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Origin of the 43 Ma Bend Along the Hawaiian-Emperor Seamount Chain: Problem and Solution

Y. Niu

4.1 Introduction

The Hawaiian-Emperor Seamount chain (H-E SMC) on the Pacific Plate (Figs. 4.1 and 4.2a,b) is the best-defined hotspot track on the Earth. If hotspots are surface manifestations of deep, fixed sources of mantle plumes (Morgan 1971, 1981), then the along-track volcanic age progression away from Hawaii (e.g., Clague and Dalrymple 1989) must record the direction, absolute velocity, and possible changes of the Pacific Plate motion. This would suggest that the prominent ~43 Ma Bend along the H-E SMC reflects a sudden change in Pacific Plate motion direction by ~60°. However, the actual cause of the 43 Ma Bend is unknown. A leading hypothesis is that the collision between India and Eurasia some ~45 Ma ago might have triggered the sudden reorientation of the Pacific Plate motion from northward to northwestward, hence the 43 Ma Bend (Dalrymple and Clauge 1976; Patriat and Achache 1984). This collision, however, is shown to have had no effect on the Pacific Plate motion (Lithgow-Bertelloni and Richards 1998). The lack of apparent mechanism for such a sudden change in Pacific Plate motion direction led to the speculation (Norton 1995) that the ~43 Ma Bend may have resulted from a southward drift of the Hawaiian hotspot prior to ~43 Ma. Indeed, recent paleomagnetic studies (Tarduno and Gee 1995; Tarduno and Cottrel 1997; Christensen 1998; Sager 2002), plate reconstructions (Acton and Gordon 1994; Norton 1995, 2000; DiVenere and Kent 1999; Raymond et al. 2000), mantle flow models (Steinberger and O'Connell 2000), and statistical analysis of plate motions using seamount geochronology (Koppers et al. 2001) all indicate that hotspots are not fixed, but they move individually or in groups at speeds up to 60 mm yr^{-1}. Specifically, using paleomagnetic data-derived paleolatitudes for the Suiko (~64.7 Ma) and Detroit (81.2 Ma) Seamounts along the Emperor Seamount chain (E-SMC), Tarduno and Cottrel (1997) suggest that the Hawaiian hotspot had drifted southward at a speed of ~30–50 mm yr^{-1} from 81 to 43 Ma. Sager (2002) suggests that this southward drift must have been even more rapid. In fact, ODP Leg 197 (July 1 to August 27, 2001) was devoted to verifying the paleomagnetic interpretations (Tarduno et al. 2001).

If the Hawaiian hotspot had indeed drifted in speed as rapidly as the lithospheric plate motion, then we have lost the best hotspot reference with which to reconstruct plate tectonic history in the Pacific and elsewhere. This would be a revolution, and we would be left with no alternative but to reconsider the tectonic history of the Pacific Plate in particular and global tectonics in general during the period from ~81 to 43 Ma. Caution is necessary!

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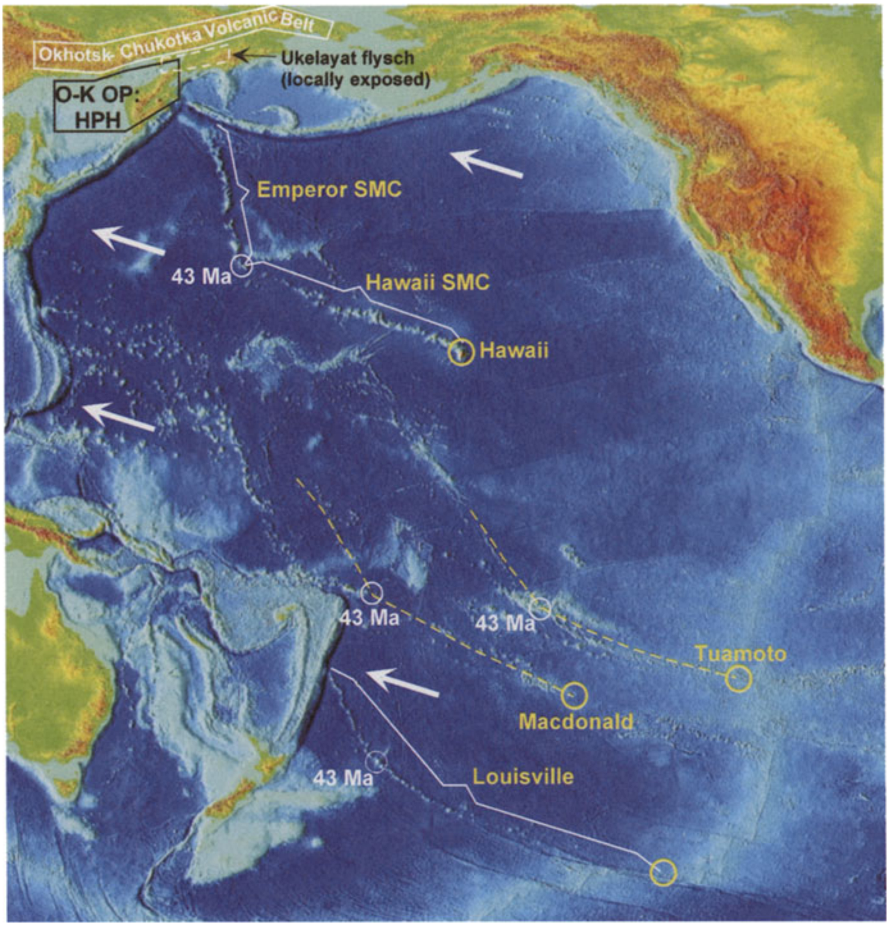

