

CHAPTER 1

INTRODUCTION

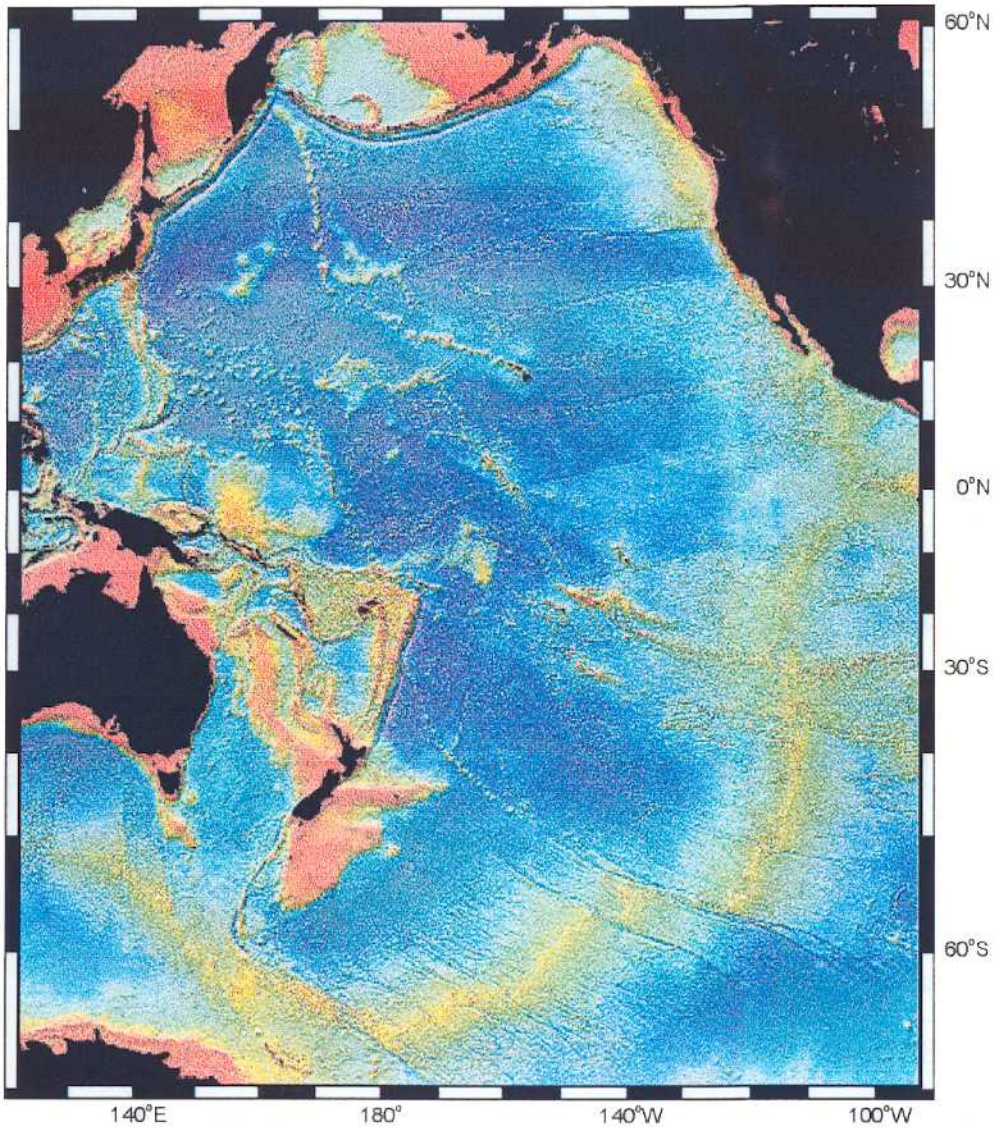


Figure 1.1 Bathymetric map by the gravity anomaly's data of the Pacific Plate and its surrounding areas (Smith, 1993). The Pacific Plate is surrounded by some trenches at northwestern edges (from the Aleutian Trench to the Kermadec Trench) and by the mid-oceanic ridge at the southeastern edges (East Pacific Rise). Many seamounts and oceanic plateaus are dominant in the western Pacific Plate.

1-1 Scope of Study

Most seamounts, islands and atolls on the present Pacific Plate (Figure 1.1) were formed by submarine intra-plate volcanism mainly during the Cretaceous period (e.g. Tokuyama, 1980; Rea and Vallier, 1983; Cox, 1991; Fuller and Weeks, 1991; Larson, 1991; 1995; Haggerty and Silva, 1995). Koppers *et al.* (1998) called the area of these seamounts the West Pacific Seamount Province (WPSP), and indicated that some Cretaceous seamount chains are significant for hotspot trails. The WPSP (Figure 1.2) is characterized as follows:

- Most seamounts were formed by submarine volcanism in the Cretaceous.
- The azimuths of seamount chains are WNW-ESE to NNW-SSE.
- Alkaline or nephelinitic series rocks are sampled from most of the seamounts.
- These seamounts can be traced back to the south Pacific isotopic and thermal anomaly (SOPITA) area (Ozima *et al.*, 1977; Duncan and Clague, 1985; Smith *et al.*, 1989; Staugel *et al.*, 1991; Bergersen, 1995; Koppers *et al.*, 1995).

The SOPITA is both isotopically and thermally an unusual area for the mantle underneath the French Polynesian region in the South Pacific Ocean (Smith *et al.*, 1989; Staudigel *et al.*, 1991), in which an anomalously large number of seamounts are produced (Bemis and Smith, 1993) (Figure 1.2).

