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Ages of seamounts, islands, and plateaus on the Pacific plate

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ABSTRACT

Hotspot theory was first proposed on the basis of the observation of linear volcanic chains on the Pacific plate and assumed age progression within these chains. Knowledge of the ages of islands and seamounts is therefore of primary importance to analyzing intraplate volcanism and deciphering the history of hotspot tracks. In this paper we review published radiometric ages of islands and seamounts on the Pacific plate to help further reconstruction. We present a compilation of 1645 radiometric ages sorted by chain and further by island or seamount, along with a brief overview of each chain. Paleomagnetic ages obtained from seamount magnetism have not been considered, except for some oceanic plateaus (e.g., Shatsky rise). We do not consider foraminifer ages, which only give minimum ages of seamounts. Reliability problems intrinsic to the samples and to the radiometric dating methods must be considered. Dating of whole rocks must generally be disregarded unless they have been subject to special treatment, Ar/Ar incremental heating dating should be preferred over other methods, and data that do not pass the reliability criteria discussed by Baksi (this volume) should be disregarded. Thus use of the ages compiled in our database must be done in the light of filtering, and we encourage the user to check critically the initial papers in which the dates were published.

Keywords: [AQ1]

Please send five or six keywords.

INTRODUCTION

Twenty-five main linear volcanic chains exist on the Pacific plate (Fig. 1). In the hotspot theory proposed by Wilson (1963; 1965) and the plume theory of Morgan (1971; 1972), they are proposed to be the traces of fixed hotspots on the seafloor and consequently parallel to the absolute motion of the plate when they were created. They should thus display linear age progressions. When these theories were proposed, almost no radiometric ages were available from the Pacific (the oldest reference in our database is 1964). However, subsequently reconstructions of hotspot tracks have been commonly proposed, and in the absence of age data geometrical considerations have been used to validate the association between a volcanic chain and a fixed hotspot. In this paper we review published radiometric ages of islands and seamounts on the Pacific plate to guide further work. We also reexamine the origins of ages commonly used in hotspot reconstruction, because some are not always correctly used and cited (e.g., foraminifer data have sometimes been used without specifying the dating method and may actually be radiometric data). Our goal is to compile the original data along with the first reference where they are presented.

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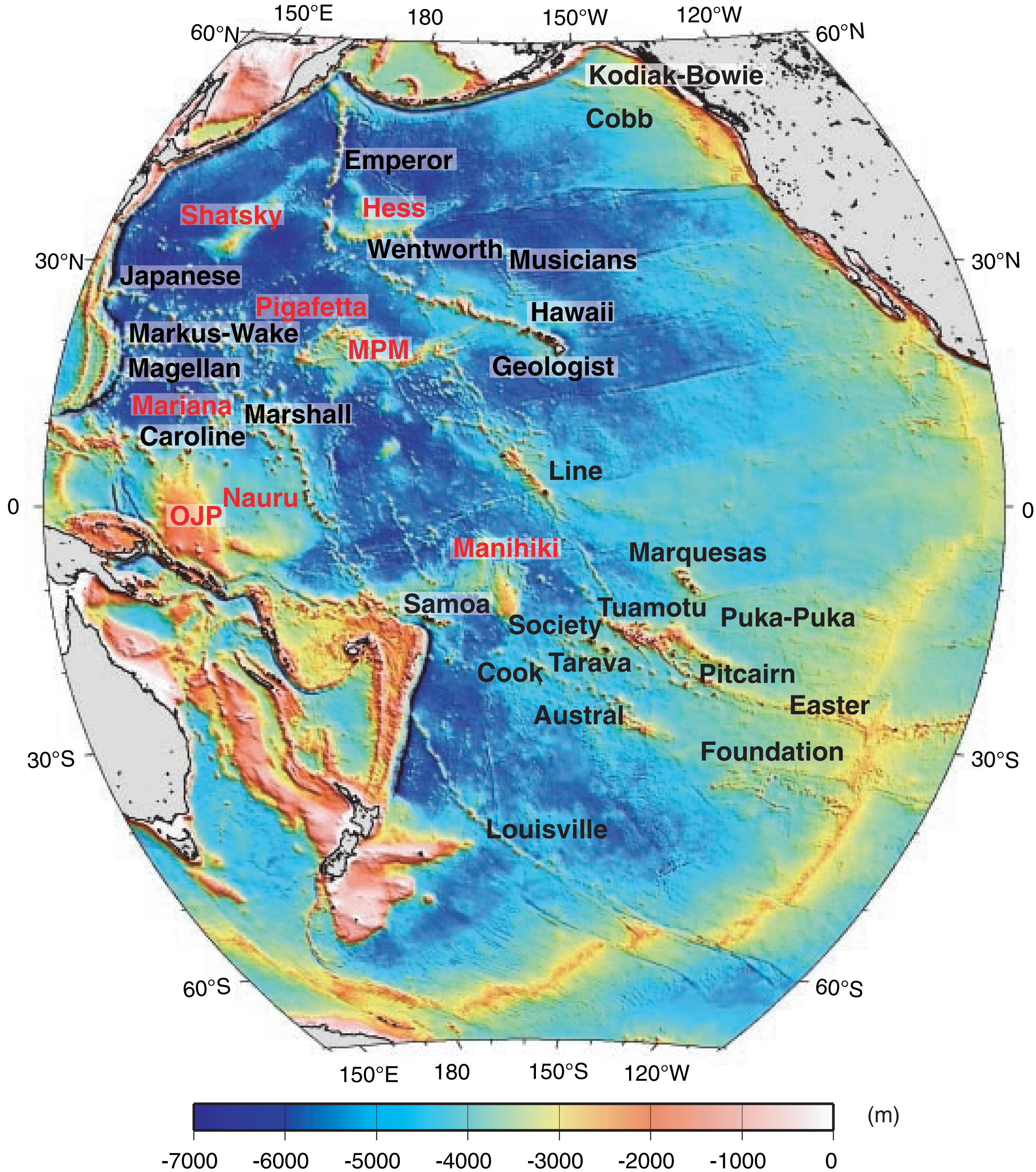

Figure 1. Linear volcanic chains shown on a bathymetric map of the Pacific plate (Smith and Sandwell, 1994). Names of the chains are in black, and names of oceanic plateaus are in red italics. MPM—Mid-Pacific Mountains; OJP—Ontong-Java plateau.

DATING METHODS

Detailed discussion of the robustness and reliability of radiometric dating methods and results is presented by Baksi (this volume). We briefly recap the main methods used for data in our database and also the basic reservations that apply to radiometric dates.

The usual dating methods are K/Ar, Ar/Ar total fusion (Ar/Ar TF), and Ar/Ar step-heating or incremental heating (Ar/Ar IH), and these can be applied either to whole rocks or to single minerals; a list of relevant minerals is proposed by Dalrymple and Lanphere (1969). Ar/Ar dating is based on the same principle as conventional K/Ar dating, i.e., the age is calculated from the ratio of radiogenic ^{40}Ar to ^{40}K. The main advantage of Ar/Ar TF as opposed to K/Ar is that only argon isotopes need to be measured. In the case of Ar/Ar IH, concordance of the results at different temperatures increases the reliability of the results (Saito and Ozima, 1976). Ar/Ar IH can be evaluated by two complementary methods, the age spectrum and isochron approachs (Dalrymple, 1991). Age established using an inverse isochron plot is affected only by trapped $^{40}Ar/^{36}Ar$ coming from atmospheric contamination and may contribute to a better age interpretation (Kuiper, 2002).

Although these methods yield the same result in an ideal case, for old seamounts the high degree of alteration of submarine rocks makes dating more difficult and the results less reliable. For subaerial material (whole rocks primarily), the high amounts of atmospheric argon make K-Ar dates suspect. Thus K/Ar dates are minimum estimates of the true crystallization ages. During normal submarine weathering, both K addition and ^{40}Ar loss will lower the apparent age, and a decrease of ^{39}Ar or adjunction of ^{40}Ar can cause anomalously old apparent ages (e.g., Dalrymple and Lanphere, 1969; Baksi, 1974; Pringle, 1993).

Pringle (1993) presented a comparative study of dating old (70–100 Ma) submarine rocks. He showed that the choice to date a whole rock or a single mineral is of primary importance. Results on whole rocks with K/Ar or Ar/Ar TF usually exhibit high dispersion (up to 38%) when compared to more reliable Ar/Ar IH ages. Results on feldspar with K/Ar are almost always younger than the best age estimate, whereas Ar/Ar TF dates on feldspar are sometimes older and sometimes younger than Ar/Ar IH dates. When this kind of test is done using Ar/Ar IH, it is also shown that groundmass samples provide more scattered results than mineral separates but that the scatter can be decreased if the groundmass samples are cleaned by acid leaching (Koppers et al., 2000).

Selection of the sample and its preparation are critical to obtaining an acceptable age estimate, as well as reliability criteria. In the case of Ar/Ar IH, these criteria represent the real power of this method because they correspond to a set of internal tests for each experiment. They were proposed by Pringle (1993) and are discussed in Baksi (this volume). The reliability criteria are as follows. An Ar/Ar IH age can be taken as an accurate estimate of the crystallization age if (1) a plateau is formed by at least three contiguous (within the 95% confidence level) steps representing more than 50% of the ^{39}Ar released, (2) a well-defined isochron exists for the plateau points, (3) the plateau and the isochron age are concordant at the 95% confidence level, and (4) the $^{40}Ar/^{36}Ar$ intercept on the isochron diagram is within the 95% confidence level from the atmospheric value of 295.5.

For all these reasons, the data compiled in our database must be filtered for reliability before use, and we encourage the user to check the initial papers in which the ages were published. Dates obtained using whole rocks must generally be eliminated unless they have been subject to special treatment such as that proposed by Koppers et al. (2000). Ar/Ar IH dating should be preferred over other methods when results have been obtained using a variety of methods. One should disregard data that do not pass the reliability criteria discussed by Baksi (this volume).

CLASSIFICATION OF DATA IN THE DATABASE

The data in Table 1 (see GSA Data Repository for Tables 1 and 2[1]) are sorted by chain, and further by island or seamount, from south to north, as this represents the general trend of Pacific plate motion since 120 Ma. Final sorting is according to the method used and the author. The different methods are those described earlier, and the type of sample is specified as “w” for whole rock and “s” for single mineral phase. A mean value is calculated for a volcanic edifice if ages come from the same author using the same method and if the difference between two ages is less than 5 m.y. (a rough estimate of the maximum time that could separate two different volcanic stages on the same edifice). To calculate this mean value, each age is weighted by the inverse of its variance, which allows data with different analytical errors to be combined without giving too much importance to poorer-quality data (Dalrymple et al., 1987). When the authors have proposed a best age estimate, it is highlighted in Table 1. The error associated with a mean age is calculated as $1/\Sigma(1/\sigma_i^2)$. This corresponds to the analytical error during age determination and gives no information on the geological accuracy of the resulting age. All the data are presented in Web supplements to this paper (Tables 1 and 2), and an ASCII file with only average ages and geographical coordinates is available for plotting purposes at http://www.mantleplumes.org/PacificAges.html. It should be noted that the decay constant convention used was adopted in 1977 (Steiger and Jager, 1977), and therefore older references may have used different values than the present ones for λ_β and λ_ε.

