Discussion of

A plate model for Jurassic to Recent intraplate volcanism in the Pacific Ocean basin

by

Alan Smith

27th December, 2006, Keith H. James

Figure 2b of Smith (this volume) shows the Caribbean Great Arc above west-dipping subduction. If one believes the Caribbean Plate came from the Pacific, then the literature shows this arc above east-dipping subduction. Arrival of the Caribbean plateau from the west choked the zone in the Albian, causing subduction reversal.

Figure 2d indicates formation of the Caribbean Plate in the late Cretaceous. Obducted Jurassic crust around the Caribbean is taken to indicate late Jurassic-early Cretaceous spreading. This would accord with Atlantic and Gulf of Mexico opening. The Caribbean plateau seems to have formed during several pulses, 130-120 Ma, 90-88 Ma and around 78-76 Ma. It is centered on the Beata Ridge. Analogy with the Scotia Plate (West Scotia Ridge) suggests this was the locus of early, Atlantic-Caribbean spreading between the Americas (James, 2005a). In this model the Caribbean Plate and its plateau formed in-place.

Figure 2d and the text indicate back-arc spreading behind the (western) “Caribbean Great Arc”. The Scotia analogy (East Scotia Ridge) would suggest back-arc spreading centered on the Aves Ridge, behind the Lesser Antilles (James, 2005a).

I have used analogy with Iceland and Manihiki to explain Caribbean plateau thickening above the Beata Ridge. Association of Ontong Java with a ridge, noted by Smith (this volume) corroborates this. The Iceland model also suggests a mechanism of Caribbean plate definition.

The Great Caribbean Arc concept holds that the Aruba-Blanquilla island chain, the Lesser Antilles, the Aves Ridge and the Greater Antilles from Cuba to the Virgin Islands formed in the Pacific as a north-south trending intra-oceanic arc around 130-120 Ma (e,g. Bouysse et al., 1990). As this entered the Caribbean area the northern and southern parts became distributed along the boundaries of the Caribbean and on Cuba. There are major problems with this.

1) In order for the Caribbean to migrate into place, the continental block of Chortis needs to be elsewhere. It is supposed to have rotated from southwestern Mexico and, in a process never explained, to have jumped onto the rear end of the migrating plate. The geologies of Chortis and southwest Mexico are not compatible (Keppie et al., 2005). Jurassic rift lineaments on Chortis

(Guayape-Patuca Faults) remain parallel to regional (inter-American) coeval structures, showing that no rotation has occurred (James, 2006a, b). Chortis has always been on the western end of the Caribbean Plate.

Crustal thicknesses, gravity data, high-silica ignimbrites, xenoliths, and quartz sands indicate continental blocks below southern Central America also. They are covered by thrusted Mesozoic oceanic and volcanic rocks and Cenozoic volcanic/sedimentary rocks. The blocks are among continental fragments dispersed around the Caribbean during Jurassic-early Cretaceous rift/drift. The Scotia analogy illustrates this, but more importantly I have compiled a variety of data that indicate that the Caribbean is at least 1/3 continental (James, in preparation). The presence of continent below the whole of Central America, on the western end of the Caribbean Plate, denies any plate migration through the area.

The idea that southern Central America is inter-oceanic has provoked inverted reasoning. Vogel et al. (2004) attribute high-silica rocks in Costa Rica to “continentalization”, while at the same time noting crustal thickness of 40 km, low seismic velocities and geochemical similarity to continental rocks. The same explanation is given for a Santonian tonalite on Aruba, “which was in the Pacific at that time” (White et al., 1999). Andesites are used to signify continental crustal input (original definition and my text books). Their presence in southern Central America is used to call this into doubt in recent texts.

2) Supposedly allochthonous (Pacific-derived) elements of the arc found along northern South America show gradational geological continuity with continental equivalents to the south. They bear chemical evidence of continental input as far back as the Albian, long before the “Great Arc” is supposed to have approached the Caribbean area. Elements of the “Great Arc” along northern South America and on Cuba carry Palaeozoic zircons.