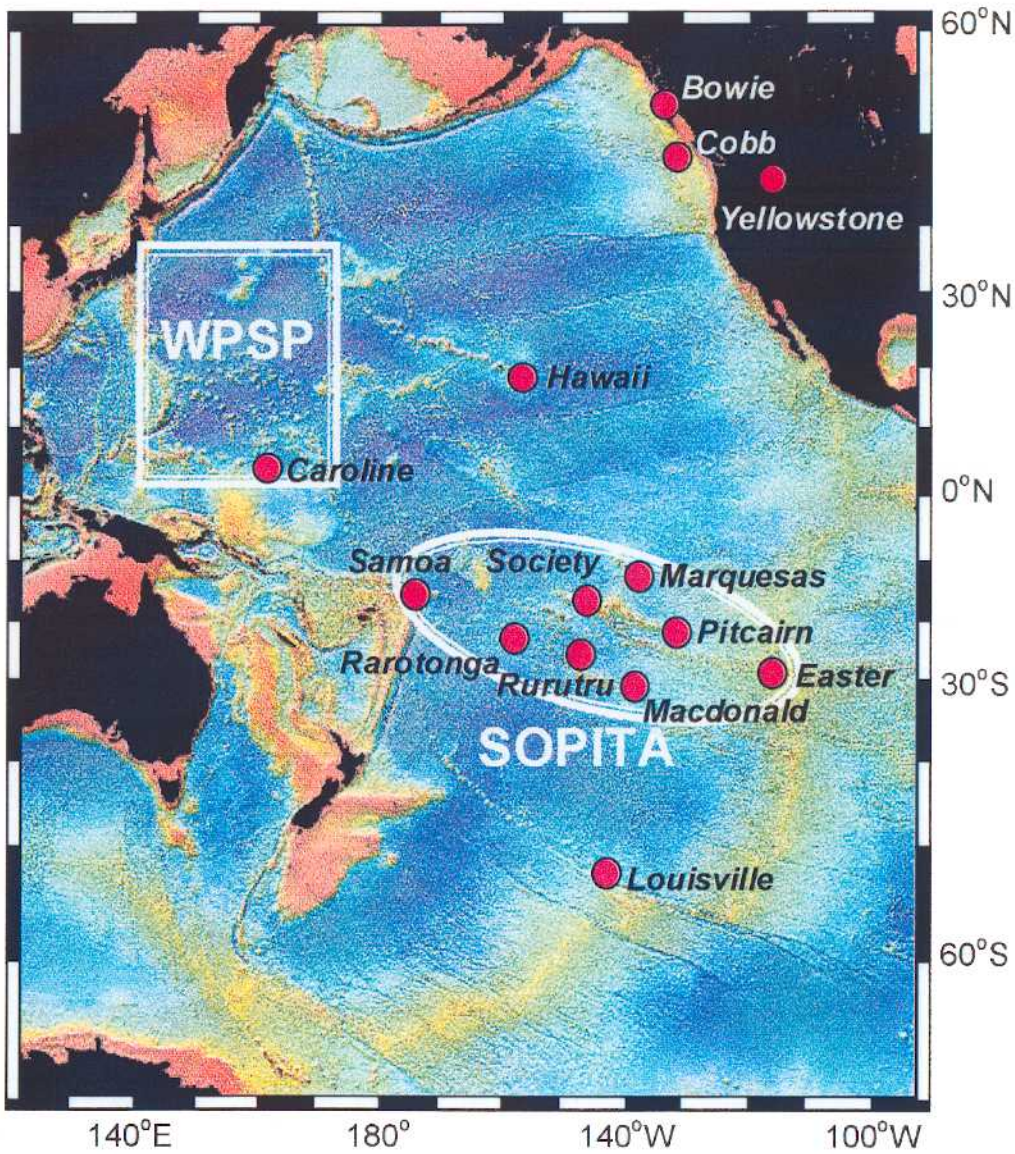


Figure 1.2 WPSP (Western Pacific Seamount Province) and SOPITA (South Pacific Isotopic Thermal Anomaly) in the Pacific Ocean. Reddish circles are active hotspots.

Intra-plate volcanism has given rise discussion since Morgan (1971, 1972) proposed the hotspot hypothesis to explain the origin of several, apparently collinear Pacific seamount chains, as resulting from plumes from the lower mantle supplying hotter materials to the surface (Figure 1.3). The hotspot hypothesis therefore assumes as follows:

- Fixed mantle plumes
- Linear age progressions in the produced seamount trails, reflecting the plate absolute motion
- Geochemical and isotopic signatures consistent with the deviation from individual mantle plumes.

The hotspot hypothesis was successful in explaining some seamount chains; for example the Hawaiian-Emperor Seamount Chain (Jackson *et al.*, 1972; Clague and Jarrard, 1973; Jarrard and Clague, 1977), the Louisville Seamount Chain (Lonsdale, 1988; Watts *et al.*, 1988) and Musicians Seamount Chain (Pringle, 1993). Dalrymple *et al.* (1980) gave the age of 72 ± 3 Ma for Meiji Seamount which is the northernmost, thus the oldest, in the Emperor Seamount Chain as a well-defined hotspot track. The motion of the Pacific Plate after this age is obtained from the Hawaiian-Emperor Seamount Chain's track. On the other hand, before this age, we cannot find the hotspot track of Hawaii-Emperor Seamount Chain as it had been subducted under the circum Pacific subduction zone. To know the absolute motions of the Cretaceous Pacific Plate, we should investigate the older hotspot tracks than the Hawaii-Emperor Seamount Chain, which could be within the WPSP.