INDIVIDUAL VOLCANIC CHAINS

The database presented in Table 1 represents the most up-to-date compilation currently available of published ages of

[1]GSA Data Repository item 2005056, Tables 1 and 2, is available online at www.geosociety.org/pubs/ft2005.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

islands and seamounts of the Pacific plate, except for the Hawaiian chain, where we mostly report the synthesis of Clague and Dalrymple (1989). For each chain we list the publications in which the ages were first presented, along with the radiometric methods used. We give a brief overview of each chain, illustrated by a figure showing the spatial distribution of the ages over the bathymetry. These reveal a number of inconsistencies with the classical fixed-hotspot theory. Full analysis of these inconsistencies is beyond the scope of this paper, but detailed discussions can be found in Clouard and Bonneville, 2001, and Natland and Winterer, this volume.

Alaska Seamounts

The Alaska seamounts (Fig. 2) form two volcanic alignments, the Cobb and Kodiak-Bowie chains. Ages are published

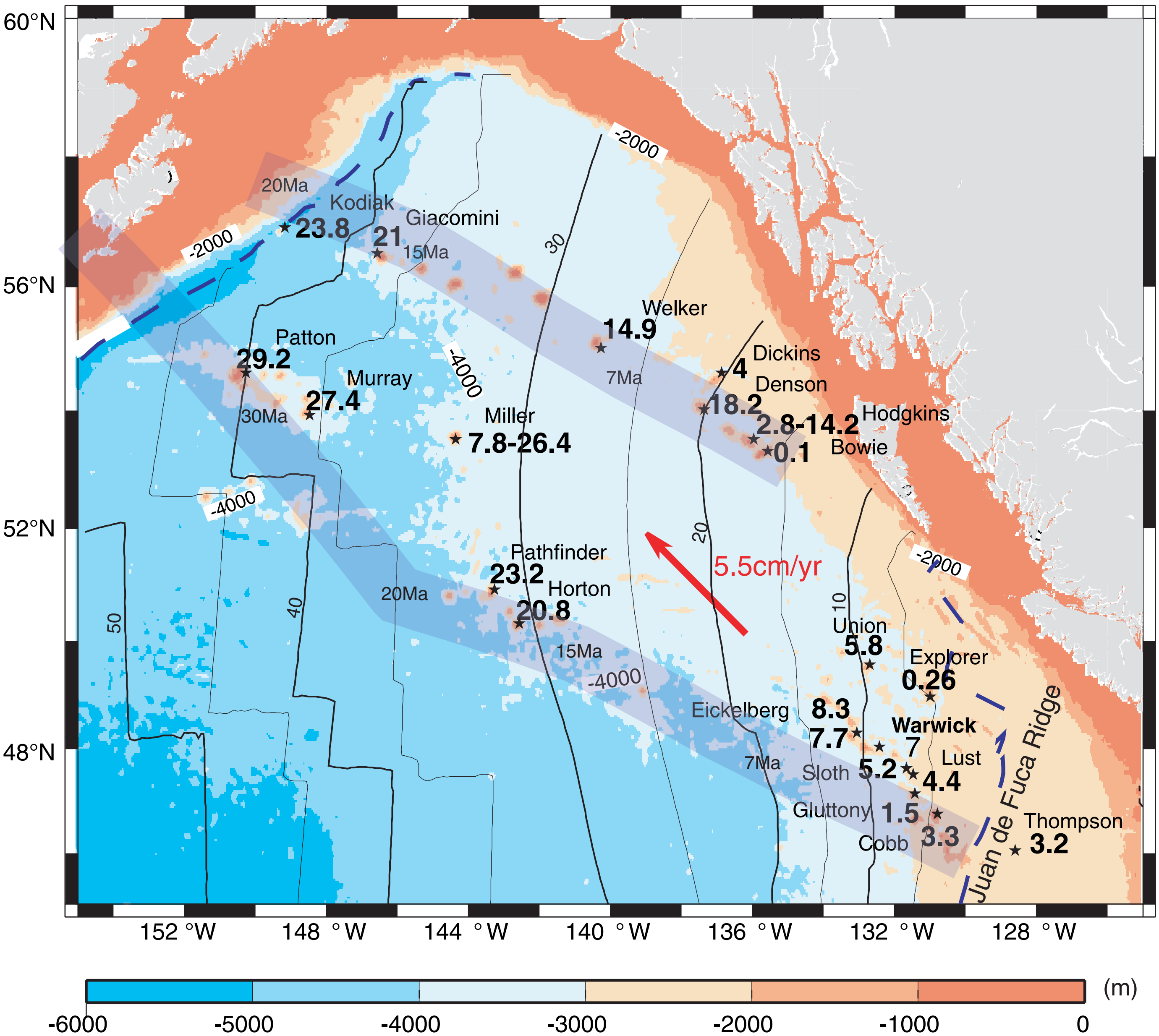

Figure 2. Alaska seamount chains shown on the bathymetric map of Smith and Sandwell (1994). Mean ages of the seamounts in Ma. The stars represent the locations of the seamounts and the dashed lines the plate boundaries. Crustal magnetic isochrons (Mueller et al., 1993) are represented every 10 Ma by thin black lines. The arrow represents the direction of present-day Pacific plate motion in the region according to the NUVEL 1A model (DeMets et al., 1994). Possible hotspot tracks are represented by bands whose widths correspond to a track 100 km wide. They are calculated using the Pacific motion stage poles of Wessel and Kroenke (1997) modified for the 0–7 Ma period with the pole of Yan and Kroenke (1993).

in three papers. The youngest part of the Cobb seamount chain has been dated by Desonie and Duncan (1990) with Ar/Ar TF and with conventional K/Ar on whole-rock samples. Dalrymple et al. (1987) used Ar/Ar TF, conventional K/Ar, and Ar/Ar IH experiments to date five seamounts using twelve whole-rock or plagioclase samples, and calculated a best age from incremental heating spectrum data. Turner et al. (1980) presented new K/Ar dating for four seamounts of the Kodiak-Bowie chain and one from the Cobb chain, and used new decay constants for previously dated samples presented by Turner et al. (1973). In Table 1 only the ages they consider reliable are reported. Figure 2 shows the distribution of ages in the northeast Pacific area, including the Cobb and the Kodiak-Bowie (also called Pratt-Welker) chains. To explain the nonlinear progression in ages from the southern Cobb-Eickelberg chain, two hypotheses have been proposed: (1) Parts of these seamounts are related to mid-plate volcanism arising from short-lived hotspots and other parts to ridge volcanism (Dalrymple et al., 1987), and (2) the Juan de Fuca Ridge moved westward with respect to the Cobb hotspot (Desonie and Duncan, 1990). The Kodiak-Bowie chain is also proposed to be a mix of ridge and hotspot volcanism with linear age progression within the chain (Turner et al., 1980).

Austral Seamounts

Figure 3 shows the distribution of dated seamounts and islands of the Austral-Cook chain. When several papers refer to the same island, we calculated an average age for each paper (Fig. 3). Duncan and McDougall (1976) used the K/Ar method on whole-rock samples. We took the average for each island, excluding their unreliable results. Turner and Jarrard (1982) used the same method, and no age is reliable for Rimatara, despite the four published ages of 4.78, 14.40, 21.20, and 28.6 Ma. For Rurutu they dated only the most recent volcanic stage younger than 1 Ma. Matsuda et al. (1984) used the same method for samples from Rurutu. They presented evidence for two volcanic stages in Rurutu, as did Duncan and McDougall (1976). For Rapa Island, Krummenacher and Noetzlin (1966) used K/Ar dating, but with ages of 147 and 156 Ma presented in the same paper for Tahiti Island, these results are questionable. The fourteen good-quality ages presented by Diraison et al. (1991) using the K/Ar method yielded an average age of 4.5 Ma. For Macdonald, Marotiri, Raivavae, Tubuai, and Rurutu, other ages can be found in Diraison (1991). They are in good agreement with previously published ages. Ar/Ar IH ages for whole-rock samples were obtained for seamounts at the southeastern end of the Austal chain by McNutt et al. (1997). They sampled two volcanic chains, Ngatemato and Taukina, and obtained ages of between 22 and 32 Ma. We also present a set of new K/Ar ages obtained for deep-sea samples dredged in 1999 from several seamounts of the Cook-Austral volcanic chains (Bonneville et al., 2004).

The Austral-Cook region is one of the most intriguing examples of intraplate volcanism. Ages range from 58 to 0 Ma, and all are younger than the underlying lithosphere. Thus the region

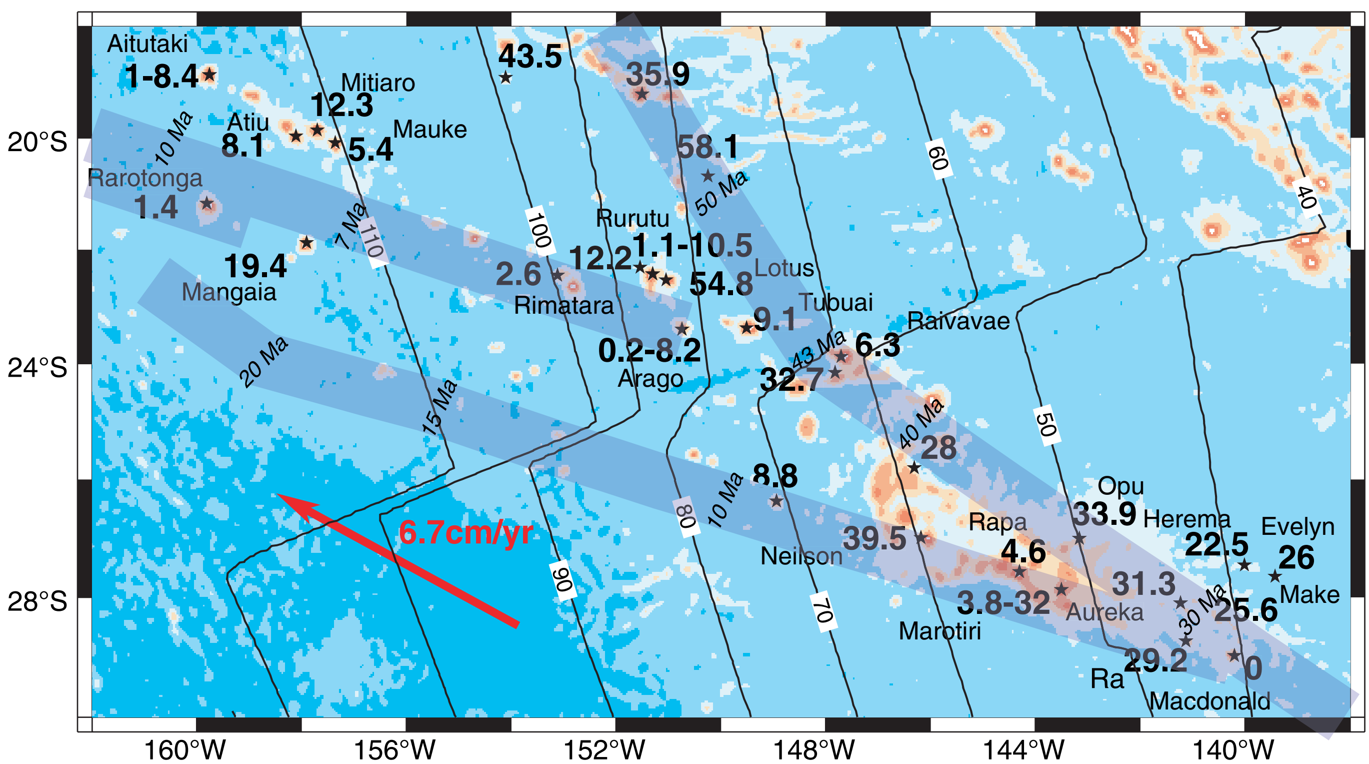

Figure 3. Same as Figure 2 but for the Austral and Cook chains.

