pinnipeds, elephant seals, dive longer and deeper than any others.

On average adult elephant seals dive to what seems to us as a punishing schedule. Average dive durations can exceed 30 minutes with about 2 minutes between dives and elephant seals maintain this pattern of diving for months on end, only stopping every few days to 'rest' at the surface for a slightly longer interval than normal but usually much less than an hour. Technically, elephant seals are more correctly seen as surfacers rather than divers.

Occasionally elephant seals dive to depths of 1500 m and dives can last up to 2 hours with no apparent effect on the time spent at the surface between dives. It is still a mystery to physiologists how elephant seals, and many other species including hooded seals and Weddell seals, manage to have such extended dives. Many physiologists believe that free-ranging seals like elephant seals are able to reduce their metabolic rate while submerged to such an extent that they can conserve precious oxygen stores and they can then rely on aerobic metabolism throughout the dives. This strategy may allow these animals to access food resources that the majority of air-breathing animals cannot reach. As described above, this is likely to be of critical importance to these large-bodied animals because of their need to find rich food sources.

See also

Krill. Marine Mammal Evolution and Taxonomy. Polar Ecosystems.

Further Reading

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SEAMOUNTS AND OFF-RIDGE VOLCANISM

R. Batiza, Ocean Sciences, National Science Foundation, VA, USA

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Summary

There are three major types of off-axis volcanism forming the abundant seamounts, islands, ridges, plateaus, and other volcanic landforms in the world's oceans. (1) The generally small seamounts that form near the axes of medium and fast-spreading ridges but less so at slow-spreading ones. These are most likely a result of mantle upwelling and melting in a wide zone below mid-ocean ridges, although off-axis 'mini plumes' cannot be ruled out. (2) The huge oceanic plateaus and linear volcanic chains that form from starting plumes and trailing plume conduits respectively. It is widely believed that mantle plumes originate in the lower mantle, perhaps near the core–mantle boundary. (3) Off-ridge volcanism that is not due to plumes, but which chemically and isotopically resembles plume volcanism. Emerging data indicate that much off-axis volcanism previously ascribed to mantle plumes is not plume-related. Several distinct types of activity seem to be the result of various forms of intraplate mantle upwelling, or pervasively available asthenosphere melt rising in conduits opened by intraplate stresses, or both. Seamounts, ridges, and plateaus produced by off-axis volcanism play important roles in ocean circulation, as biological habitats, and in biogeochemical cycles involving the ocean crust.

Introduction

The seafloor that is produced at mid-ocean ridges is ideally quite uniform, and except for the regular abyssal hills and the rugged linear traces of ridge offsets, it is essentially featureless. In strong contrast, real ocean crust in the main ocean basins and the marginal basins and seas is decorated with volcanic islands, seamounts, ridges, and platforms that range in size from tiny lava piles only tens of meters high to vast volcanic outpourings covering huge areas of seafloor. Volcanoes that are active close to mid-ocean ridges are related to the ridge processes that build the ocean crust, whereas those erupting farther away, so-called off-axis, off-ridge, or intraplate volcanic features, are the result of processes that are unrelated to mid-ocean ridges. The largest oceanic volcanic features, oceanic plateaus and linear chains of islands and seamounts (known as large igneous provinces or LIPs) (*see* **Large Igneous Provinces**), are considered to be the result of rising plumes of hot material that may originate as deep as the core-mantle boundary. Laboratory models suggest that when first initiated, plumes consist of large buoyant 'heads' (so-called starting plumes) trailed by much narrower cylindrical conduits that continue to feed material upward. In these models, the massive starting plume experiences decompression melting and eruption of this melt produces large oceanic plateaus. When starting plumes rise below continents, they produce huge volcanic outpourings called flood basalts. After passage of the starting plume, further melting of the rising cylindrical conduit can build linear island and seamount chains on the moving, over-riding plate. Plumes are found within plate interiors and also at and near mid-ocean ridges, with which they interact.

While volumetrically plumes may be responsible for most off-ridge volcanism, there are other forms of off-ridge volcanism that do not appear to be related to mantle plumes, although chemically and isotopically their magmas are very similar to those of supposed plumes. These diverse and less voluminous volcanic features include individual isolated seamounts, *en echelon* volcanic ridges, clustered seamounts, and lava fields. The distinct tectonic settings in which they occur suggest that their origin is related to stresses induced in moving lithospheric plates; however, the manner in which melt is produced is uncertain.

This article describes near-ridge seamounts, plume-related volcanism, and off-axis volcanism that is not related to mantle plumes. For each of these three major types, their characteristics are reviewed briefly and the evidence for their origin and evolution is discussed. A common theme is the question of whether volcanism is principally controlled by the availability of mantle-derived melt, or alternatively, the extent to which the thermomechanical properties of ocean lithosphere variably influence the eruption of this melt. It is clearly more difficult for magma to penetrate and erupt through thick, cold, and fast-moving lithosphere than through thin, hot, and slow-moving lithosphere.

Another common thread is the extent to which different kinds of off-axis volcanism can be linked with patterns of mantle flow occurring at various levels within the Earth's mantle: flow which is linked in fundamental ways to the Earth's heat loss and the dominant plate tectonic processes that control the dynamic outer layer of the Earth. Finally, diverse oceanic volcanic features interact in important ways with ocean currents and biological organisms. Because of volcanic degassing, hydrothermal activity, and slow weathering processes, these volcanic features also affect the chemistry of sea water and influence patterns of sedimentation. the oceanographic effects of seamounts and other off-axis volcanic features are briefly discussed.

Near-ridge Seamounts

The most abundant seamounts on Earth, probably numbering in the millions, are the relatively small, mostly submerged volcanoes that occur on the flanks of mid-ocean ridges. They originate at and grow fairly close to the active mid-ocean ridges, so despite their huge numbers only a small percentage are active at any given time, and because of their small size they contribute only a few percent of material to the ocean crust. Although the existence of abundant seamounts on the ocean floor has been known since the earliest exploration of the ocean, the availability in the early 1980s of multibeam swath mapping sonar systems (*see* **Ships**) has made it possible to study large numbers of these seamounts. Several dozen have been studied in detail with deep-sea research submersibles (*see* **Manned Submersibles, Deep Water**).

Individual volcanic seamounts vary in size from small dome-shaped lava piles only tens of meters high, to large volcanic edifices several kilometers in height. Commonly, they have steep outer slopes, flat or nearly flat circular summit areas, and collapse features such as calderas and pit craters (**Figure 1**). In general, the smallest volcanoes tend to have the most diverse shapes. They occur as both individual volcanoes and as linear groups consisting of a few to several dozen individual volcanoes (**Figure 2**). In general, those volcanoes comprising chains tend to be larger than the isolated individual ones. Large numbers of seamounts, mostly occurring as linear chains, have been mapped on the flanks of the Juan de Fuca ridge and both the northern (**Figure 3**) and southern (**Figure 4**) East Pacific Rise (EPR).

At the Juan de Fuca ridge and along the southern East Pacific Rise (**Figure 4**), there is a marked asymmetry to the distribution of seamount chains, with most chains present on the Pacific plate. This asymmetry is absent or much less marked along the Pacific-Cocos portion of the northern EPR, and occurs, but with the opposite sense, along the Pacific-Rivera boundary. In contrast with seamount chains, isolated small seamounts near the southern EPR are symmetrically distributed on both flanks of the EPR axis.