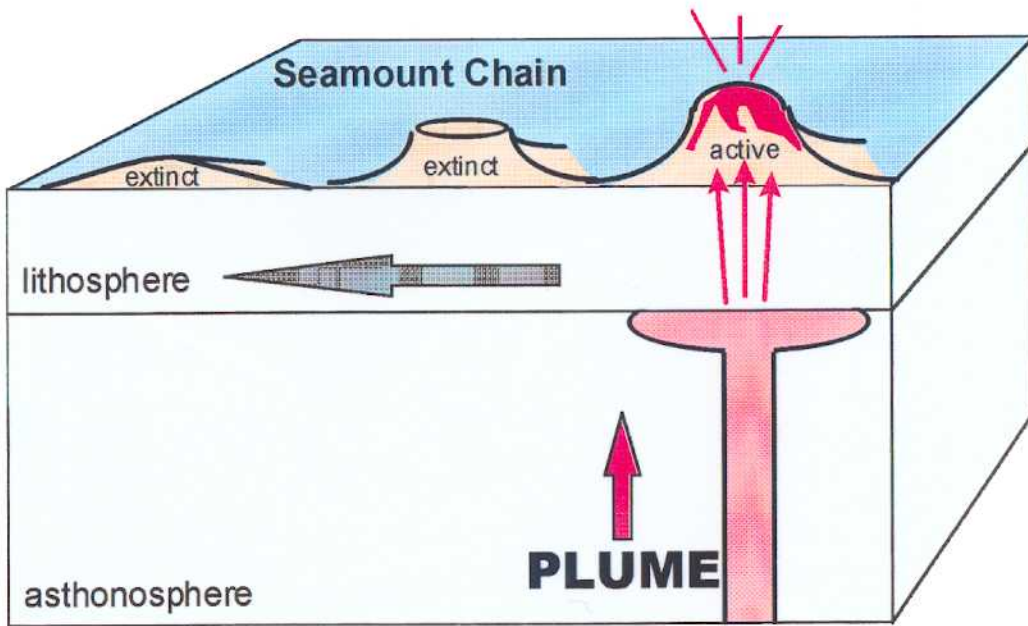


Figure 1.3 The hotspot hypothesis. Cross-section view of an oceanic plate moving with constant velocity over the mantle and a fixed plume.

Each seamount trail in the WPSP has each specific trend; ranging WNW-ESE in the Marcus-Wake, Japanese and Caroline Seamount Chains, and NNW-SSE to NW-SE in the Marshall-Gibert and Magellan Seamount Chains, respectively. Particularly in the Magellan and Marcus-Wake Seamount Chains, and Mid-Pacific Mountains, the seamount trails have WSW-ENE, WNW-ESE and WN-SE azimuths, respectively, and seem to be complicated (Figure 1.4).

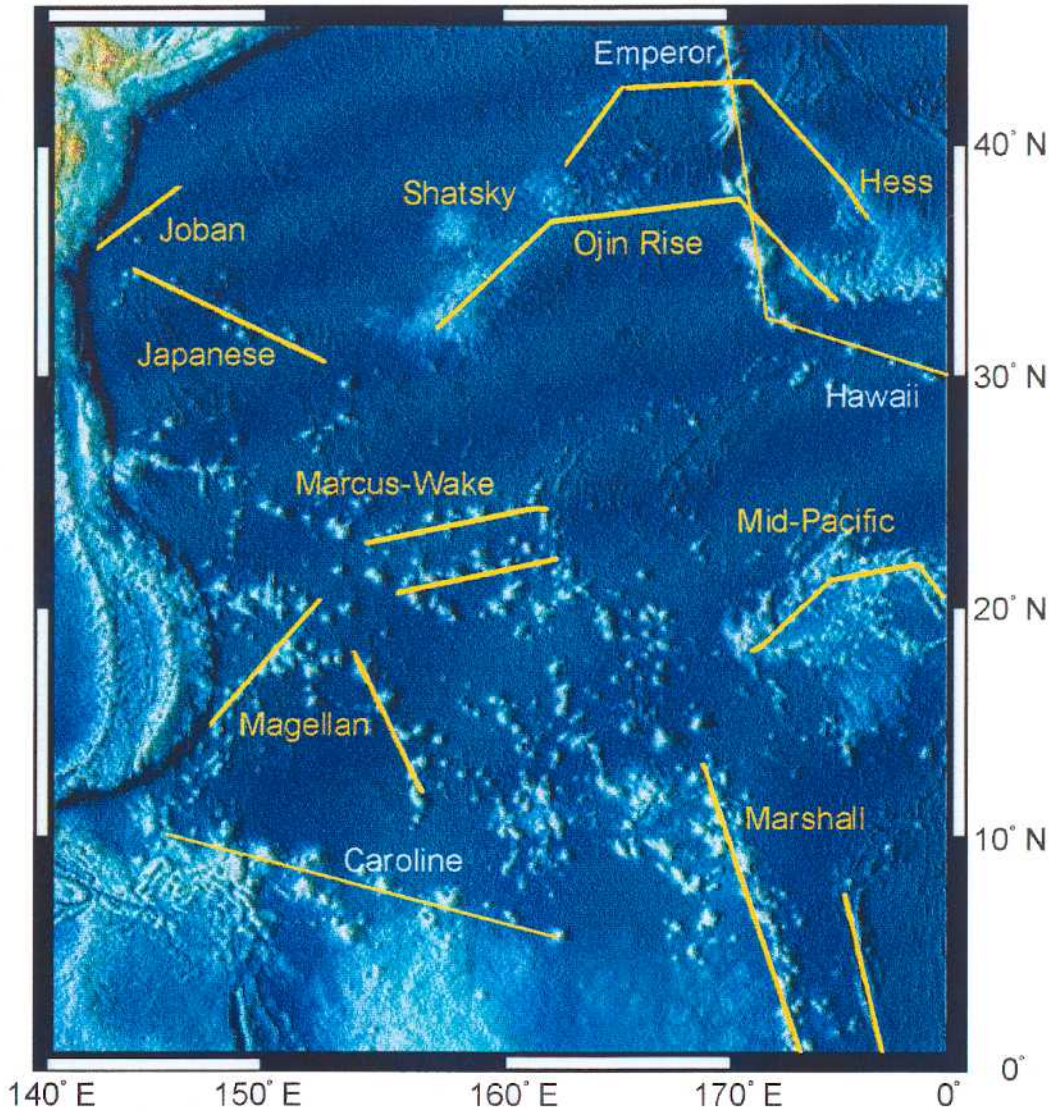


Figure 1.4 Seamount chains and oceanic plateaus in the WPSP. Heavy lines show anticipated Cretaceous seamount chains based on bathymetric observations. Thin lines are seamount chains at present to Tertiary.