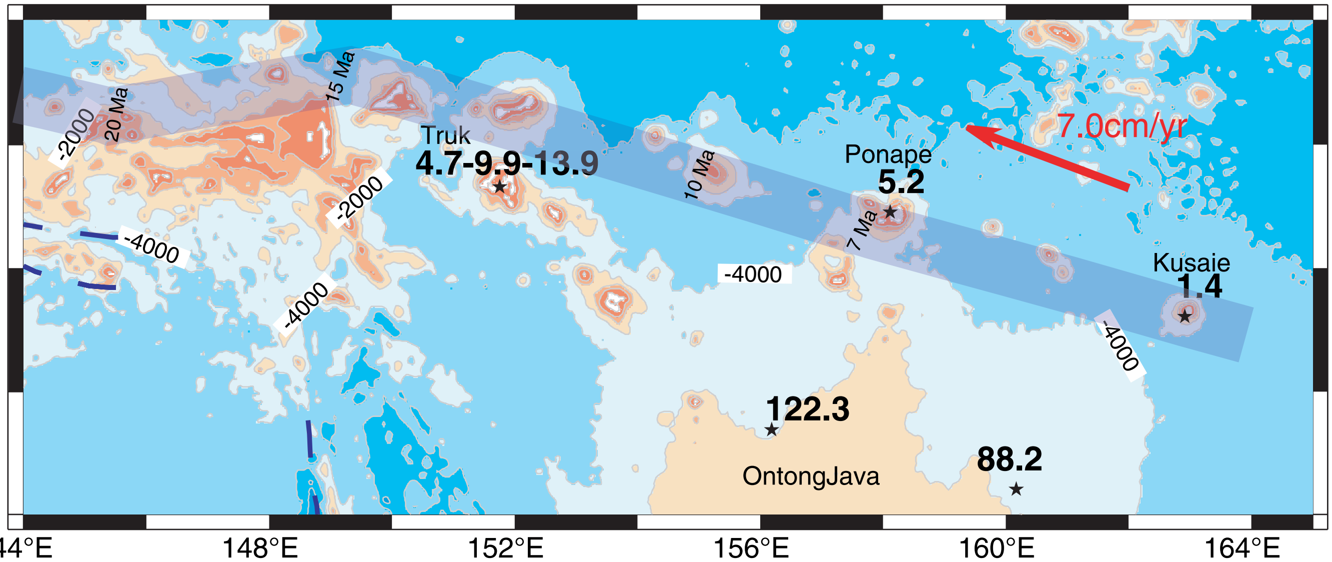

Figure 4. Same as Figure 2 but for the Caroline Islands.

represents intraplate volcanism. At least eight hotspots would be needed to explain the twenty-nine ages distributed over less than 2000 km length! Various seamounts or islands (Rurutu, Arago seamount, Marotiri) have undergone different volcanic stages separated by more than 8 m.y. Only the tracks of recognized active hotspots are reported in Figure 3. This figure illustrates well the links between seamounts and hotspots, and it may be noted than about half of the dated seamounts are not related to any of the four proposed active hotspots whose tracks pass through this region. From Figure 3 it is obvious that the Austral Islands, except Rapa, are not related to the Macdonald hotspot as was previously proposed (e.g., Duncan and McDougall, 1976). One extinct hotspot and one still active one are needed to explain the observed volcanic alignments (Bonneville et al., 2004).

Caroline Islands

All reliable data come from Keating et al. (1984b), and some concerning Truk Atoll (Fig. 4) are published in Keating et al. (1984a). They were obtained on whole-rock samples using conventional K/Ar dating. Truk Atoll contains numerous small islands that are remnants of a shield volcano. As proposed by Keating et al. (1984b), we calculate a mean age for each islet and a mean age for the entire atoll omitting the young ages of Ulalu and Tol. Only three islands are dated, and the results on Truk Island range from 4.7 to 13.9 Ma, making the assumption of simple age progression along the chain unsupported (Fig. 4).

Cook Islands

Turner and Jarrard (1982) applied the K/Ar method to whole-rock samples from the islands of Rarotonga, Atiu, Muake, Aitutaki, Mitioro, and Mangaia (Fig. 3). We report not minimum values but only the ages they consider reliable. In addition, another K/Ar age exists for Rarotonga (Matsuda et al., 1984), which confirms the young age of 1.4 Ma of this island. Because Cook volcanism is usually associated with the Austral hotspots, the Cook ages are shown jointly with those from the Austral area (Fig. 3).

Easter Chain

The Easter chain lies mostly on the Nazca plate, ranging from the Easter microplate to Nazca ridge, but it also contains a seamount chain on the Pacific plate (Fig. 5). The first ages from the Easter volcanic chain on the Nazca plate are given by Bonatti et al. (1977). The K/Ar technique is used on small whole-rock samples, and the authors caution that the results must be considered minimum ages for the seamounts. We disregard their ages of 8 and 10 Ma for Easter Island, as all other dates of the island are less than ca. 3 Ma. A set of seven K/Ar dates on whole-rock samples from the three volcanoes of Easter Island (Miki et al., 1998) confirms an age of less than 1 Ma. Recent samples dredged by the research vessel *Sonne* were dated by O'Connor et al. (1995). They used incremental heating experiments on separated and cleaned plagioclases. Twenty-four unpublished ages also exist, obtained during a cruise of the research vessel *Revelle* in 2001 (Duncan et al., 2003). We add these dates to the map of the Easter chain (Fig. 5). With very sparse data, Bonatti et al. (1977) initially suggested that the Easter chain might correspond to a hotline with active hotspot centers near Easter, Sala y Gomez, and San Felix Islands. With more ages, O'Connor et al. (1995) proposed a single hotspot only, located in the Sala y Gomez area, magma from which would be partially channeled to the Pacific-Nazca ridge to explain volcanism in the Easter Island area.

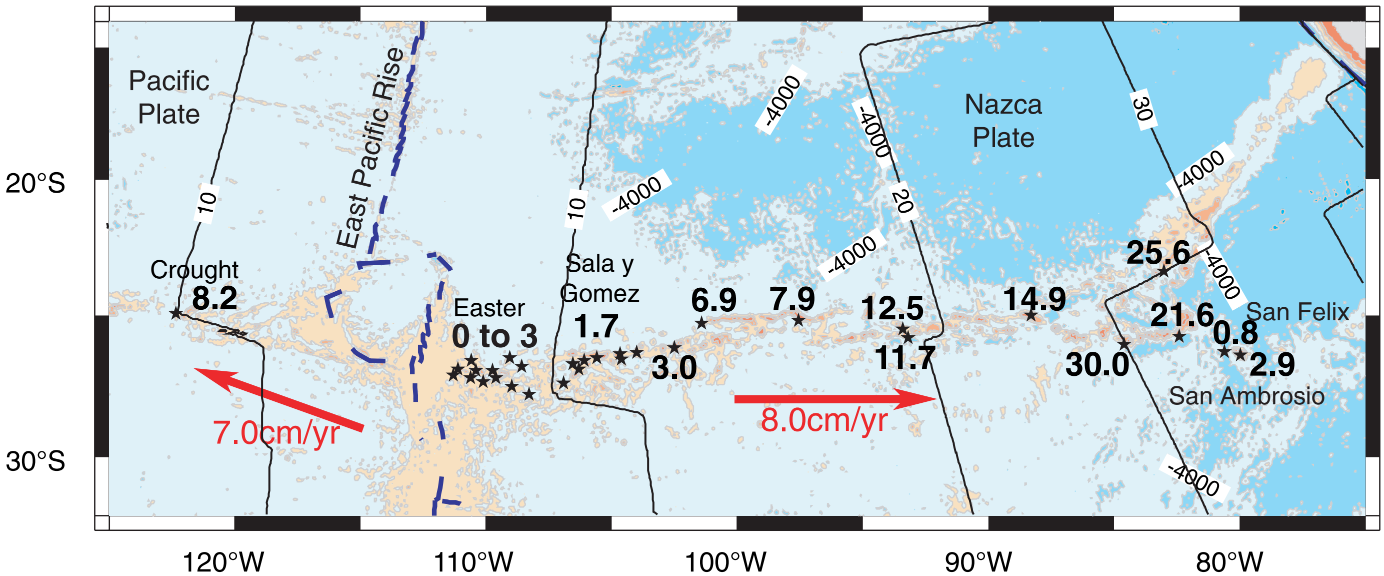

Figure 5. Same as Figure 2 but for the Easter chain.

Foundation Seamounts

O'Connor et al. (1998) calculated ages along the whole chain on whole rock or plagioclase, and for each sample they present the plateau age, the normal and the inverse isochron age, and the total fusion age (Fig. 6). They report only ages that passed the criteria of reliability of Pringle (1993). The mean age given in Table 1 is from O'Connor et al. (1998). The model of a stationary hotspot explains fairly well the age distribution within the Foundation seamount chain for at least the past 21 m.y., and