Fig. 4.1. Portion of the world's topographic map (from http://www.ngdc.noaa.gov/mgg/image/) showing Hawaiian hotspot, Hawaiian-Emperor Seamount chain, and the 43 Ma bend. Highlighted are also several other present-day hotspots (Louisville, Macdonald, Tuamotu) and the 43 Ma bends along these respective hotspot tracks on the Pacific Plate (e.g., Norton 2000). "*O-K OP: HPH*" outlines the suggested Okhotsk-Kamchatka oceanic plateau: the Hawaiian mantle plume head material. Note that the Emperor Seamount chain is perpendicular to the Cretaceous-Tertiary Okhotsk-Chukotka active continental margin, which the Pacific Plate moved towards and subducted beneath prior to 43 Ma. Note also the area where the Kamchatka forearc Ukelayat flysch sandstones are exposed and studied by Garver et al. (2000)

In this chapter, I accept that the Hawaiian hotspot is not as fixed as was previously thought, but emphatically point out that interpretations based on paleomagnetic data will have difficulties in reconciling important observations. I then present an alternative interpretation for the origin of the 43 Ma Bend, which is consistent with simple physics as well as many observations. It is my intention that this contribution will offer a stimulus to the community for a better understanding of fundamental tectonic problems, such as this one, which we should understand, but which we still have not yet mastered.

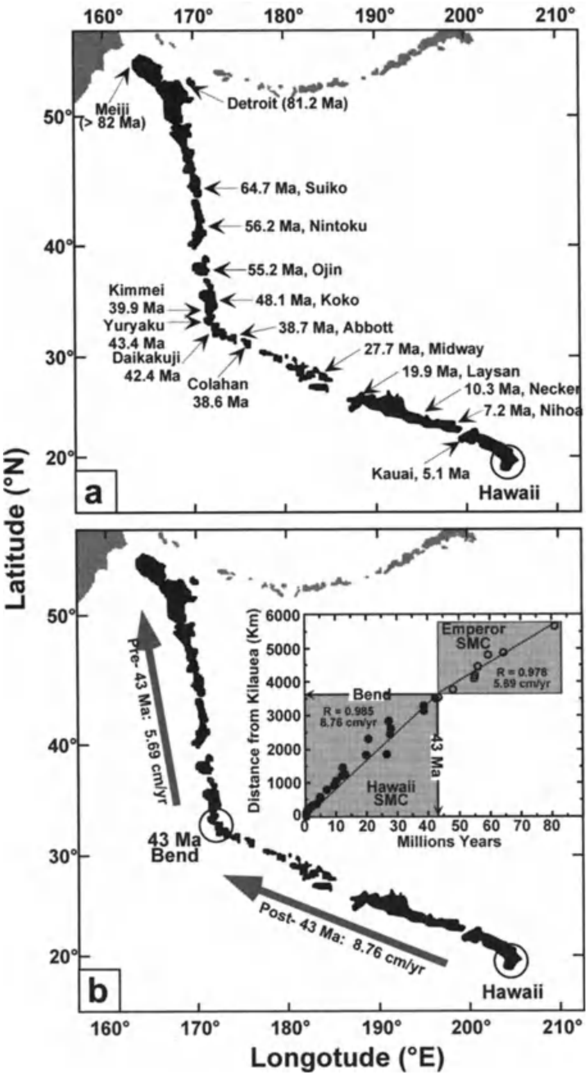

Fig. 4.2. a A simplified map of Hawaiian-Emperor Seamount chain in the Pacific after Clauge and Dalrymple (1989). K-Ar age dates of seamount lavas are also from these authors except for Detroit Seamount for which an Ar-Ar age date is from Keller et al. (1995). b Assuming the Hawaiian hotspot is fixed, the age data indicate a significant spreading rate change from ~5.69 $cm\,yr^{-1}$ during the Emperor Seamount volcanism (~81 to 43 Ma) to 8.76 $cm\,yr^{-1}$ of the present-day Hawaiian Seamount volcanism since 43 Ma