Ages and origin of the Cretaceous intra-plate volcanisms are largely open to investigation, even though the ages of the oceanic crust of the Pacific ocean are well known from marine magnetic lineations, and from DSDP and ODP studies. Therefore it is imperative to obtain the radiometric age of each seamount in order to establish the

evolutionary processes of the Pacific Plate.

In this thesis, the Joban, Marshall and Magellan Seamount Chains in the WPSP area are focused in the studies of the Ar-Ar geochronology, petrology and geochemistry, in order to know the complicated trend which may be older than the established hotspot trails. These data will show that:

- an Early Cretaceous seamount trail before 120 Ma is identified
- some eruption patterns of Cretaceous seamounts were different from the present ones
- possible factors to disturb age progressions of the seamount chain are known.

1-2 Disturbed Age Progression of Collinear Chains

The gradual accumulation of age data of seamounts in Cenozoic collinear chains makes it difficult to understand why some seamount chains have no constant younging pattern along them, but display irregular ages within some chains of the Austral-Cook Seamount Chain (Jarrard and Clague, 1977; McNutt *et al.*, 1997) and the Line Seamount Chain (Epp, 1984).

Jarrard and Clague (1977) mentioned a reason that an age progression of the Austral-Cook Chain is disturbed by passing on some active hotspot, Macdonald, Rurutu, Rarotonga and Aitutaki hotspots. Lately, the studies by McNutt *et al.* (1997) show that the locations of volcanism in this area are controlled not by the locus of plume rising (hotspot hypothesis) but by stress in the lithosphere, because the Austral-Cook Seamount Chain is near the East Pacific Rise (mid-oceanic spreading ridge). Epp (1984) listed many possible reasons for disturbed age progression in the Line Chain as follows:

- The hotspot is located near the spreading ridge.
- Volcanic chains cross the transform faults.
- The lithosphere is reheated and thinned either by rapid onset of injection of magma into the lower lithosphere or by mechanical thinning asthenospheric flow.
- The thermal runaway or feedback by flow results from stress, and the local temperature rises in the asthenosphere.
- A spreading ridge crosses over a hotspot.
- The motion of the lithosphere bends the hotspot conduits.

Thus, the disturbed age progressions on the collinear chains may be largely caused by near-ridge eruptions of intra-plate volcanisms. Hotspot hypothesis will be applied except for the case that the seamount is near the spreading ridge or that the ages between the seamount and lithosphere below are the same.

1-3 Tectonic History of the Pacific Plate

Origin of the Pacific Plate

The Pacific Plate is thought to be originated at a “ridge-ridge-ridge (RRR)” triple junction in the original WPSP approximately 190 Ma (Larson and Chase, 1972; Hilde *et al.*, 1976, Handschumacher *et al.*, 1988; Nakanishi *et al.*, 1992). The Pacific Plate at the beginning was roughly triangular in shape from the identification of low-amplitude magnetic lineations in the Jurassic Quiet Zone (Handschumacher *et al.*, 1988). Three oceanic plates, Kula, Farallon and Phoenix Plates, surrounding the Pacific Plate until 100 Ma at which time the Pacific Plate started subducting underneath the Asian plates (Larson and Chase, 1972; Hilde *et al.*, 1977; Nakanishi *et al.*, 1989) (Figure 1.5).

Over the last 100 m.y. the spreading systems of the western Pacific have shown a prevalent movement and subduction to the north and west, while the Pacific Plate has increased in size due to high spreading rates from the East Pacific Rise and related ridges (up to 100 mm/yr at maximum).