My understanding is that there never was a “Caribbean Great Arc” in the Pacific. Instead, volcanic activity occurred around and within the Caribbean Plate. It probably began along with spreading (Jurassic volcaniclastic rocks in Costa Rica, upper Jurassic volcanic rocks on Cuba, Hispaniola, Puerto Rico and La Désirade and volcaniclastic rocks at least as old as Albian in the north-eastern Lesser Antilles).

Data I have compiled show that Caribbean volcanism paused in the Albian and Cenomanian and ceased (except for the free faces in the east and west) in the middle Eocene. Each pause was accompanied by uplift to wavebase and development of an erosional unconformity covered by shallow marine limestones.

The approximate coincidence of the Albian and Cenomanian Caribbean episodes with plate reorganizations highlighted by Smith (this volume) is significant. The Middle Eocene Pacific/Caribbean episodes are exactly coeval. Around the Caribbean, mixtures of oceanic, volcanic and continental-margin rocks were emplaced in continent-verging thrust systems (see James, 2005b for a discussion). Ophiolite/arc nappes up to 5 km thick and 100s of km long occur in Cuba and Venezuela. This event appears to have been short and violent. It was a coeval, regional affair recorded in the Caribbean, Mexico, Colombia, Ecuador and Peru. This was recognized as long ago as 1938 (by Hess) but it is ignored by models that show the Caribbean Plate diachronously interacting with north and south boundaries as it migrated eastward.

How much uplift occurred? Ocean floor and deep faunal assemblages (radiolarinan cherts, pelagic forams) ended up on continental margins.

Some questions:

1) "Large regions of shallow mantle are close to or at the peridotite solidus. Intraplate volcanism is related to plate reorganizations, suggesting that it is controlled by fracturing and extension that allows melt to be released (Anderson, 1998; Favela and Anderson, 2000; Foulger and Natland, 2003; Foulger this volume)."

The Caribbean is in an extensional setting: fracture zones in the Atlantic and Pacific diverge towards the Caribbean. The same is true east and west of the Scotia Plate. I see decompression melting occurring in this extensional habitat. What caused extension in the Pacific? If extension results in decompression melting and plateau formation, what causes coeval convergence along plate margins? I wonder if change of density, once begun, results in run-away melting ("melt-down").

2) How confident does the author feel about modern geochemical distinctions of MORB, intraplate, and margin products? I suspect that esoteric data (often without statistical analysis) are selected to fit preferred ideas. The sampling bias of dated rocks from Ontong Java, noted by Smith (this volume), makes me wonder if similar bias enters into distinctions of oceanic igneous/volcanic rocks.

29th December, 2006, Rex H. Pilger

There are a few points Smith (this volume) has made that are deserving of clarification:

(1) On p. 2, Smith writes, "*The final major change in the stress field occurred in the Late Oligocene as a result of breakup of the Farallon into the Cocos and Nazca plates, and caused a hiatus in Hawaiian volcanism, initiated the Sala y Gomez, Foundation, and Samoan chains, and terminated the Louisville chain*". Pilger and Handschumacher (1981) showed that the Sala y Gomez chain may have originated from the same melting anomaly responsible for the Tuamotu and Nazca ridges. This would have occurred when southward motion of the anomaly relative to the overlying Pacific and Farallon plates resulted in the anomaly's displacement from beneath the spreading center, crossing under a transform fault, to be entirely under the Farallon plate (prior to its fragmentation).

(2) Further, the Foundation chain may significantly predate fragmentation of the Farallon plate; its calculated older extension (to ~40 Ma) corresponds with isotopic ages from seamounts proximate to the Austral Islands (Pilger, 2003). Nevertheless, the paucity in seamounts between the Austral region and the Foundation chain could represent the stress mechanism history Smith proposes.

