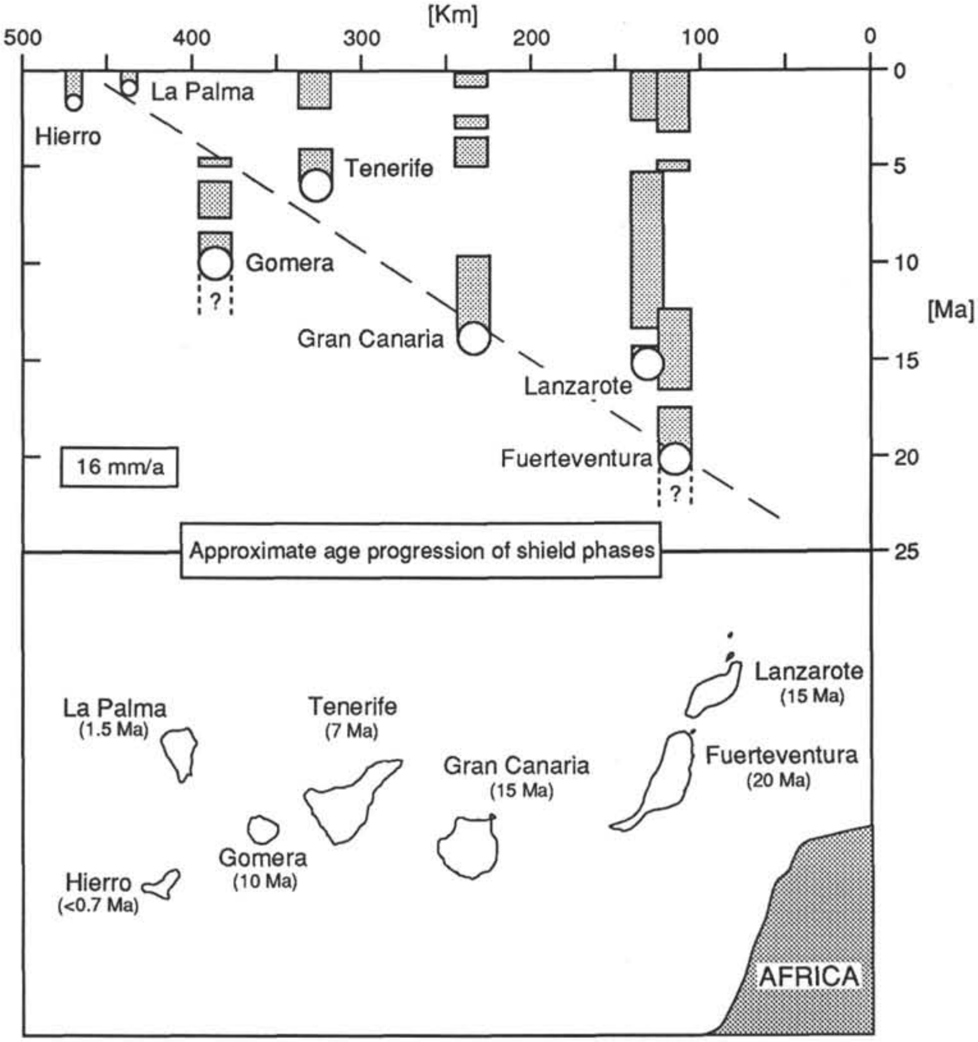

[Km]
500
400
300
200
100
0
[Ma]
0
5
10
15
20
25
Hierro
La Palma
Tenerife
Gomera
?
Gran Canaria
Lanzarote
Fuerteventura
?
16 mm/a
Approximate age progression of shield phases
La Palma
(1.5 Ma)
Tenerife
(7 Ma)
Gran Canaria
(15 Ma)
Lanzarote
(15 Ma)
Fuerteventura
(20 Ma)
Gomera
(10 Ma)
Hierro
(<0.7 Ma)
AFRICA

Figure 6

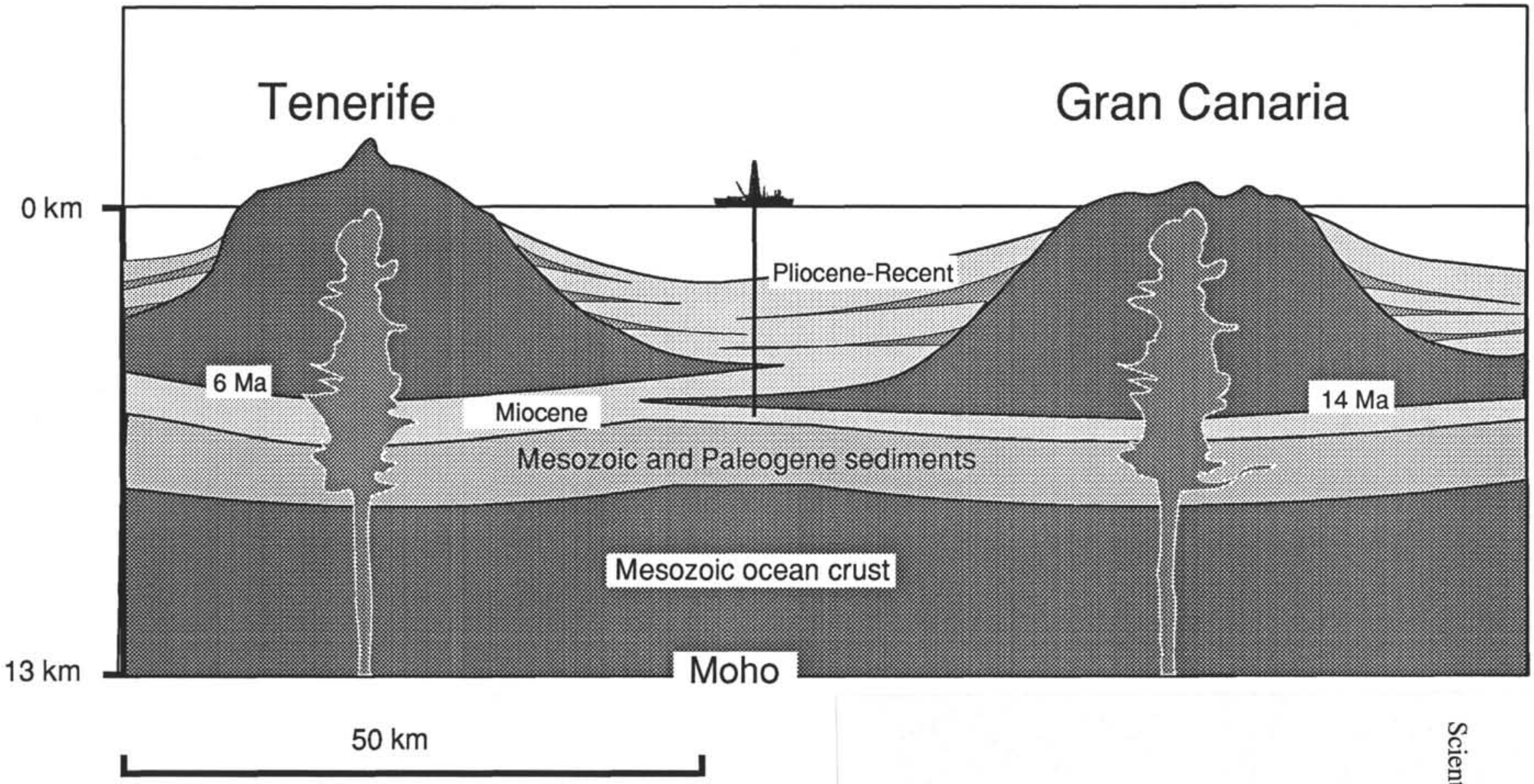

Tenerife
Gran Canaria
0 km
13 km
Pliocene-Recent
6 Ma
Miocene
14 Ma
Mesozoic and Paleogene sediments
Mesozoic ocean crust
Moho
50 km

Figure 7

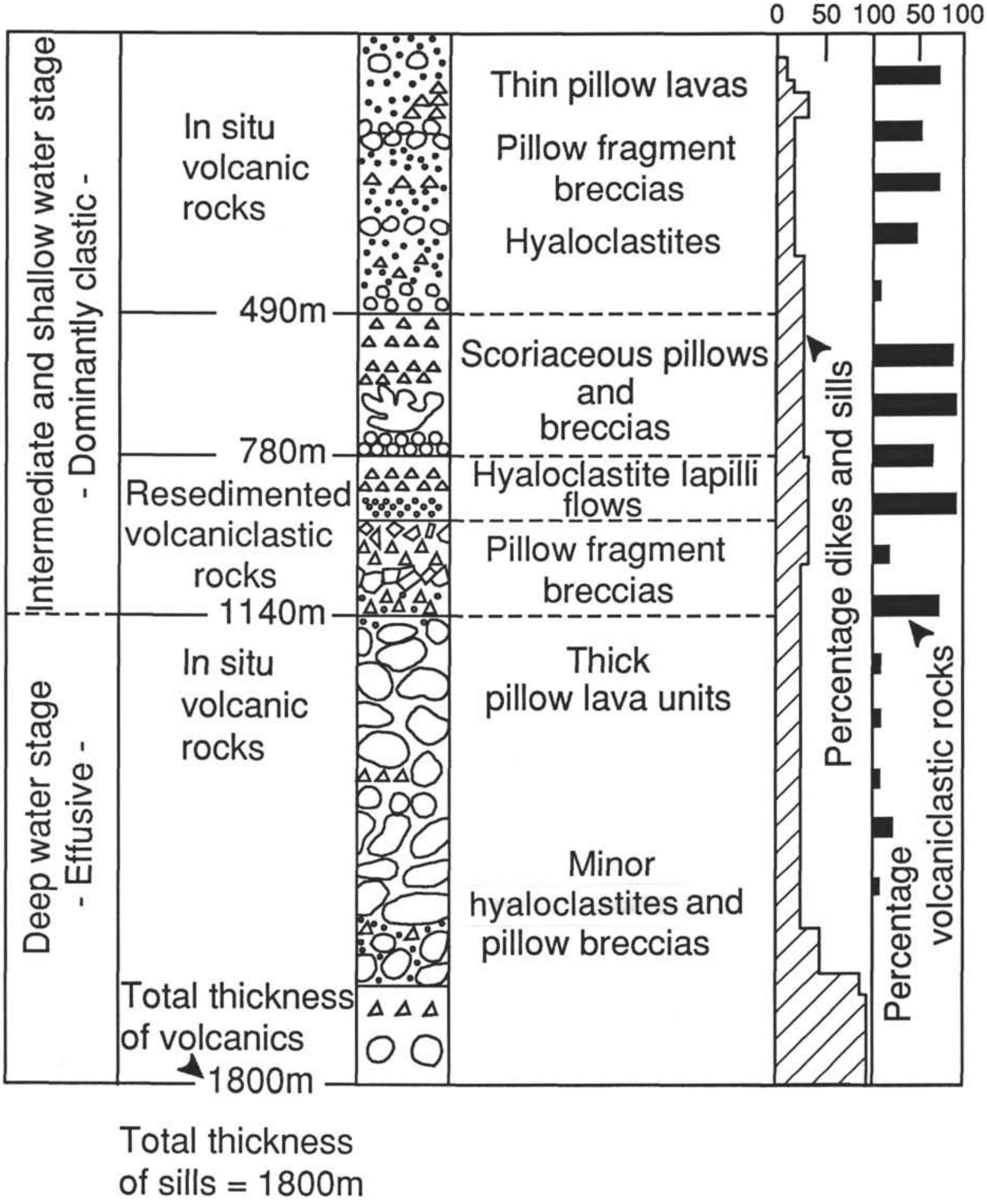

0 50 100 50 100
Intermediate and shallow water stage
- Dominantly clastic -
Deep water stage
- Effusive -
In situ
volcanic
rocks
490m
780m
Resedimented
volcaniclastic
rocks
1140m
In situ
volcanic
rocks
Total thickness
of volcanics
1800m
Total thickness
of sills = 1800m
Thin pillow lavas
Pillow fragment
breccias
Hyaloclastites
Scoriaceous pillows
and
breccias
Hyaloclastite lapilli
flows
Pillow fragment
breccias
Thick
pillow lava units
Minor
hyaloclastites and
pillow breccias
Percentage dikes and sills
Percentage
volcaniclastic rocks

Figure 8

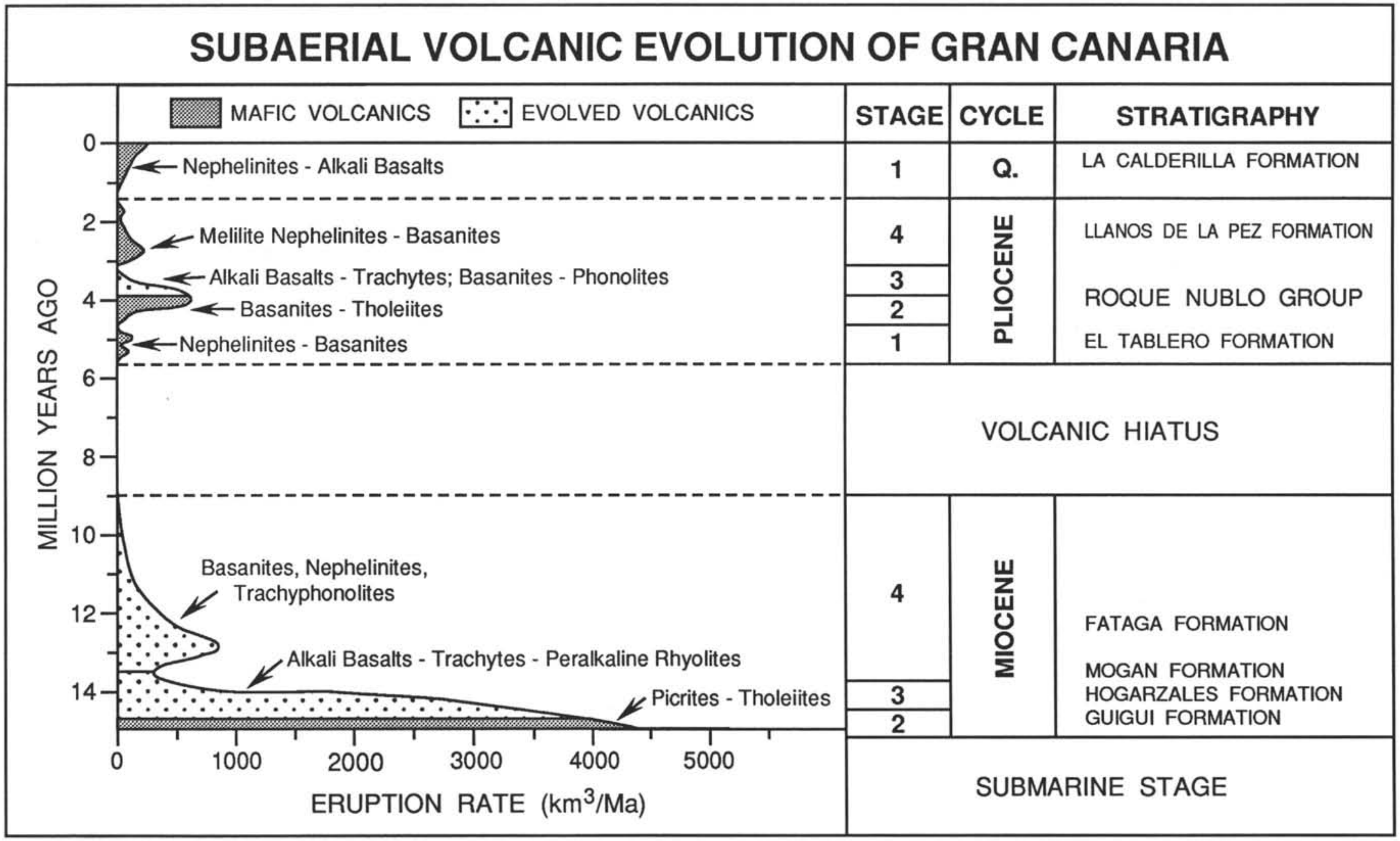

SUBAERIAL VOLCANIC EVOLUTION OF GRAN CANARIA
MAFIC VOLCANICS
EVOLVED VOLCANICS
MILLION YEARS AGO
0
2
4
6
8
10
12
14
ERUPTION RATE (km³/Ma)
0
1000
2000
3000
4000
5000
Nephelinites - Alkali Basalts
Melilite Nephelinites - Basanites
Alkali Basalts - Trachytes; Basanites - Phonolites
Basanites - Tholeiites
Nephelinites - Basanites
Basanites, Nephelinites, Trachyphonolites
Alkali Basalts - Trachytes - Peralkaline Rhyolites
Picrites - Tholeiites
STAGE
CYCLE
STRATIGRAPHY
1
Q.
LA CALDERILLA FORMATION
4
3
2
1
PLIOCENE
LLANOS DE LA PEZ FORMATION
ROQUE NUBLO GROUP
EL TABLERO FORMATION
VOLCANIC HIATUS
4
3
2
MIOCENE
FATAGA FORMATION
MOGAN FORMATION
HOGARZALES FORMATION
GUIGUI FORMATION
SUBMARINE STAGE