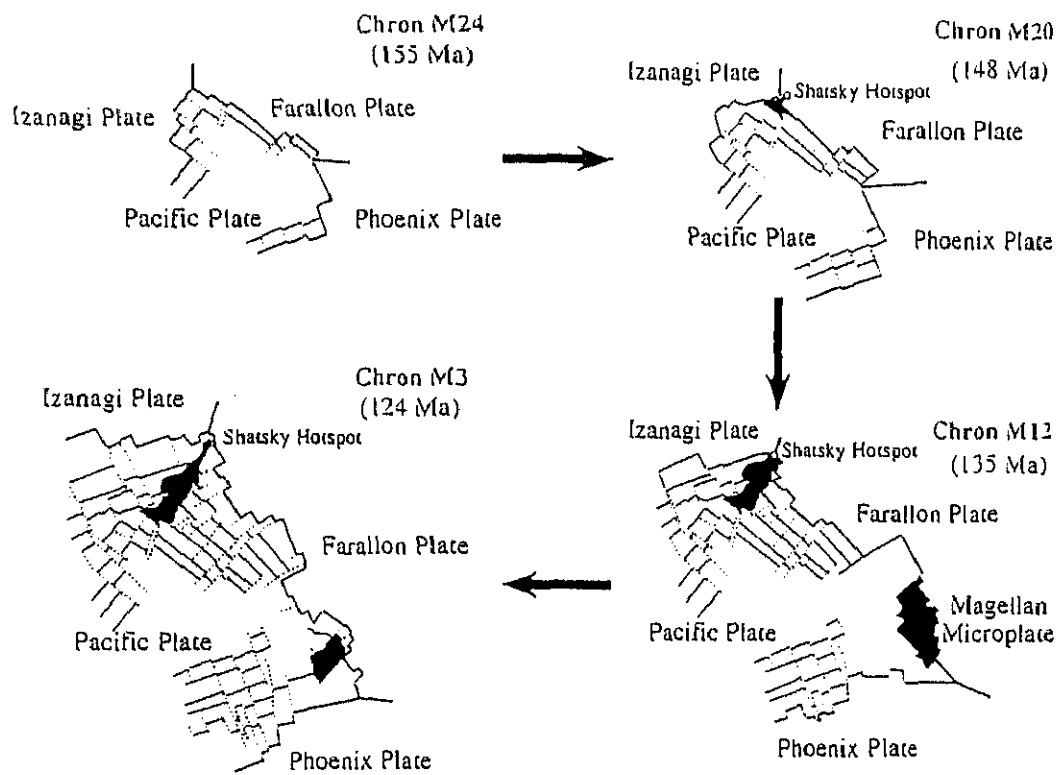


Figure 1.5 Origin and development of the Pacific Plate and the Shatsky hotspot on the Cretaceous spreading ridge. The Magellan Plate is the Cretaceous microplate occupied the Pacific Plate based on the present Megellan Magnetic Lineation Set at the southern Mid-Pacific Mountains. Adopted from Nakanishi *et al.* (1992).

Hotspot Tracks of Cretaceous Intra-plate Volcanism

On the Pacific Plate, a large number of seamounts and oceanic plateaus were produced between 140 to 60 Ma (Figure 1.6) in the WPSP at present. Distribution of these intra-plate volcanic edifices is morphologically more complicated than the Hawaii-Emperor and Louisville Seamount Chains which are well-defined hotspot tracks (Figure 1.7A). The oceanic plateaus probably originated at the Mesozoic spreading centers (Kroenke & Wessel, 1997), whereas the WPSP seamounts were formed by hotspot activities after at least 20-60 m.y. of the age of the oceanic crust.

Some cases of disturbed age progression have actually been reported at each seamount chain in the WPSP area. Lincoln *et al.* (1993) show possible seamount rejuvenation by passing over other hotspots later from the gap between the Early and Late Cretaceous fossil ages of some seamounts in the Marshall-Gilbert Seamount Chain where coexisting Early and Late Cretaceous seamounts are reported from Ar-Ar ages (Figure 1.6). Although Koppers *et al.* (1998) reported a NNW-SSE hotspot track of 100 to 88 Ma Vlinder, Pako and Ioah guyots in the Magellan Seamount Chain, the southernmost Ita Mai Tai guyot shows disharmonically 120 Ma Ar-Ar age. The Joban Seamount Chain may allow us to identify a good liner chain of the azimuth from NE to SW (Figure 1.3), but Masalu *et al.* (1998) did not agree a single hotspot origin based on the paleomagnetism of the 10 seamounts.

Complicated geomorphology in the WPSP has troublesome in interpreting a single hotspot model for each seamount chains, and it may be the result of overlapping hotspots. In order to interpret the complicated hotspot volcanisms, studies combined with the datings and petrological viewpoints can explain such complicated age distribution of seamounts.