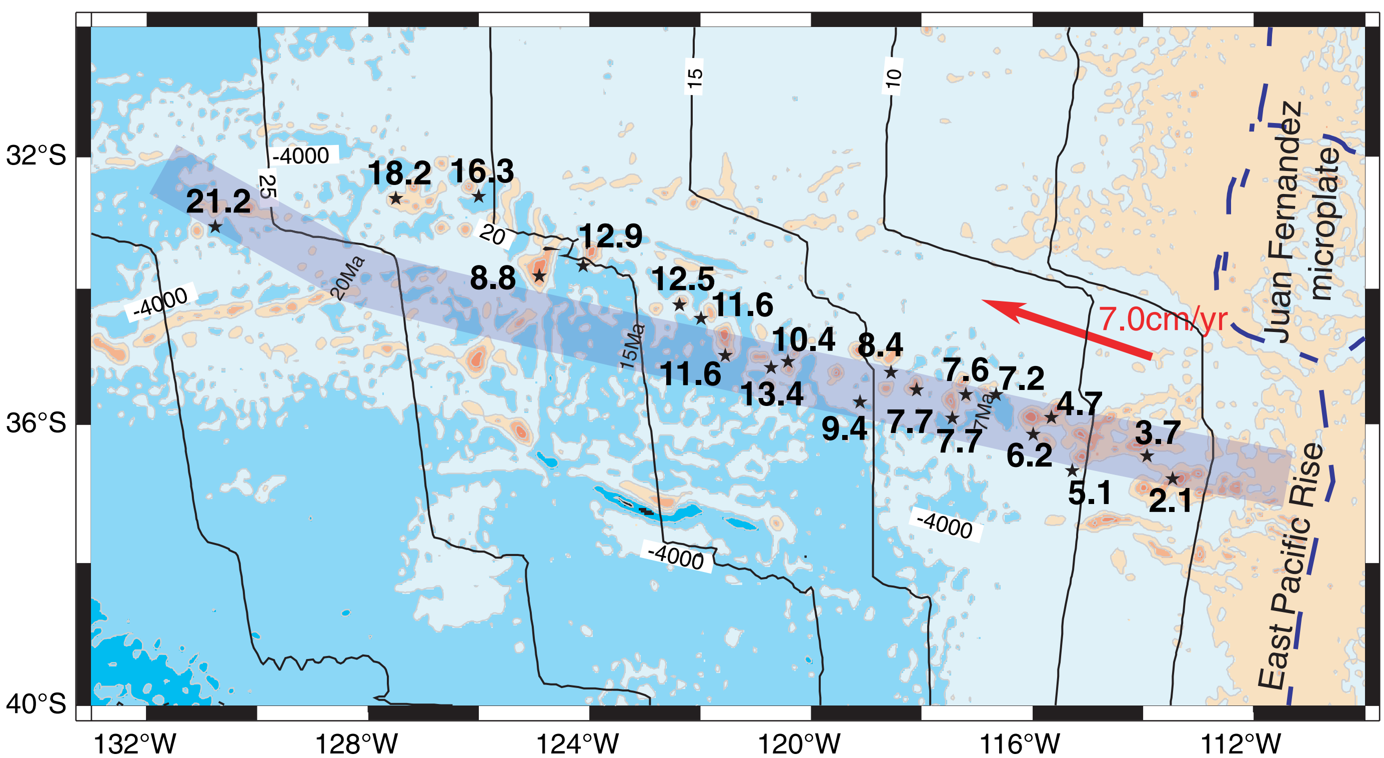

Figure 6. Same as Figure 2 but for the Foundation seamount chain.

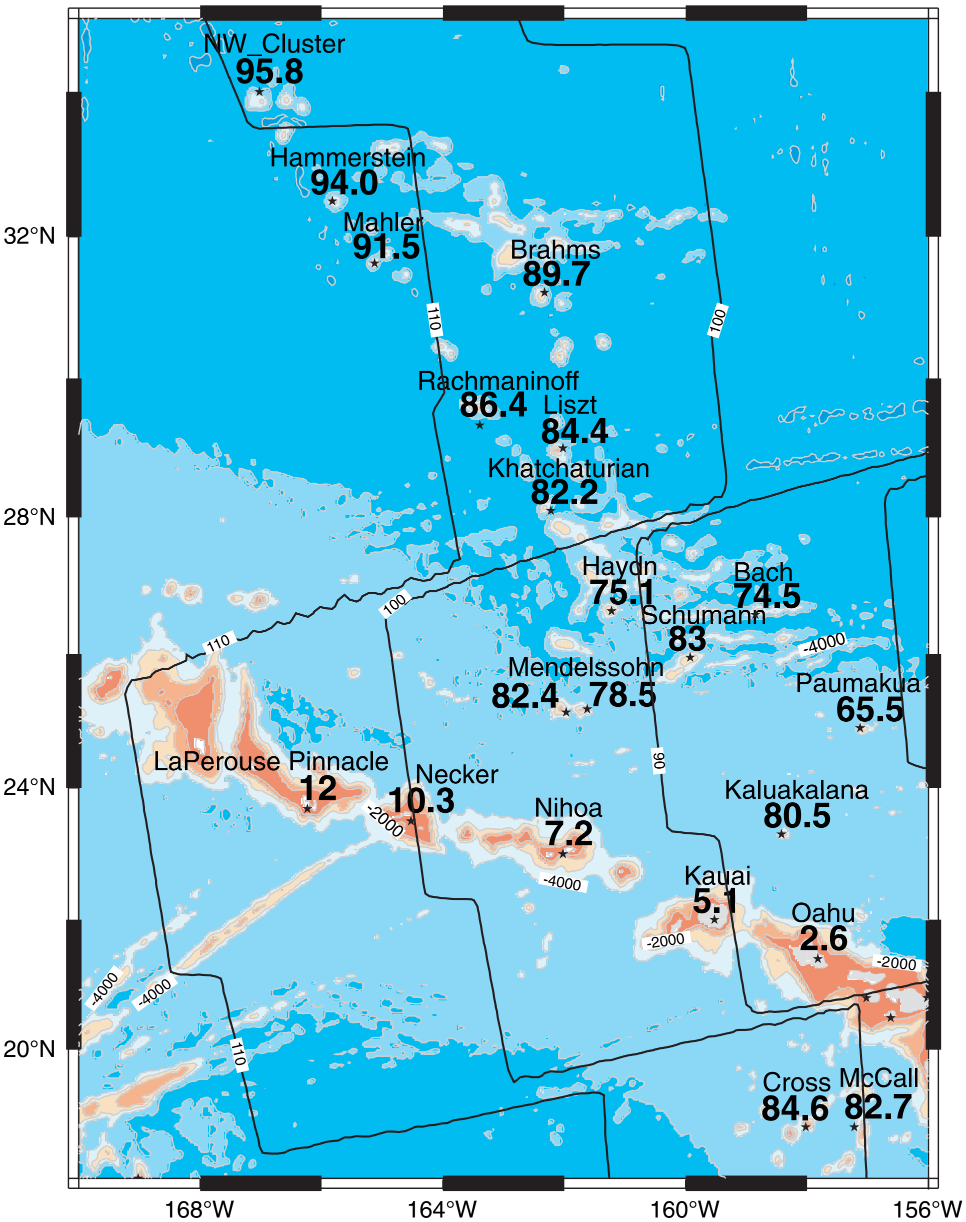

Figure 7. Same as Figure 2 but for the Geologist and Musicians seamounts.

perhaps this hotspot could also be responsible for the old seamounts of the easternmost part of the Austral chain (O'Connor et al., 1998).

Geologist Seamounts or South Hawaiian Seamounts

The Geologist seamounts are a small group of old seamounts located to the southwest of the island of Hawaii and, in the case of Kauluakalana, south of the Musicians seamounts. Sager and Pringle (1987) presented four radiometric ages. Their proposed ages were obtained by total fusion dating on plagioclase, sometimes averaged with whole-rock total fusion ages when those were concordant. Other ages given in Table 1 are from Dymond and Windom (1968). No age progression exists between these seamounts (dated between 80 and 54 Ma) or within the Musicians seamounts to the north (Fig. 7).

Hawaii-Emperor Chain

Our main source of dates for this chain is the synthesis of Clague and Dalrymple (1989). We added Ar/Ar IH spectra ages obtained by Duncan and Keller (2004) on previously dated seamounts and a new one, Detroit seamount, at the north end of the Emperor chain, and Ar/Ar IH plateau ages obtained by Sharp and Clague (2002) on six seamounts that bracket the Hawaii-Emperor bend (Fig. 8). The difference between these latter dates

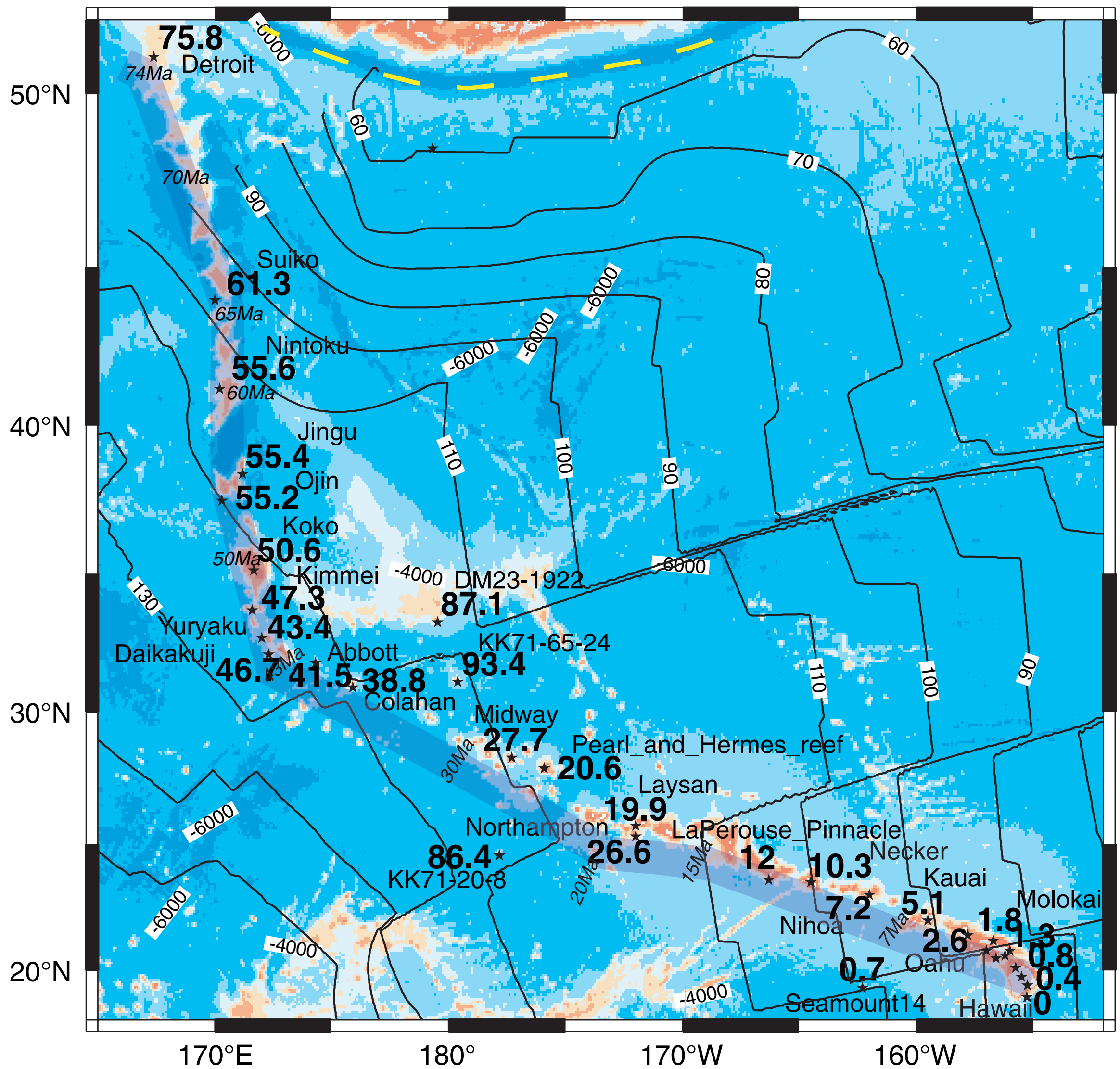

Figure 8. Same as Figure 2 but for the Hawaiian chain and Wentworth seamounts.

and previous ones can be as large as 7 m.y. (for Kimmei seamount, 39.9 Ma is the previous K/Ar age on whole rock, 47.3 Ma the new Ar/Ar age on feldspars). This illustrates how careful one must be when using ages to decipher the history of intraplate volcanism or to calculate absolute motion stage poles. Figure 8 shows the whole Hawaiian chain, from the active hotspot to the Detroit seamount (75.8˜/0.6 Ma) near the subduction zone It can be seen that even for this, the most famous Pacific hotspot chain, the progression of the ages along the hotspot track is irregular. This is shown to be the case for the Hawaii-Emperor bend by the new dates obtained by different methods and different authors (Ar/Ar IH, Sharp and Clague, 2002; K/Ar, Dalrymple and Clague, 1976) and also along the Hawaiian chain, where Dalrymple et al. (1981) obtained an age of 19.9 ± 0.3 Ma for Laysan and an age of 26.6 ± 2.7 for Northhampton Bank, its closest neighbor.