Figure 9

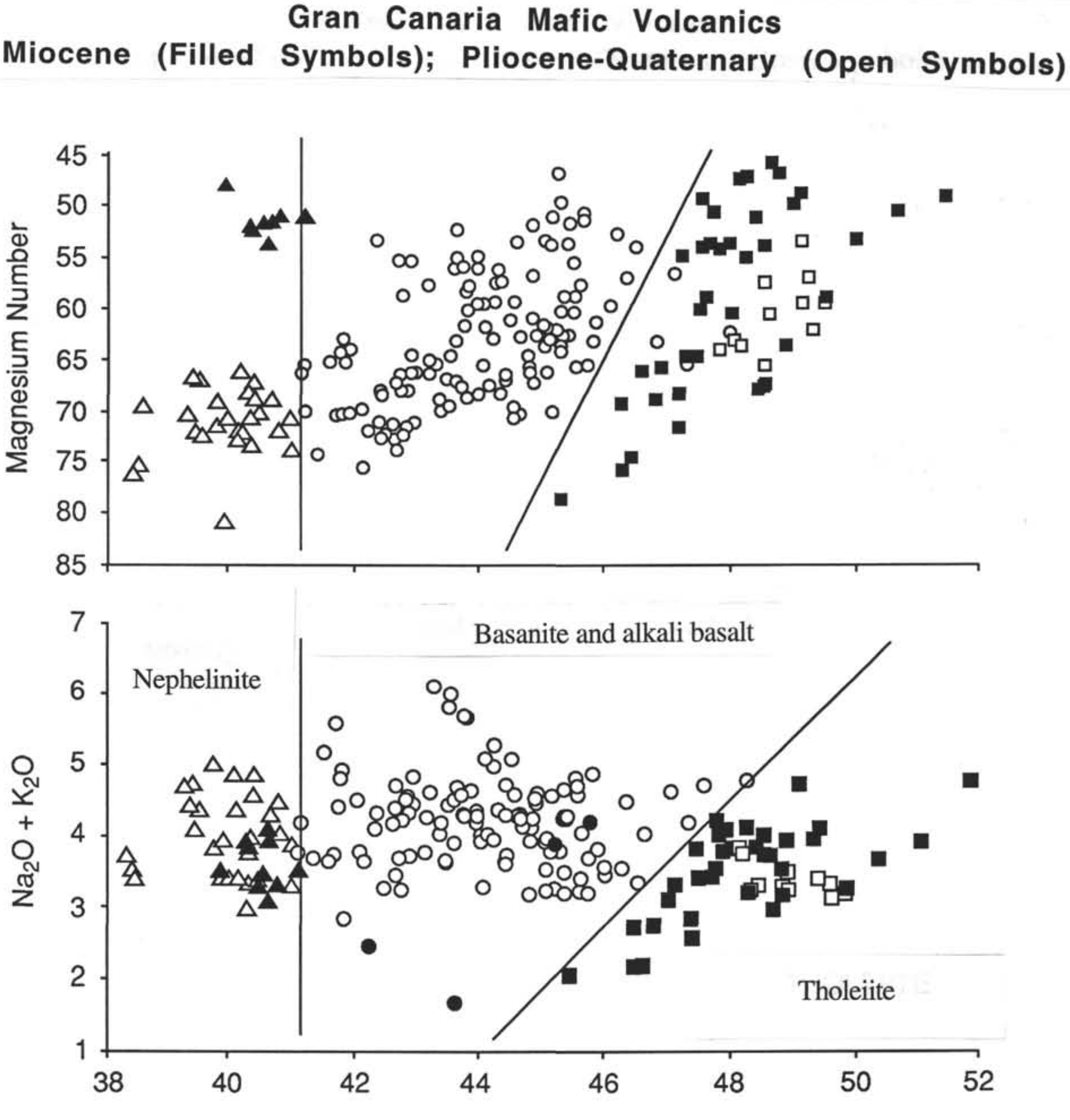

Gran Canaria Mafic Volcanics
Miocene (Filled Symbols); Pliocene-Quaternary (Open Symbols)
Magnesium Number
45
50
55
60
65
70
75
80
85
$Na_2O + K_2O$
7
6
5
4
3
2
1
Nephelinite
Basanite and alkali basalt
Tholeiite
38
40
42
44
46
48
50
52

Figure 10

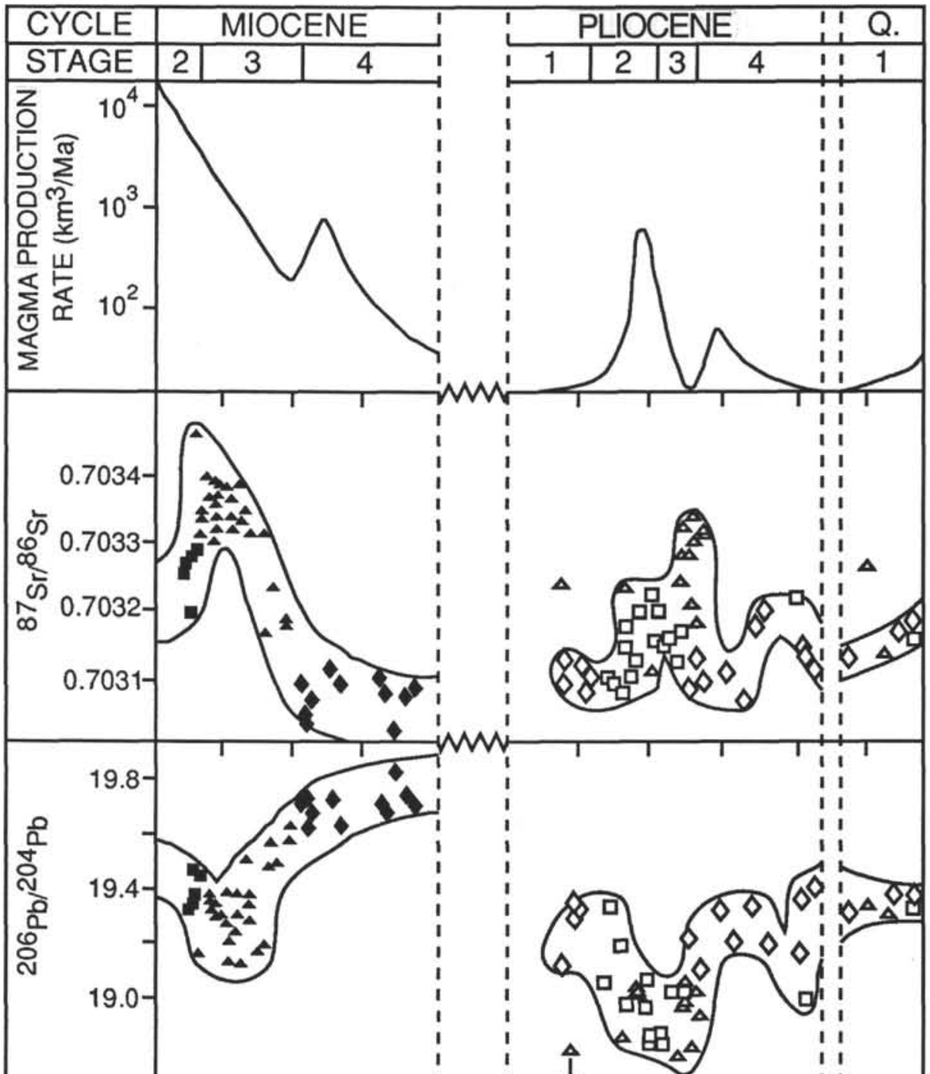

CYCLE
MIOCENE
PLIOCENE
Q.
STAGE
2
3
4
1
2
3
4
1
MAGMA PRODUCTION RATE (km³/Ma)
10⁴
10³
10²
⁸⁷Sr/⁸⁶Sr
0.7034
0.7033
0.7032
0.7031
²⁰⁶Pb/²⁰⁴Pb
19.8
19.4
19.0
15
14
13
12
11
6
5
4
3
2
1
0

Figure 11

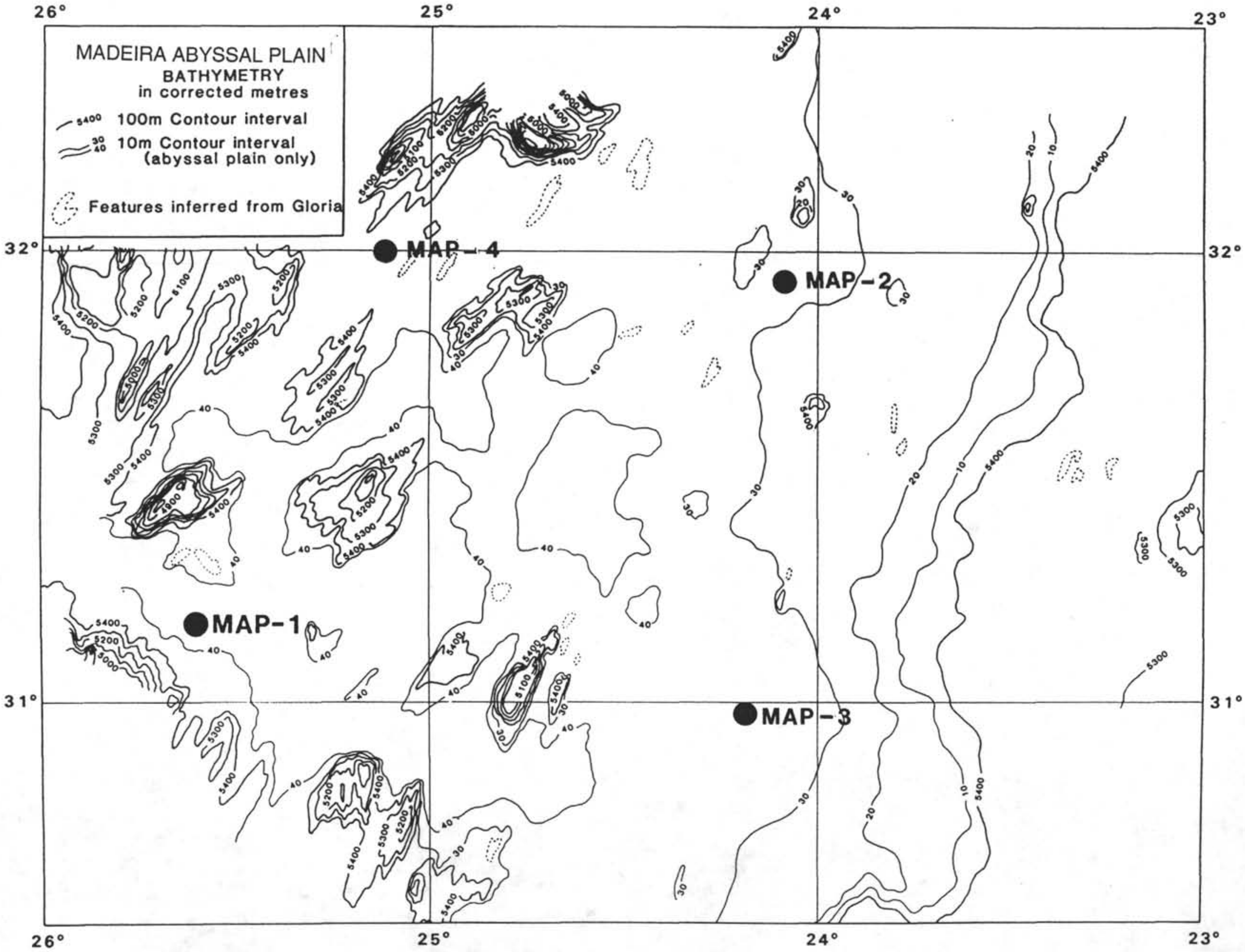

MADEIRA ABYSSAL PLAIN
BATHYMETRY
in corrected metres
5400 100m Contour interval
30 40 10m Contour interval (abyssal plain only)
Features inferred from Gloria
MAP-1
MAP-2
MAP-3
MAP-4
26°
25°
24°
23°
32°
31°

Figure 12

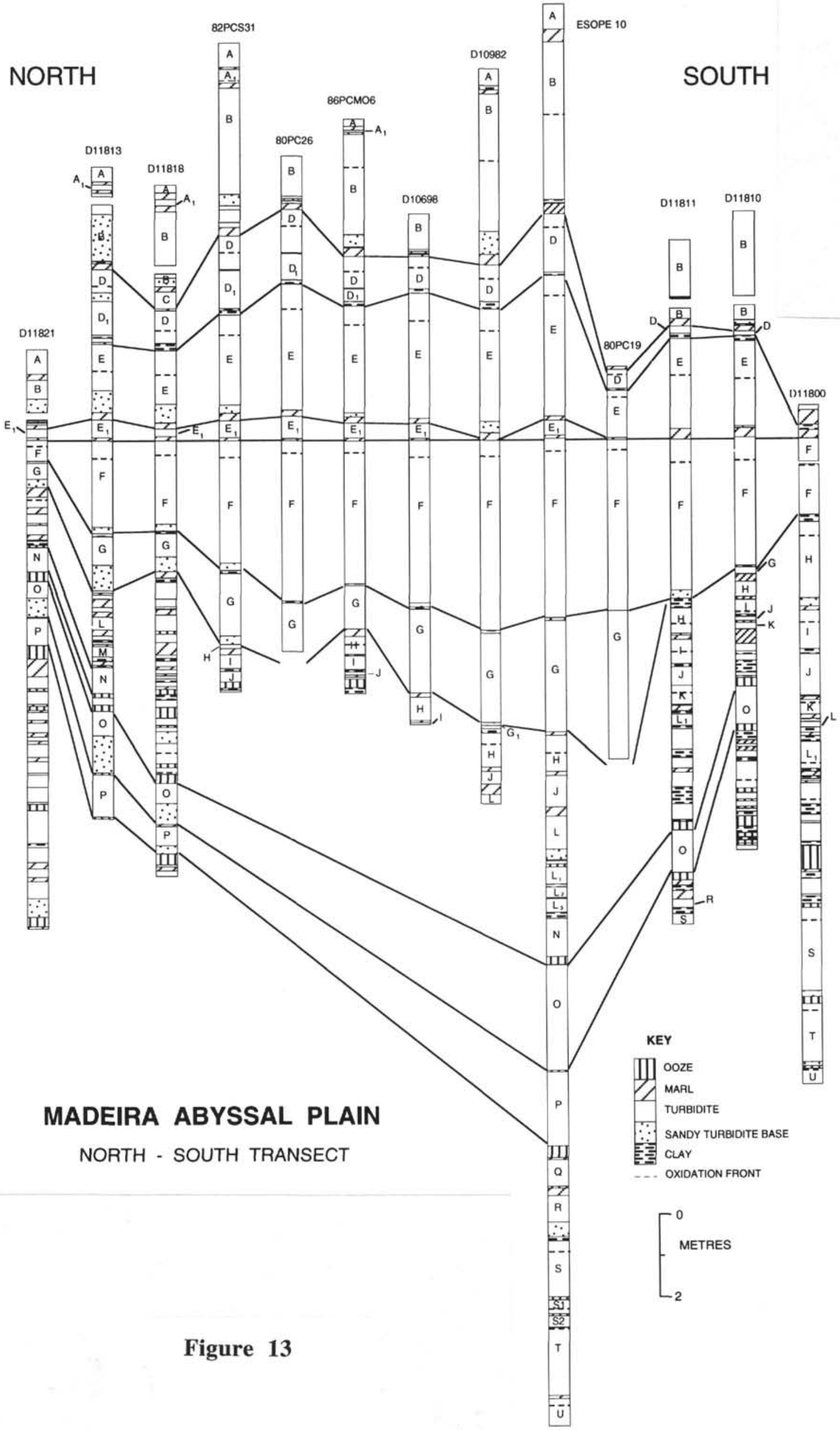

NORTH
SOUTH
D11821
D11813
D11818
82PCS31
80PC26
86PCMO6
D10698
D10982
ESOPE 10
80PC19
D11811
D11810
D11800
MADEIRA ABYSSAL PLAIN
NORTH - SOUTH TRANSECT
KEY
OOZE
MARL
TURBIDITE
SANDY TURBIDITE BASE
CLAY
OXIDATION FRONT
0
METRES
2