4.2 The Emperor Seamount Chain Paradox

4.2.1 Paleomagnetic Interpretations

If the Hawaiian hotspot has remained fixed, then ancient lavas erupted on the Emperor Seamounts should record paleolatitudes similar to the present-day latitude of Hawaii at ~19.5° N. This does not seem to be the case. Lavas from the Suiko Seamount (64.7 Ma) give a paleolatitude of 27.5° (±2°) (Kono 1980), and lavas from the Detroit

Seamount (81.2 Ma) give a paleolatitude of 36.2° (+6.9°/−7.2°) (Tarduno and Cottrell 1997). Very recently, using more samples from different drill holes of the Detroit Seamount, Sager (2002) obtained an even higher paleolatitude of 42.8° (+13.2°/−7.6°). If the effect of true polar wander (TPW) can indeed be ruled out (Tarduno and Cottrell 1997), then these high paleolatitudes of seamounts during eruption can only be explained by the southward drift of the Hawaiian hotspot. Using the paleolatitudes derived from paleomagnetic data of the Detroit Seamount lavas, the Hawaiian hotspot would have drifted southward during the 38 Myr period (from 81 to 43 Ma) at a speed of ~50 mm yr^{-1} (between 30 to 70 mm yr^{-1}, Tarduno and Cottrell 1997) or at a speed of ~68 mm yr^{-1} (between 46 to 107 mm yr^{-1}, Sager 2002). Such drift is remarkable, as the speeds are on the order of quite fast plate motion.

4.2.2
A Simple Test

We can carry out some simple exercises to see (1) whether such high speed drift of the Hawaiian hotspot is possible, and (2) whether the 43 Ma Bend is due to the cessation of the hotspot drift without changing the direction of the Pacific Plate motion. Figure 4.3 shows the results of the exercises. From the subtle and more Hawaii-like "trend" between the Meiji and Detroit Seamounts at the northern end of the Emperor chain (Figs. 4.1 and 4.2a,b), we can assume that the Hawaiian hotspot started the drift from the time of Detroit Seamount volcanism at ~81 Ma. We can also assume, for this testing purpose, that the Pacific Plate had spread both in direction and speed during the 38 Myr period (from 81 to 43 Ma) the same as it does today. Figure 4.3b gives several scenarios. If the Hawaiian hotspot had not drifted, the present-day E-SMC would simply be a western extension of the Hawaiian Seamount chain (H-SMC) as labeled A. If the Hawaiian hotspot had indeed drifted southward at speeds of 30 mm yr^{-1} and 60 mm yr^{-1}, respectively, then the present-day E-SMC would be in the positions B and C, respectively. Obviously, none of the three scenarios can be practically correct, as they do not match the present-day location of the E-SMC. In order to reproduce the E-SMC, we must consider several variables: (1) possible variations in both direction and velocity of the Pacific Plate motion, and (2) possible changes in the speed of southward drift of the Hawaiian hotspot. Although paleomagnetic data cannot resolve longitudinal changes, as the E-SMC is essentially north-south (~350° NNW; see Fig. 4.3a), we thus know that the Pacific Plate must have had limited motion to the west (~293° NWW; Fig. 4.3a) prior to 43 Ma. The meaningful variables to be considered are thus limited to (1) southward drift of the Hawaiian hotspot, (2) northward motion of the Pacific Plate, and/or (3) their combination.

These considerations lead to an essentially unique solution that best fits the E-SMC (Fig. 4.3c). The velocity component of the Pacific Plate motion in the 293° NWW direction is limited to 10 mm yr^{-1}. The combination of southward Hawaiian hotspot drift and the northward velocity component of the Pacific Plate motion gives a net effect of 50 mm yr^{-1} along the E-SMC. This best-fit result is in fact very close to the lava age progression rate of ~57 mm yr^{-1} along the E-SMC (Fig. 4.2b). If neither the Hawaiian hotspot nor the Pacific Plate were stationary during the formation of E-SMC, then both should have moved at a speed less than ~57 mm yr^{-1} (say, ~60 mm yr^{-1}). In other words, if the Hawaiian hotspot had stayed fixed, the Pacific Plate must have moved north-