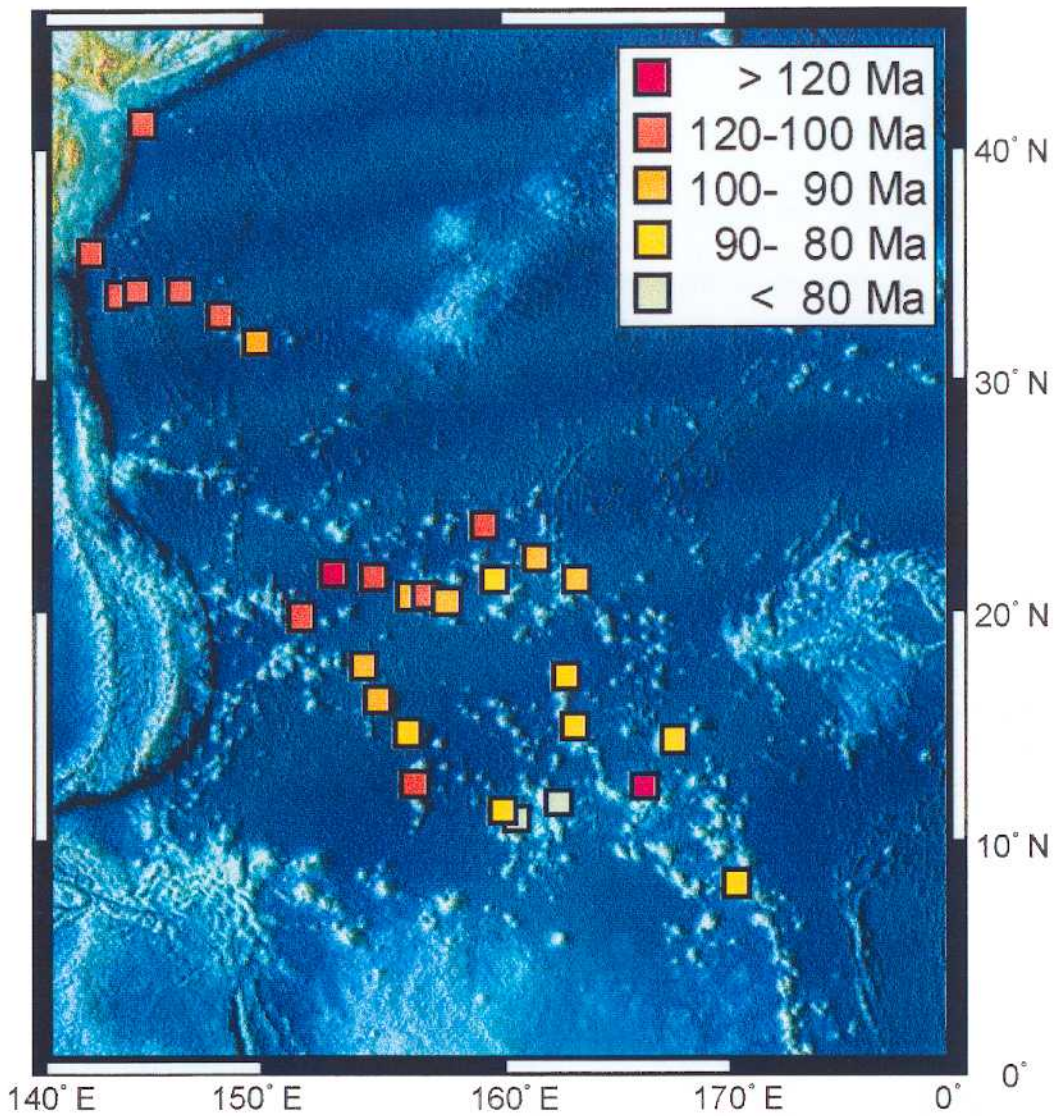


Figure 1.6 Distributions of seamount Ar-Ar ages. Refer to Ozima *et al.* (1977), Smith *et al.* (1989), Davis *et al.* (1989), Takigami *et al.* (1989), Lincoln *et al.* (1993), Winterer *et al.* (1993), Pringle & Duncan (1995a,b), Wijibran *et al.* (1995), Koppers *et al.* (1998).

Absolute Motion of the Pacific Plate

When assuming the fixed hotspot hypothesis we can describe absolute plate motion. In this case, the trend of the seamount chain with an age progression is determined by the location of the Euler pole. Euler pole at a certain period is displayed by three component of latitude, longitude and angular velocity.

Before the age of the Meiji Seamount in the Emperor Seamount Chain (Figure 7A), the Cretaceous absolute motions of the Pacific Plate can be understood from many seamounts in the WPSP. However, as mentioned previously, age distributions of some seamount chains in the WPSP are complicated.

Duncan and Clague (1985) and Engebretson *et al.* (1985) report the Cretaceous absolute motions of the Pacific Plate. In spite of the dramatic change of the Pacific Plate motion in the Cretaceous, Duncan and Clague (1985) shows one Euler pole before 100 Ma using only a few ages of the Mid-Pacific Mountains. On the other hand, Engebretson *et al.* (1985) obtain four Euler poles based on the M-shaped arrangement in the Mid-Pacific Mountains to show the consistent seamount arrangement in the Hess and Shatsky Rises as in Figure 7B. I adopted the Euler poles by the Engebretson *et al.* (1985), although ages of activity of the Shatsky Rise and the Mid-Pacific Mountains have not yet been obtained by Ar-Ar method. The hotspot track of the Shatsky might have formed on the Mesozoic spreading center at the Pacific-Izanagi-Farallon RRR triple junction (e.g. Kroenke and Wessel, 1997; Nakanishi *et al.*, 1992) (Figure 1.5). Because the Mid-Pacific Mountains are controlled by fossil ages, the interpretation of the absolute motions of the Early Cretaceous Pacific Plate need Ar-Ar ages from the seamounts in the WPSP.