Figure 13

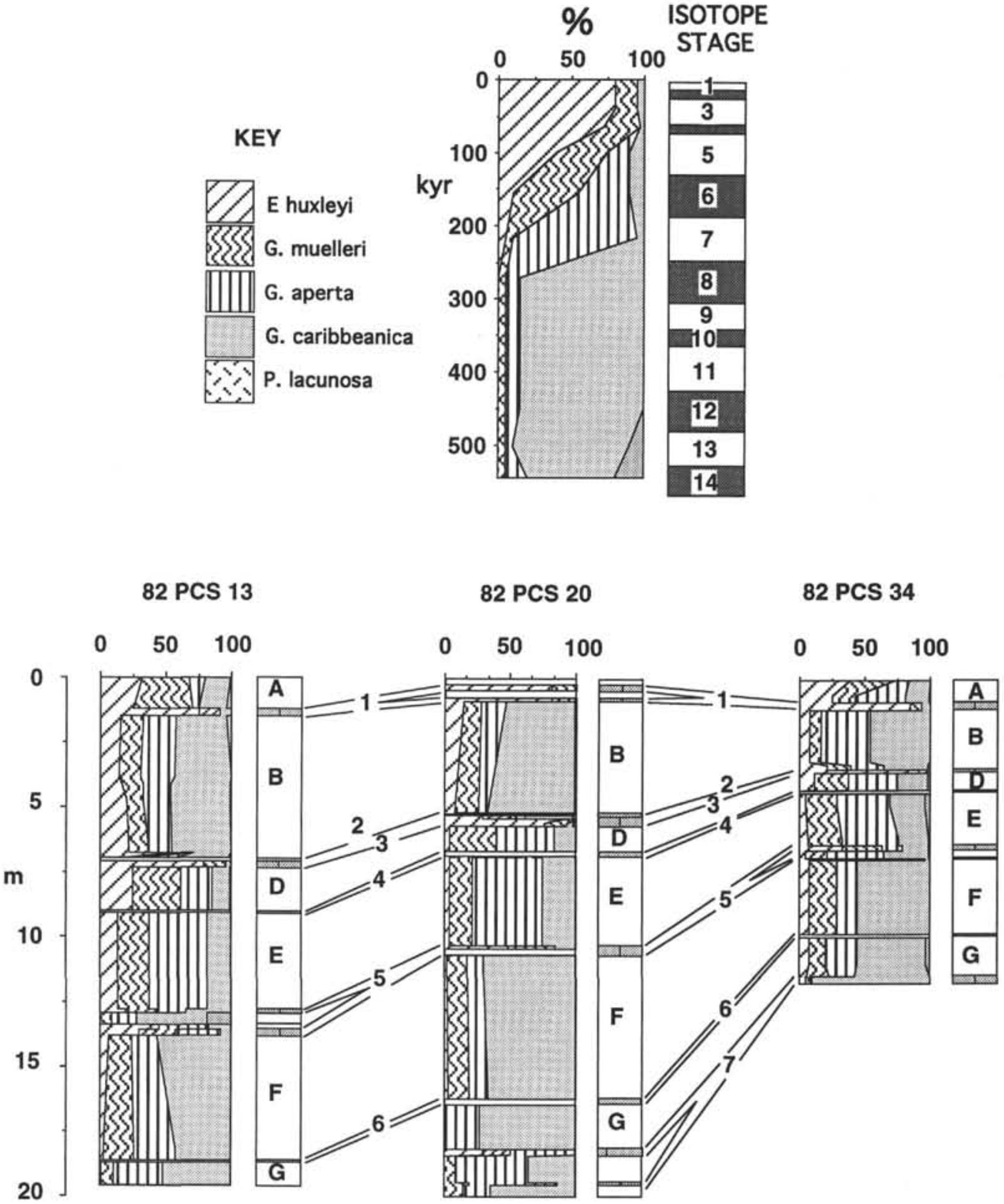

KEY
E huxleyi
G. muelleri
G. aperta
G. caribbeanica
P. lacunosa
%
0
50
100
kyr
ISOTOPE STAGE
1
3
5
6
7
8
9
10
11
12
13
14
82 PCS 13
82 PCS 20
82 PCS 34
m
A
B
D
E
F
G
1
2
3
4
5
6
7

Figure 14

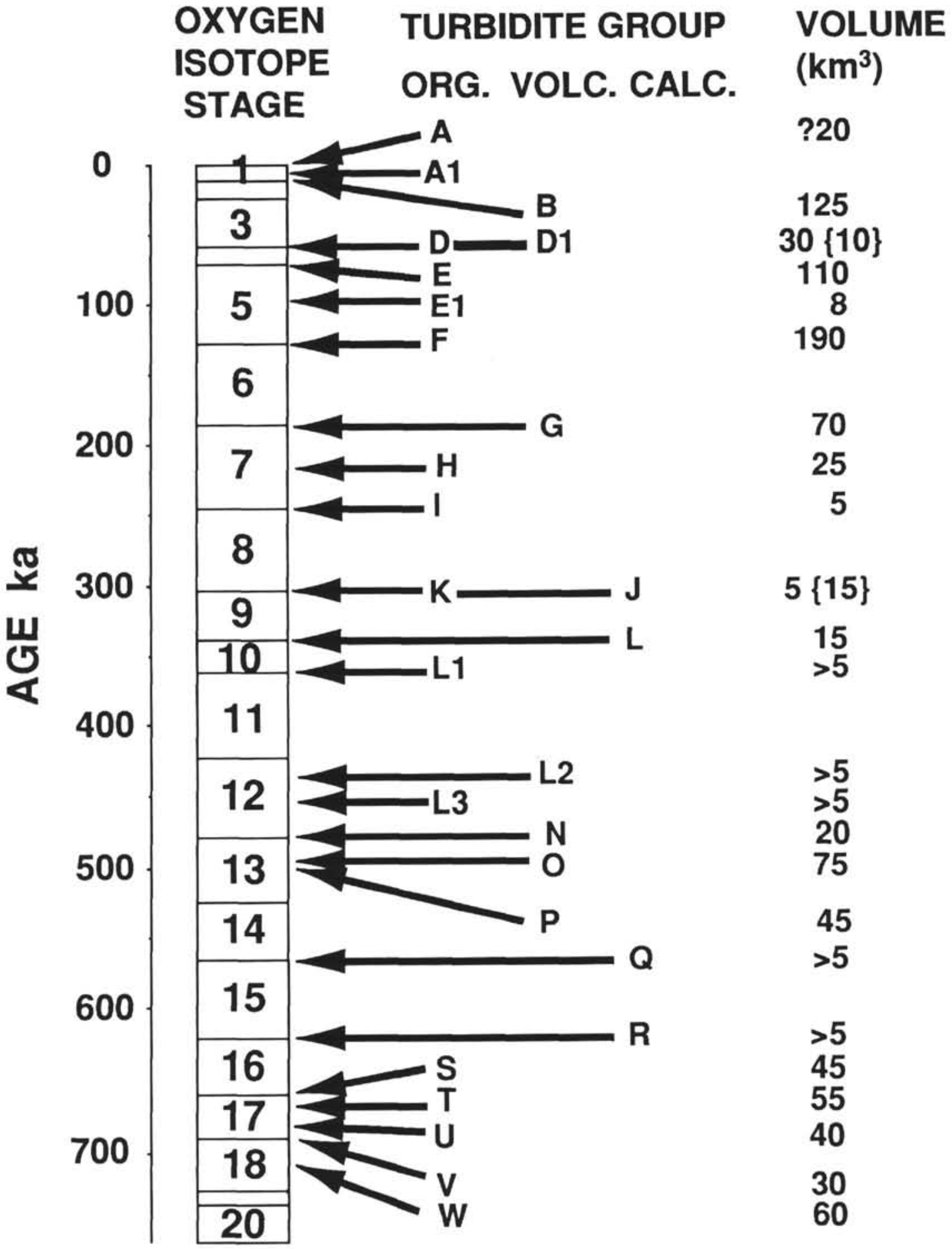

OXYGEN ISOTOPE STAGE
TURBIDITE GROUP
ORG. VOLC. CALC.
VOLUME (km³)
AGE ka
0
100
200
300
400
500
600
700
1
3
5
6
7
8
9
10
11
12
13
14
15
16
17
18
20
A ?20
A1
B 125
D D1 30 {10}
E 110
E1 8
F 190
G 70
H 25
I 5
K J 5 {15}
L 15
L1 >5
L2 >5
L3 >5
N 20
O 75
P 45
Q >5
R >5
S 45
T 55
U 40
V 30
W 60

Figure 15

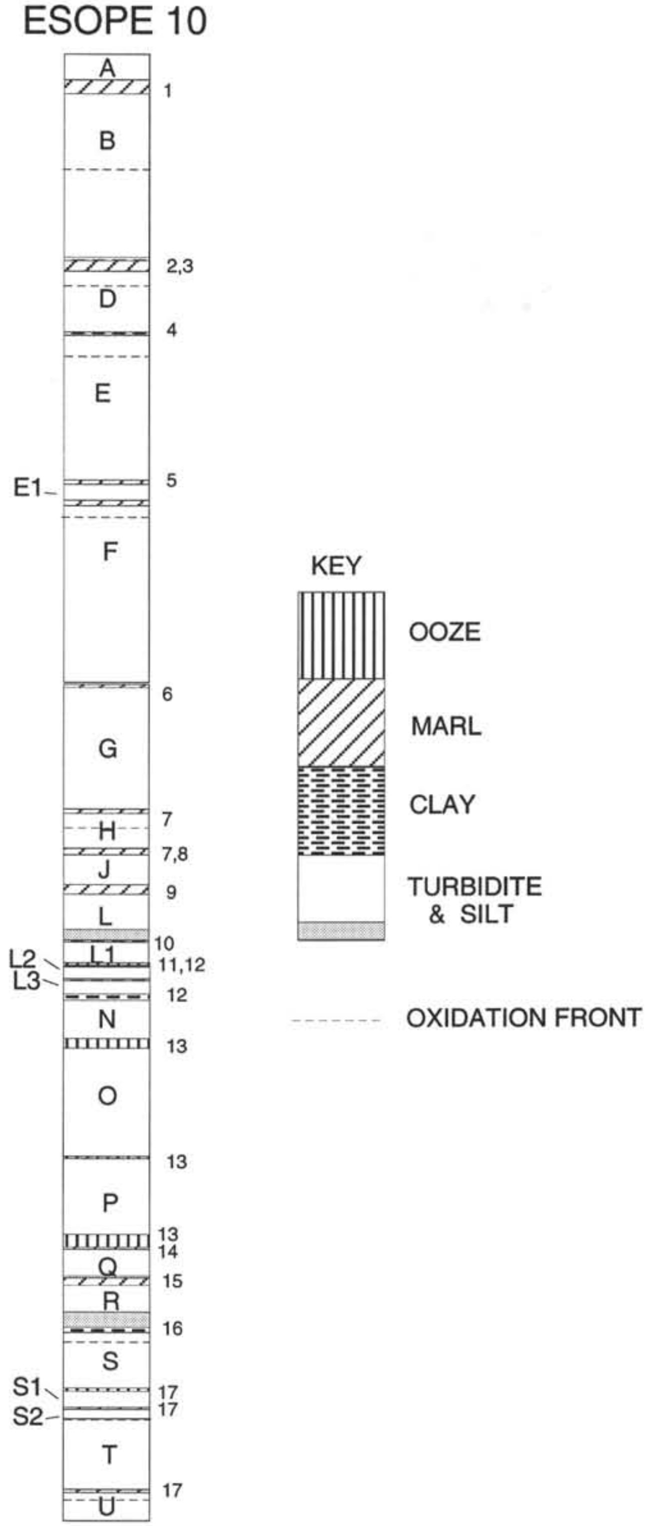

ESOPE 10
A
1
B
2,3
D
4
E
E1
5
F
6
G
7
H
7,8
J
9
L
10
L1
L2
11,12
L3
12
N
13
O
13
P
13
14
Q
15
R
16
S
S1
17
S2
17
T
17
U
KEY
OOZE
MARL
CLAY
TURBIDITE & SILT
OXIDATION FRONT