(3) Smith (p. 22) writes, "*The Juan Fernandez ridge was noted to coincide with a change in slab dip at 33˚S… In conventional models, the assumption of a plume origin for the volcanism has resulted in the changes in slab geometry being attributed to subduction of topographic features associated with the intraplate volcanism… the slab flexure at 33˚S cannot result from subduction of the Juan Fernandez ridge as the older section of the ridge curves northeast and intersects the convergent margin at 31˚S.*" Projection of Juan Fernandez ridge to the low-angle subduction segment beneath central Chile includes an elongate seamount at ~ 32.8˚S, 73.7˚W and intersection of the further projected ridge with the Chilean coast at ~32.5˚S, supported by the calculated locus of Nazca plate motion relative to the "hotspot" (e.g., Pilger, 1984). In Fig. 1, bathymetry from Google Earth (2006) shows the same feature originally interpreted as part of the Juan Fernandez "hotspot trace" and which is inferred to be genetically related to the low-angle subduction segment (also supported by the volcanic gap documented by published isotopic age dates; Pilger, 1984). The northeast-trending feature at ~ 31.5˚S, 73.7˚W could well be a paleo-fracture zone, as its orientation parallels other mapped fractures of the Easter plate, instead of continuation of Juan Fernandez trace, as Smith has apparently interpreted it.

(4) Smith (p. 22) also noted that eastern extrapolation of the Sala y Gomez chain coincides with a change in slab geometry at 28˚S. Since in his model the chain formed as a result of Farallon plate fragmentation, this extrapolation would be irrelevant. The melting anomaly model for the Sala y Gomez-Nazca trace has the same implications.

These observations remove some of the supporting evidence for Smith's model, but do not invalidate it, especially if the stress-mechanism is accompanied by sublithospheric melting anomalies as Beutel and Anderson (this volume) propose in their second model and have been argued for previously (Pilger and Handschumacher, 1981; see also Pilger, 2007).

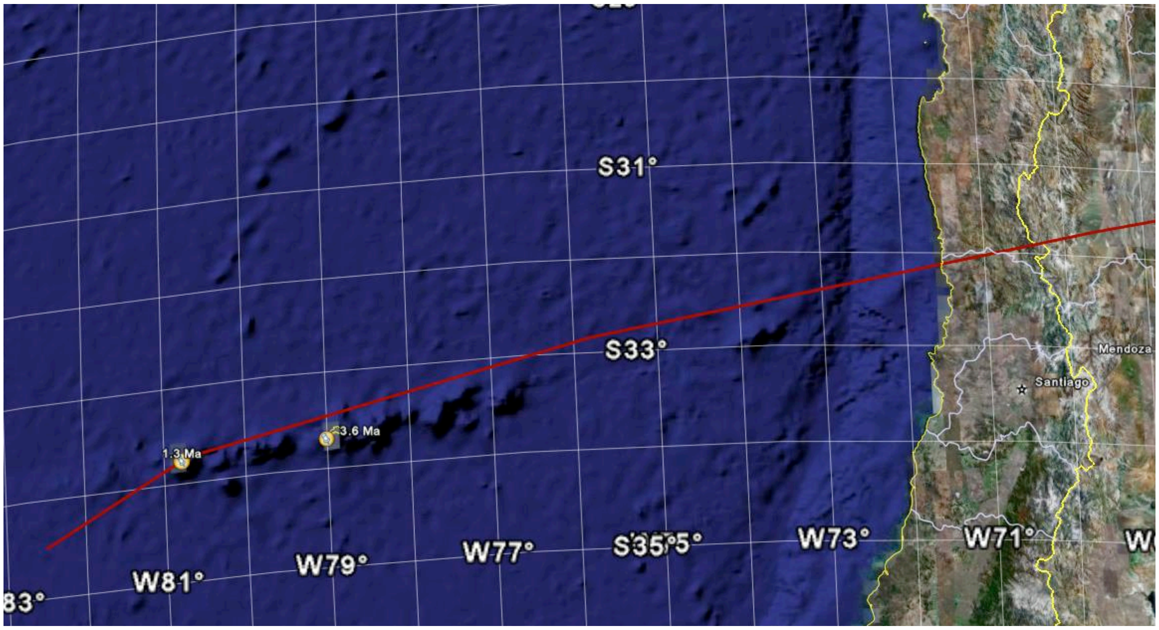

Figure 1. Shaded bathymetry and topography of the region around Juan Fernandez ridge, together with the calculated hotspot motion locus using the parameters of Pilger (2007) corrected to the timescale of Gradstein et al. (2004). Projection of the ridge through the seamount at ~ 32.8˚S, 73.7˚W would produce a coastal intersection near 32.5˚S. Age dates citations are in Pilger (2003).