Studies at Santa Barbara indicate that near-axis seamounts, whether isolated or in chains, form close

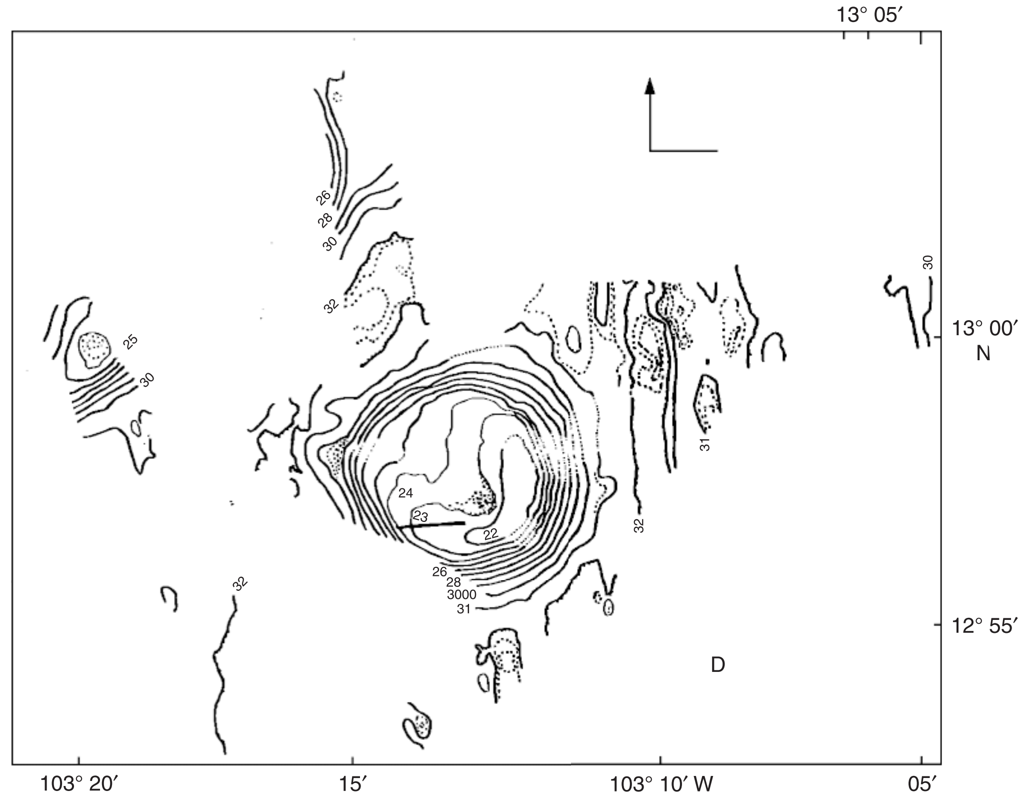

Figure 1 Seabeam map of Seamount 'D' in the eastern equatorial Pacific. Depth contours are in meters (four digits) or hundreds of meters (two digits). The arrow shows the direction of ridge-parallel abyssal hills. Note the relatively flat summit region and the caldera that is breached to the northwest. (Reproduced with permission from Elsevier from Batiza R and Vanko D (1983) Volcanic development of small oceanic central volcanoes on the flanks of the East Pacific Rise inferred from narrow-beam echo-sounder surveys. *Marine Geology* 54: 53–90.)

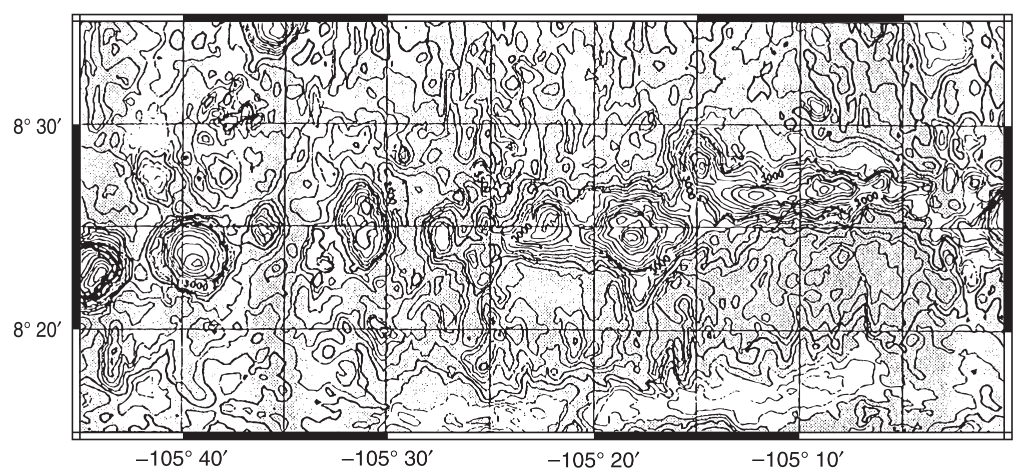

Figure 2 Seabeam map of the seamount chain at 8°20′N (see Figure 3 for location). Note the diverse seamount shapes. (Reproduced with permission from Schierer DS and Macdonald KC (1995) Near-axis seamounts on the flanks of the East Pacific Rise, 8°N to 17°N. *Journal of Geophysical Research* 100: 2239–2259.)

to the axis in a zone that is about 0.2–0.3 million years wide and is independent of spreading rate. Many may continue to grow within a wider zone and a much smaller number may continue to be active at even great distances (several hundred kilometers) from the axis. Far from the axis it is difficult to distinguish near-axis seamounts that remain active for very long periods, from near-axis seamounts that are volcanically reactivated, from true intraplate volcanism that was initiated far from the axis.

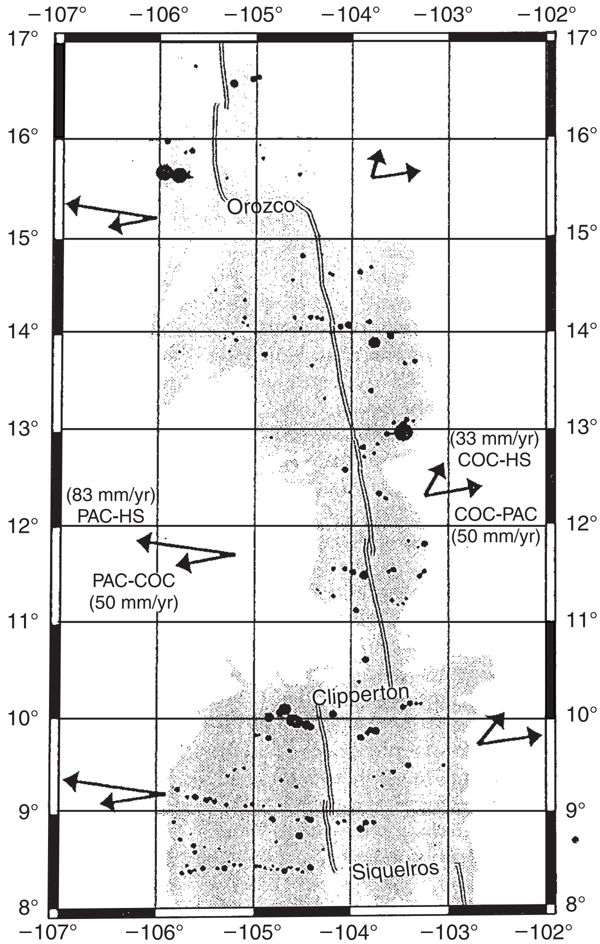

Figure 3 The northern East Pacific Rise (EPR) study area of Schierer and Macdonald (1995). Seamounts $>200\,m$ in height are shown as dots, and the double line is the axis of the EPR. The arrows show the magnitude and direction of relative and absolute plate motions. (Reproduced with permission from Schierer DS and Macdonald KC (1995) Near-axis seamounts on the flanks of the East Pacific Rise, 8°N to 17°N. *Journal of Geophysical Research* 100: 2239–2259.)