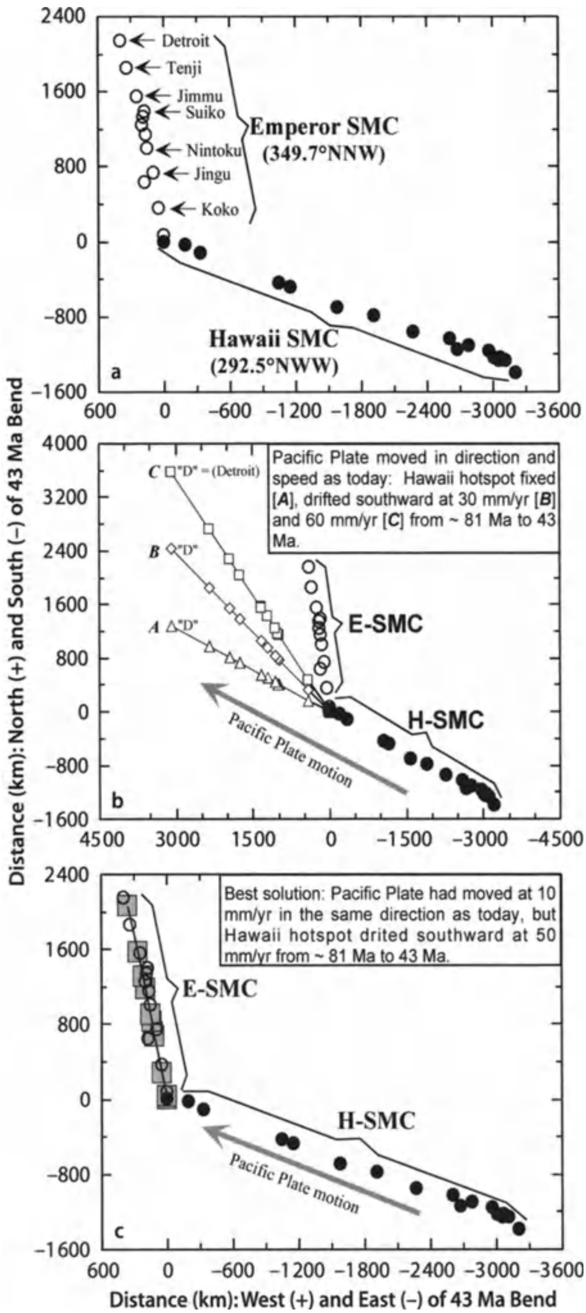

Fig. 4.3. a Plot of the Hawaiian-Emperor Seamount chain in a Cartesian coordinate system in kilometers (recalculated in terms of "great circle distance" from latitude and longitude values) with the 43 Ma Bend chosen as the origin. **b** Several hypothetical scenarios (*A*, *B* and *C*) illustrating where and in what direction the Emperor Seamount chain would be located today, each symbol point corresponding to a seamount of the Emperor Seamount chain. I assume for this testing purpose that the Pacific Plate had spread in both direction and speed during the ~81–43 Ma period the same as it does today. Scenario A: With Hawaiian hotspot fixed, the Emperor Seamount chain would simply be an extension of the Hawaiian Seamount chain. Scenarios B and C: Hawaiian hotspot had drifted south-ward at speeds of 30 mm yr^{-1} and 60 mm yr^{-1}, respectively. This exercise indicates that one cannot reproduce the Emperor Seamount chain with Hawaiian hotspot drift only without changing the speed, direction or both of the Pacific Plate; **c** Keeping Pacific Plate motion direction as it is today, but varying speeds of both Pacific Plate motion and Hawaiian hotspot drift due south, the Emperor Seamount chain can be reproduced, essentially and uniquely, in both the orientation and length (*shaded squares*). The Pacific Plate moves to the NWW (292.5°) at a speed of only 10 mm yr^{-1}, while the Hawaiian hotspot drifts southward at a speed of 50 mm yr^{-1}. The latter is essentially the same as the 57.1 mm yr^{-1} northward motion motion of the Pacific Plate prior to 43 Ma, assuming the fixed Hawaiian hotspot (Fig. 4.2). This suggests that if the interpretations based on paleomagnetic data were correct, the Pacific Plate would have been essentially stationary during the ~38 Myr period of Emperor Seamount chain formation

ward at a speed of ~60 mm yr^{-1}. Alternatively, if the Hawaii hotspot had indeed drifted continuously southward at a speed of ~60 mm yr^{-1}, the Pacific Plate would have to have been nearly stationary for 38 Myr (from 81 to 43 Ma).