Figure 16

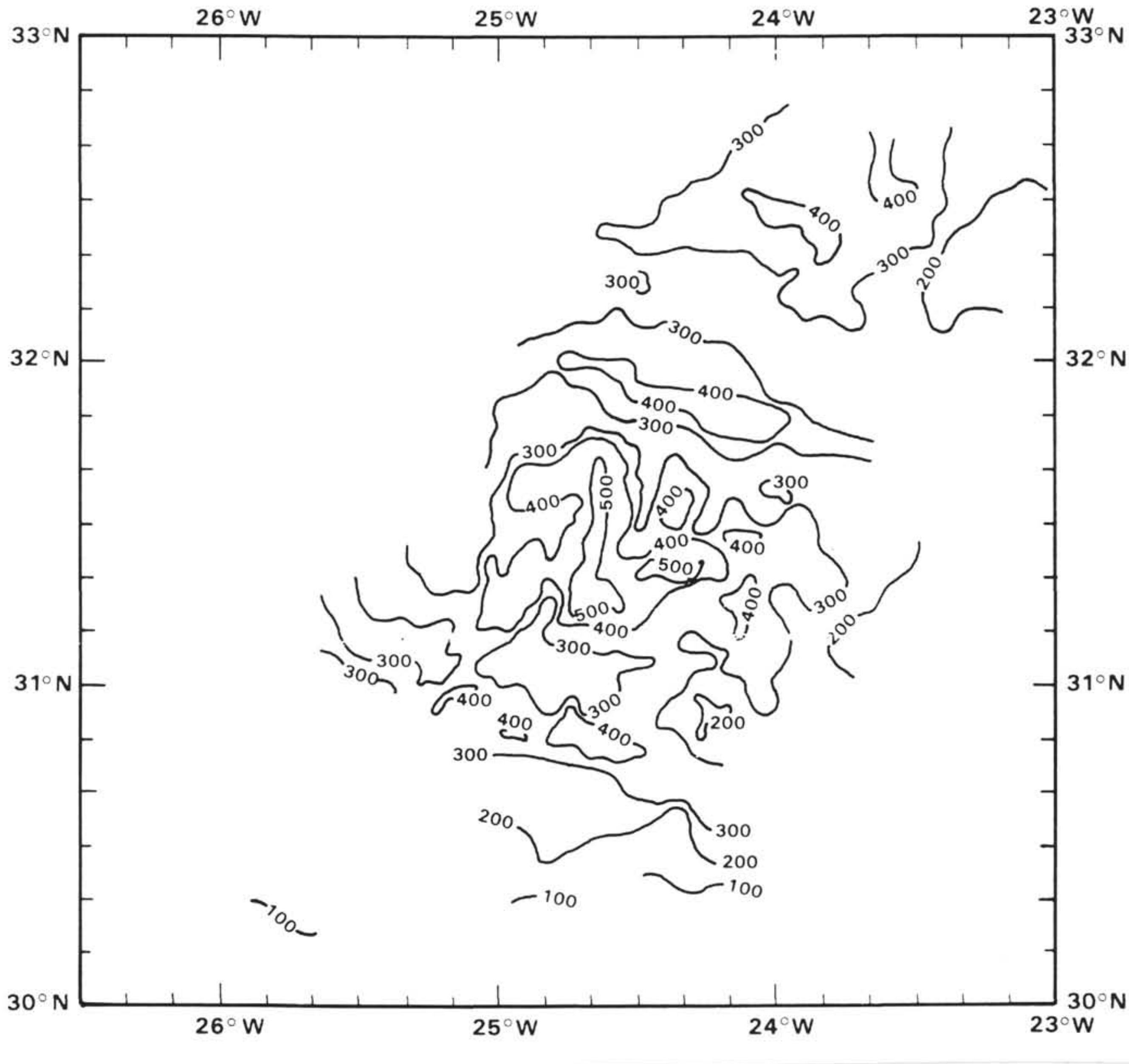


Figure 17

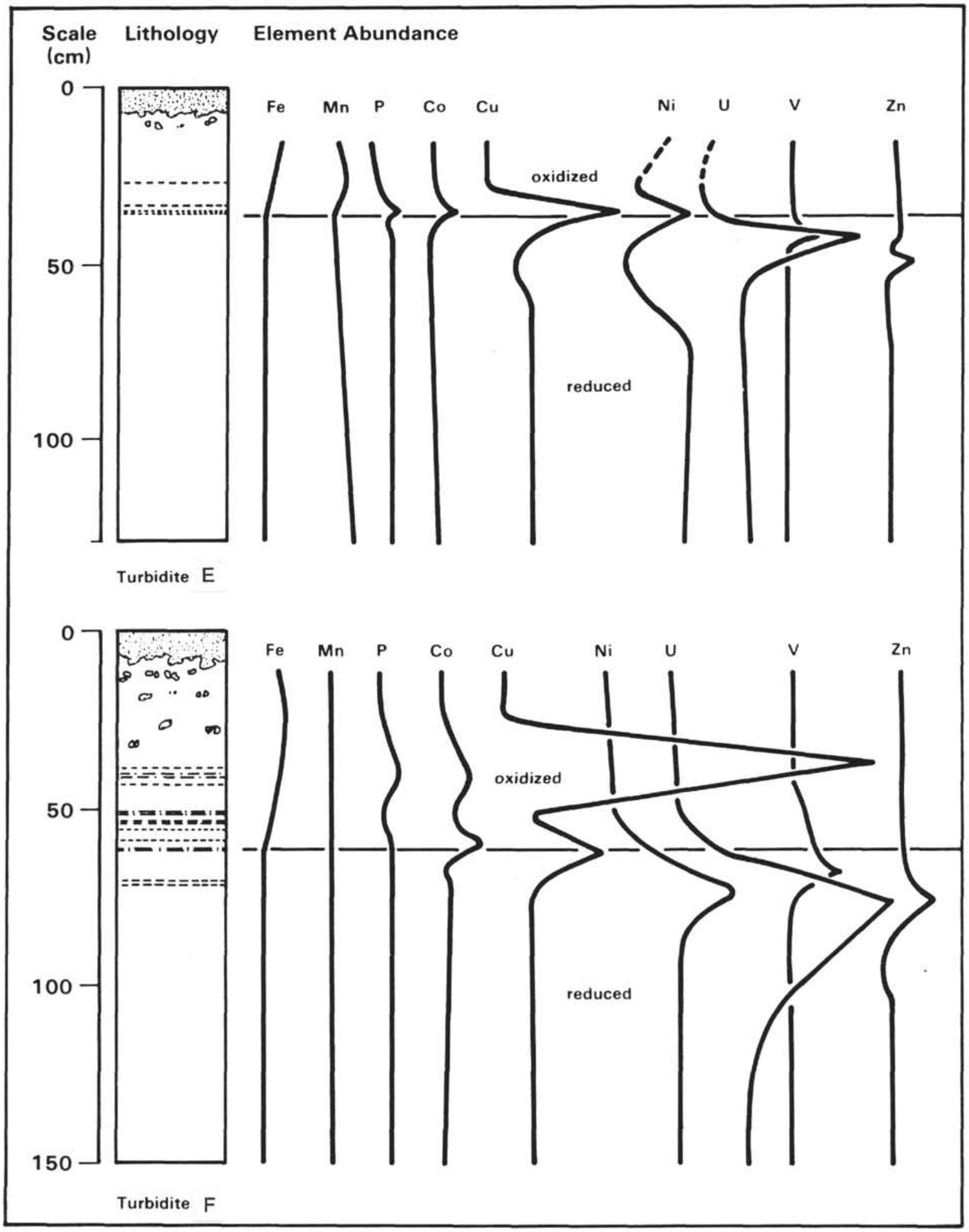
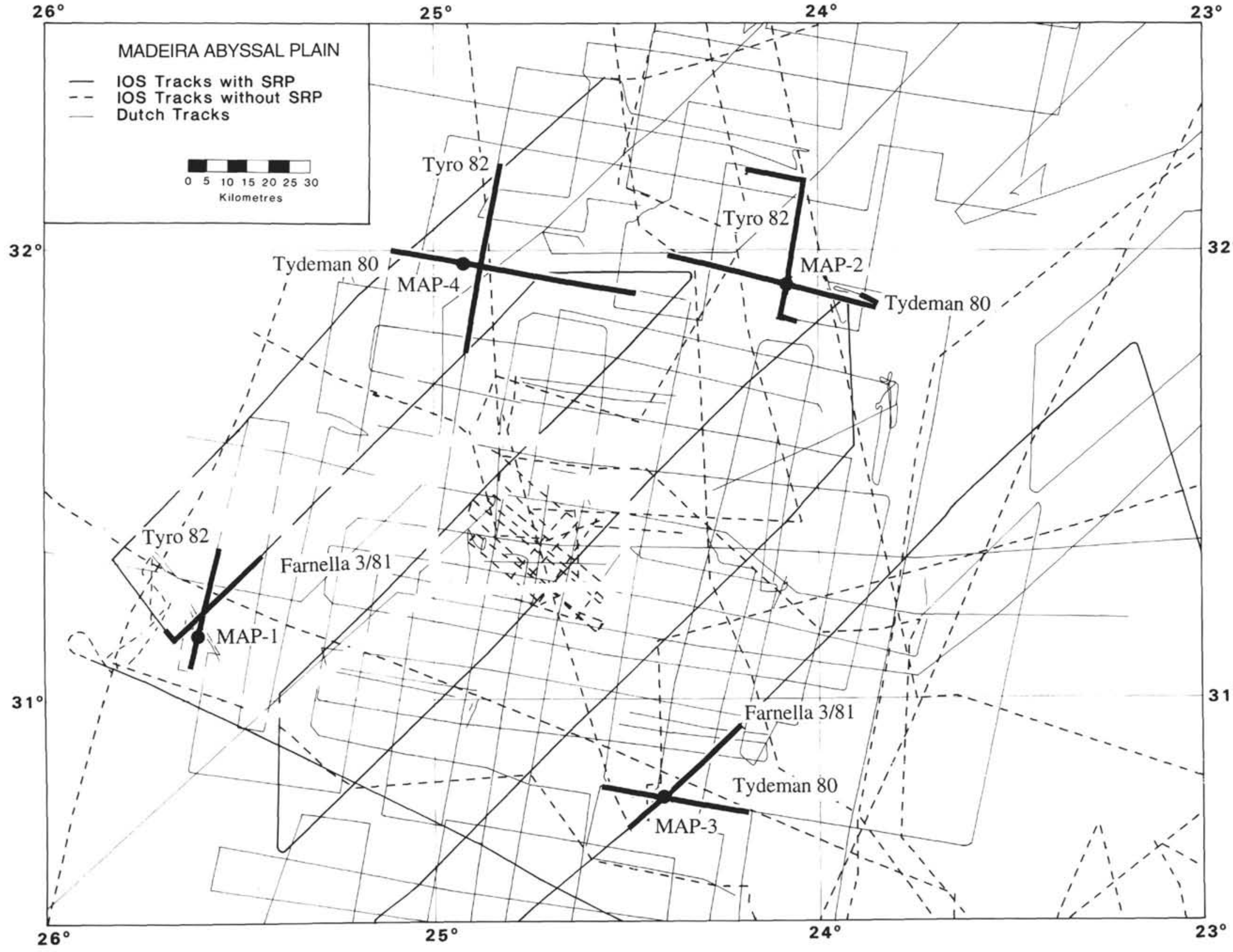
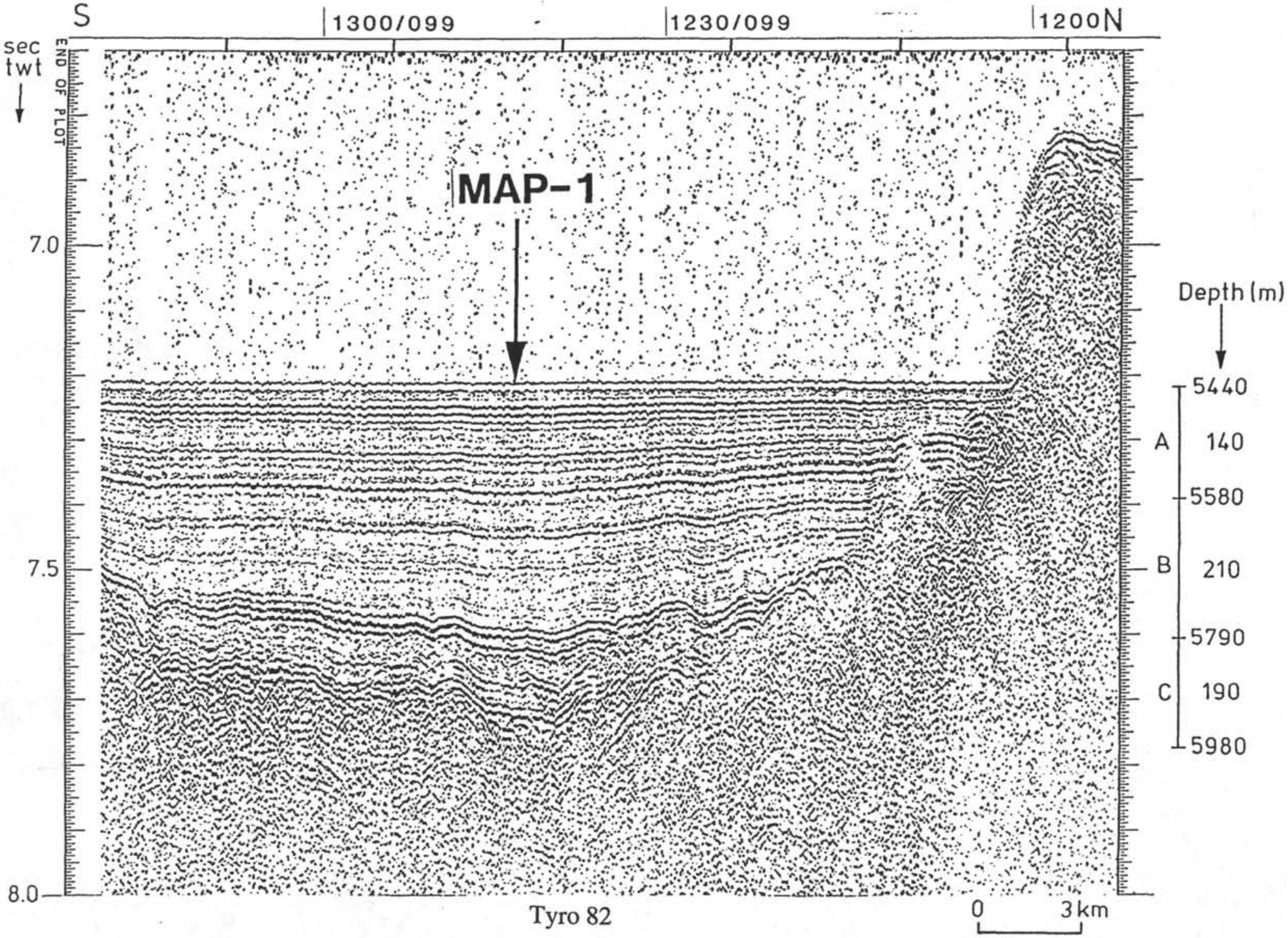

Scale (cm)
Lithology
Element Abundance
0
50
100
Fe
Mn
P
Co
Cu
Ni
U
V
Zn
oxidized
reduced
Turbidite E
0
50
100
150
Fe
Mn
P
Co
Cu
Ni
U
V
Zn
oxidized
reduced
Turbidite F

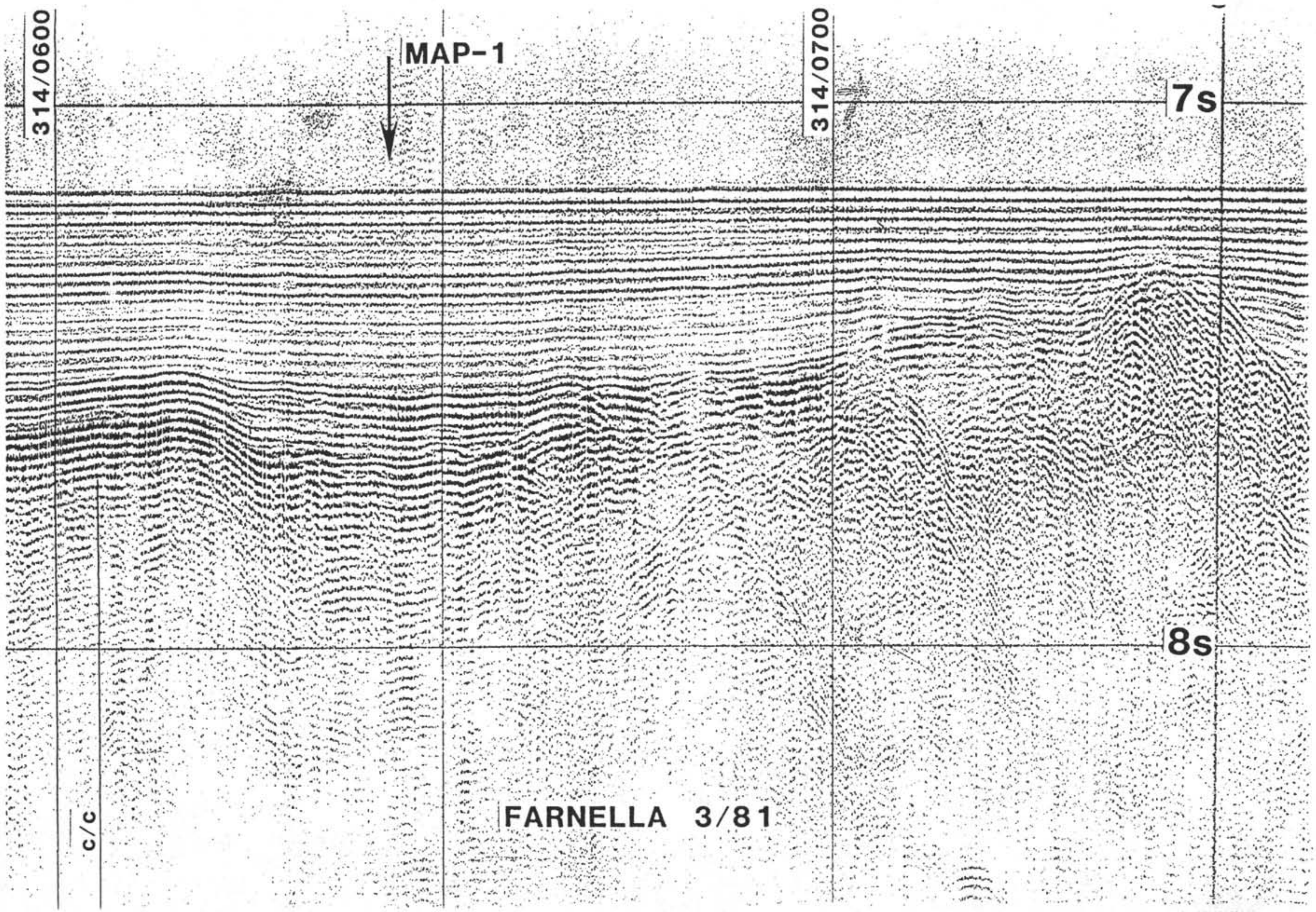
Figure 18

LEG 157

PROPOSED SITES


26°
25°
24°
23°
32°
31°
MADEIRA ABYSSAL PLAIN
IOS Tracks with SRP
IOS Tracks without SRP
Dutch Tracks
0 5 10 15 20 25 30
Kilometres
Tyro 82
Tydeman 80
MAP-4
Tyro 82
MAP-2
Tydeman 80
Tyro 82
Farnella 3/81
MAP-1
Farnella 3/81
Tydeman 80
MAP-3


S
1300/099
1230/099
1200
N
sec
twt
END OF PLOT
7.0
7.5
8.0
MAP-1
Depth (m)
5440
A
140
5580
B
210
5790
C
190
5980
Tyro 82
0
3km