Japanese Seamounts

The first data for the Japanese seamounts (Fig. 9) where obtained by K/Ar dating (Ozima and Kaneoka, 1968) and were also presented along with other ages by Ozima et al. (1970). Unfortunately, the results differ from one paper to another (except for Riofu seamount), and it is impossible to know which are the correct values. Among the K/Ar ages for Japanese seamounts that appear in Ozima et al. 1970, only the Erimo seamount age is new. More reliable data are given by Ozima et al. (1983), with ages determined using the Ar/Ar IH method on whole-rock samples and interpretation of isochron, spectrum, and total fusion results, and by Winterer et al. (1993) using the same method. The ages of the Japanese seamounts range between 71.6 and 108.3 Ma, and no clear age progression exists within this chain (Fig. 9).

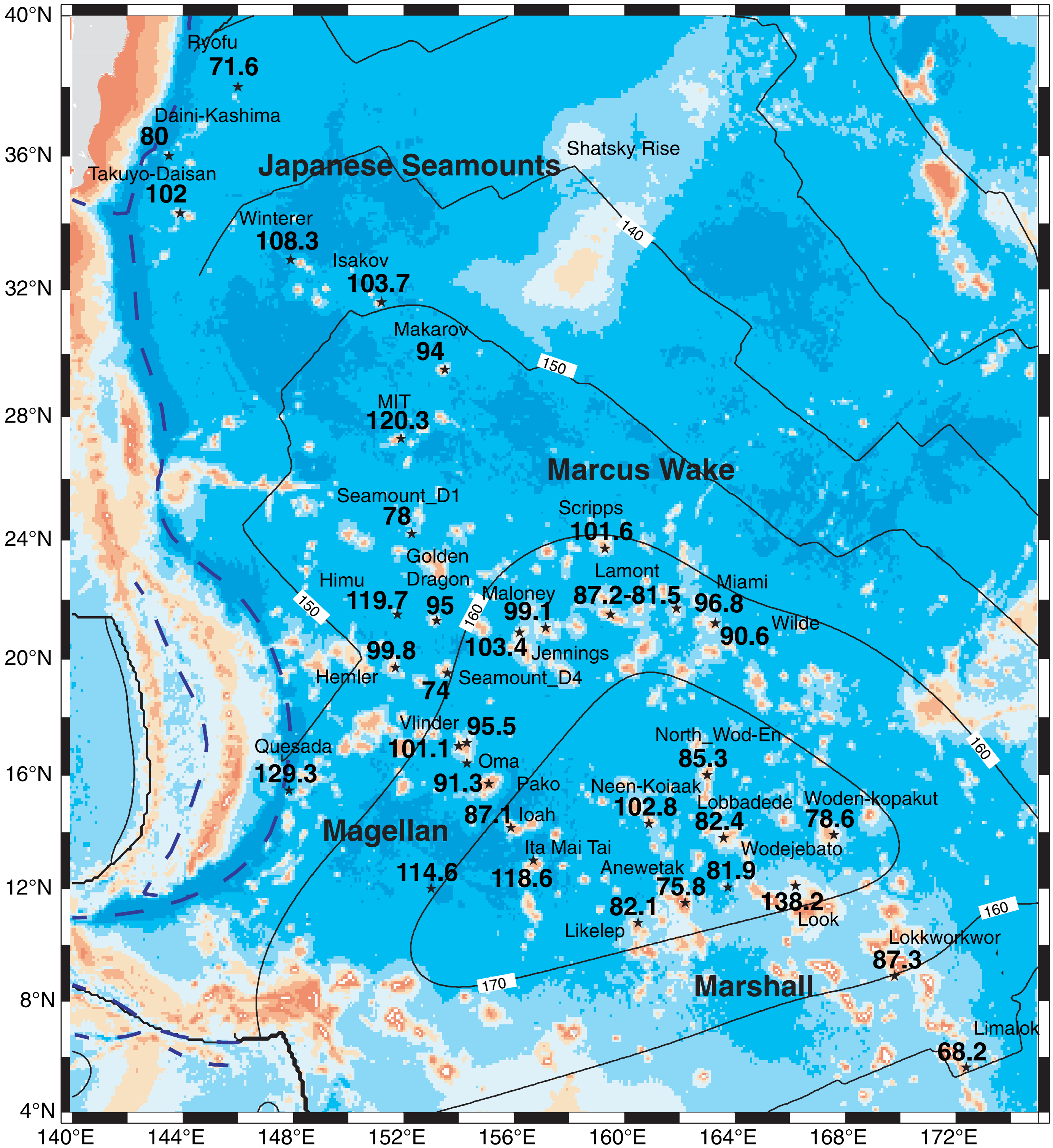

Figure 9. Same as Figure 2 but for the Marshall Islands, Magellan, Marcus Wake, and Japanese seamounts (western Pacific seamounts).

Line Islands

The geochronology of the Line Islands (Fig. 10) is summarized by Schlanger et al. (1984). They carried out both Ar/Ar TF and K/Ar dating on the same samples. For each seamount their preferred age is always the Ar/Ar TF one, because the K/Ar ages for the same samples are significantly younger. Recently Davis et al. (2002) reported thirty-four new Ar/Ar IH age determinations for sixty-eight samples from nine edifices in the northern Line Islands chain. Initially (before any dating) this chain of 4000 km length was assumed to be associated with the Tuamotu archipelago and was considered by Wilson (1973) and Morgan (1971) to have formed over a hotspot because it is parallel to the Hawaii-Emperor chain. However, the spatial distribution of the dates casts doubt on this hypothesis (Fig. 10), and Davis et al. (2002) proposed volcanism based on lithospheric extension. An alternative explanation, based on the pattern of sets of seamount ridges parallel to old transform faults, is that the Line Islands represent lines of weakness in the lithosphere that developed at different times in response to the changing stress field of the Pacific plate (Natland and Winterer, this volume).

Louisville Chain

Except for the Osbourn seamount, which has been dated by K/Ar (Ozima et al., 1970), all the ages for the Louisville chain initially come from Watts et al. (1988), including that of a small 0.5 Ma seamount used to relocate the Louisville hotspot (Fig. 11). These authors used Ar/Ar TF dating on whole-rock samples and got a similar result with K/Ar dating of a pyroxene separate from one seamount. For the same group of samples, Koppers et al. (2004) report new Ar/Ar ages based on high-resolution incremental heating dating. Generally these new ages are slightly older than previous ones except for that of the northwesternmost seamount, Osbourn seamount, whose age changes from 66.25 ± 0.42 Ma to 77.28 ± 0.68 Ma between the paper of Watts et al. (1988) and that of Koppers et al. (2004). It should be noted that, jointly with the Hawaii-Emperor chain, the Louisville chain is the one usually used to reconstruct Pacific plate motion stage poles in the hotspot reference frame, in particular between 43 and 65 Ma (e.g., Wessel and Kroenke, 1997). Thus these new data are of particular interest for analysis of Pacific plate history. They indicate that the Louisville chain age progression (Fig. 11) shows both plate and hotspot motion, with an additional rotational change of the Pacific plate required by a fixed-hotspot model around 62 Ma and a significant eastward hotspot motion of 5° between 80 and 30 Ma (Koppers et al., 2004).

Magellan Seamounts

The Magellan seamounts are part of the western Pacific seamounts that also include the Japanese and Marcus Wake seamounts (Fig. 9). Koppers et al. (1998, 2000) provide ages for four Magellan seamounts obtained from Ar/Ar whole-rock and plagioclase dating with age spectrum, total fusion, and inverse isochron analysis. Two volcanic stages are inferred for Vindler Guyot. The preferred ages for each seamount are the mean value deduced from the age spectrum. Finally, Quesada seamount, to the east of the chain near the Mariana Trench, has been dated by Hirano et al. (2002) and exhibits a reliable plateau age of 129 Ma. Because a 7 Ma linear age progression exists among four seamounts of this chain (Fig. 9), from 87 Ma (Ioah seamount) to 95 Ma (Vindler seamount), a hotspot origin was proposed by Koppers et al. (1998), excluding the first volcanic stage of Vindler (101 Ma). However, in the context of the widespread mid-Cretaceous volcanism of the Pacific plate, reflected by the western Pacific seamounts, age progression and linear geographical distribution for this seamount chain are questionable (Winterer et al., 1993; Natland and Winterer, this volume).

Marcus Wake Seamounts

This group of western Pacific seamounts has been dated by Ar/Ar methods (Fig. 9). Several authors (Ozima et al., 1977; Ozima et al., 1983; Winterer et al., 1993) used whole-rock samples and incremental heating methods. Smith et al. (1989) published Ar/Ar TF ages on phenocryst phases for two seamounts, Hemler and Himu, for which we calculate a mean weighted value. These two seamounts were considered to be of the Magellan seamounts (Smith et al., 1989), but due to geographical considerations we prefer to associate them with the Marcus Wake seamounts. For Maloney and Jennings seamounts, comparison of ages obtained from mineral separates and groundmass shows that increase of incremental heating steps after acid leaching of the sample can greatly improve the results from whole-rock samples (Koppers et al., 2000). The ages of the Marcus Wake seamounts range between 74 and 120 Ma. They are all younger than the underlying lithosphere, but no clear age progression is evident. Natland and Winterer (this volume) consider the widespread, apparently randomly distributed volcanoes and the recurrent volcanism of Wake and Magellan seamounts inconsistent with formation by any type of mantle plume.