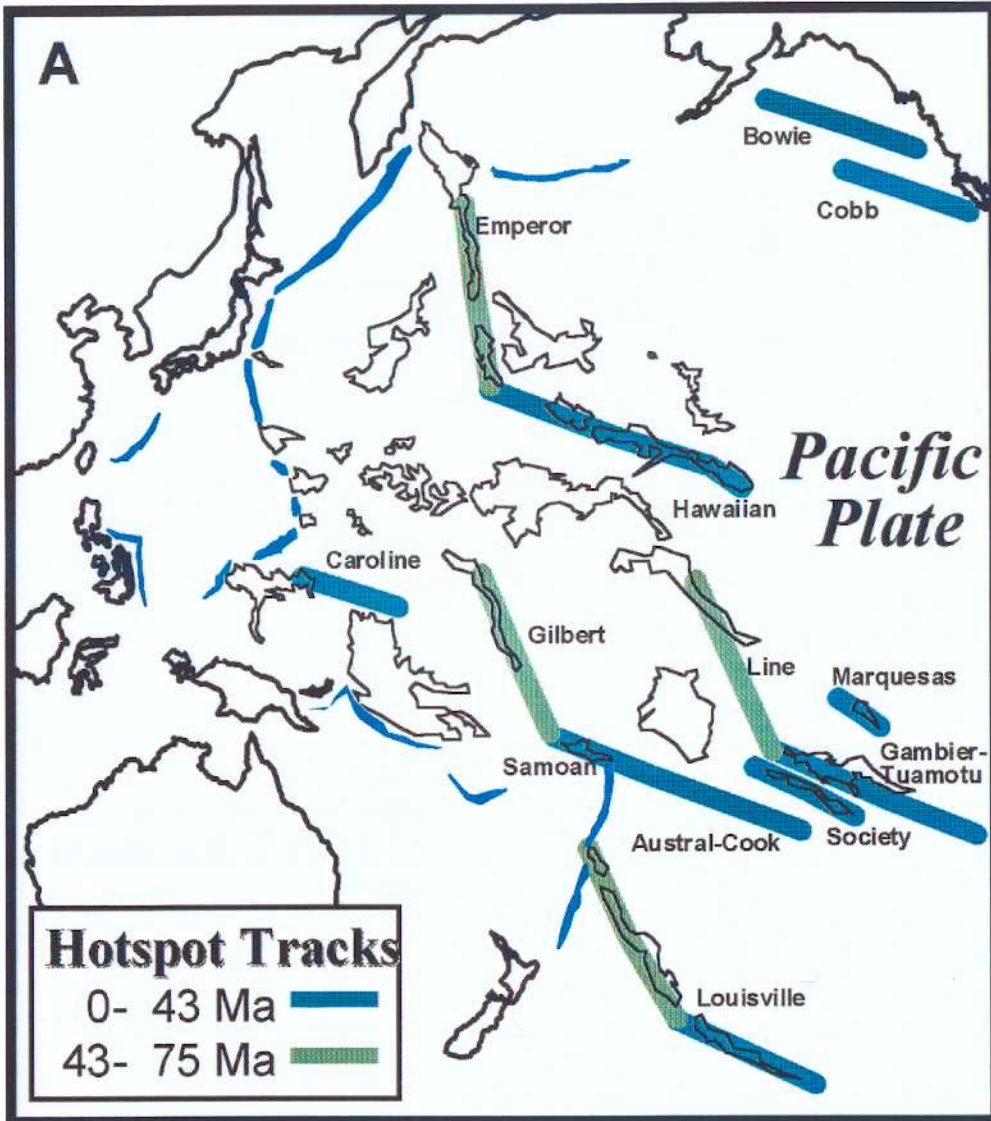


Figure 1.7 Possible hotspot tracks in the Pacific Plate at present to 75 Ma (A) and at 75 to 140 Ma (B; next page). Refer to Jackson (1973), Henderson *et al.* (1984), Engebretson *et al.* (1985), Pringle & Dalrymple (1993), Koppers *et al.* (1998) and Koppers (1998MS).

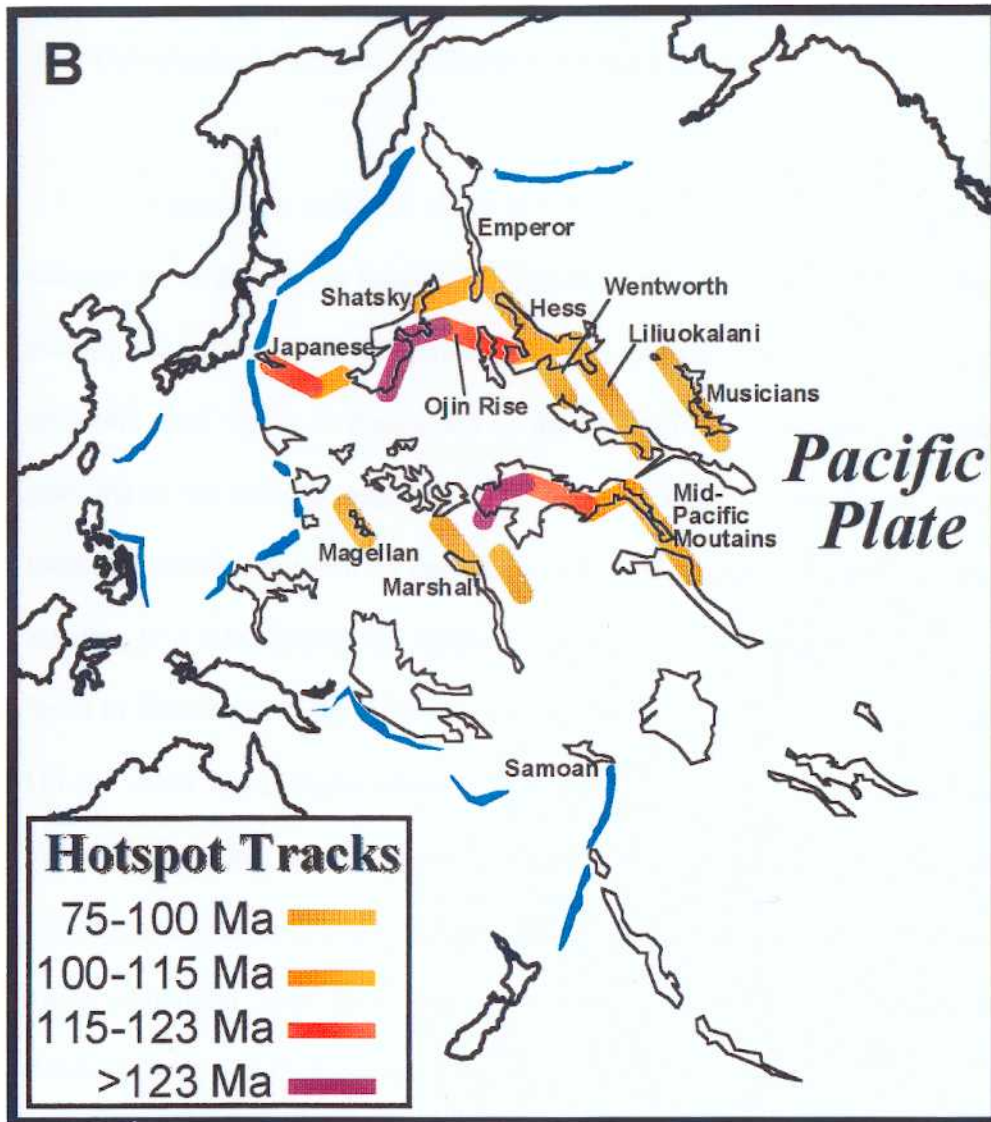


Figure 1.7 continued.

1-4 Petrological Variation of Oceanic Island Lavas

Among the volcanic rocks in the oceanic islands, both tholeiitic and alkaline magma series have been recognized. Alkali basalts and more evolved alkaline magmas occupy the upper flanks and crests of most oceanic islands and seamounts. However, tholeiitic rock series is dominated at the base of the Hawaiian volcanoes, submarine portions of the volcanic edifices. The shield volcanoes of the Hawaii are dominated by tholeiitic basalts, but still in the late in the shield stage volcanic activity is invariably alkaline (e.g. Macdonald and Katsura, 1964). The origins of these tholeiitic and alkalic lavas in Hawaiian shield stage volcanisms are controversial as the remaining questions. On the other hand, many other active oceanic island volcanoes are alkaline, such as French Polynesian Islands in the south Pacific Ocean, and St. Helena and Tristan da Cunha and Gough Islands in the Atlantic Ocean (Table 1.1). Almost all the volcanic rocks obtained ever from the WPSP are also of alkaline or nephelinitic series (Moberly *et al.*, 1971; Fukuyama, 1982).