314/0600
MAP-1
314/0700
7s
8s
c/c
FARNELLA 3/81

Site: MAP-1
Priority: 1
Position: 31°09'N, 25°36'W
Water Depth: 5440 m
Sediment Thickness: ~580 m
Total Penetration: ~500 m
Seismic Coverage: SCS Tyro 1982 airgun/watergun, IOS Farnella 3/81 + various

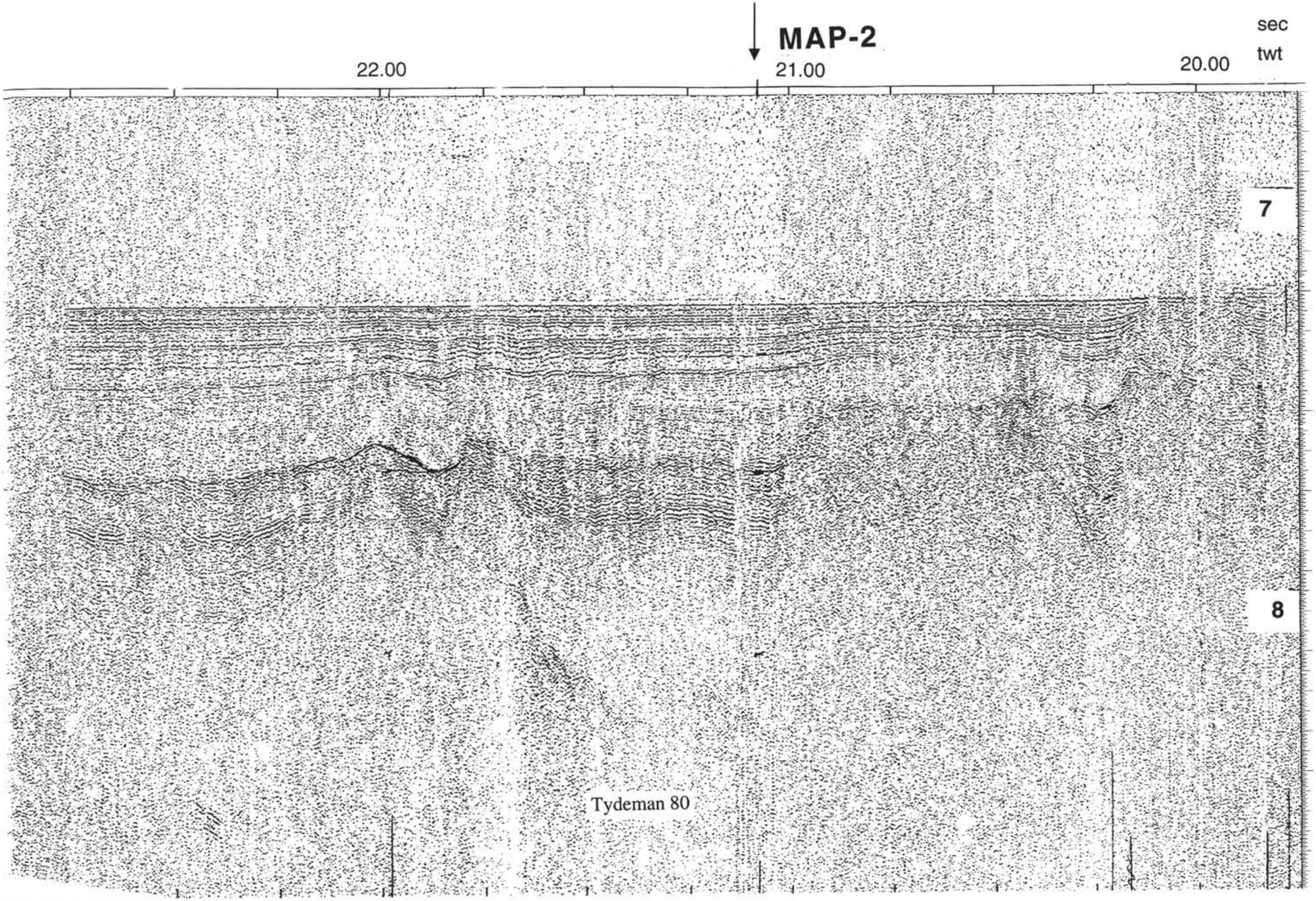
Objectives:

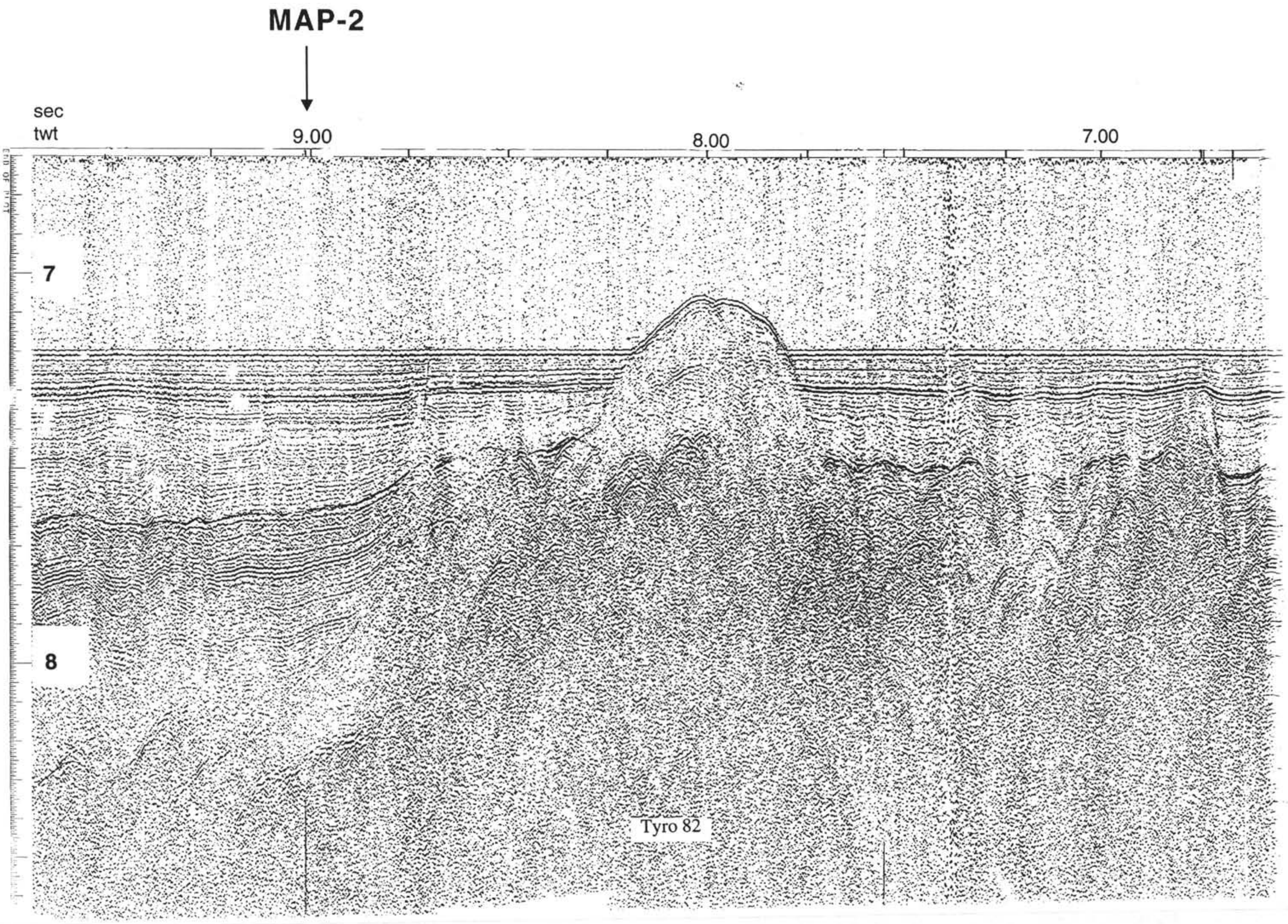
- High-resolution stratigraphy for the Pliocene-Quaternary fill of the Madeira Abyssal Plain.
- Dating the age of inception of the plain.
- Geochemical analysis of the sedimentary diagenetic history of the turbidite sequence.
- Together with sites MAP-3 and MAP-4 determination of the volume of each individual turbidite and identification of its source.
- Calculation of sediment budgets for mass wasting in the Canary Basin.
- Determination of the nature of the pre-turbidite sediment facies and identification of turbidites in this sequence.

Drilling Program: APC, XCB.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: 0-350 m, turbidite muds and thin pelagic marls and clays; below 350 m, pelagic clay with some turbidites.


MAP-2
sec
twt
22.00
21.00
20.00
7
8
Tydeman 80


MAP-2
sec
twt
9.00
8.00
7.00
7
8
Tyro 82

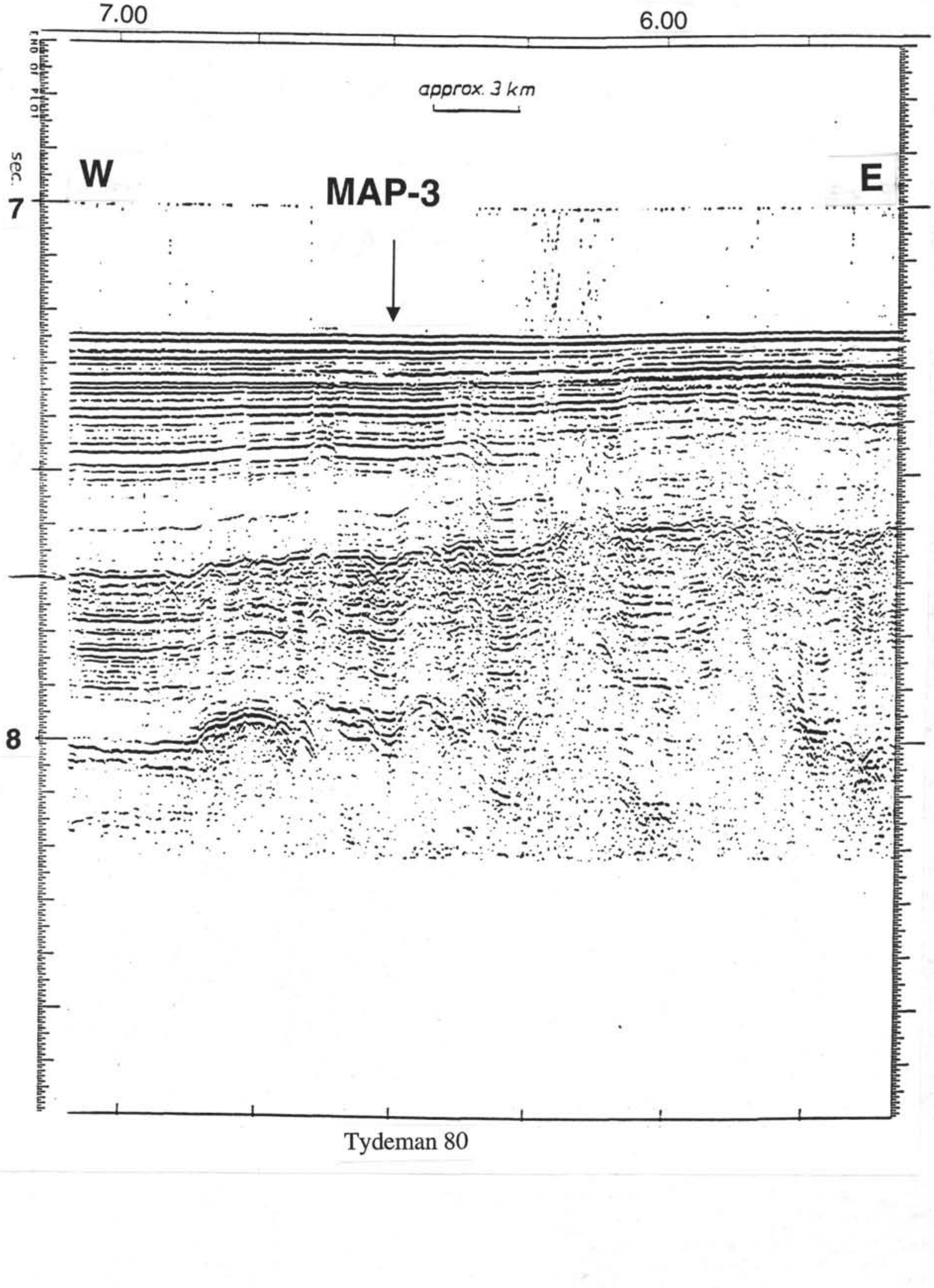
Site: MAP-2
Priority: 2
Position: 31°56'N, 24°05'W
Water Depth: 5430 m
Sediment Thickness: ~1000 m
Total Penetration: ~300 m
Seismic Coverage: SCS Tydeman 1980 water gun, Tyro 1982, IOS Farnella 3/81 + various

Objectives:

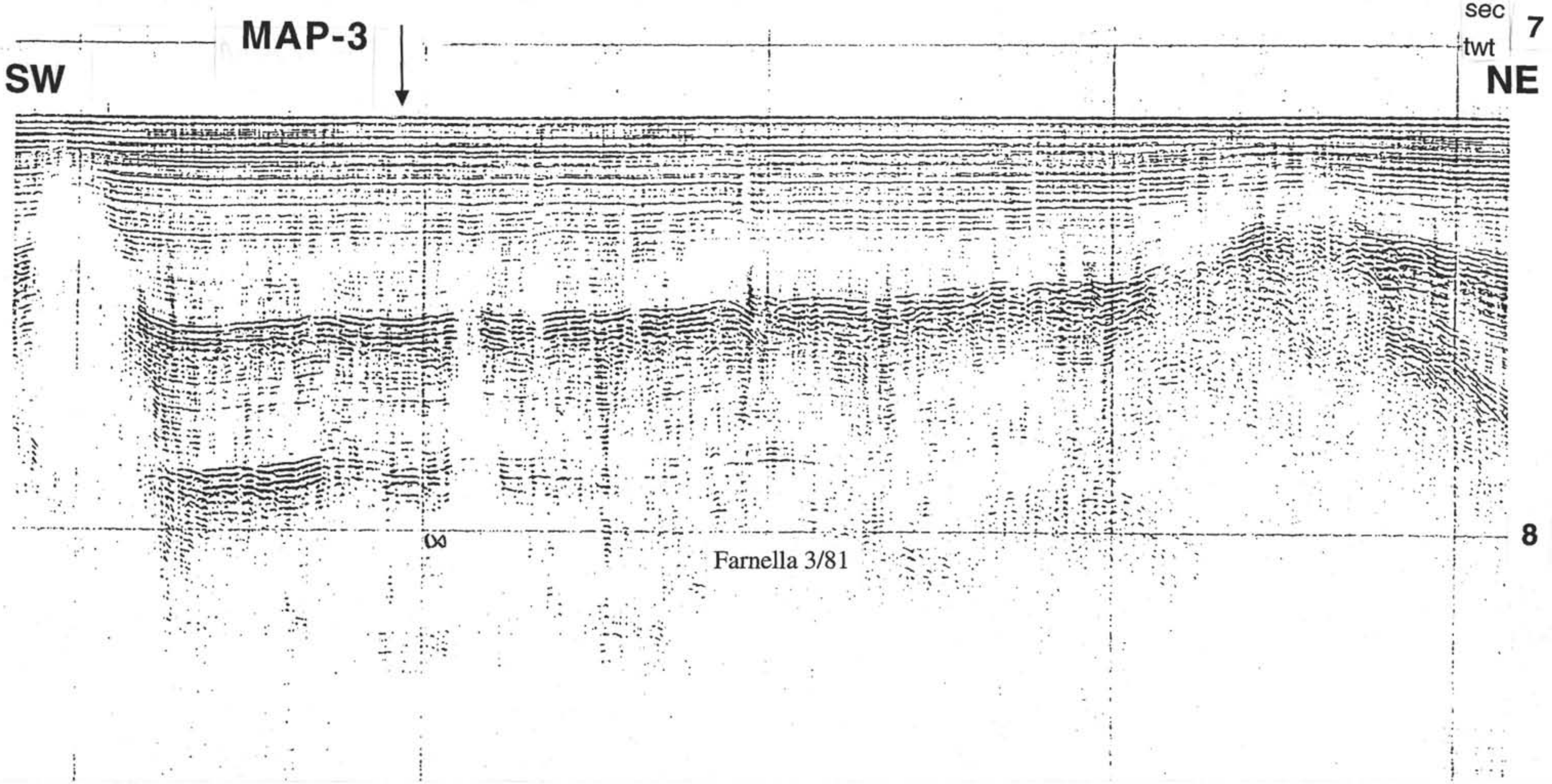
- High-resolution stratigraphy for the Pliocene-Quaternary fill of the Madeira Abyssal Plain.
- Dating the age of inception of the plain.
- Geochemical analysis of the sedimentary diagenetic history of the turbidite sequence.
- Together with sites MAP-1, MAP-3, and MAP-4, determination of the volume of each individual turbidite and identification of its source.
- Calculation of sediment budgets for mass wasting in the Canary Basin.