4.2.3
The E-SMC Paradox and Solution

If we accepted the paleomagnetic interpretations that the Hawaiian hotspot had drifted continuously at a speed of 50 mm yr^{-1} (Tarduno and Cottrell 1997) or 70 mm yr^{-1} (Sager 2002) during E-SMC formation, we would also have to accept that the Pacific Plate had been essentially stationary (only 10 mm yr^{-1} drift to ~293° NWW; Fig. 4.3c) during this 38 Myr period. This reasoning is simply wrong, because it is inconsistent with observations. The well-established magnetic anomalies on the Pacific Plate at its present-day latitude of 20–35° N shows that from 81 Ma (Chron 34) to 43 Ma (Chron 18), the Pacific Plate spread at a speed of ~54 to 63 mm yr^{-1} in a relative motion direction due west (Atwater 1989). Furthermore, during this same period, the Pacific Plate continued to subduct to the NW and NNW beneath northeast Asia (Zonenshain et al. 1990; Norton 2000). This situation is indeed a paradox! To resolve the paradox means that we must make a choice between observations and interpretations. I choose to accept the observations based on well-established magnetic anomalies that the Pacific Plate was not stationary, but spread at ~54–63 mm yr^{-1} in the relative plate motion direction due west. But as "absolute" plate motion to the west (e.g., 293° NWW) is limited to ~10 mm yr^{-1} (Fig. 4.3c), the Pacific Plate would have had to move in an "absolute" direction due north. Considering that the Hawaiian hotspot may indeed have drifted southward and regarding the ~57 mm yr^{-1} vector (Fig. 4.2b) along the E-SMC, it is difficult to know how much contribution came from a northward Pacific Plate motion and how much from the southward Hawaiian hotspot drift. However, if we consider continuous Pacific Plate production and consumption (Atwater 1989; Norton 2000) regardless of the net growth in size during that 38 Myr period, we must accept that the Pacific Plate motion due north is significant, and must be greater than the Hawaiian hotspot drift to the south. I do not doubt the motion of the Hawaiian hotspot, but request careful re-evaluation of the paleolatitudes of E-SMC derived from lava paleomagnetic data. The errors associated with the current paleolatitude estimates are too large (>25%) to allow a quantitative evaluation of the actual speed of the Hawaiian hotspot drift. Furthermore, precise evaluation of the effects of both TPW and apparent polar wander of the Pacific in the Cretaceous is required.

4.3
The Origin of the 43 Ma Bend

4.3.1
Reasoning Towards a Preferred Model

Having argued above that the northward motion of the Pacific Plate must be significant during E-SMC formation, I consider that the reorientation of the Pacific Plate motion at 43 Ma best explains the origin of the 43 Ma Bend. This is supported by the expression of other hotspots and their tracks on the Pacific Plate (Fig. 4.1) (Morgan 1971, 1981; Norton 1995, 2000). In particular, the Louisville Seamount chain in the southern Pacific (Hawkins et al. 1987; Lonsdale 1988) behaves essentially the same as the H-E SMC (Harada and Hamano 2000; Norton 2000; Raymond et al. 2000; Koppers et al. 2001) and has fairly well defined along-chain age progression with a recognized 43 Ma bend (Lonsdale 1988;

Watt et al. 1988). If the Pacific Plate had not changed its direction of motion at 43 Ma, these observations would require a simultaneous multi-hotspot source swing in the Pacific deep mantle. Given the size of these mantle hotspots/plumes, their probable derivation from the core-mantle boundary (e.g., Richards and Griffiths 1988; Zhao 2001) and the very high viscosity in the deep mantle (Richards and Griffiths 1988; Davies and Richards 1992), it is indeed difficult to imagine that all these hotspot sources moved at the same time, in the same direction and by the same amount. It is, however, physically straightforward to envision that the Pacific Plate, a single unit, may have reoriented itself.

The question is, what might have caused the reorientation of the Pacific Plate motion at that period? To answer this question, we need to understand what controls the direction and speed of a moving oceanic plate. This is the same question as what causes the plate motion. The answer is straightforward – the forces that act on plate boundaries, such as subducting slab pull, ridge push etc. (Forsyth and Uyeda 1975; Gordon et al. 1978). As slab pull is the dominant driving force for an oceanic plate (Forsyth and Uyeda 1975; Davies and Richards 1992) and accounts for >90% of all the possible forces (Lithgow-Bertelloni and Richards 1998), our task is to identify a paleo-trench/subduction zone to the north towards which the Pacific Plate had moved prior to 43 Ma and to understand why the Pacific Plate failed to continue due north, but suddenly moved towards a northwest direction at 43 Ma.

4.3.2
"Trench Jam" at 43 Ma Caused by the Arrival of Hawaiian Plume Head/Oceanic Plateau

A topographically prominent feature in the far-east northeast Asia is the Late Cretaceous-Early Tertiary Okhotsk-Chukotka Andean-type active continental margin with a well-developed volcanic arc (Fig. 4.1) and subduction zone dipping gently (20°) northwest (Zonenshain et al. 1990). It was inferred, based on this shallow dipping, that the trench must have been ~500 km from the present edge of the volcanic belt within the Sea of Okhotsk (Zonenshain et al. 1990). This is the only subduction system known to exist in the region prior to the present Kamchatka-Aleutian subduction system. It is important to note that the elongation of the Okhotsk-Chukotka continental margin is essentially perpendicular to the orientation of the E-SMC. We can infer that the Pacific Plate may have moved towards and subducted beneath this continental arc prior to 43 Ma. Also note that if the subduction zone's dipping is gentle (20°), the slab-pull force, the rate of subduction and Pacific Plate motion may not be very fast, although the actual rate cannot be constrained.