In such cases, the distinction between ridge-related volcanism and true intraplate volcanism can be somewhat blurred.

Near-axis seamounts occur most commonly on the flanks of inflated ridges with large cross-sectional areas and abundant melt supply, and the abundance of large ones ($>400\,m$ high) is strongly correlated with spreading rate (**Figure 5**). Abundant seamounts characterize not only modern fast-spreading ridge flanks, but also crust produced at fast spreading rates in the past, for example, in the Indian Ocean before the collision of India with Asia.

While near-axis seamounts form preferentially at inflated portions of fast-spreading ridges, they also occur near offsets (*see* **Mid-Ocean Ridge Tectonics, Volcanism and Geomorphology**). such as overlapping spreading centers (OSCs), where they form closer to the ridge axis. They may also occur on fracture zones, although this is much more common on old versus young ocean crust. At the slow-spreading Mid-Atlantic Ridge (MAR), studies show that small seamounts are very common within the floor of the axial valley. Many or most of these appear to be a manifestation of ridge axis volcanism from both primary volcanic vents as well as off-axis eruptions fed by lava tubes.

Exactly how and why seamounts form near mid-ocean ridge axes is not known, although the composition of their lavas suggests strongly that they have the same mantle sources as volcanics erupted at the axis. Since the zone of melting that feeds the axes of fast-spreading ridges is very wide, extending several hundred kilometers on both sides of the axis, it is possible that near-axis seamounts are simply due to rising axial melt that was ineffectively focused at the axis. This idea explains their chemistry but not why they so commonly form chains. An appealing idea to explain chains is that they are due to mantle heterogeneities akin to 'mini' mantle plumes, which would help explain the occurrence of chains trending in the direction of absolute plate motion and possibly the observed asymmetry of distribution on the flanks of some ridges, as seen at the Juan de Fuca ridge. However, on the Cocos plate, where the absolute and relative motion are very different, most chains are parallel to relative motion, suggesting that perhaps the movement of the lithosphere or convection rolls parallel to relative motion might trigger seamount formation.

However, not all near-axis seamount chains trend parallel or subparallel to relative or absolute plate motion. Lonsdale showed that the oblique trend of the Larson seamounts near the EPR at $\sim 21°N$ is consistent with its being fed by an asthenospheric melt diapir rising beneath the ridge axis, as envisioned in the model of Schouten and others. A problem with testing this idea further is that, along most of the EPR, the relative and absolute plate motions are quite similar and in this case the Schouten *et al.* trend is not distinct enough from the absolute and relative motion directions to be recognized. In summary, a widely applicable, self-consistent hypothesis to explain all the observations of near-axis seamounts and seamount chains is not yet available.

Finally, on the flanks of the southern EPR (**Figure 4**), numerous chains of near-axis seamounts show an inverse correlation of seamount volume between adjacent chains, suggesting that the magma might originate in plume-like sources in the upper

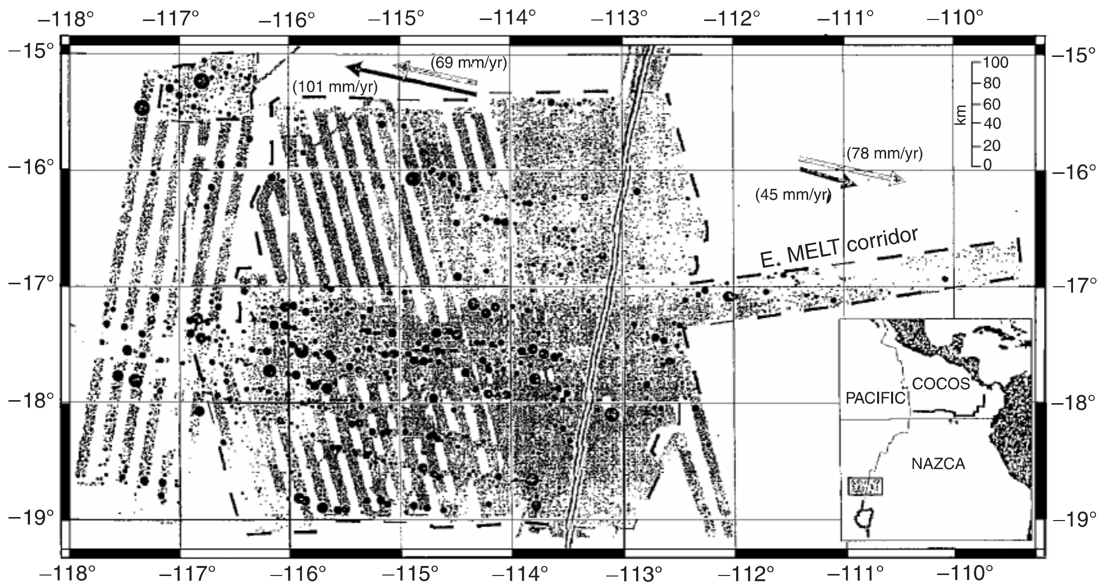

Figure 4 Study area along the southern East Pacific Rise showing the EPR axis (double line) and seamounts as dots. Arrows show the relative (gray) and absolute (black) plate motion vectors. Later studies show much more complete mapping on the Nazca plate to the east of the EPR. Note the very abundant seamount chains present especially on the Pacific plate. (Reproduced with permission from Klewer from Scheirer DS, Macdonald KC, Forsyth DW and Shen Y (1996) Abundant seamounts of the Rano Rahi seamount field near the southern East Pacific Rise, 15° to 19°S. *Marine Geophysical Researches* 18: 14–52.)

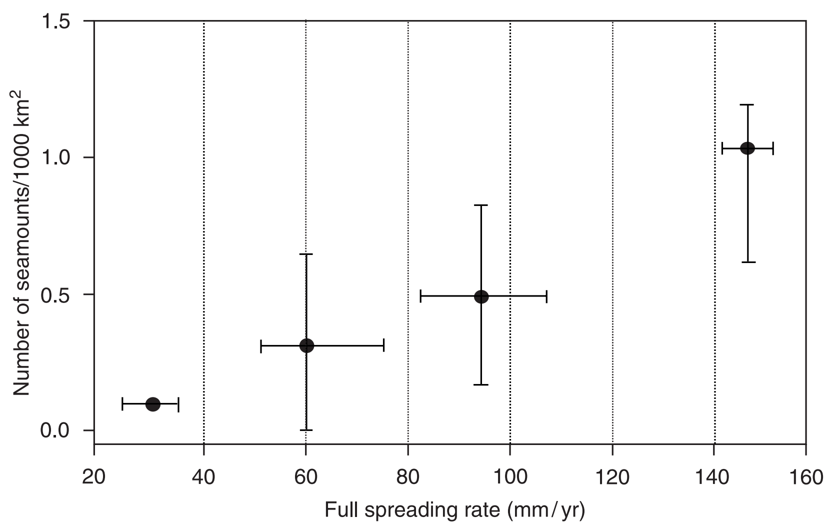

Figure 5 Plot of number of seamounts >400 m in height per 1000 km^2 versus the full spreading rate for the Mid-Atlantic Ridge, various medium-spreading ridges, and the northern and southern EPR. Faster spreading ridges produce more near-axis seamounts and inflated ridge segments produce more and larger seamounts than segments with smaller cross-sectional area. (Reproduced with permission from Schierer DS and Macdonald KC (1995) Near-axis seamounts on the flanks of the East Pacific Rise, 8°N to 17°N. *Journal of Geophysical Research* 100: 2239–2259.)

mantle. This is an interesting observation, suggesting that near-axis seamounts are controlled by melt availability. However, the fact that seamounts form in a narrow zone near the axis that corresponds to a lithosphere thickness of 4–8 km and is independent of spreading rate suggests that the lithosphere plays an important role in the origin of near-axis seamounts. In general, the extent to which near-axis seamounts are controlled by magma availability (and whether their sources are distinct from those feeding the axis), or lithospheric vulnerability or both, is presently unknown.