Marshall Islands

The present names of atolls and guyots should be used, and we took the list established by Lincoln et al. (1993) where the new names (and respective old names) are as follows (see Fig. 9): Anewetak (Enewetak), Pikinni (Bikini), Wodejebato (Sylviana), Woden-kopakut (Ratak), Lokkworkwor (Erikub), Limalok (Harrie), Lomjenaelik (von Valtier), and Likelep (Lalibjet). K/Ar, Ar/Ar TF, and Ar/Ar IH ages were determined by Davis et al. (1989) for Ratak and Erikub using whole-rock samples. For conventional K/Ar dating they tested the effect of acid-leaching techniques on samples dated without treatment, and as their results are greatly improved by this treatment, we do not report the K/Ar dates for untreated samples. Lincoln et al. (1993) dated new samples using the Ar/Ar method. Whole rocks were analyzed

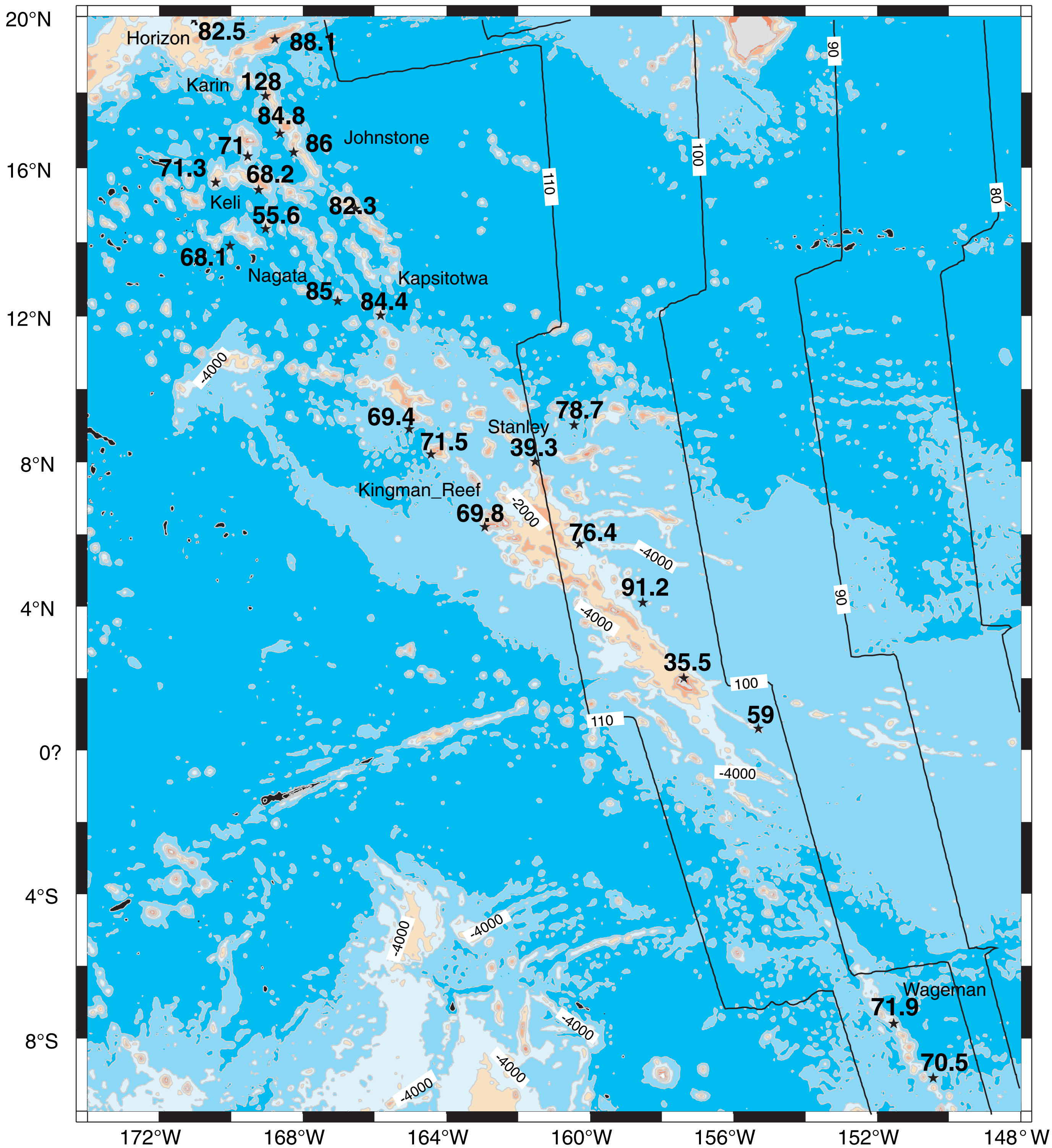

Figure 10. Same as Figure 2 but for the Line Islands.

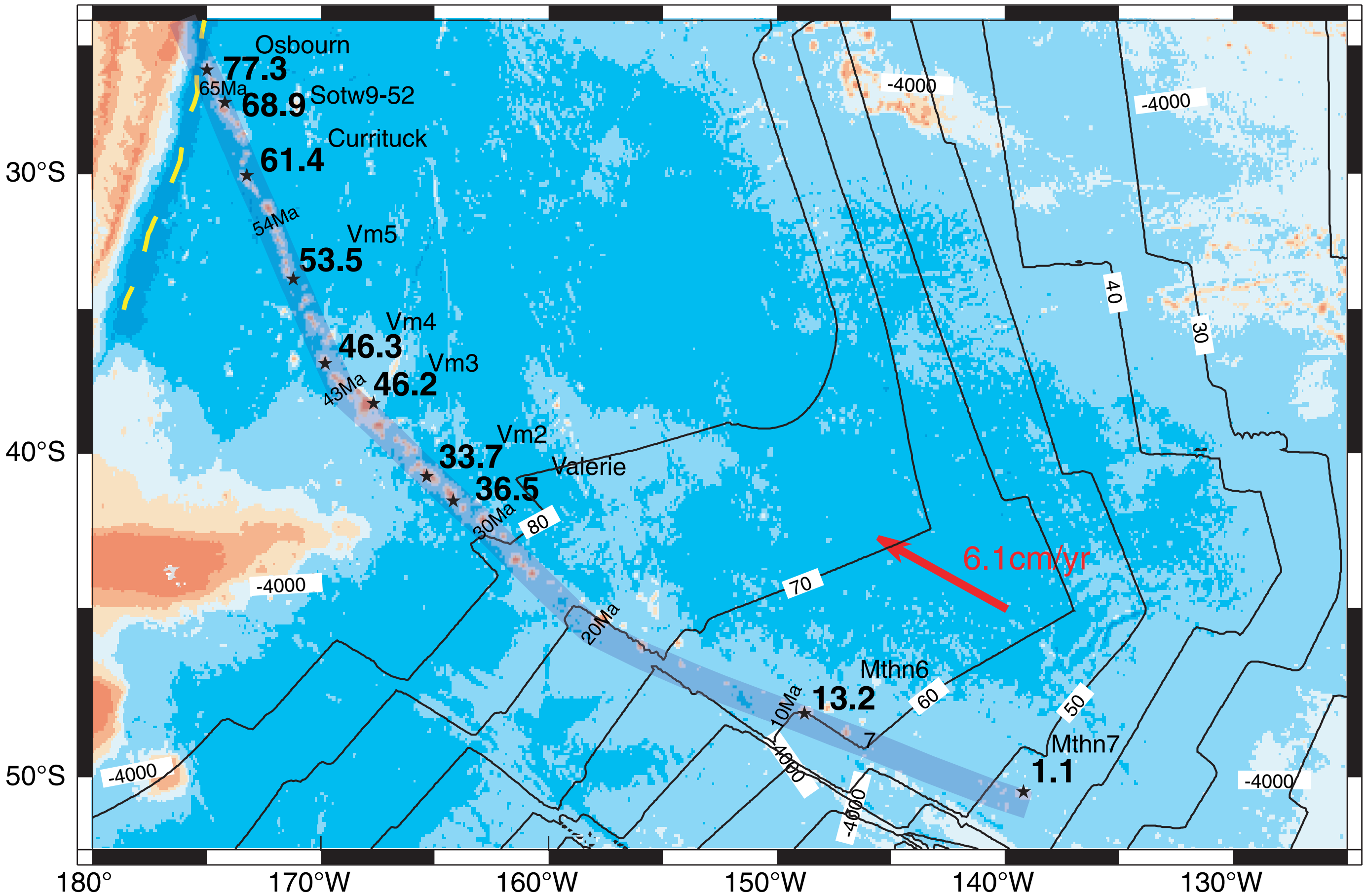

Figure 11. Same as Figure 2 but for the Louisville chain.

using incremental heating, and minerals were analyzed using Ar/Ar TF. The isochron age is generally the preferred result. As for the northwestern Pacific seamounts, the spatial distribution of dated seamounts within the Marshall Islands (Fig. 9) illustrates widespread Middle Cretaceous volcanism in this region, which is inconsistent with fixed-hotspot theory.

Marquesas Islands

Age determinations for subaerial samples exist for all islands of the archipelago (Fig. 12). For Nuku Hiva, Ua Huka, Hiva Oa, Ua Pou, and Tahuata we report the dates determined by Duncan and McDougall (1974), and for Nuku Hiva by Le Dez et al. (1996). In addition, unpublished data exist for Ua Pou, Eiao, Hatutaa, Nuku Hiva, Fatu Huku, Hiva Oa, Tahuata, Fatu Hiva, and Motane in the Ph.D. thesis of Diraison (1991, p 147). Ages for Fatu Hiva and eight dredge hauls are given by Desonie et al. (1993). They used K/Ar, Ar/Ar TF, and incremental heating experiments, and we took an average of their values. An age progression from the southeastern part of the chain to the northwestern part occurs, but the migration velocity is 3 cm/yr slower than expected for a fixed hotspot, and the trend of the chain is different by ~30° from the absolute motion direction of the Pacific plate (Desonie et al., 1993).

Mid-Pacific Mountains

Winterer et al. (1993) present Ar/Ar ages for whole-rock samples from three seamounts of the Mid-Pacific Mountains (Fig. 13). According to them, the age of Jacqueline seamount is unreliable. The results of Resolution Guyot dating were published only in a meeting abstract (Pringle et al., 1993). Changes in the trend of the Mid-Pacific Mountains have been used to calculate the Pacific plate stage pole as between 100 and 145 Ma (Yan and Kroenke, 1993). Inspection the age distribution along this chain (Fig. 13) and the uncertainties in the age determination (old submarine seamounts, whole-rock dating) suggest that these poles are questionable.

Musicians Seamounts

Pringle (1993) used several methods, including conventional K/Ar and Ar/Ar TF on individual feldspars, Ar/Ar TF on whole rocks, and Ar/Ar IH on both whole rocks and mineral separates

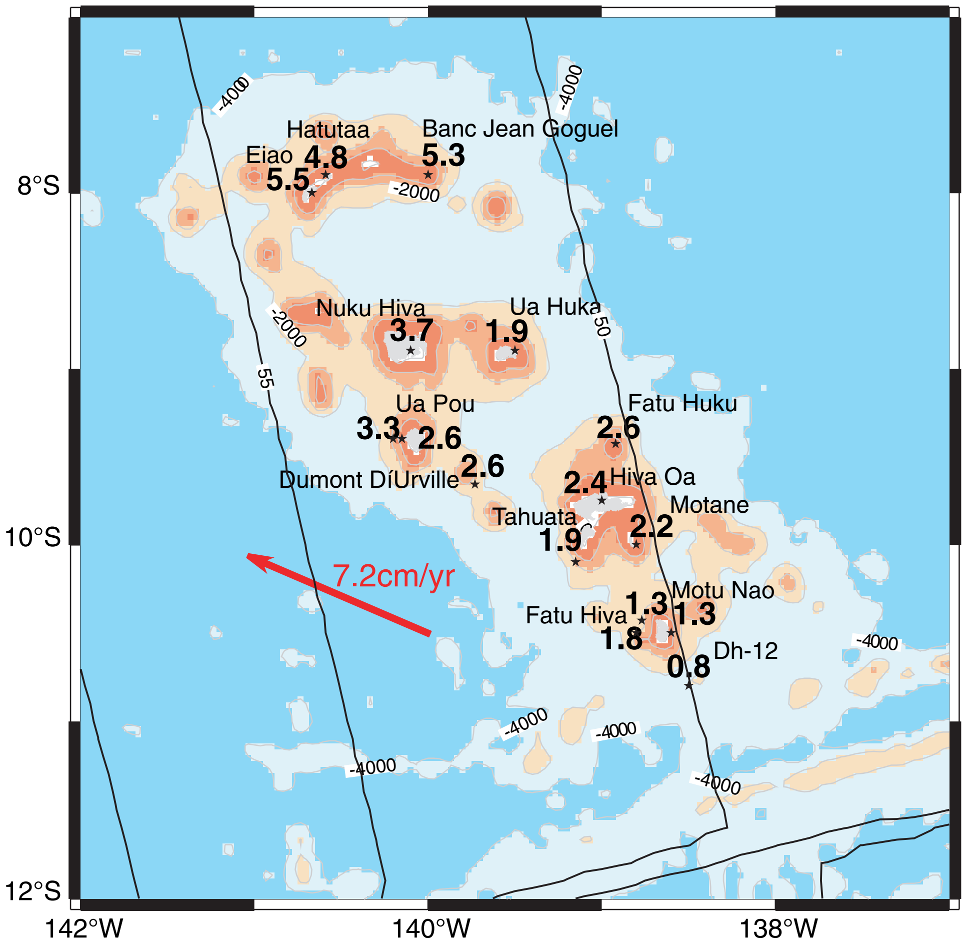

Figure 12. Same as Figure 2 but for the Marquesas Islands.