15th January, 2007, Alan Smith

The reconstruction of an arc fringing the Arperos basin in Figure 2 was based on Tardy et al. (1994), who correlated the Guerrero terrane of Mexico with the Western Cordillera of Colombia on the basis of similar ages and magmatic evolution sequences. Tardy et al. (1994) also included correlations with the Greater Antilles (not used in the reconstruction), which suggests influence by the plume model. I therefore agree with James that the reconstruction contains elements reminiscent of models in which the Caribbean plateau originates over the Galapagos hotspot, although it was not intended to imply such an origin for the plateau. I have no objection to the model that James outlines in his comment. If Central America formed in situ, the Arperos basin would not extend south of the Guerrero terrane in Figure 2.

The growth of the Pacific plate was controlled by the motion of the Izanagi, Farallon, and Phoenix plates until the Late Cretaceous. The latter were large, long-lived oceanic plates, which were likely subject to strong slab-pull forces. Oceanic plateau formation occurred along ocean ridge systems as a result of melt focusing at triple junctions (Georgen and Lin, 2002), or entrainment of fertile mantle into the ocean ridge upwelling (Korenaga, 2005). The geochemistry of several plateaus indicates an EM1 source component, such that the fertile component may be equated with continental mantle or lower continental crust entrained in the shallow mantle

(Smith and Lewis, 1999; Anderson, 2005). Formation of ocean island chains is envisaged to result from lithospheric fracturing allowing the escape of melts generated from shearing of volatile-rich sources in the asthenosphere (Smith and Lewis, 1999; Doglioni et al., 2005).

I consider there has been considerable bias in the focus of the plume model on island chains such as Hawaii and large igneous provinces such as the Ontong Java plateau. As noted by Okal and Batiza (1987) regarding the difficulty of applying hotspot models to the south-central Pacific: "one starts wondering whether hotspot theory would have emerged as it did, had more cases of Austral-type chains been documented (especially if located in more accessible regions) early in the game". Similarly, Natland and Winterer (2005) note the thousands of seamounts of the Pacific Ocean floor that do not show any regular distribution, but are capped by OIB-type basalts. Such features suggest the sources of OIB are widely distributed throughout the shallow mantle, and the simplest way to accomplish this would be to mix subducted oceanic crust directly into the convecting mantle (Meibom and Anderson, 2003; Smith, 2005).

The Pilger and Handschumacher (1981) model attributes the Tuamotu plateau and Nazca ridge to a Morgan-type hotspot that subsequently formed the Sala y Gomez chain. However, such a model does not explain differences in morphology between the Nazca ridge and Sala y Gomez chain (Woods and Okal, 1994). The Nazca ridge may also extend to the Roggeveen Rise at 31˚S, 91˚W, 1000 km further southwest than commonly depicted, which would further preclude any relationship with the Sala y Gomez chain (Woods and Okal, 1994). A more complex scenario than a single melting anomaly may also be required from the Tuamotu plateau, where the identification of three sets of intersecting ridges may indicate protracted growth over several stages (Natland and Winterer, 2005).

Correlating the Austral and Foundation chains would produce a more linear age progression favorable to a plume model, but there is no volcanic record from 131˚W to 140˚W to support such a model. Instead, I suggest the Austral chain may be comprised of ridges aligned with the Line Islands and Puka-puka trends proposed for the Tuamotu plateau by Natland and Winterer (2005).

I agree with the co-ordinates given by Pilger for intersection of the Juan Fernandez chain with the continental margin. The track depicted in Figure 5 should intersect the continental margin approximately 1˚ further south of the position shown, but this does not affect the interpretation of Pliocene-Recent volcanism along the chain being controlled by slab geometry.