Off-ridge Plume-related Volcanism

At the opposite end of size spectrum from the small near-axis seamounts are the huge oceanic plateaus

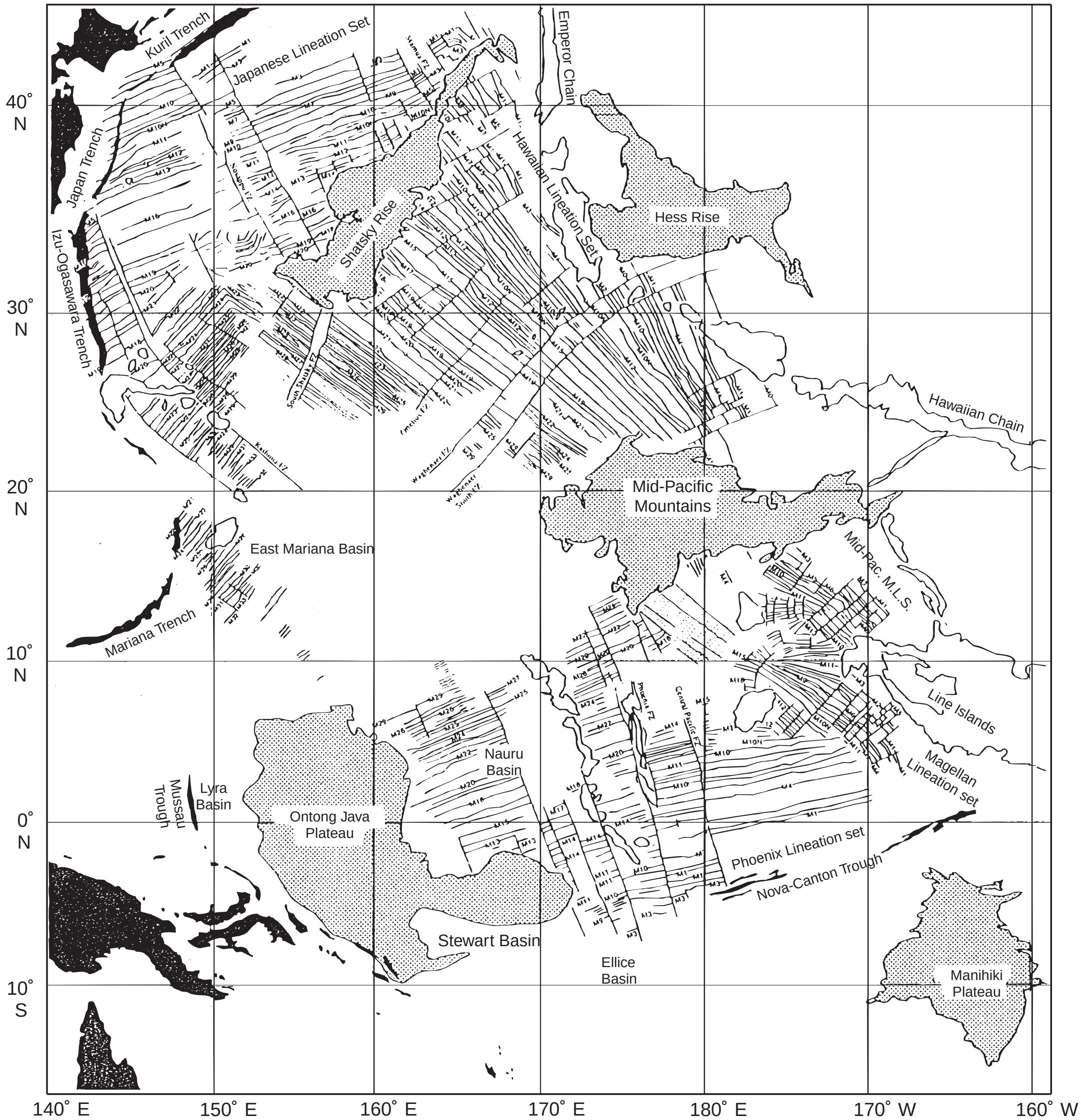

Figure 6 Map of the west and central Pacific showing the major oceanic plateaus of the region. Note also the outline north of the Mid-Pacific Mountains of the Hawaii-Emperor seamount chain with its dogleg just south of the Hess Rise. (Reproduced with permission from Neal CR, Mahoney JJ, Kroenke LW, Duncan RA and Petterson MG (1997) The Ontong Java Plateau. In: *Large Igneous Provinces*, Geophysical Monograph 100, pp. 183–216. Washington, DC: AGU.)

(**Figure 6**) that occur in all the major ocean basins. As previously discussed, these large igneous provinces (LIPs) are thought to be the result of melting of starting plumes, and it has been proposed that the Pacific plateaus were produced by an immense superplume or group of plumes in Cretaceous time. In addition to these huge plateaus, mantle plumes are thought to produce the long linear island and seamount chains that are so common in the ocean basins (**Figure 7**). Widely held corollaries of the plume hypothesis are that plumes are nearly fixed relative to one another and that they originate in the lower mantle, possibly at the core–mantle boundary. Further, the conventional wisdom is that most of the intraplate volcanism on the planet is due to plumes. The Hawaii-Emperor chain of islands, atolls, seamounts, and drowned islands (guyots) is the classic example of a 'well-behaved' plume, with an orderly and predictable age progression of eruptive ages and bend in direction (**Figure 6**) at 43 Ma