The reorientation of the Pacific Plate at ~43 Ma requires that the northward motion and subduction stopped at this time. Physically, the cessation of a plate subduction can only be caused by "trench jam", e.g., the arrival of buoyant and unsubductable terranes (Ben-Avraham et al. 1981). Figure 4.4a–c illustrates the concept and physical likeliness of trench jam, and also gives reasons why the "trench jam" can lead to the reorientation of the Pacific Plate motion. Mantle plumes are probably derived from a deep thermal boundary layer, which is most likely at the core-mantle boundary as predicted theoretically (e.g., Griffiths and Campbell 1990; Davies and Richards 1992) and detected seismically (e.g., Zhao 2001). Mantle plumes ascend because of thermal buoyancy and because of the growth of the more buoyant plume heads (Whitehead and Luther 1975;

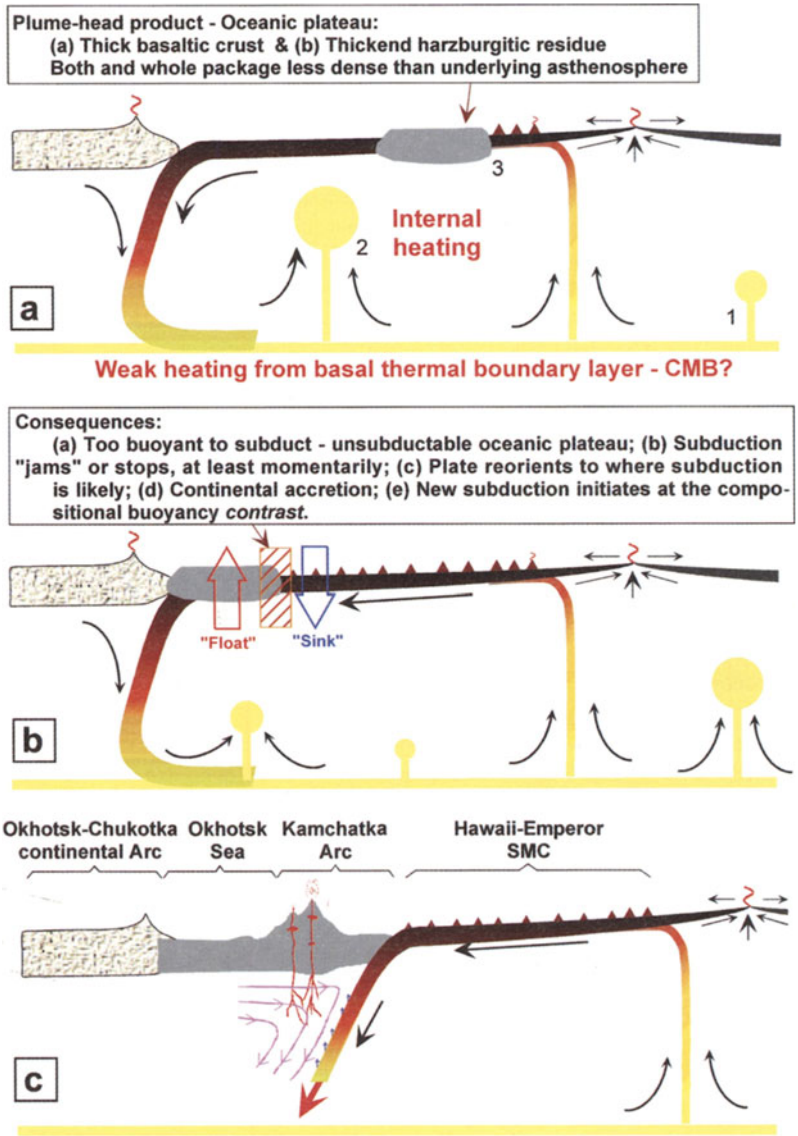

Fig. 4.4. Cartoon illustrating the consequences when a buoyant oceanic plateau (mantle plume head) collides with a subduction zone. **a** The initiation, thickening and subduction of an oceanic lithosphere. Initiation and rise of a mantle plume from a basal thermal boundary layer (*1*), development of plume head (*2*), and formation of oceanic plateau by decompression melting of plume head. **b** The plateau moves with the plate leaving a hotspot track on the younger sea floor. This plateau, when reaching the trench, has important consequences as indicated. If the trench jam leads to the cessation of the subduction, the subducting plate will reorient its motion to where subduction is likely. A large compositional buoyancy contrast at the plateau edge becomes the focus of the stress within the plate in favor of the initiation of new subduction zones (Niu et al. 2001, 2003). **c** Initiation and subduction of the dense oceanic lithosphere soon leads to dehydration-induced mantle wedge melting for arc magmatism. Note that *C* is meant to illustrate the concept, which is simplified and exaggerated to schematically describe the present-day H-E SMC, Kamchatka arc, Okhotsk Sea and abandoned Andean-type Okhotsk-Chukotka continental arc (see text for details)