The re-organisation of the Pacific-Farallon ridge at ~25 Ma has been attributed to the transmission of stresses from the convergent margin (Natland and Winterer, 2005). After the re-organisation the Nazca plate would have been stressed by the slab flexure into which I extrapolate the Sala y Gomez chain. The origin of the chain is thus related to both the plate re-organisation and convergent margin geometry.

16th January, 2007, Rex H. Pilger

In the context of the “Plate Model”, the differences in morphology of the Nazca Ridge to the Sala y Gomez Chain are a result of the former having formed from a “hotspot” (or melting anomaly) located beneath a spreading center and the latter having formed within a single plate of the anomaly and as a result of intraplate stresses focused by the “hotspot” (as explained by Pilger and Handschumacher, 1981).

The Tuamotu Ridge, which has a similar morphology to its conjugate, the Nazca Ridge, is the only part of the Tuamotu “plateau” to have formed at a spreading center. The remainder of the complex consists of multiple isolated islands and seamounts indicative of formation within a plate. In the context of the plate model, a large fertile zone is required to explain the Tuamotu complex. However, the concentration of the islands, seamounts, and ridge on the south side of the Austral fracture zone is understandable given the significant difference in age and plate thickness (older and greater on the north side): pressure release melting occurs progressively within the fertile zone as the fracture zone passes over it (Raddick et al., 2002; Pilger, 2003) and focused extensional stresses produce the Tuamotus and Nazca Ridge (with part of the fertile zone extending beneath the spreading center).

The older seamounts near the Austral chain could represent the same fertile zone responsible for the Foundation chain. The gap between the Austral and Foundation chains would then be indicative of a period of compressive stress that did not tap the melting anomaly. The older seamounts near the Austral chain are closer to the oldest portions of the Foundation chain than they are to the Line Islands chain(s) and few older seamounts occur between them.

Implicit in this interpretation is recognition that the fertile zones responsible for the principal chains of the Pacific have not moved significantly with respect to one another (although they may be moving collectively relative to the spin axis and the melting anomalies of the Atlantic and Indian Oceans; Pilger, 2003). The origin of the fertile zones remains uncertain, however; the kinematic arguments emphasized in my comments do not rule out either shallow or deep (“plume”) origins; neither do they prefer either mechanism. Nevertheless, the importance of intraplate stresses in controlling magmatism still appears to be significant.

21st January, 2007, Alan Smith

The term “Hotspot” is misleading. Petrological evidence suggests the sources of OIB are volatile-rich and melt within the temperature range of normal mantle (e.g. Green and Falloon, 2005; Falloon et al., this volume). Nor is there evidence for significant thermal anomalies from oceanic swells (e.g. DeLaughter et al., this volume).

An alternative model for the Tuamotu plateau is that initial volcanism occurred along a trend contemporaneous with the Line Islands. A second set of seamount ridges was then generated orthogonal to the NNW orientated-Pacific-Farallon spreading centre (then along the Roggeveen and Mendoza Rises; Mammerickx et al., 1980) akin to Puka-puka ridges. The Pacific-Farallon ridge then jumped westwards and re-aligned NNE, with a third set of seamount ridges forming orthogonal to the new spreading centre. The Tuamotu plateau is where the three sets of ridges intersect (Natland and Winterer, 2005). Such an origin is consistent with the observations of Ito et al. (1995) that the northwestern part of the plateau formed 600 km away from the Pacific-Farallon spreading centre, although the southeastern part of the plateau may have formed closer to the spreading centre (Okal and Cazenave, 1985).

Melting anomalies may appear quasi-fixed between different ocean basins without having a deep mantle origin. In a plate model, the sources of intraplate volcanism lie within the asthenosphere (e.g. Cuffaro and Doglioni, this volume). Motion between melting anomalies in the Pacific and Atlantic/Indian Oceans is the result of differences in flow regime in the asthenosphere beneath the plates in these basins (Smith and Lewis, 1999). Changes in plate configuration will change the drift of the melting anomalies. Rapid motion of melting anomalies may result from propagation of fractures.