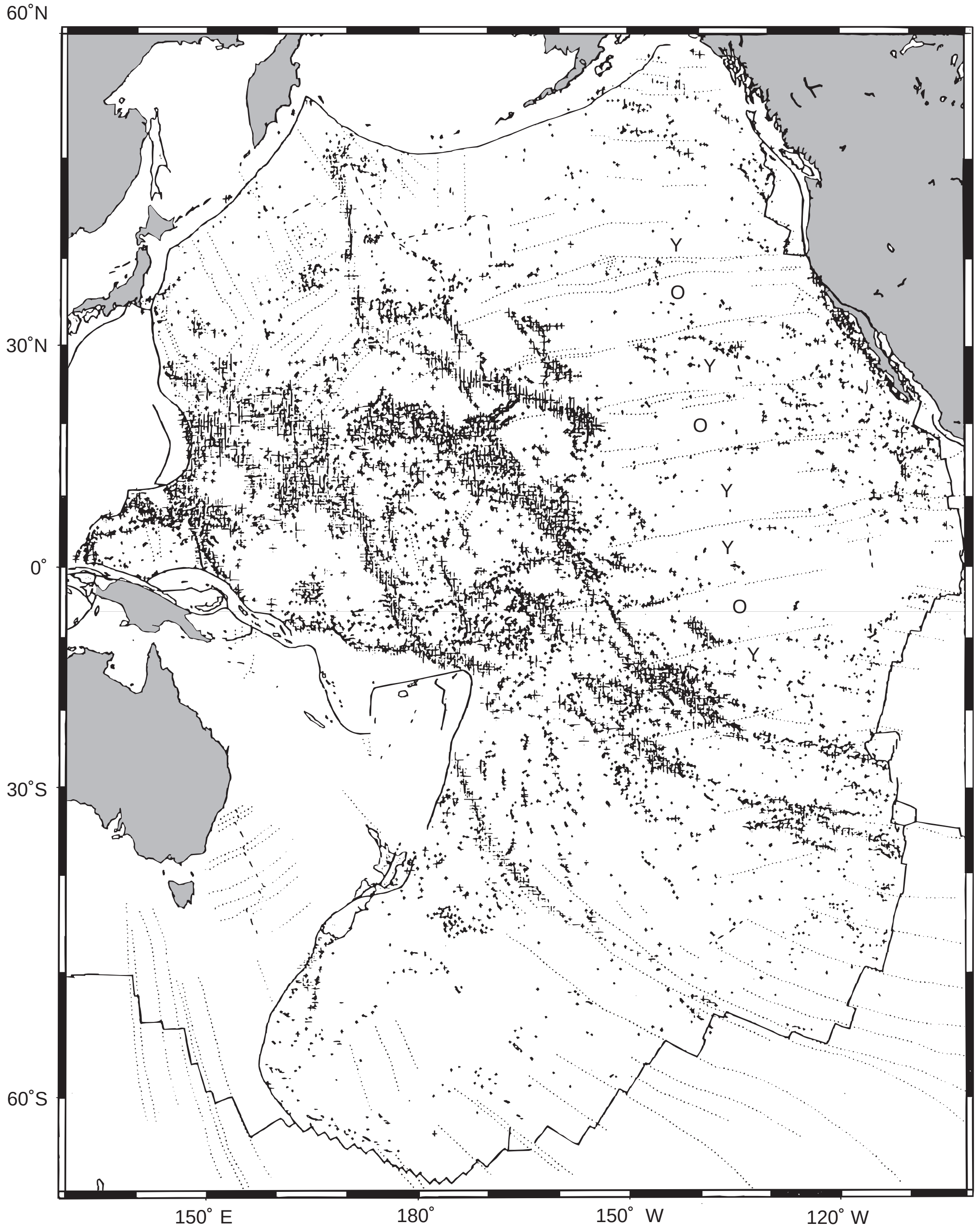

Figure 7 Locations of about 9000 seamounts mapped in the Pacific by satellite gravity methods (crosses), with cross size proportional to the maximum vertical gravity gradient. Note that the western and central Pacific have the most numerous large seamounts. Note that while many seamounts are clustered into linear chains and equant clusters, some are relatively isolated. (Reproduced with permission from Wessel P and Lyons S (1997) Distribution of large Pacific seamounts from Geosat/ERS-1: Implications for the history of intraplate volcanism. *Journal of Geophysical Research* 102: 22 459–22 475.)

when the Pacific plate motion changed from NNW to WNW. Finally, the composition of Hawaiian lavas and those of many other suspected mantle plumes are distinct from the sources that supply mid-ocean ridges, consistent with the hypothesis that plumes sample a different and perhaps deeper region of the Earth's mantle.

Interestingly, in many cases mantle plumes are close to or centered on active mid-ocean ridges, in which case the plume and ridge interact and mixing

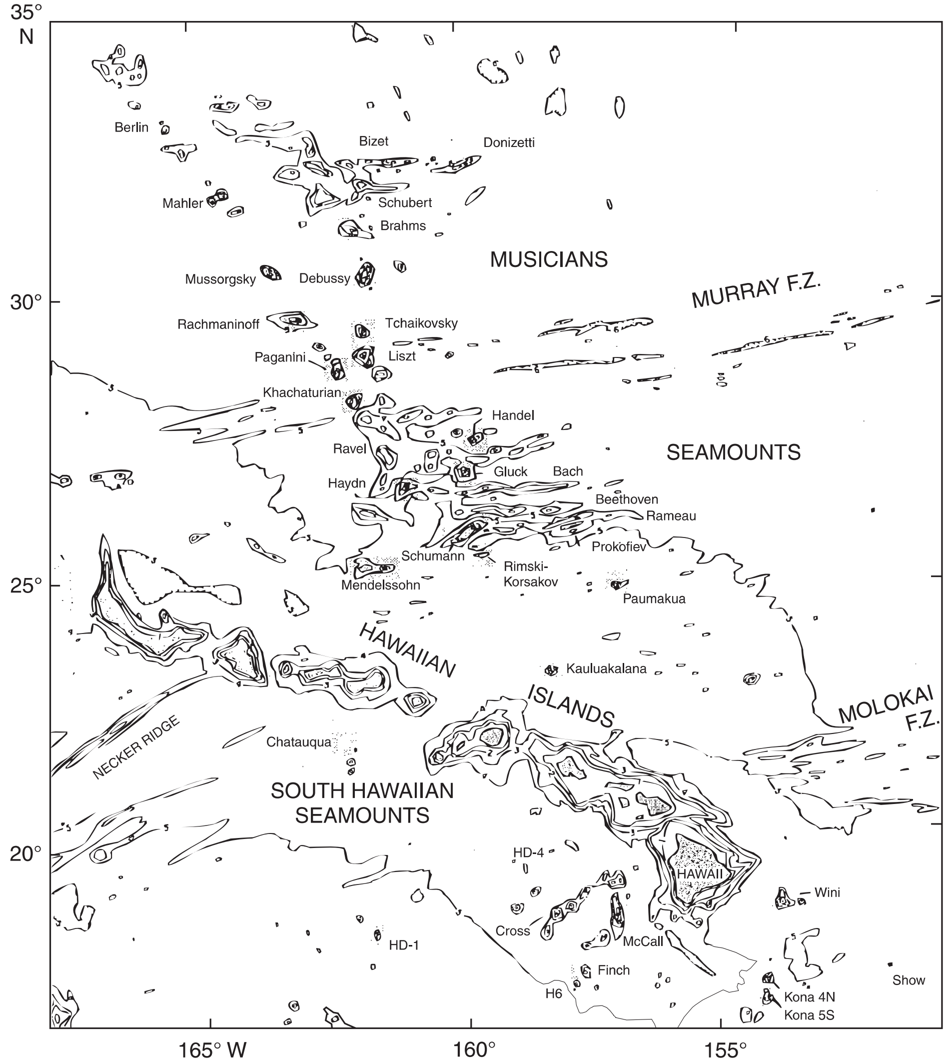

Figure 8 Generalized map of the central Pacific (contours in km) showing a portion of the Hawaiian island chain and the Musicians seamounts. Note that the group comprises a chain of NW trending seamounts including Mahler, Berlin, and Paganini and also E–W trending ridges such as those including Bizet and Donizetti to the north and Bach and Beethoven to the south. (Reproduced with permission from Sager WW and Pringle MS (1987) Paleomagnetic constraints on the origin and evolution of the Musicians and south Hawaiian seamounts, central Pacific Ocean. In: *Seamounts, Islands, and Atolls*, Geophysical Monograph 43, pp. 133–162 Washington, DC: AGU.)

of mantle sources is observed. Iceland is the classic example of a ridge-centered plume; whereas Galapagos is a good example of plume–ridge interaction. In addition to mixing between plume and ridge mantle sources, plume–ridge interaction can lead to the formation of the second type of hot spot island chain discussed by Morgan, in which case the orientation of the linear chain is not parallel to the absolute plate motion (as for normal plumes), but rather has a trend intermediate between the absolute and relative plate motions. An example of this type of seamount chain may be the Musicians seamounts (**Figure 8**), which consists of a western chain of seamounts oriented NW, with roughly E–W trending ridges progressing eastward. The NW trending chain has the proper orientation for a normal hot spot chain, whereas the E–W ridges appear to have been produced by plume–ridge interaction and are intermediate in trend between the absolute and relative plate motions in the Cretaceous when the Musicians plume interacted with the Pacific-Farallon spreading center.