Drilling Program: APC, XCB.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.
Nature of Rock Anticipated: Turbidite muds and thin pelagic marls and clays.



Tydeman 80



Farnella 3/81

Site: MAP-3
Priority: 1
Position: 30°47'N, 24°24'W
Water Depth: 5430 m
Sediment Thickness: ~750 m
Total Penetration: ~300 m
Seismic Coverage: SCS Tydeman 1980 water gun, IOS Farnella 3/81 + various

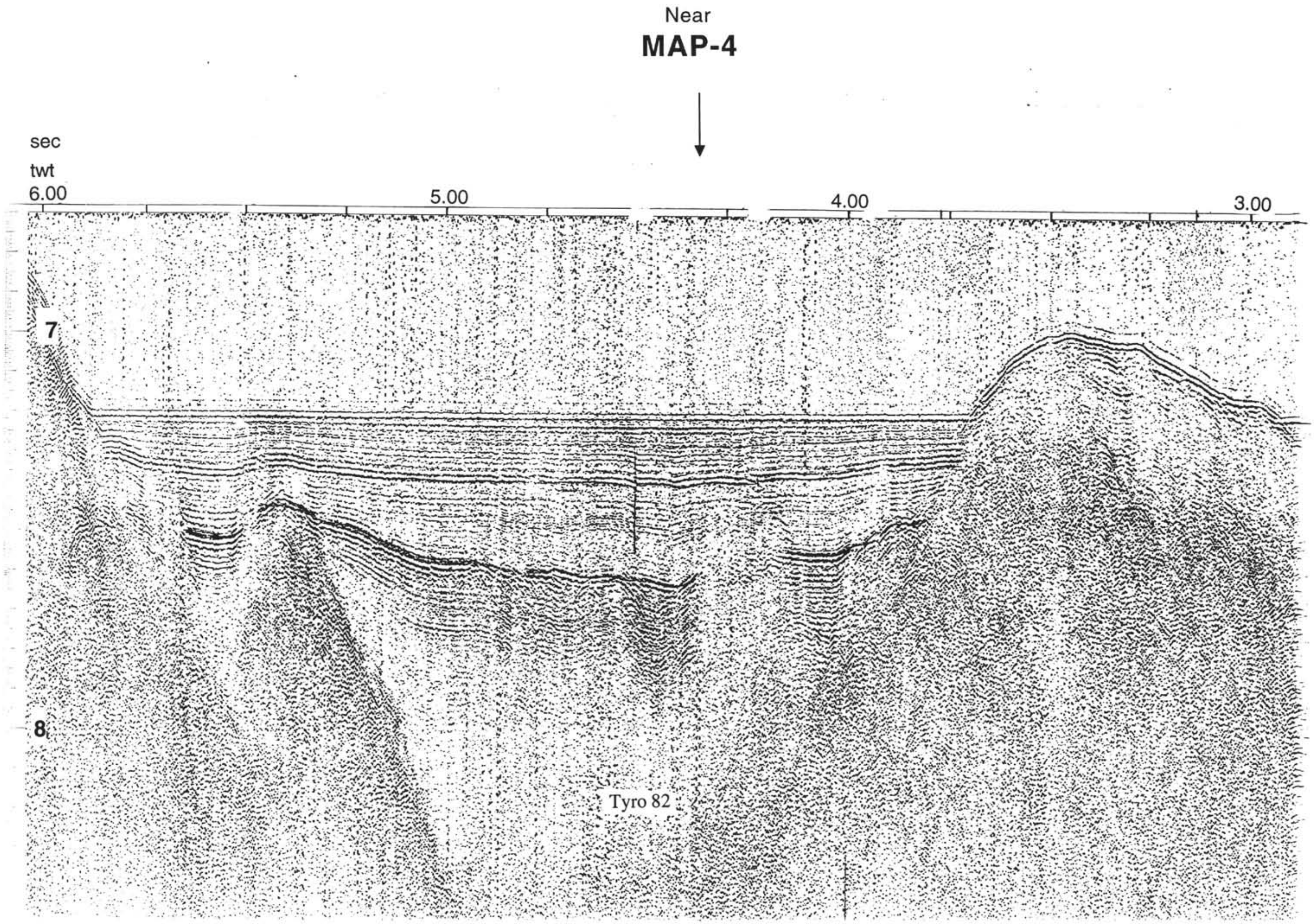
Objectives:

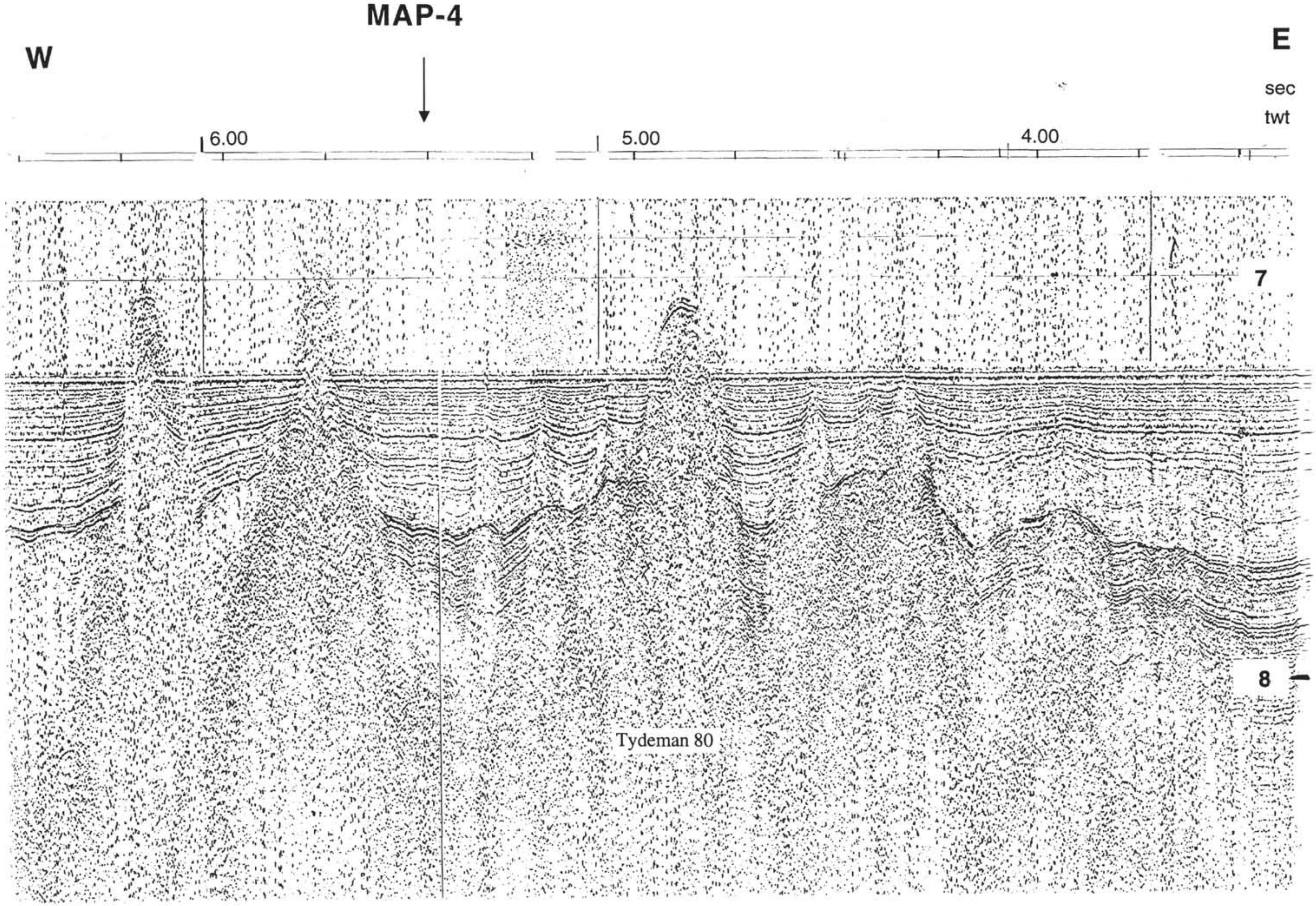
- High-resolution stratigraphy for the Pliocene-Quaternary fill of the Madeira Abyssal Plain.
- Dating the age of inception of the plain.
- Geochemical analysis of the sedimentary diagenetic history of the turbidite sequence.
- Together with sites MAP-1 and MAP-4, determination of the volume of each individual turbidite and identification of its source.
- Calculation of sediment budgets for mass wasting in the Canary Basin.
- Determination of lateral variation in the turbidite facies between this more proximal site and the more distal MAP-1.

Drilling Program: APC, XCB.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Turbidite muds and thin pelagic marls and clays.


Near
MAP-4
sec
twt
6.00
5.00
4.00
3.00
7
8
Tyro 82


MAP-4
W
E
sec
twt
6.00
5.00
4.00
7
8
Tydeman 80

Site: MAP-4

Priority: 1

Position: 31°58.2'N, 24°54.2'W

Water Depth: 5440 m

Sediment Thickness: ~750 m

Total Penetration: ~300 m

Seismic Coverage: SCS Tyro 1982 water gun, SCS Tydeman 1980 water gun + various

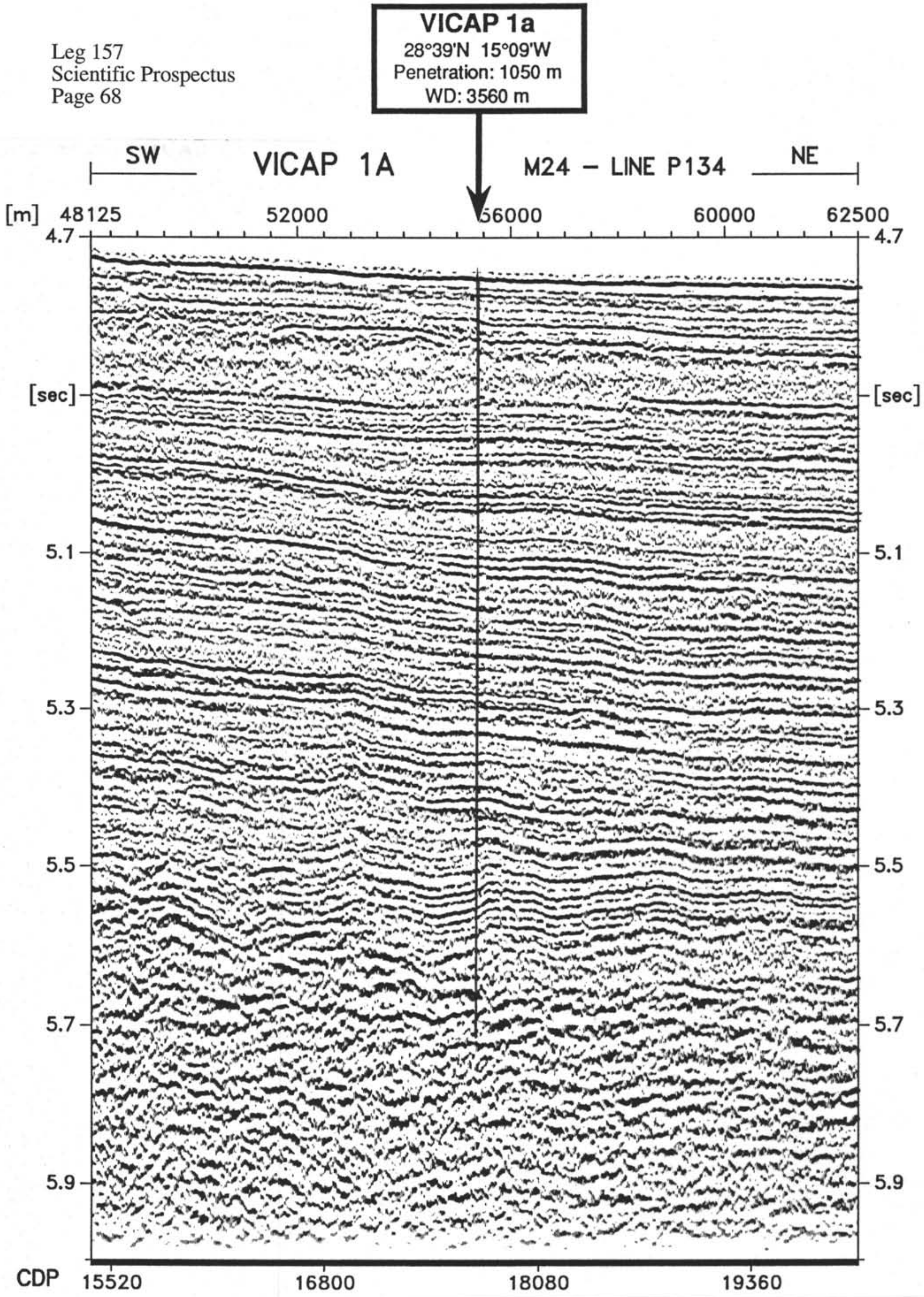
Objectives:

- High-resolution stratigraphy for the Pliocene-Quaternary fill of the Madeira Abyssal Plain.
- Dating the age of inception of the plain.
- Together with sites MAP-1 and MAP-3, determination of the volume of each individual turbidite and identification of its source.
- Calculation of sediment budgets for mass wasting in the Canary Basin.
- Determination of volumes of low-volume turbidite input from the NE corner of the plain.

Drilling Program: APC, XCB.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Turbidite muds and thin pelagic marls and clays.


VICAP 1a
28°39'N 15°09'W
Penetration: 1050 m
WD: 3560 m
SW
VICAP 1A
M24 – LINE P134
NE
[m]
48125
52000
56000
60000
62500
4.7
[sec]
5.1
5.3
5.5
5.7
5.9
CDP
15520
16800
18080
19360

Site: VICAP-1a
Priority: 1
Position: 28°39'N, 15°09'W
Water Depth: 3560 m
Sediment Thickness: ~4000 m
Total Penetration: 1050 m
Seismic Coverage: MCS lines M 24, P 134/203, and 135/204

Objectives:

1) Inception of volcanism at the site of Gran Canaria with implications for the hotspot migration on a slow-moving plate by drilling through the outer flank (seismic apron).
2) Lithostratigraphy of basin sediments north of Gran Canaria.
3) High-resolution compositional, temporal, structural, and sedimentological evolution of an intraplate volcanic island system.
4) Calibration of the biostratigraphic and paleomagnetic record against single crystal ^{40}Ar/^{39}Ar age dates.
5) Detailed compositional and temporal correlation of subaerial and submarine volcanic events (large eruptions, magmatic phases, major slumps) with distinct submarine reflectors.
6) Calculation of sediment budgets for the submarine growth, subaerial evolution, and unroofing of Gran Canaria and Tenerife.
7) Quantification of the long-term effects of sediment burial and diagenesis in a sequence of mixed organic-poor, volcaniclastic, and organic-rich sediments, especially chemical fluxes between volcanic glass and seawater.
8) Response of the lithosphere to loading and heating during magmatic activity and to enhanced levels of stress associated with temporal changes in plate dynamics.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.