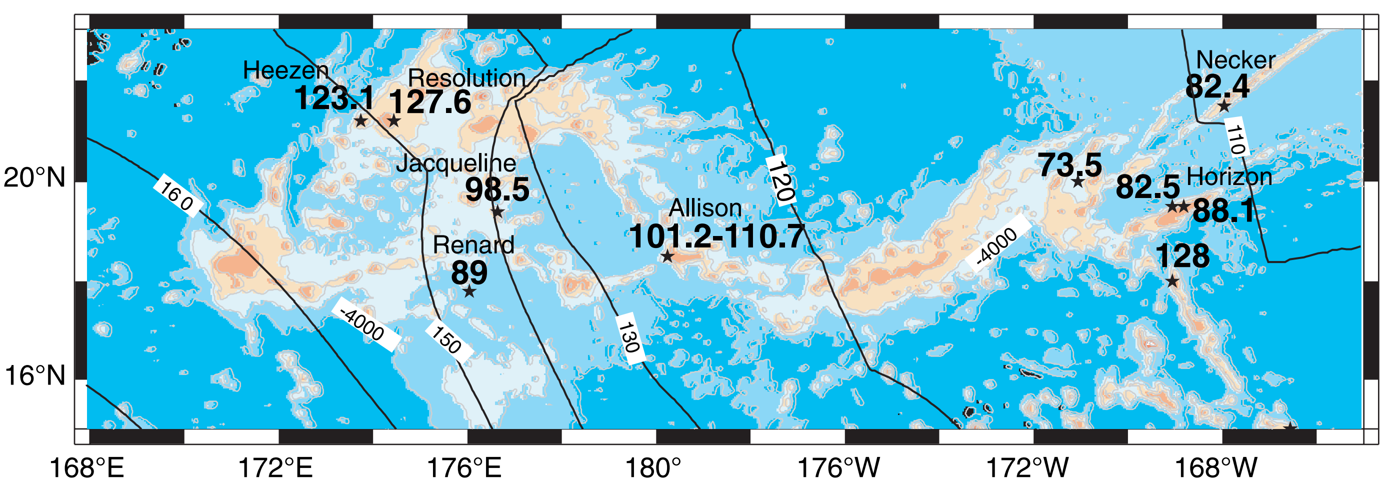

Figure 13. Same as Figure 2 but for the Mid-Pacific Mountains.

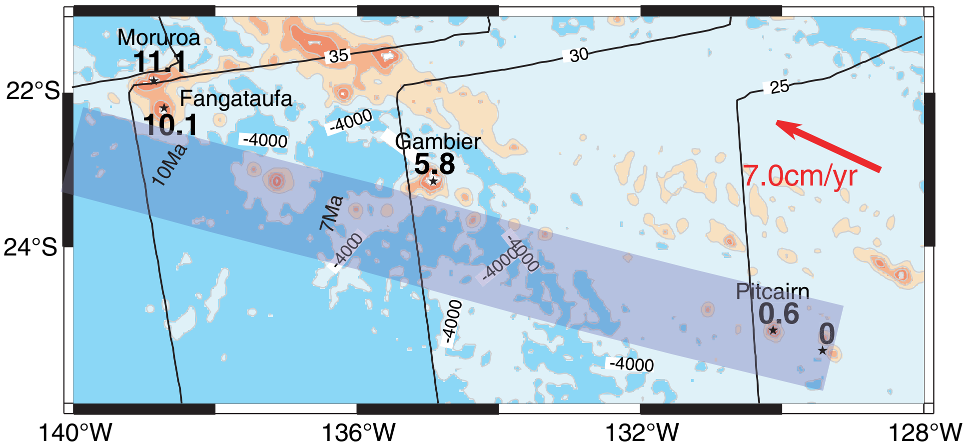

Figure 14. Same as Figure 2 but for the Pitcairn Islands.

(Fig. 7). His preferred ages are the weighted average of isochron results or of total fusion results in the case of the plagioclase samples. As Malher seamount ages range from 91.4 to 83.9 Ma, the preferred interpretation of this author is that the volcanism persisted all this time. Thus two preferred ages appear in Table 1 (see footnote 1). The age distribution apparent in Figure 7 might show a progression from south to north. Kopp et al. (2003) proposed that the Musicians seamounts have resulted from the interaction between a hotspot and a spreading center.

Pitcairn Islands

The first dating of this chain was reported by Duncan et al. (1974) from Pitcairn Island (where they used conventional whole-rock K/Ar dating) (Fig. 14). The region of active volcanism was discovered later (Stoffers and Scientific Party, 1990). K/Ar dating of the Gambier-Pitcairn alignment was all done by the same laboratory on microcrystalline samples. For Fangataufa we report only aerial volcanic ages (Guillou et al., 1993); for Gambier Island, only the mean value for each islet (Guillou et al., 1994); and for Moruroa (old spelling: Mururoa) we report three ages from the same borehole (Guillou et al., 1994). Age progression along the Pitcairn-Gambier-Moruroa alignment is in good agreement with a fixed hotspot origin, as originally proposed by Duncan et al. (1974).

Pukapuka Ridge

The Pukapuka ridge is a submarine ridge that extends from north of the Tuamotu Islands to the East Pacific rise (Fig. 15). Submarine samples were dated using Ar/Ar IH by Sandwell et al. (1995). Spectrum and isochron ages are concordant, and, following the authors, we use the plateau ages as the best ages. The rate of age progression within this chain is inconsistent with formation by a fixed hotspot (Sandwell et al. 1995). It is one of the best examples of this kind, and Sandwell et al. (1995) proposed an origin associated with lithospheric extension.

Samoa Islands

Matsuda et al. (1984) applied the K/Ar method to whole-rock samples from Upolu (Fig. 16). K/Ar and Ar/Ar TF age

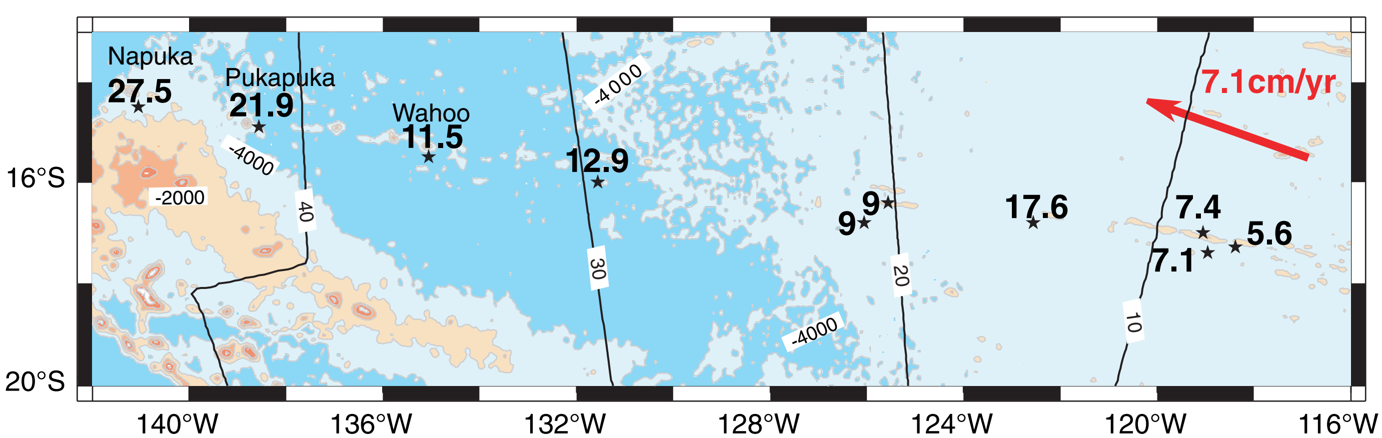

Figure 15. Same as Figure 2 but for the Pukapuka ridge.

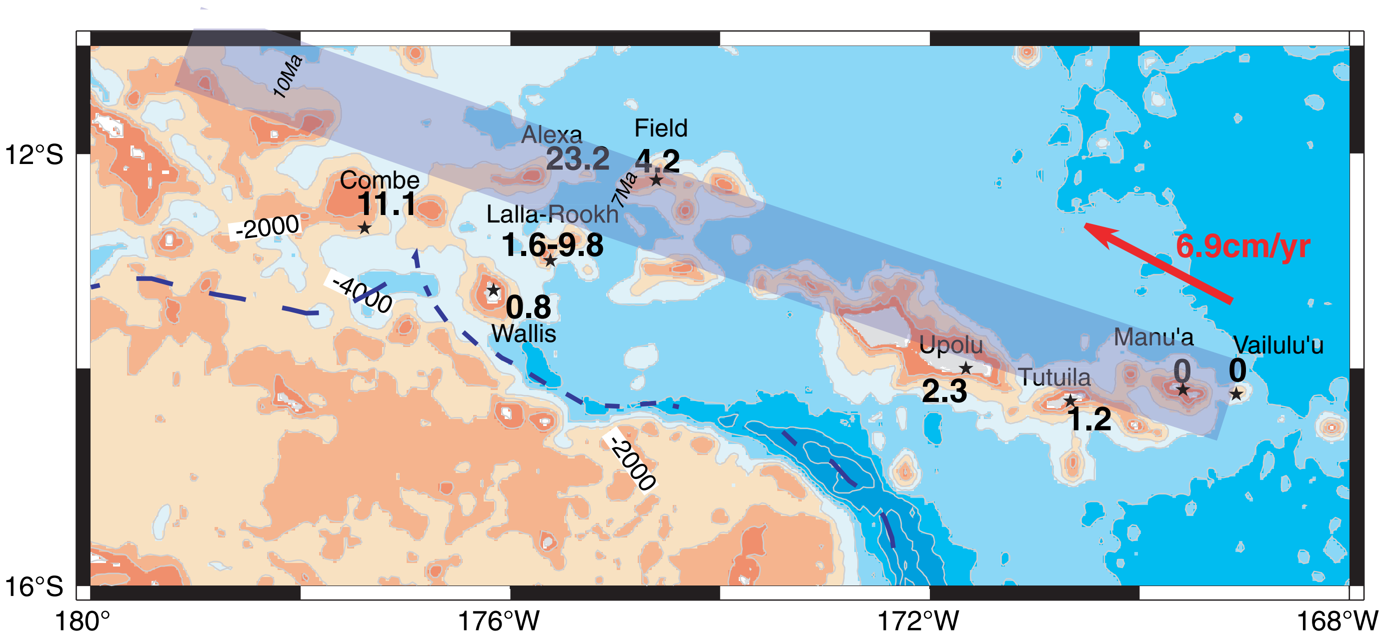

Figure 16. Same as Figure 2 but for the Samoa Islands.

determinations for dredged samples were made by Duncan (1985). Tutuila and Upolu Island subaerial samples were dated by Natland and Turner (1985) using the K/Ar method. Present-day eruptions on Vailulu'u and the analysis of the $^{210}Pb/^{210}Po$ and $^{210}Pb/^{226}Ra$ ratios yield ages of 50–15 yr for the most recent volcanic activity (Hart et al., 2000). Duncan (1985) calculated a linear age progression within the Samoa chain between Comb Bank and Tutuila Island (Fig. 16) and assumed a fixed-hotspot origin coupled with subduction tectonic processes. However, inconsistencies with the hotspot model occur because of the young ages of LallaRookh and Sava'i. This was explained by Hart et al. (2004) as volcanism rejuvenation, whereas Natland (2004) relates these young volcanic stages and the morphology of the Samoa chain to a series of lithospheric fractures that are produced by deformation of the underlying Pacific plate near the Tonga Trench.