Off-axis Volcanism not Related to Plumes

There is increasing evidence that plumes may not be the only, or even the most abundant form of intra-plate volcanism within the ocean basins. While studies of non-plume intraplate volcanism are just beginning, at least several distinct types of occurrences have been documented. A considerable obstacle to non-plume hypotheses of intraplate volcanism has been the general belief that mantle upwelling is required for melting, as at ridges and plumes, combined with the fact that most models of mantle convection show no upwelling in intraplate regions. One way around this problem is to show that secondary upwelling can occur in intraplate regions, as with Richter and Parson's longitudinal upper mantle convective rolls (called Richter rolls). Another way is to invoke localized upward mantle flow into depressions or recesses in the base of the lithosphere. A final possibility is to invoke diffuse regional mantle upwelling, as might be generated by a weak mantle plume. A completely different way around the problem, discussed by Green and others, is to cause melting not by decompression, but rather by an influx of volatiles, as is thought to occur at convergent margins. In mid-plate settings, volatiles could perhaps migrate upward from the low velocity zone of the asthenosphere. If this occurs, then magmas may generally be present and available below most ocean lithosphere, and would need only an appropriate pathway for eruption.

Recent surveys have documented the presence on older Pacific seafloor, of long, *en echelon*, linear ridges whose trend is distinct from that of plume traces on the Pacific plate. For example, the Puka Puka ridges (**Figure 9**), stretch for at least several thousand kilometers and their morphology suggests that they are due to eruptions accompanying tensional cracking of the Pacific plate. Interestingly, the lavas of the Puka Puka ridges are chemically similar to those of supposed plumes on the Pacific plate; however, the trend of the ridges and the measured age progression of volcanism indicate that the ridges could not be due to a mantle plume.

Another form of intraplate volcanism not involving mantle plumes is the very common formation of large volcanoes of alkali basalt within the axes of inactive or fossil spreading ridges. Lonsdale has documented their very common existence in fossil ridges of the extinct Pacific-Farallon ridge system, the Mathematician fossil ridge, and the fossil Galapagos Rise (**Figure 10**). In some cases, these volcanoes are large enough to form islands, for example, Guadalupe Island off the coast of Baja California. Samples from these islands, and rarer samples from submerged seamounts, indicate that these lavas also are indistinguishable from supposed plume lavas on the Pacific plate.

A third form of non-plume volcanism that appears to be fairly widespread is associated with flexure caused by loading of the ocean lithosphere. Examples of this type of volcanism include lava fields found on the flexural arch associated with the Hawaiian island chain. The so-called North Arch and South Arch lava fields contain lavas not unlike those of the Hawaiian plume, but they erupted several hundred kilometers from the presumed location of the plume. An example on a smaller scale is Jasper seamount (**Figure 11**), which is surrounded by a ring of seamounts built on its flexural arch. Finally, there is the example of the southern Austral islands and seamounts, which recent studies suggest cannot be explained by a mantle plume, as previously proposed. Instead, it appears that these volcanoes are the result of available melts erupting in response to flexural loading by nearby edifices. In all these cases where samples are available, the lavas are chemically and isotopically similar to supposed plume lavas.

The most incompletely documented occurrences of non-plume volcanism, but potentially important in terms of volumes, are isolated large seamounts and groups of seamounts forming clusters rather than linear chains. About a dozen examples of iso-

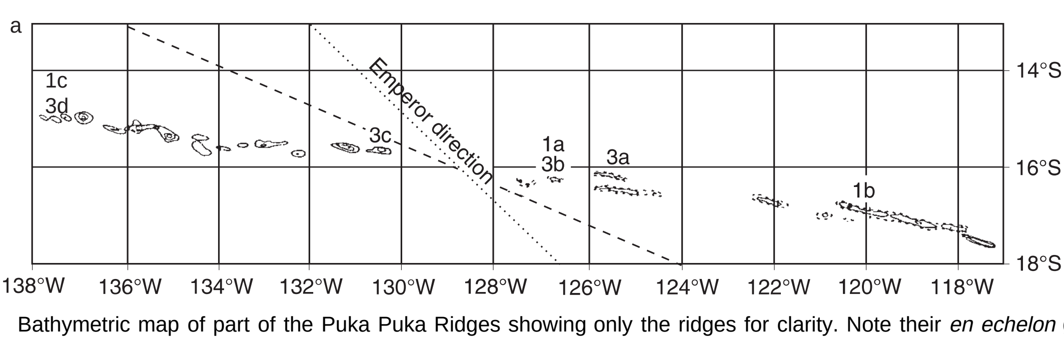

Figure 9 Bathymetric map of part of the Puka Puka Ridges showing only the ridges for clarity. Note their *en echelon* geometry and their trend which is distinct from the Hawaiian chain direction (dashed) and the Emperor chain direction (dotted). (Reproduced with permission from Lynch MA (1999) Linear ridge groups: evidence for tensional cracking in the Pacific Plate. *Journal of Geophysical Research* 104: 29 321–29 333.)