Richards et al. 1989; Griffiths and Campbell 1990). When the plume head reaches a shallow level, it melts by decompression and produces thick basaltic crust and thickened, highly depleted residues (Campbell and Griffiths 1990; Hill et al. 1992; Herzberg and O'Hara 1998; Herzberg 1999; Niu et al. 2001, 2003), which have low Fe/Mg ratios and low aluminum, preventing the formation of dense garnet minerals (Niu 1997). As a result, the whole assemblage is less dense than the underlying asthenosphere (Niu and Batiza 1991), thus forming the buoyant oceanic plateau (Burke et al. 1978; Ben-Avraham et al. 1981; Abbott et al. 1997; Niu et al. 2003). This plateau moves with the plate leaving a hotspot track on the younger sea floor (Fig. 4.4a). When this buoyant plateau reaches a subduction zone (Fig. 4.4b), (1) it is too buoyant to subduct and thus will become part of a newly accreted continent (e.g., Ben-Avraham et al. 1981; Abbott et al. 1997; Albarède 1998; Herzberg 1999; Niu et al. 2003); (2) subduction stops (or in other words, the "trench jams") at least momentarily; and (3) the plate reorients its motion to where subduction is more likely (Niu et al. 2001, 2003).

In the context of this model, I hypothesize that the arrival of a buoyant Hawaiian plume head/oceanic plateau at ~43 Ma caused the trench jam, which stopped the subduction of the Pacific Plate beneath the Okhotsk-Chukotka active continental margin, and consequently led the Pacific Plate to reorient its motion in the direction where subduction was more likely, i.e., the present-day western Pacific, where subduction zones had formed some ~7 Myr earlier (Moberly 1972; Taylor 1993). This readily explains the 43 Ma Bend along the H-E SMC, and also explains why this 43 Ma Bend is less sharp along hotspot tracks further to the south such as the Tuamotu, Macdonald, and Louisville Seamount chains on the Pacific Plate (Fig. 4.1). Note that since subducting slab pull is the major drive force for plate motion, a trench jam can easily lead to the reorientation of the plate motion as is the case of the Pacific Plate during late Neogene as a result of the collision between the Ontong Java Plateau and the northern Australian Plate (Wessel and Kroenke 2000). The question is, where is the unsubductable Hawaiian plume head/oceanic plateau? Niu et al. (2001, 2003) hypothesized that the "exotic Okhotia terrane" (Zonenshain et al. 1987), now beneath the northern Okhotsk Sea, and at least part of the Kamchatka arc lithosphere are the best candidates for the Hawaiian plume head (Figs. 4.1 and 4.4c). The Okhotia terrane has been speculated to be a continental fragment (Zonenshain et al. 1987), but its long march carried by the Pacific/Kula Oceanic Plates away from any continents since some ~130 Ma ago makes it more like a buoyant oceanic plateau rather than a continental fragment. In fact, recent geological and geophysical work by Bogdanov and Dobretsov (2002) confirms the "volcanic oceanic plateau" nature of the Okhotsk Sea terrane.

4.3.3
Evidence Versus Coincidence

The above interpretation is strongly supported by recent work of Garver et al. (2000). These authors established that ~44 Ma is the youngest fission track grain age (FTGA) of primary igneous zircons in the far-east Kamchatka forearc Ukelayat flysch sandstones derived from the Okhotsk-Chukotka continental arc (Garver et al. 2000) (Figs. 4.1 and 4.5a). This minimum age strongly suggests the termination of the Chukotka continental arc volcanism – the provenance of the FTGA zircons. This termination of the arc volcanism as a result of subduction cessation is likely to be the consequence of the col-