Society Islands

Duncan and McDougall (1976) made the first systematic geochronologic study of the Society Islands (Fig. 17). They dated whole-rock samples using the K/Ar method. New K/Ar dating from Duncan et al. (1994) and Hildenbrand et al. (2004) was performed on Tahiti samples. On Tupai Atoll, a block of volcanic rock was lifted by a hurricane in 1983. It was dated by Diraison et al. (1991) using the K/Ar method. In their paper they also mentioned unpublished ages from Duncan for Meetia (old spelling: Mehetia) Island of between 0.26 Ma and the present. The zero age of Meetia is deduced from a 3000-yr-old coral reef overlain by young lava flows (Binard et al., 1993). Age progression within the Society chain is in good agreement with the fixed-hotspot hypothesis (e.g., Duncan and McDougall, 1976).

Tarava Seamounts

The Tarava seamounts form a linear chain parallel to the Society Islands and 200 km to the south of those islands (Fig. 17). Two seamounts were dated applying the K/Ar method to plagioclase crystals (Clouard et al., 2003). To a first order, ages, morphology, and alignments are compatible with a fixed-hotspot origin, but a large discontinuity exists in the track at 43 Ma, where the chain splits into two distinct alignments. This has been explained as the influence of the lithospheric stress field on a hotspot track that was decomposed into a field due to deflection of the lithosphere under the new volcanic load plus a preexisting regional field (Clouard et al., 2003).

Tuamotu Islands

This archipelago, which comprises more than sixty atolls, has been dated only at its northwestern end, near Mataiva Atoll, by the K/Ar and Ar/Ar TF methods on whole-rock dredged samples (Schlanger et al., 1984), yielding a minimum age of 47.4 Ma. No relevant information concerning the origin of this chain ~2000 km long can be deduced from this single age.

Wentworth Seamounts

The Wentworth seamounts are located between the Hess rise and the Hawaiian chain (Fig. 1). Clague and Dalrymplye (1975)

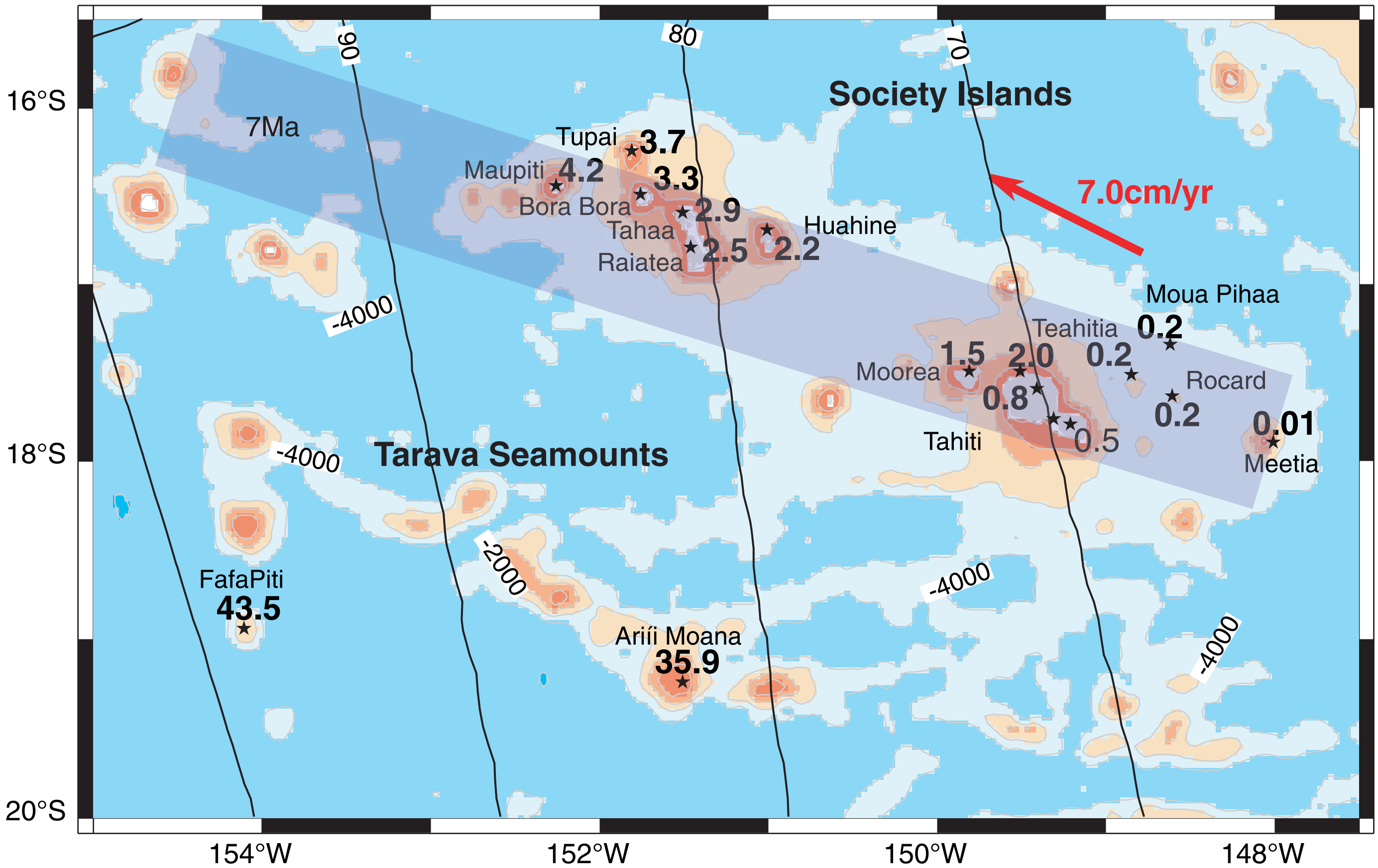

Figure 17. Same as Figure 2 but for the Society Islands and Tarava seamount chain.

and Garcia et al. (1987) determined K/Ar ages for three seamounts, and Pringle and Dalrymple (1993) resampled the same rocks to perform Ar/Ar IH dating on whole rocks or plagioclases. These three ages are reported in Figure 8 and do not reveal any age progression.

Plateaus

Because of the lack of radiometric ages for some Pacific plateaus, we include ages based on magnetic anomaly interpretations for Magellan rise and Shatsky rise (Fig. 1; see also Sager, this volume).

The age of the Magellan rise was deduced by Tamaki and Larson (1988) from reconstruction of the history of the former Magellan microplate using magnetic data. This result is in agreement with an Early Cretaceous sediment age (DSDP [Deep Sea Drilling Program] 167). Ages for the Ontong-Java plateau were obtained from drilled samples (DSDP 289, ODP [Ocean Drilling Program] 803, ODP 807) and dated using the Ar/Ar IH method on whole rocks and separated plagioclases (Mahoney et al., 1993). Ages for Pigafetta Basin (ODP 800) and East Mariana Basin (ODP 802) are from Castillo and Pringle (1991) and were determined using Ar/Ar IH. Pringle (1990) presents the first Ar/Ar ages from site 801 (Pigafetta Basin). During ODP leg 185, site 801C was deepened, and Koppers et al. (2003) proposed complementary Ar/Ar ages. We do not report the ages they obtained for the oceanic crust.

The Hess rise volcanic basement was reached at sites 464, 465, and 466 during DSDP leg 62. The first analysis comes from Vallier et al. (1980) from interpretation of sequences of carbonate sediments. These authors proposed that volcanic activity ended in the Early Albian to the north (site 464, ca. 110 Ma) and in the Late Albian to the south (site 465–466, ca. 97 Ma). A radiometric age for sample 465 yielded disturbed age spectra (Pringle and Dalrymple, 1993). Pringle and Dalrymple (1993) proposed a 90–94 Ma minimum age for this sample. Note that the age on a seamount (dredge DM-1922) at the southern end of Hess rise is reported with other ages for the Wentworth seamounts.

A maximum age for the Shatsky rise formation has been estimated from magnetic seafloor anomalies and a minimum age from recovered sediment ages (Sager and Han, 1993). A K/Ar age of 51.8 Ma has also been reported (Ozima et al., 1970), which may be considered a minimum age.

The Mid-Pacific Mountains plateau is parallel to the M4 (127.0 Ma) magnetic lineation (e.g., Thiede et al., 1981). The

DSDP site 463 reached sediments from the middle Barremian (ca. 120 Ma) (Thiede et al., 1981), and the westernmost dated seamount, Heezen, is 123 Ma (Winterer et al., 1993). Therefore, we took a 127 Ma age for the plateau itself.

CONCLUSIONS

Our compilation of seamount and island dates enabled us to assemble 1685 ages from 290 different dated volcanoes. Analysis of the radiometric dating methods shows that some of these ages are probably only a minimum estimate of the crystallization age. Thus one must be cautious when deducing the history of intraplate volcanism or motion of the Pacific plate. Among the twenty-five volcanic chains for which ages are available, almost all show inconsistencies with the classical fixed-hotspot theory, and more inconsistencies appear as more ages are measured. These inconsistencies include wrong rate of age progression (e.g., Pukapuka ridge), trend incompatible with Pacific absolute plate motion (e.g., Marquesas Islands), lack of an active hotspot for all the oldest chains except Louisville and Hawaii and even for recent ones (e.g., Austral Islands), occurrence of several volcanic stages on the same seamount (e.g., Samoa Islands), no age progression at all (e.g., northwestern Pacific seamounts) but merely clusters of intraplate volcanism (e.g., Line Islands), and geographical distribution of seamounts away from the proposed hotspot track (e.g., Tarava and Musicians seamounts). Most of these anomalies are typically explained by the interaction of a hotspot with other plate tectonic mechanisms such as a mid-oceanic ridge, a subduction zone, plate reorganization, or an inherited lithospheric stress field.

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