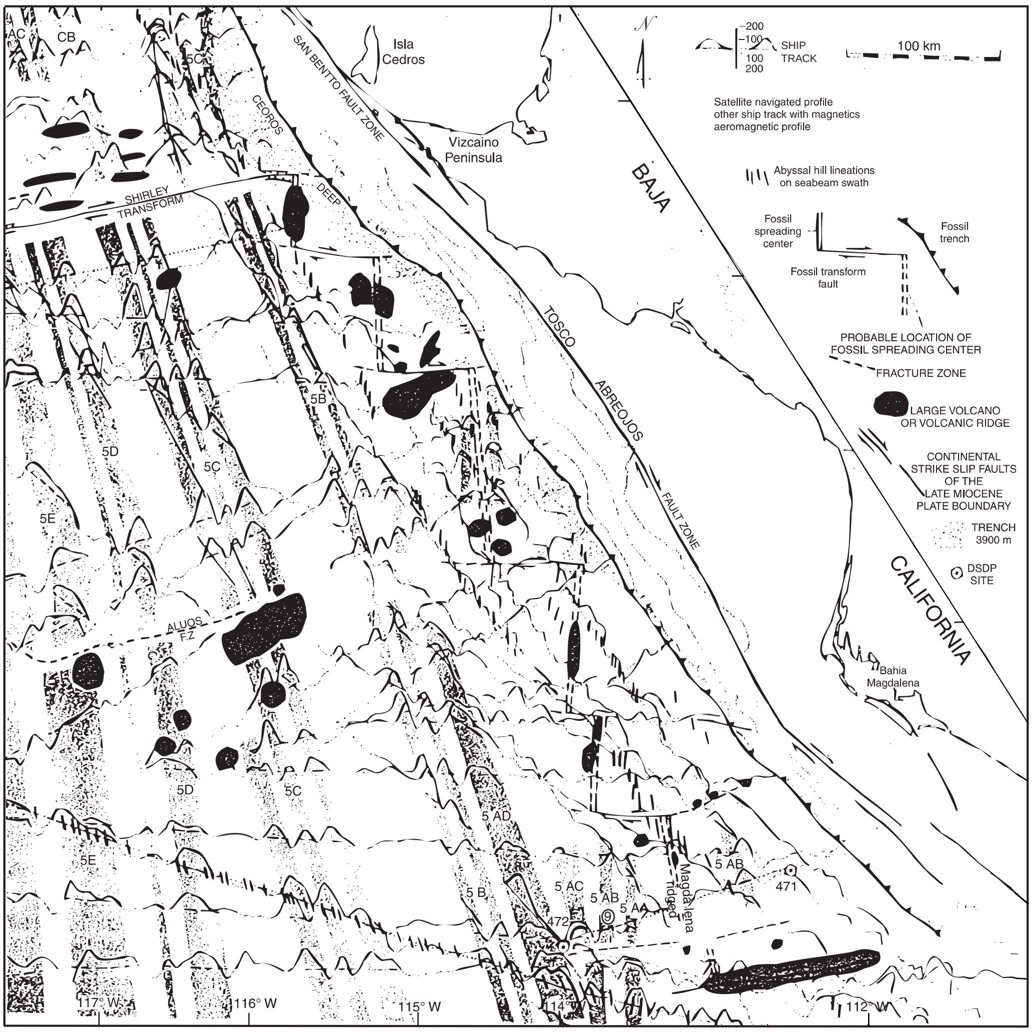

Figure 10 Interpretation of magnetic anomalies off the coast of Baja California showing the locations of probable fossil spreading centers (double dashed lines). Note that many of the fossil spreading centres have large volcanoes or volcanic ridges built in their axes. (Reproduced with permission of the American Association of Petroleum Geologists from Lonsdale P (1991) Structural patterns of the Pacific floor offshore of Peninsular California. In: *The Gulf and Peninsular Province of the Californias*, AAPG Memoir 47, pp. 87–125.Tulsa, OK: AAPG.)

lated large intraplate seamounts not due to mantle plumes have been documented in several studies, for example Vesteris seamount (**Figure 12**). However, there are potentially many hundreds or even thousands of such volcanoes in the ocean basins. It is possible that every large volcano that is not clearly associated with a linear chain is a member of this group. Additional examples of large isolated intraplate seamounts are Shimada seamount and Henderson seamount in the eastern Pacific. As shown by the recent studies of Wessel and Kroenke, there are many large seamounts in the Pacific that are not members of linear chains. Further, Chapel and Small have shown that while many of the very largest volcanoes in the Pacific are associated with linear chains, many large volcanoes are clustered in nonlinear groups.

In addition to these forms of non-plume volcanism, recent studies have questioned the plume origin of several linear island chains. Wessel and Kroenke propose that many short island chains without clear age progressions, such as the Cook-Australs, the Marqueses, and the Society Islands, are ‘crackspots’: sites of extensional volcanism along reactivated zones of weakness induced by intraplate stresses. While these ideas are controversial, they suggest that the Pacific may contain only about five mantle plumes, instead of the several dozen that have previously been proposed. If these suggestions prove to be correct, then much, perhaps even most intraplate

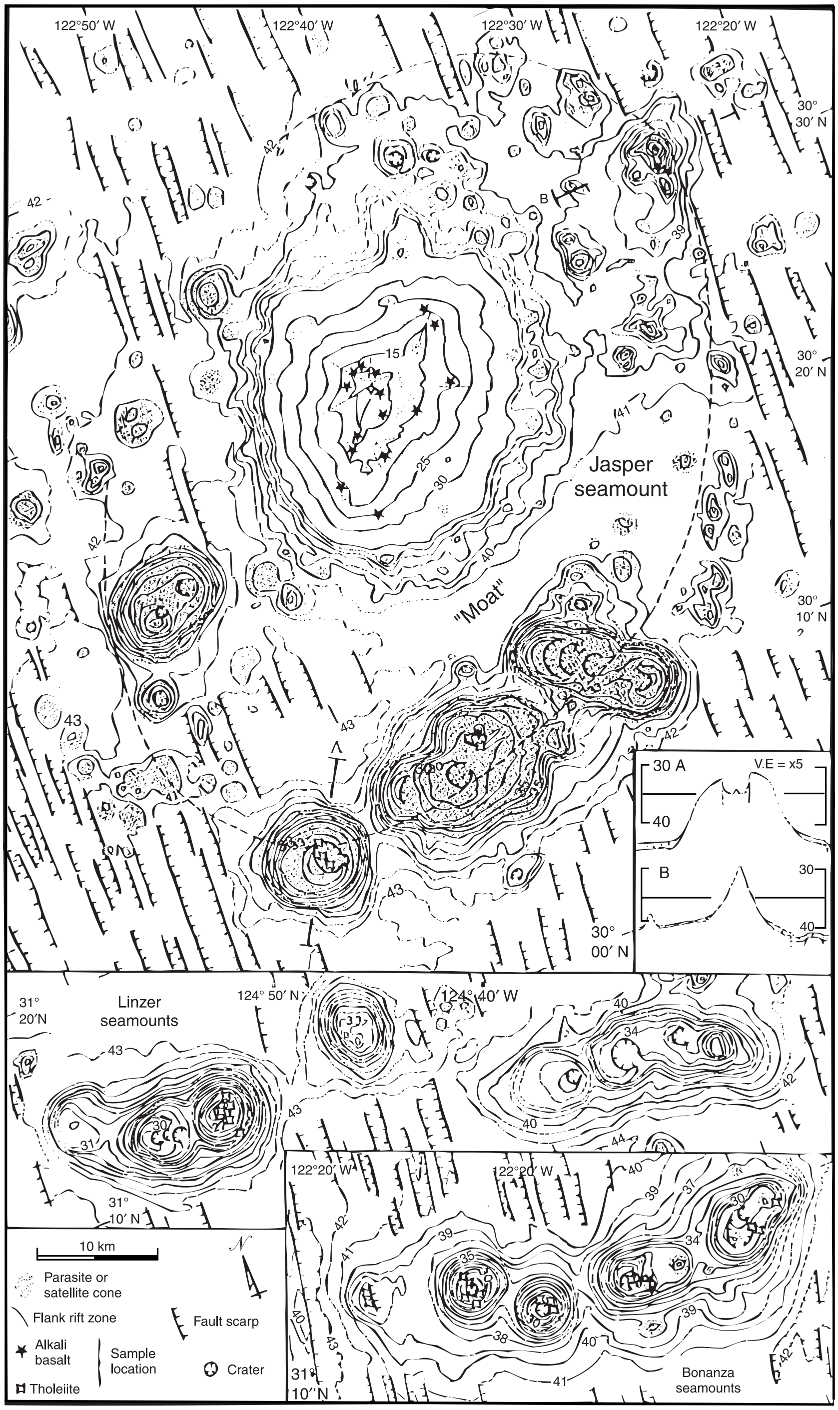

Figure 11 Bathymetric maps of several seamounts (two-digit contours are hundreds of meters). Note the elliptical group of seamounts surrounding Jasper seamount. These are presumed to have erupted on Jasper's flexural arch, similar to seamounts and lava beds elsewhere in the Pacific basin. The Linzer and Bonanza Seamounts are additional examples of near-ridge seamounts built on older Pacific crust, although Linzer, like Jasper, may be part of the Fieberling hot spot chain. (Reproduced with permission of the American Association of Petroleum Geologists from Lonsdale P (1991) Structural patterns of the Pacific floor offshore of Peninsular California. In: *The Gulf and Peninsular Province of the Californias*, AAPG Memoir 47, pp. 87–125. Tulsa, OK: AAPG.)