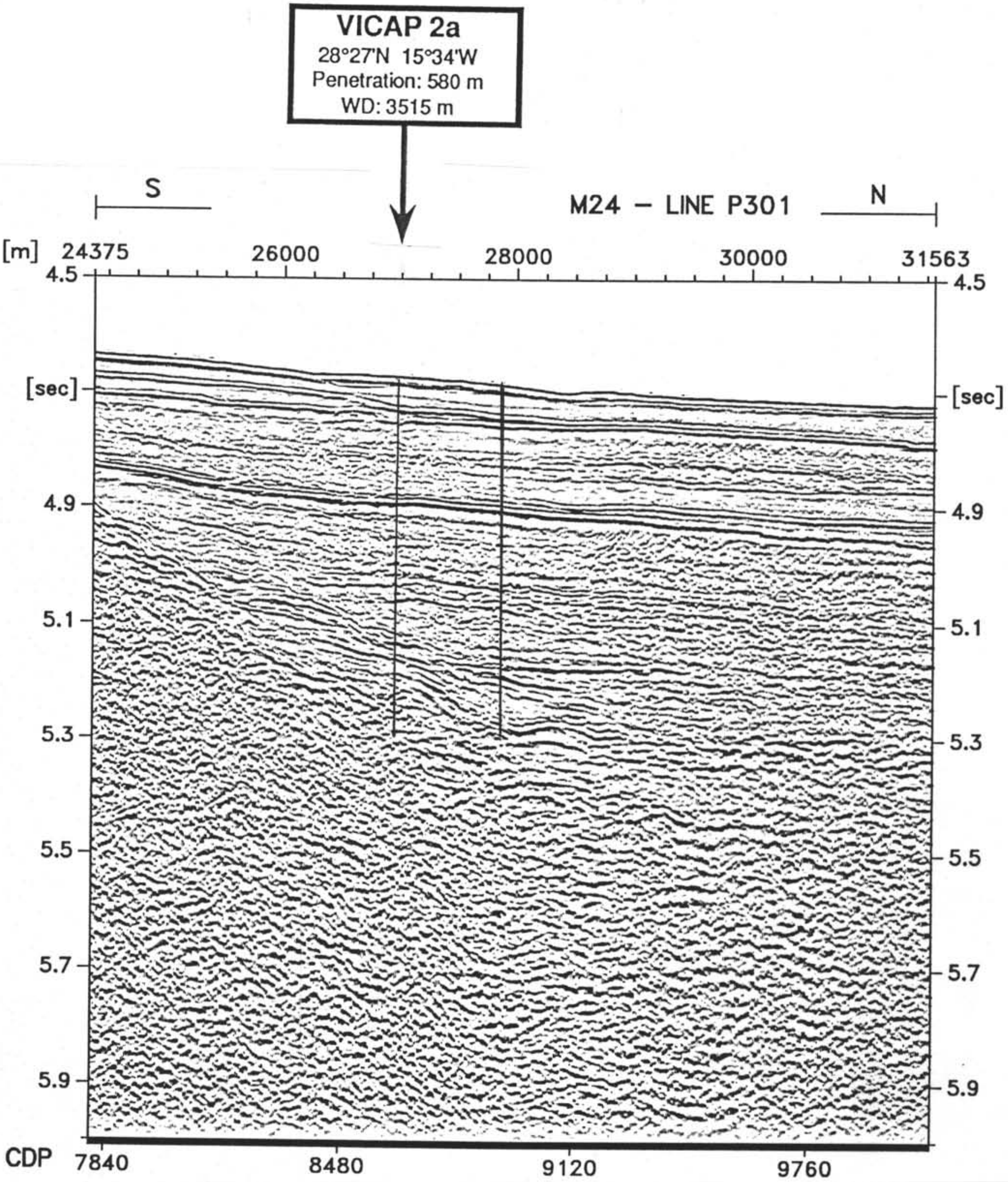
Site: VICAP-1(backup site to VICAP-1a)
Priority: 2
Position: 28°44'N, 15°04'W
Water Depth: 3560m
Sediment Thickness: ~4000 m
Total Penetration: 1000 m
Seismic Coverage: MCS lines M 24, P 134/203, and 135/204

Objectives: Same as for proposed site VICAP-1a.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


VICAP 2a
28°27'N 15°34'W
Penetration: 580 m
WD: 3515 m
S
M24 – LINE P301
N
[m]
24375
26000
28000
30000
31563
4.5
[sec]
4.9
5.1
5.3
5.5
5.7
5.9
4.5
[sec]
4.9
5.1
5.3
5.5
5.7
5.9
CDP
7840
8480
9120
9760

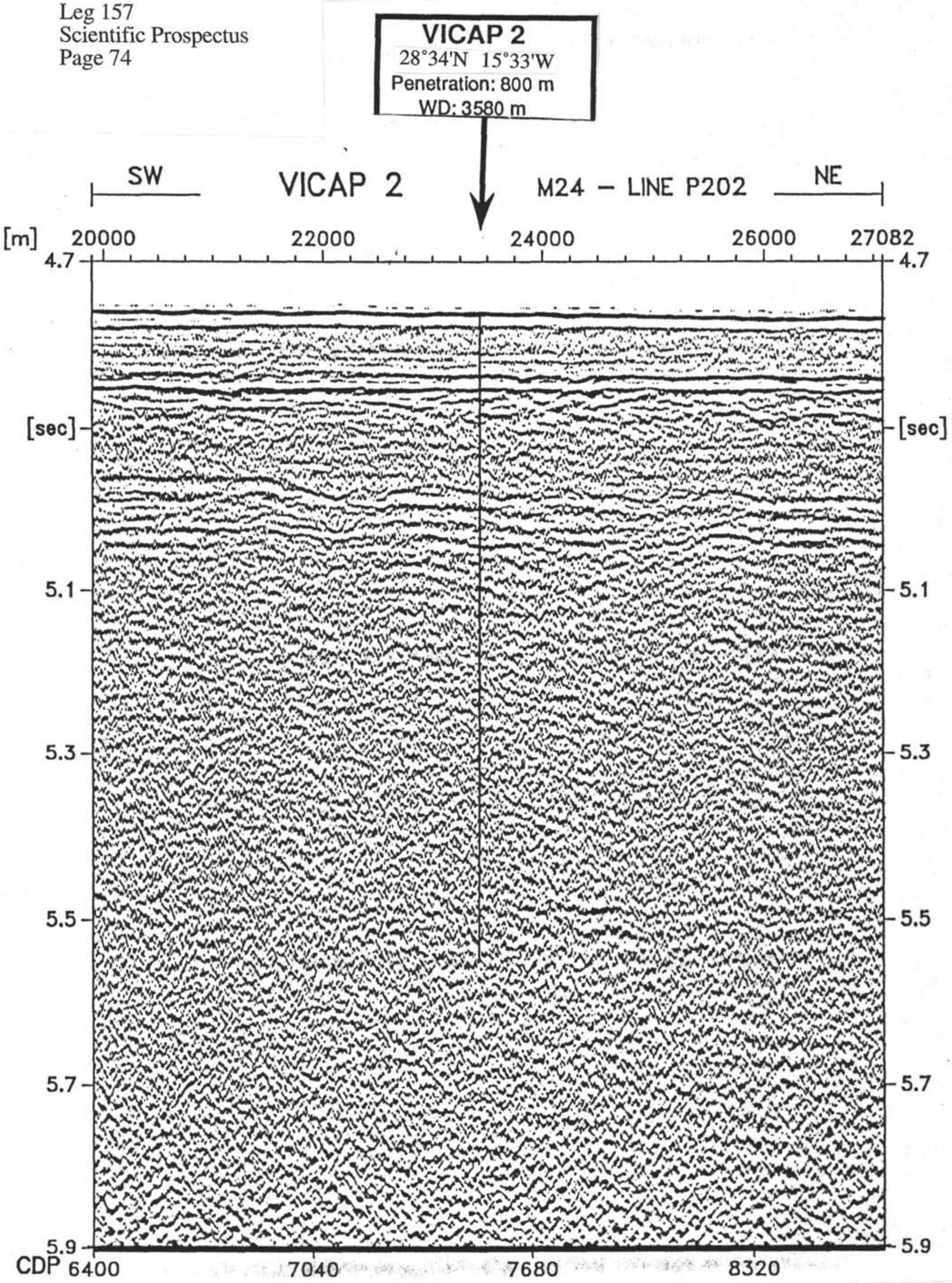
Site: VICAP-2a
Priority: 1
Position: 28°27'N, 15°34'W
Water Depth: 3515 m
Sediment Thickness: 570 m
Total Penetration: 580 m
Seismic Coverage: MCS lines M 24, P 202, and 301

Objectives: Same as for proposed site VICAP-1a.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


VICAP 2
28°34'N 15°33'W
Penetration: 800 m
WD: 3580 m
SW
VICAP 2
M24 – LINE P202
NE
[m]
20000
22000
24000
26000
27082
4.7
[sec]
5.1
5.3
5.5
5.7
5.9
CDP
6400
7040
7680
8320

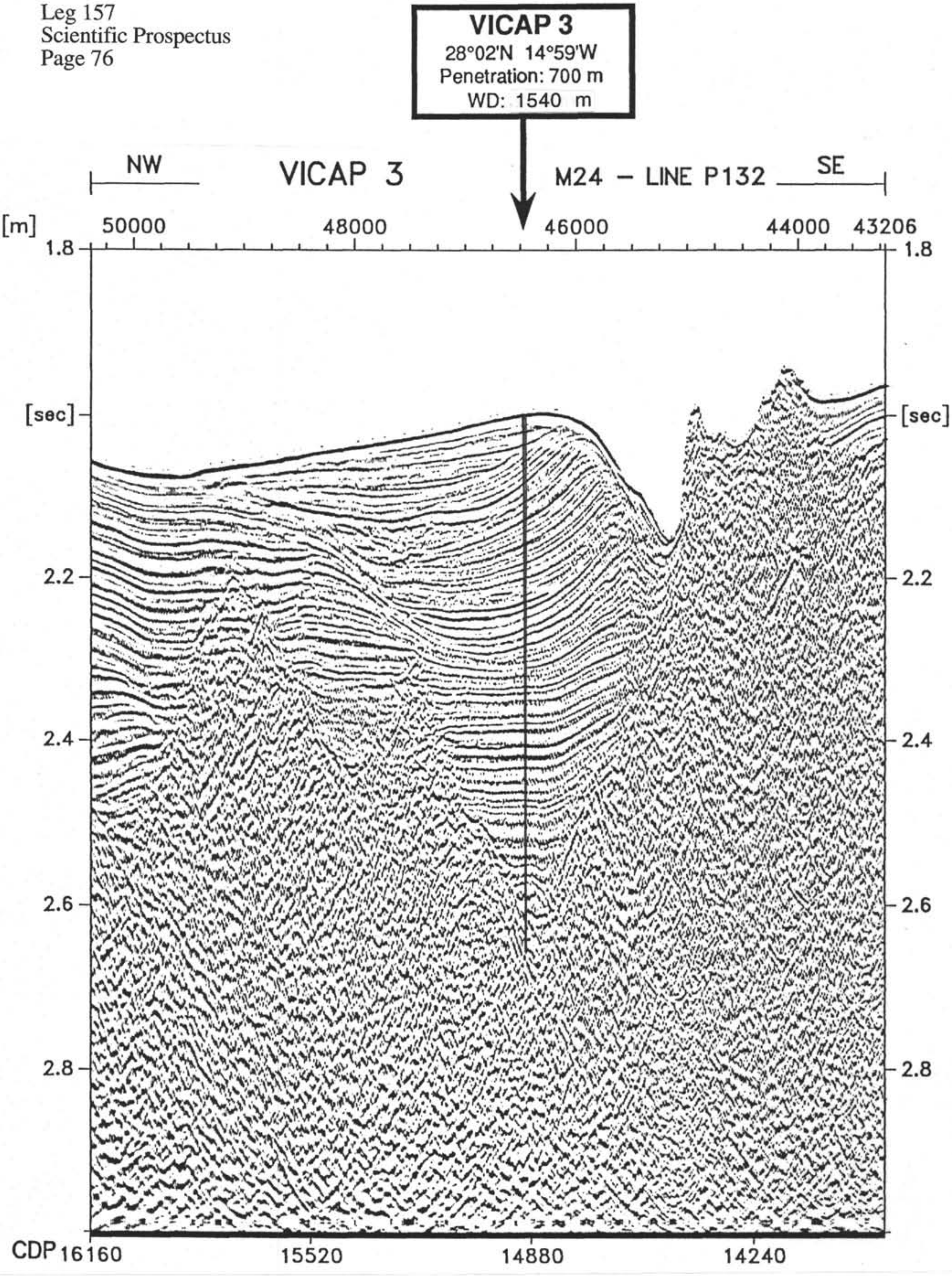
Site: VICAP-2 (backup site to VICAP-2a)
Priority: 2
Position: 28°34'N, 15°33'W
Water Depth: 3580 m
Sediment Thickness: ~3800 m
Total Penetration: 800 m
Seismic Coverage: MCS lines M 24, P 202, and 301

Objectives: Same as for proposed site VICAP-1a.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


VICAP 3
28°02'N 14°59'W
Penetration: 700 m
WD: 1540 m
NW
VICAP 3
M24 – LINE P132
SE
[m]
50000
48000
46000
44000
43206
1.8
[sec]
2.2
2.4
2.6
2.8
CDP 16160
15520
14880
14240

Site: VICAP-3
Priority: 2
Position: 28°02'N, 14°59'W
Water Depth: 1540 m
Sediment Thickness: ~700 m
Total Penetration: ~700 m
Seismic Coverage: MCS lines M 24, P 130, and 132/133

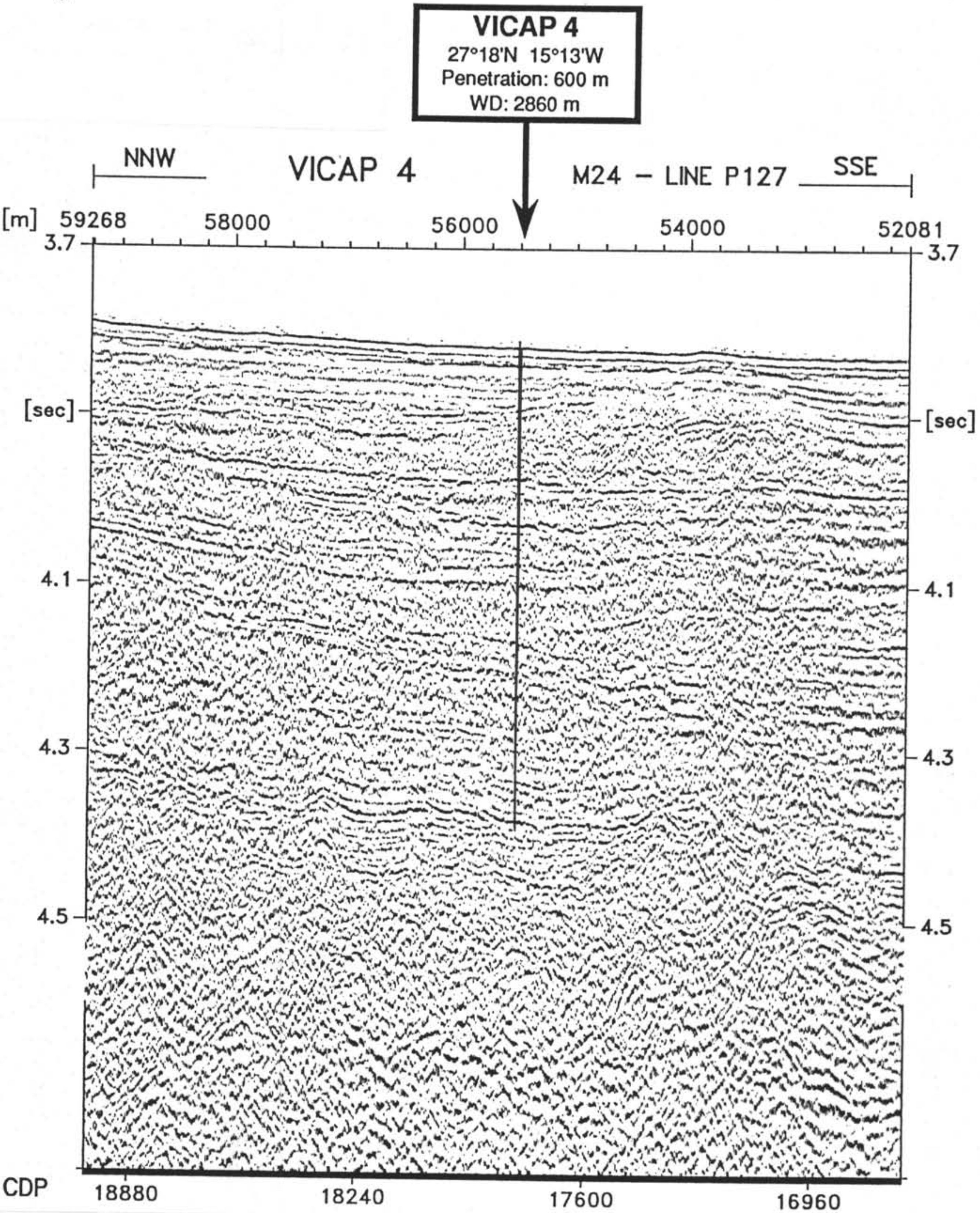
Objectives: Objectives 4 and 6 as presented for proposed site VICAP-1a and