22nd January 2007, Don L. Anderson

Rex Pilger's comment of 16th January, 2007 rightly notes that in the context of the plate model, a large fertile zone is required to explain some melting anomalies and that concentrations of islands and seamounts along fracture zones (FZ) is understandable given a significant difference in age and plate thickness. This also applies to Hawaii (Winterer and Natland, comment of 11th January on Chapter by Laske et al., this volume), particularly the peak in activity at the Molokai FZ. Pressure release melting occurs within the fertile zone as the FZ passes over it; fertile blobs also rise and melt beneath thin plates and spreading centers. I also agree that intraplate stress ultimately controls the location of magmatism and the access to fertile zones. In contrast to the plume model, the amount of melting depends on the fertility, or eclogite content, of the underlying mantle, and the duration or size of the melting anomaly depends on the volume of the fertile blob or streak, not the absolute temperature.

Pilger also points out that it is implicit in this interpretation that the fertile zones responsible for the volcanic chains of the Pacific have not moved significantly with respect to one another (although they may move collectively relative to the spin axis and the melting anomalies of the Atlantic and Indian Oceans). This is exactly the prediction of the asthenospheric counterflow model; embedded fertile blobs or streaks (from subducted aseismic ridges) under a given plate will move parallel to one another and antiparallel to the overriding plate. This is not the case for whole-mantle convection, or for weak plumes. The origin of the fertile material is discussed in Foulger et al. (2005) and Anderson (this volume and comment of 20th January on Yamamoto et al, this volume). The sources include delaminated crust, trapped and abandoned mantle wedges, and subducted seamount chains; these account for the total volume of so-called hotspots (which Smith in his comment rightly points out are not hot; magma volume is not a proxy for high absolute temperature).

In the shallow counterflow model, the flow is directed away from lithospheric sinks and toward hotspots, not radially away from them, as in the model of Yamamoto et al. (this volume); anisotropy should mimic plate motions, and not be radial to hotspots (Figure 1). The flow lines in

Figure 1 are consistent with the anisotropy, and can be compared with those in Yamamoto et al. (this volume).

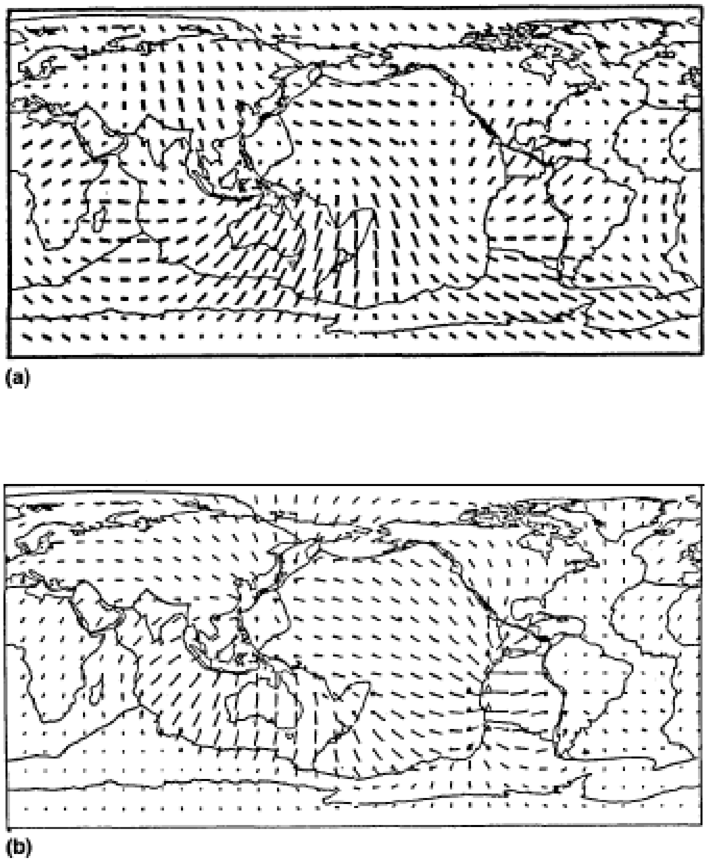

Figure 1. (a) Azimuthal anisotropy of 200-s Rayleigh waves. (b) Flow lines at 260 km depth for the upper-mantle kinematic flow model. This model includes a low-viscosity channel in the upper mantle [see Chapter 15 http://caltechbook.library.caltech.edu/14/]. Fertile blobs embedded in the counterflow will define a fixed reference system for each plate and will move slowly compared to plate velocities, consistent with observations (Wang and Liu, 2006). The vectors in Figure 1b are about 1/5th of the plate velocity.