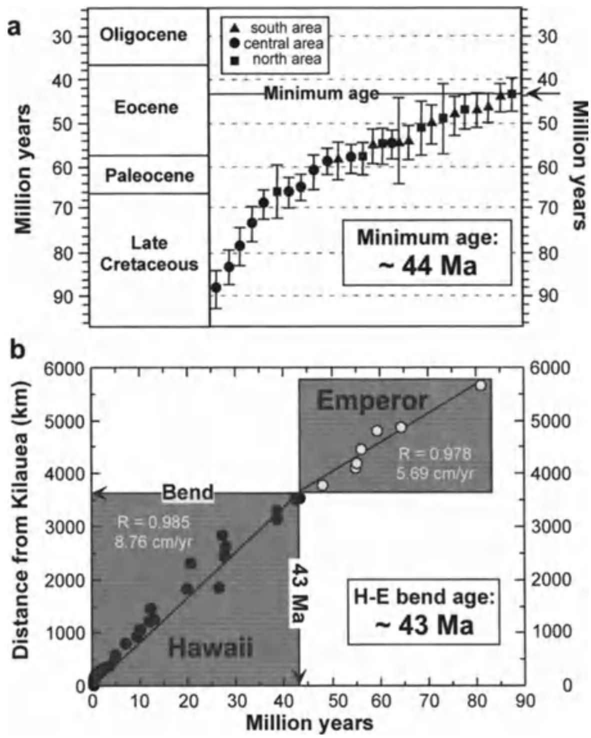

Fig. 4.5. **a** Simplified from Garver et al. (2000) to show the fission track grain age (FTGA) of primary igneous zircons in the Cretaceous-Tertiary Ukelayat flysch. The provenance of the zircons is the Andean-type Okhotsk-Chukotka continental magmatic arcs. Note that the minimum zircon age of ~44 Ma is essentially the same as the age of the ~43 Ma Bend along the Hawaiian-Emperor Seamount chain; **b** as the *inset* in Fig. 4.2b, used to compare with the minimum FTGA age in Fig. 4.5a

lision of the Hawaiian mantle plume head. I believe that the collision at ~44 Ma is the actual cause of, not coincidental with, the sudden reorientation of the Pacific Plate at ~43 Ma, marked by the bend along the H-ESC (Fig. 4.5b). Assuming that the oldest Meiji Seamount along the H-E SMC is ~82 Ma, the Hawaiian mantle plume would be ~125 Ma old, which is an interesting age as it is not significantly different from the ~122 Ma of the first phase of Ontong Java Plateau volcanism (Mahoney et al. 1993).

4.4 Summary and Conclusion

While we have known for a long time that hotspots are not really fixed (e.g., Molnar and Atwater 1973), the advertisement "Fixed Hotspots Gone with the Wind" (Christensen 1998) has stirred up our way of thinking in an unusual way – all that we thought we knew about plate motions must be wrong or at least in huge error! In particular, the suggestion based on interpretations of paleomagnetic data that the E-SMC resulted from southward drift of the Hawaiian hotspot (Tarduno and Cottrell 1997; Sager 2002) provides us with an even more severe challenge. The suggested speed of Hawaiian hotspot drift is huge, 50–70 mm yr^{-1}, which is on the order of fast plate motion velocity. If this were indeed correct, this would represent a revolution. Caution is thus necessary before we accept this suggestion. Because the total apparent velocity along the E-SMC is ~57 mm yr^{-1} (Figs. 4.2b and 4.5a,b), if the Hawaiian hotspot drifted southward at this speed, the Pacific Plate would have had to be stationary for 38 million years from 81 to 43 Ma. The latter cannot be correct, because well-established magnetic anomalies on the Pacific Plate indicate its relative motion due west at a speed of ~54 to 63 mm yr^{-1} during that period (Chron 34, ~81 Ma to Chron 18, ~43 Ma). Because significant "absolute" motion to the west is unlikely (Fig. 4.3c), mass conservation requires that the Pacific Plate moved to the north at a significant speed, probably much more so than the southward drift of the Hawaiian hotspot. This analysis requires a reconsideration of the paleomagnetic data interpretation about the speed of hotspot drift. I suggest that the 43 Ma Bend along the E-SMC is caused by the reorientation of the Pacific Plate motion at that time. The arrival of a buoyant Hawaiian mantle plume head/oceanic plateau to the Andean-type Okhotsk-Chukotka active continental margin led to a "trench jam", and subsequent cessation of the Pacific Plate motion to the north. The Pacific Plate reoriented its motion to the northwest, where the present-day western subduction zones had formed some ~7 Myr earlier. This interpretation is supported by the fact that the Okhotsk-Chukotka continental arc volcanism stopped, as a result of trench jam and subduction cessation, at ~44 Ma, the same time as the age of the 43 Ma Bend. I further suggest that the "exotic Okhotia terrane" beneath the northern Okhotsk Sea and perhaps a significant portion of the Kamchatka arc lithosphere are the best candidates for the buoyant Hawaiian mantle plume head – an unsubductable oceanic plateau. The geology in the broad Kamchatka region is complex. Drilling at ideal sites of the Kamchatka peninsula or into the northern Okhotsk Sea lithosphere is required to verify this hypothesis.

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Cover Montage – Background: A three-dimensional map of the Pitcairn hotspot seafloor's volcanic landscape located in the South Pacific near 25°30' S–129°30' W using multibeam data processed by E. Le Drezen and A. Le Bot (IFREMER and GENAVIR). Overlay photographs (courtesy of IFREMER): An active hydrothermal chimney at 1457 m depth on top of the Teahitia Volcano (Society hotspot) and the submersible *Nautile*.

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