- Lithostratigraphy of channel sediments east of Gran Canaria.
- To drill through a sediment pocket in the channel between Gran Canaria and Fuerteventura (condensed stratigraphy?) on top of a major Pliocene land-generated volcanic debris avalanche deposit well dated on land.
- To correlate North to South Canary Basin stratigraphy across channel.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


VICAP 4
27°18'N 15°13'W
Penetration: 600 m
WD: 2860 m
NNW
VICAP 4
M24 – LINE P127
SSE
[m]
59268
58000
56000
54000
52081
3.7
[sec]
4.1
4.3
4.5
CDP
18880
18240
17600
16960

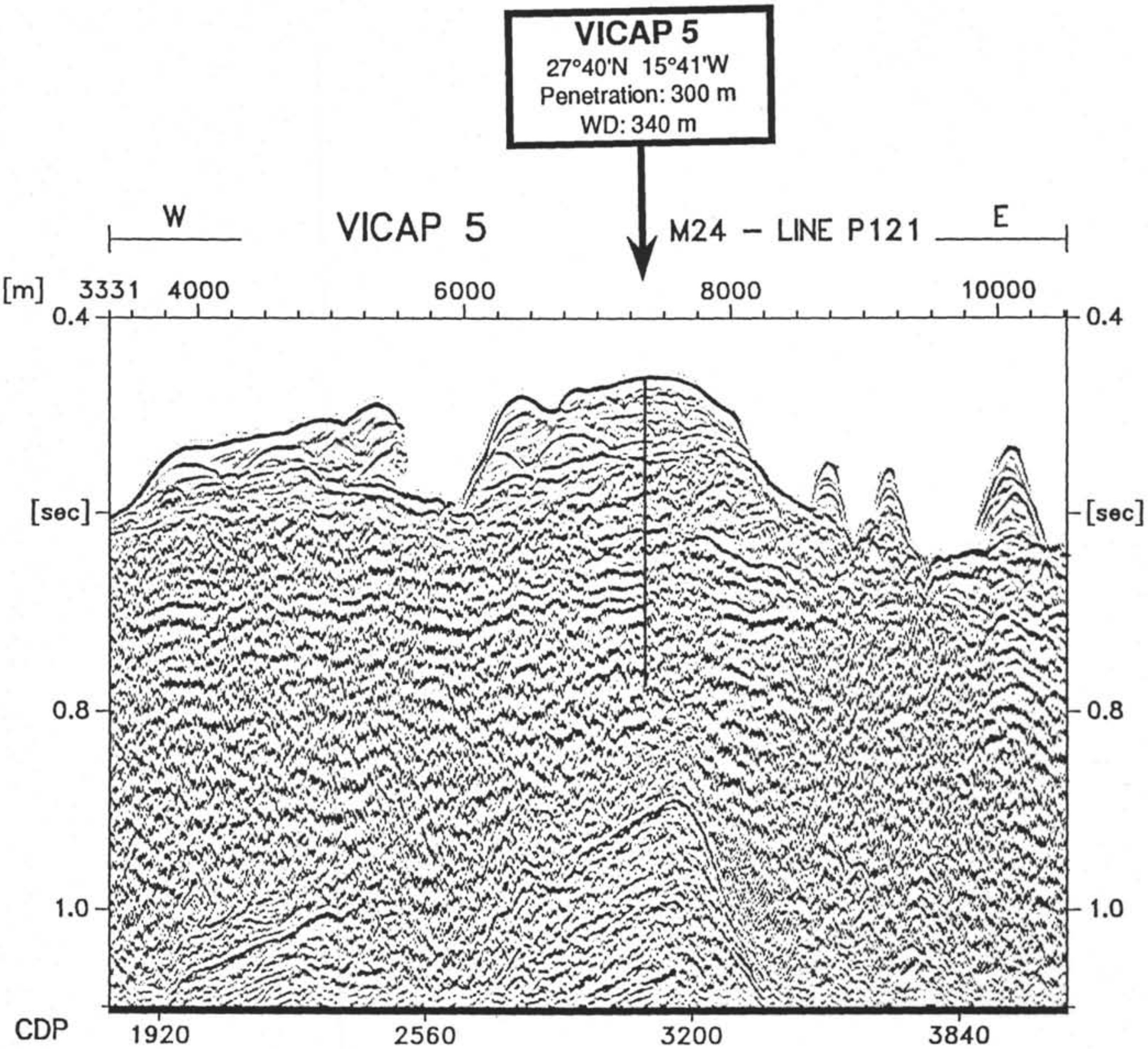
Site: VICAP-4
Priority: 1
Position: 27°18'N, 15°13'W
Water Depth: 2860 m
Sediment Thickness: total unknown, to R7 540 m
Total Penetration: 600 m
Seismic Coverage: MCS lines M 24, VEMA 30-05, and P 127

Objectives: Same as for proposed site VICAP-1a.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


VICAP 5
27°40'N 15°41'W
Penetration: 300 m
WD: 340 m
W
VICAP 5
M24 - LINE P121
E
[m]
3331
4000
6000
8000
10000
0.4
[sec]
0.8
1.0
CDP
1920
2560
3200
3840

Site: VICAP-5
Priority: 2
Position: 27°40'N, 15°41'W
Water Depth: 340 m
Sediment Thickness: ~300 m (to top of island flank)
Total Penetration: ~300 m
Seismic Coverage: MCS lines M 24 and P 121

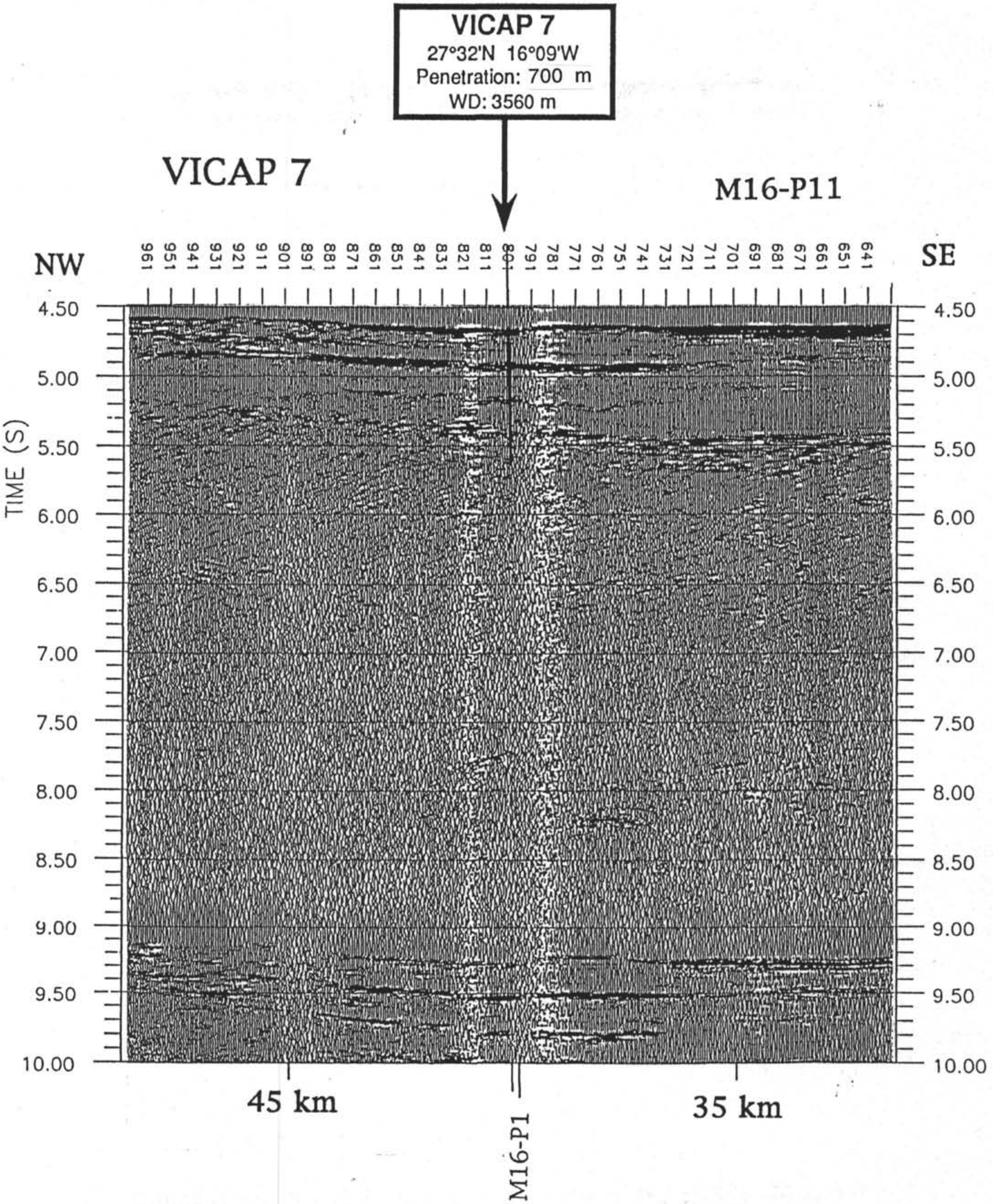
Objectives: Objectives 2, 3, 4, 5, 6, and 7 as presented for proposed site VICAP-1a and

- To drill through the continuation of a large on-land canyon to determine sedimentation rates for a major drainage system that has operated since the Miocene shield stage.
- To characterize the proximal volcaniclastic deposit facies south of Gran Canaria.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


VICAP 7
27°32'N 16°09'W
Penetration: 700 m
WD: 3560 m
VICAP 7
M16-P11
NW
SE
961
951
941
931
921
911
901
891
881
871
861
851
841
831
821
811
801
791
781
771
761
751
741
731
721
711
701
691
681
671
661
651
641
TIME (S)
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
9.50
10.00
45 km
35 km
M16-P1

Site: VICAP-7
Priority: 1
Position: 27°27'N, 16°23'W
Water Depth: 3560 m
Sediment Thickness: ~4500 m
Total Penetration: 700 m
Seismic Coverage: MCS lines M 16-4, P 1, and 113

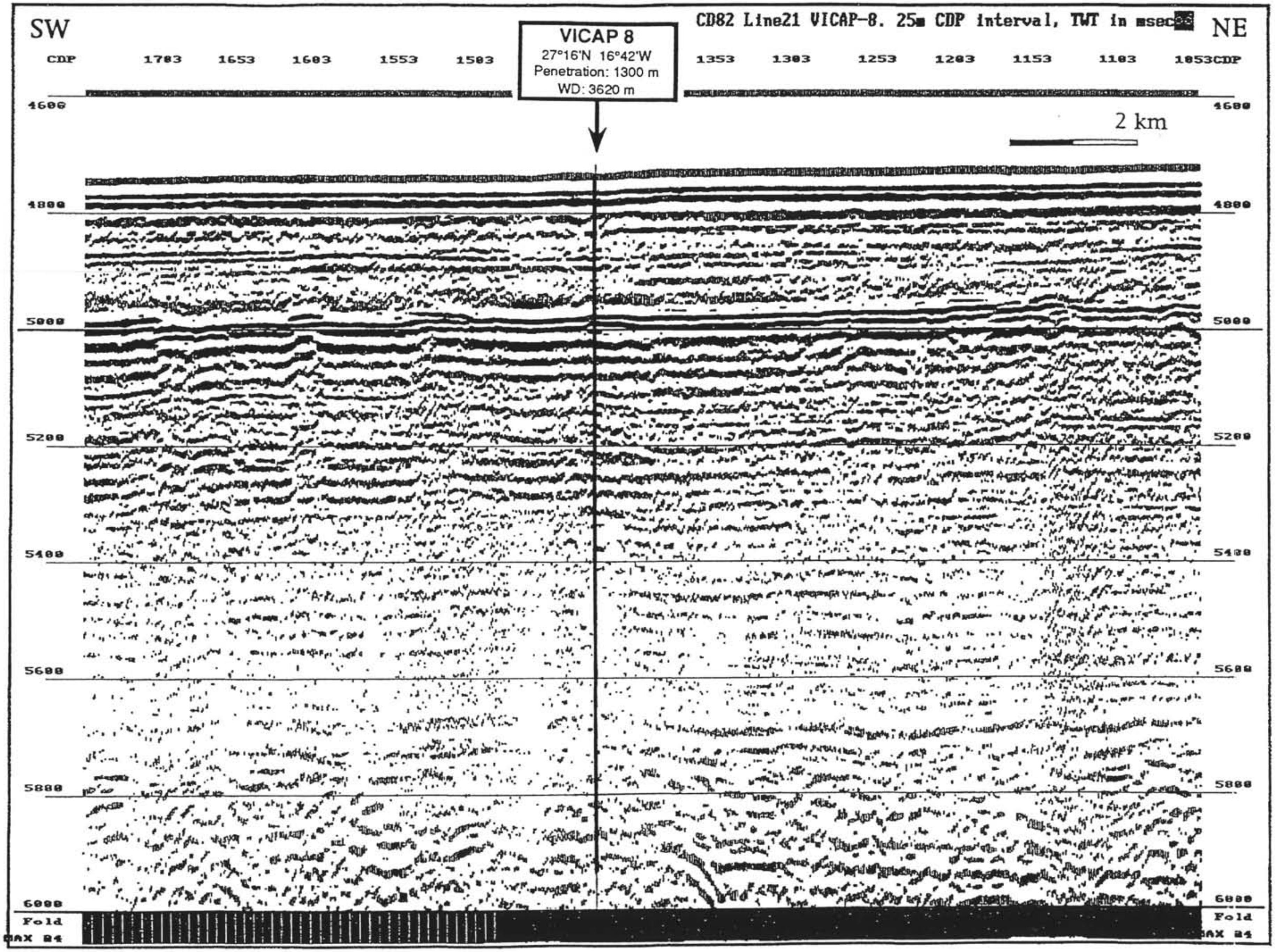
Objectives: Objectives 1, 3, 4, 5, 6, 7, and 8 as presented for proposed site VICAP-1a and

- To determine the thickness of the Gran Canaria shield stage and younger Gran Canaria and Tenerife deposits (medial facies) southwest of Gran Canaria and southeast of Tenerife.
- Volcaniclastic facies changes closer to Tenerife (and Gran Canaria) and farther off the continent compared to proposed site VICAP-4 and DSDP Site 397.
- To identify Gran Canaria and Tenerife shield stages within the South Canary Basin stratigraphy.
- Thickness of the medial/distal facies of the shield stage and younger volcaniclastic deposits north of Gran Canaria.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.


SW
NE
CD82 Line21 VICAP-8. 25m CDP interval, TWT in msec
VICAP 8
27°16'N 16°42'W
Penetration: 1300 m
WD: 3620 m
CDP
1703
1653
1603
1553
1503
1353
1303
1253
1203
1153
1103
1053CDP
2 km
4600
4800
5000
5200
5400
5600
5800
6000
Fold
MAX 24

Site: VICAP-8
Priority: 2
Position: 27°16'N, 16°42'W
Water Depth: 3620 m
Sediment Thickness: ~4000 m
Total Penetration: ~1300 m
Seismic Coverage: MCS lines M 16-4, V 30-05, and P 1

Objectives: Objectives 1, 3, 4, 5, 6, 7, and 8 as presented for proposed site VICAP-1a and

- To determine the thickness of the Gran Canaria shield stage and younger Gran Canaria and Tenerife deposits (distal facies) southwest of Gran Canaria and south of Tenerife.
- To identify the position of Gran Canaria and Tenerife shield stages within the South Canary Basin stratigraphy.

Drilling Program: HPC, XCB, and RCB coring.

Logging and Downhole Operations: Quad combo, FMS, and geochemical, if appropriate.

Nature of Rock Anticipated: Volcaniclastics and hemipelagic.

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