References

Anderson, D.L, 2005, Large igneous provinces, delamination, and fertile mantle: Elements, v. 1, p. 271-275.

Beutel, E., and Anderson, D. L., this volume, Ridge-crossing seamount chains: a non-thermal approach, in Foulger, G.R., and Jurdy, D. M., eds., Plates, Plumes, and Planetary Processes, Volume Special Paper ###, Geological Society of America.

Bouysse, P., D. Westercamp and P. Andreieff, 1990, The Lesser Antilles Island Arc: Procs. Ocean Drilling Program, Scientific Results, v. 110, p. 29-44.

Doglioni, C., Green D.H., and Mongelli, F., 2005, On the shallow origin of hotspots and the westward drift of the lithosphere, in Foulger, G. et al., eds., Plates, Plumes, and Paradigms, Geological Society of America Special Paper 388, p. 735-749, doi:10.1130/2005.2388(42).

Foulger, G.R., Natland, J.H., and Anderson, D.L., 2005. A source for Icelandic magmas in remelted Icelandic crust: Journal of Volcanology and Geothermal Research., v. 141, p. 23-44.

Georgen, J.E. and Lin, J., 2002, Three-dimensional passive flow and temperature structure beneath oceanic ridge-ridge-ridge triple junctions: Earth and Planetary Science Letters, v. 204, p. 115-132.

Google Earth Plus, 2006, Version 4.0 1657 (Beta), http://earth.google.com/.

Gradstein, F. M., Ogg, J. G., Smith, A. G., editors, 2004, Geologic Time Scale 2004, Cambridge University Press, Cambridge, 610 p.

Green, D.H., and Falloon, T.J., 2005, Primary magmas at mid-ocean ridges, "hotspots," and other intraplate settings: Constraints on mantle potential temperature, in Foulger, G.R. et al., eds., Plates, Plumes, and Paradigms, Geological Society of America Special Paper 388, p.217-247, doi:10.1130/2005.2388(14).

Hess, H. H., 1938, Gravity anomalies and island arc structure with particular reference to the West Indies: Am. Philos. Soc. Proc., v. 79 (1), p. 71-96.

Ito, G., McNutt, M., and Gibson, R.L., 1995, Crustal structure of the Tuamotu Plateau, 150S, and implications for its origin: Journal of Geophysical Research, v. 100, p. 8097-8114.

James, K. H., 2005a, A simple synthesis of Caribbean geology: Transactions, 16th Caribbean Geological Conference, Barbados, Caribbean J. of Earth Sciences, v. 39, p. 71-84.

James, K. H., 2005b, Palaeocene to middle Eocene flysch-wildflysch deposits of the Caribbean area: a chronological compilation of literature reports, implications for tectonic history and recommendations for further investigation: Transactions, 16th Caribbean Geological Conference, Barbados, Caribbean J. of Earth Sciences, v. 39, p. 29-46.

James, K. H., 2006a, Arguments for and against the Pacific origin of the Caribbean Plate: discussion, finding for an inter-American origin: In: Iturralde-Vinent, M. A. and E. G. Lidiak (Eds.), Caribbean Plate Tectonics, Geologica Acta, v. 4, no. 1-2, p. 279-302.

James, K. H., 2006b, Structural Geology: in: Bundschuh, J. and G. E. Alvarado, (Eds.) Central America: Geology, Resources and Hazards, Ed. Balkema, Chapter 11, p. 277-321.

James, K. H., in prep. In-situ Caribbean-the data, GSL Special Publication.