volcanism in the oceans will be of the non-plume type, with important implications for mantle convection and mechanisms of advective heat loss. Haase has shown that chemically and isotopically, various types of plume and non-plume intraplate volcanism seem to define a single population that

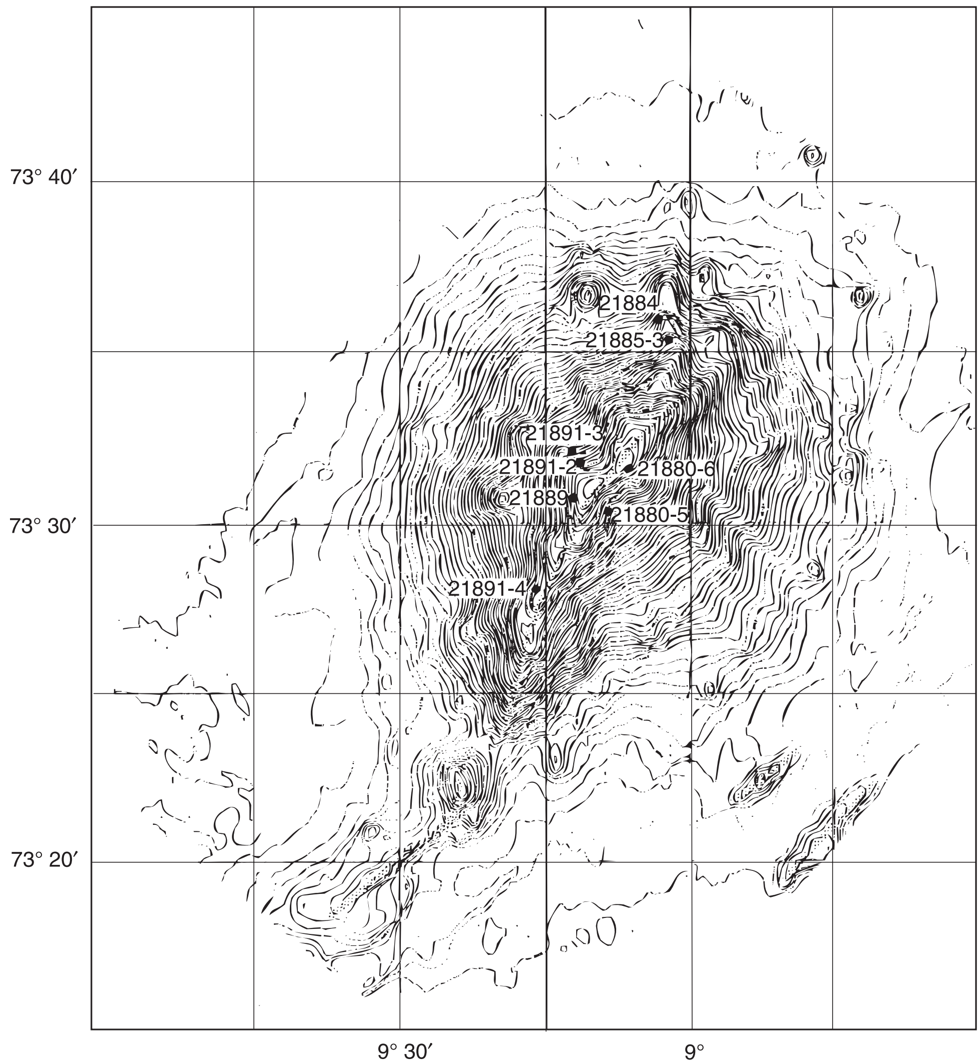

Figure 12 Bathymetric map of Vesteris seamount, an isolated intraplate seamount in the north Atlantic ocean. Note the volcanic rift zones shown with heavy dark lines. Sample locations and numbers are shown. (Reproduced with permission from Oxford University Press from Haase KM and Devey CW (1994) The petrology and geochemistry of Vesteris seamount, Greenland basin – an intraplate alkaline volcano of non-plume origin. *Journal of Petrology* 35: 295–328.)

exhibits chemical systematics as a function of the age of the lithosphere affected by intraplate volcanism. This chemical coherence, along with emerging evidence for the volumetric importance of non-plume volcanism, suggests that much oceanic intraplate volcanism originates in the upper mantle, not in the lower mantle as suggested by the plume hypothesis.

Oceanographic Effects

Seamounts of all types, including large plateaus and platforms, may contribute about 10% or more to the mass of oceanic crust. Since seamounts are volcanic and host active hydrothermal convective systems, seamounts should have a significant effect on element cycles involving sea water and its dynamic interaction with the ocean crust. Likewise, because normal abyssal sedimentation patterns are severely disturbed in the vicinity of seamounts, they exert a significant influence on the average composition of oceanic sediments, including their hydrothermal and biogenic components (*see* **Authigenic Deposits; Calcium Carbonates**).

Seamounts may also have a significant influence on global ocean circulation patterns (*see* **Ocean Circulation; Water Types and Water Masses**) because their presence induces much greater mixing than is measured in areas with smooth bottom topography. At a more local scale, seamounts have a great effect on circulation patterns and currents, which in turn have very important effects on seamount biota, including populations of fishes (*see* **Pelagic Fish; Deep-Sea Fauna**). In general, seamounts host very diverse and abundant faunas, with important effects on oceanic biology. Thus, while seamounts and off-axis volcanism are interesting on their own, seamounts are also of great interest as obstacles to current flow, biological habitats, and for biogeochemical cycles involving the ocean crust.

See also

Authigenic Deposits. Calcium Carbonates. Deep-sea Fauna. Manned Submersibles, Deep Water. Ocean Circulation. Igneous Provinces. Mid-ocean Ridge Tectonics, Volcanism and Geomorphology. Pelagic Fishes. Ships. Water Types and Water Masses.

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SEDIMENT CHRONOLOGIES

J. K. Cochran, State University of New York, Stony Brook, NY, USA

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Introduction

Although the stratigraphic record preserved in deep-sea sediments can span up to 200 Ma, techniques of isotopic dating commonly used to extract sediment accumulation time scales are useful for only a fraction of this range. In addition, the temporal record is blurred by the mixing activities of the benthic fauna living in the upper centimeters of the sediment column. Radionuclide distributions in the sediments provide the most straightforward way of resolving mixing and accumulation rates in deep-sea sediment over the past $\sim$5–7 Ma. The basis for these techniques is the supply of radionuclides to the oceanic water column, followed by their scavenging onto sinking particles and transport to the sediment–water interface. Decay of the radionuclides following burial provides chronometers with which mixing and accumulation rates can be determined.

Radionuclide Supply to the Sediment–Water Interface

Table 1 lists the most frequently used radionuclides for determining chronologies of deep-sea sediments. Many of these are members of the naturally occurring ^{238}U and ^{235}U decay series. Both ^{238}U and ^{235}U, as well as ^{234}U, are supplied to the oceans by rivers