Table 1.1 Variation of magma series of some oceanic islands. Adopted from Fukuyama (1982), and refer to Macdonald and Katsura (1964) and Caroff *et al.* (1999).

Oceans	Pacific			Indian	Atlantic	Tristan da		(MORB)	
Volcanoes	Hawaii	Tahiti	Marquesas	Reunion	St. Helena	Chunha	Gough	Iceland	
Magma Series	Tholeiitic	○	×	△	×	×	×	×	○
	Alkaline	△	○	○	○	○	○	○	△
	Nephelinitic	△	×	△	×	×	×	×	×
Differentiated Lavas	Tholeiitic	×	×	×	-	×	×	×	○
	Alkaline	○	○	○	-	○	○	○	×
	Nephelinitic	×	×	×	-	×	△	△	×

○ : dominated, △ : a little, × : nothing

Studies of the Hawaiian Islands have played a fundamental role in the development of models for the origins of linear island chains and the evolution of the oceanic islands central volcanoes. All of the Hawaiian volcanoes display a characteristic evolutionary sequence, from a voluminous tholeiitic shield-building phase, to a late stage alkali-basaltic and their differentiated phase, ultimately culminating in a post-erosional (rejuvenated) nephelinitic stage. Similar patterns have been observed in other oceanic islands (e.g. Samoan Islands, southern Pacific Ocean by Hawkins and Natland (1975); Comores Islands, western Indian Ocean by Strong (1972)). In general, nearly all the oceanic-island volcanoes situated on a mature oceanic crust evolve from an early, less alkaline voluminous shield building phase to later more alkaline volcanic phases. However, it is not clear that the shield building stage of most oceanic islands and seamounts are all composed of tholeiitic lavas, because there is no direct evidence to prove this.

The origin of the post-erosional nephelinitic stage lavas remains more puzzling

questions in the hotspot volcanisms. Of recent studies, Ribe and Christensen (1999) proposed that post-erosional lavas derive from a secondary melting region within the ascending Hawaiian plume that results from the lateral spreading of the buoyant plume material beneath the lithosphere. But this theory cannot explain the isotopic difference (Roden *et al.*, 1984; Clague and Darlymple, 1988; Maaløe *et al.*, 1992) and the erupted lavas of different type between the shield and rejuvenated stages. On the other hand, in both areas of Hawaii and Samoa, the post-shield volcanisms are thought to erupt along ruptures in the oceanic lithosphere, which may be originated from tensional cooling after passing the hotspot as known from Hawaiian post-erosional volcanism (Nakamura, 1986) or from rupturing by deformation of the oceanic lithosphere like Samoan rejuvenated volcanism (Hawkins and Natland, 1975; Natland, 1980).

1-5 Ar-Ar Geochronology for Submarine Rocks

Submarine rocks often show alterations in certain degrees, because they have been left in cold seawater for a geologically long time. Such an altered sample would not give a meaningful K-Ar age due to loss of radiogenic Ar from the sample. Even if we can get a very fresh sample, it is possible that excess ^{40}Ar (see Chapter 3) caused by quenching under low temperature and high water pressure also prevents us from obtaining a geologically meaningful age. Thus, conventional K-Ar ages of submarine rocks are not thought to be very reliable. On the other hand, the ^{40}Ar - ^{39}Ar dating of a submarine rock adopted the stepwise heating method may give us a confident age. If we obtain a plateau age or a well-defined isochron age by the ^{40}Ar - ^{39}Ar method, we can judge that the age is geologically reliable.

In order to obtain radiometric ages from submarine volcanic rocks, it is important to use samples as fresh as possible. In this study, most of the submarine rock samples are from outcrops appeared and displaced by the normal-faults. On the subducting oceanic plate are the most suitable for such place to obtain the fresh samples, if we use submersibles.

1.7 Thesis Organization

Chapter 2

Mainly previous studies in the sampling site, Japan Trench oceanward slope, Joban Seamount Chain, Uyeda Ridge in the Marcus Seamount Chain and Unnamed Seamount in the Magellan Seamount Chain.

Chapter 3

The methodology for geochemical analysis and Ar-Ar dating. These are the bulk geochemistry by XRF analysis, compositions of rock-forming minerals by microprobe analysis and Ar-Ar method.

Chapter 4 and 5

The disturbed age progression patterns of seamount chains in the Joban Seamount Chain, Uyeda Ridge and Japan Trench oceanward slope. Especially in chapter 5 this paper describes the very young alkali-basalt eruption for the first time on the Late Cretaceous Pacific Plate by Hirano *et al.* (submitted).

Chapter 6 and 7

The main discussion of this thesis. Based on the age and chemistry of the Unnamed Seamount in the western tip of the Magellan Seamount Chain, this thesis discusses the Early Cretaceous intra-plate volcanism (chapter 6) and offers new Early Cretaceous Euler pole (chapter 7). This thesis names this Unnamed Seamount the “Fukunaga Seamount” after the Ar-Ar dating scientist of Yamagata University, who died doing this study.

Bathymetric maps of the study area and WPSP

Seafloor topographic maps are printed in some figures. These maps feature detailed bathymetry derived from the predicted bathymetry database of GTOPO30 (Smith and Sandwell, 1997), and are produced using the Genetic Mapping Tools (GMT version 3.3.4) of Wessel and Smith (1991; 1998).