Keppie, J. D. and D. J. Morán-Zenteno, 2005, Tectonic Implications of Alternative Cenozoic Reconstructions for Southern Mexico and the Chortis Block: International Geology Review, v. 47, p. 473-491.

Korenaga, J., 2005, Why did not the Ontong Java plateau form subaerially? Earth and Planetary Science Letters, v. 234, p. 385-399.

Mammerickx, J., Herron, E., and Dorman, L., 1980, Evidence for two fossil spreading ridges in the southeast Pacific: Geological Society of America Bulletin, v. 91, p. 263-271.

Meibom, A. and Anderson, D.L., 2003, The statistical upper mantle assemblage: Earth and Planetary Science Letters, v. 217, p. 123-139.

Natland, J.H., and Winterer, E.L., 2005, Fissure control on volcanic action in the Pacific, in Foulger, G., et al., eds., Plates, Plumes, and Paradigms, Geological Society of America Special Paper 388, p. 687-710, doi: 10.1130/2005.2388(39).

Okal, E.A. and Batiza, R., 1987, Hotspots: The first 25 years, in Keating, B.H et al., eds., Seamounts, Islands, and Atolls, American Geophysical Union, Washington D.C., Geophysical Monograph 43, p. 1-11.

Okal, E.A. and Cazenave, A., 1985, A model for the plate tectonic evolution of the east-central Pacific based on Seasat investigations: Earth and Planetary Science Letters, v. 72, p. 99-116.

Pilger, R. H., and Handschumacher, D.W., 1981, The fixed hotspot hypothesis and origin of the Easter–Sala y Gomez trace: Geological Society of America Bulletin, v. 92, p. 437–446.

Pilger, R. H., 1984, Cenozoic plate kinematics, subduction and magmatism: South American Andes: Geological Society of London Journal, v. 141, p. 794–802.

Pilger, R.H., 2003, Geokinematics: Prelude to Geodynamics: Berlin, Springer-Verlag, 338 p.

Pilger, R. H., 2007 (in press), The Bend: Origin and significance, Bulletin of the Geological Society of America, doi: 10.1130/B25713.1, http://www.gsajournals.org/perlserv/?request=get-toc-aop&issn=0016-7606

Raddick, M. J., Parmentier, E. M., and Scheirer, D. S., 2002, Buoyant decompression melting: A possible mechanism for intraplate volcanism: Journal of Geophysical Research, v. 107, no. B10, 2228, doi: 10.1029/2001JB000617.

Smith, A.D., 2005, The streaky-mantle alternative to mantle plumes and its bearing on bulk-Earth geochemical evolution, in Foulger, G. et al., eds., Plates, Plumes, and Paradigms, Geological Society of America Special Paper 388, p.303-325, doi:10.1130/2005.2388(19).

Smith, A.D. and Lewis, C., 1999, The planet beyond the plume hypothesis: Earth Science Reviews, v. 48, p. 135-182.

Tardy, M., and twelve others, 1994, The Guerrero suspect terrane (western Mexico) and coeval arc terranes (the Greater Antilles and the Western Cordillera of Colombia): a late Mesozoic intra-oceanic arc accreted to cratonal America during the Cretaceous: Tectonophysics, v. 230, p. 49-73.

Vogel, T. A., L. C. Patino, G. E. Alvarado and P. B. Gans, 2004, Silicic ignimbrites within the Costa Rican volcanic front: evidence for the formation of continental crust: Earth and Planetary Science Letters, v. xx, p. xxx-xxx, preprint

Wang, S. and Liu, M. 2006. Moving hotspots or reorganized plates? Geology, 34, 465-468.

White, R. V., J. Tarney, A. C. Kerr, A. D. Saunders, P. D. Kempton, M. S. Pringle and G. T. Klaver, 1999, Modification of an oceanic plateau, Aruba, Dutch Caribbean: Implications for the generation of continental crust: Lithos, v. 46, p. 43-68.

Woods, M.T. and Okal, E., 1994, The structure of the Nazca ridge and the Sala y Gomez seamount chain from dispersion of Rayleigh waves: Geophysical Journal International, v. 117, p. 205-222.