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"Wilson Study Cycles - Research Relative to Ocean Geodynamic Cycles"

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"Wilson Cycle Studies"

Five topics dealing with different aspects of the plate tectonic process, and their effects on the long-term development of the continental lithosphere of this planet, were studied during this project.

1. Conversion of Atlantic (rifted) margins to convergent plate boundaries.

An extensive literature search and compilation was done on the geology of 21 originally Atlantic-type margins, whose rifting age ranges from Neogene (30 m. y.) back to about 2000 m. y. in the early Proterozoic, that is to one of the earliest easily recognizable rifted margin sequences preserved in the geological record. Of the 21 examples (Table 1), 19 show definite evidence, in the form of distinctive stratigraphic sequences, and characteristic relative timing of magmatism and structural deformation, of conversion by collision with an island arc and/or microcontinental fragment, not by the direct initiation of subduction beneath a previously passive Atlantic-type continental margin. Only two examples show evidence, derived from the same kind of data as the others, for direct initiation of subduction at a previously passive margin. Both of those are cases where a narrow, laterally extensive microcontinental fragment with passive margins on both sides collided with a subducting margin. Convergence was transferred from the earlier subduction zone, across the microcontinental object, to the passive margin on the other side. Passive margins developed on large continents were in no case found to change directly into Andean convergent margins. Even in the two cases of microcontinents where direct conversion did happen, the age of rifting of their margins was not a large amount older than the age of collision of the microcontinent across the first subduction zone. Thus, the oceanic lithosphere adjacent to the passive margin of the microcontinent that was converted to a subducting margin was young, warm, and as a result, thin and relatively weak. Margins of similar type (with a narrow microcontinent involved) with a significantly greater span between rifting and convergence were not found and are thus not among the 21 cases studied. It would be of considerable interest to try to find such examples to test whether the direct conversion to Andean margin is more a function of age of oceanic lithosphere adjacent to the margin or to the specific geometric constraints of such microcontinental collisions.

Future work is probably needed to test the hypothesis that we put forward from this study that Atlantic-type margins do not generally convert directly to Andean margins (Burke, Kidd and Bradley, 1984; m. s. in preparation; Figs. 1-5 and Table 1 from part of this m. s.). Many of the examples we use have a limited Andean history subsequent to conversion and before a major continental collision event closed the particular oceanic tracts involved. The passive margin sequences and their fate are, as a result, relatively easy to recognize. Where extensive Andean magmatism (and deformation) has occurred, the earlier passive margin geology can become much harder to decipher. These kind of margins with an extensive Andean history are, however, the kind of which additional examples are most needed and study of which will form the best test of the hypothesis derived from this work.

2. Oceanic plateaus and their fate at subduction zones

There are oceanic plateaux of several distinct types, all, however, being distinguished by above average elevation relative to the ocean floor age where they are located and, in well-documented examples, possessing significantly thicker crust than normal ocean. They include microcontinents (e. g. Rockall, Seychelles) variably thinned from normal continental thickness, and (less abundant) extinct arcs (e. g. Shirshov Ridge). However, the most abundant type of oceanic plateau, especially in the western Pacific, are the varieties that have been constructed by hot-spot-type magmatism, producing objects ranging in large-scale form from the Hawaiian-Emperor Ridge to the Ontong-Java plateau. In some circumstances these plateaux sustain a substantial carbonate bank accumulation (e. g. Bahamas). There appears to be a direct relation, shown best by Iceland, between large hot-spots, the generation of hot-spot-type oceanic plateaux, and flood basalts and continental dike swarms. Both from this connection and the observation that many of these plateau were formed, like Iceland now, on spreading center axes, it can be concluded with confidence that the bulk composition of these plateaux is basaltic. Geophysical measurements are wholly consistent with this general notion. Small samples preserved in subduction accretion prisms (e. g. Malaita) confirm that basalt sills are a major component of the upper part of some, and limited direct sampling by DSDP drilling is also consistent with this.

Livaccari et.al (1981) suggested that subduction of an oceanic plateau, a pair to the present Hess Rise (Fig. 6) occurred under western North America 65-40 m. y. ago contributing to the Laramide orogeny through the abnormal buoyancy it created in the subducting plate. Burke et al (1978) identified most of the Caribbean as floored by a presently hard-to-subduct oceanic plateau, but this example leaves open the question whether the plateau will be subducted in the future. Two questions related to oceanic plateaux were addressed in this study, derived from the suggestions summarized above. One concerns the inference that the general and usual fate of an oceanic plateau is to be subducted; the other is whether, if remnants of plateaux can be found in older orogenic belts, the timing of their arrival can be correlated, like in western North America, with Laramide-like orogenic effects.

There seems little doubt from the rarity in orogenic belts of lithologic sequences appropriate for derivation from oceanic plateaux that almost all of them have been subducted, at least below the level generally exposed in the crust. Only two possible examples have been clearly identified besides those in the Caribbean and the fragment of the Ontong Java plateau in the Solomon Islands. These two examples are in Alaska, previously described as ophiolite, and forming a large proportion of the terrane called Wrangellia in British Columbia and southern Alaska. The latter example is somewhat dubious in that the field relations currently described have the potential plateau rocks in stratigraphic contact above a Paleozoic island arc assemblage. If the contact is a regional overthrust, which seems possible, it is a good candidate for a remnant of an ocean plateau, but field work would be needed to establish this. Otherwise it would be a rift-event flood basalt assemblage sited within an older convergent arc. Since so few examples have been identified, and the geological relations of these two with their surroundings are not well established, no valid inferences can be made about possible effects of changes in orogenic activity correlated with their arrival at a convergent margin. At least some of the difficulty we encountered in finding possible remnants of oceanic plateaux is perhaps due to mistaken field relations reported in available literature, lack of detailed investigations in others, and inappropriate grouping of plateau-derived magmatic and sedimentary sequences with other unrelated ones. However, at least part must be a real absence reflecting efficient eventual subduction of the plateaux, despite the Caribbean's present pause before descent.

A short publication discussing these findings is planned, but is not yet in an advanced stage of preparation, being given lower priority in the light of the somewhat negative findings.

3. Continental Collision and Tectonic Escape

Collisional studies have proved one of the most productive parts of these Wilson Cycle studies. Reviews have been made of the Cenozoic geology of the Caribbean area, the Aegean and Turkey, the Carpathian-Pannonian area and Mongolic-China, together with late Mesozoic eastern Asia-SE Asia, and a similar area for the late Tressic, and Pan-African events for most of Africa and Arabia.

All of these collisional events show the importance of tectonic escape and the development of very large strike-slip fault systems during this process. Because of the complexity of the geology in most of these areas, the importance of the tectonic escape process during collisions had not been fully realized until this comparative study. Publications deriving in whole or in part from this portion of the project are Burke (1983), and Sengor and Burke (1986).

4. Rift Studies

Studies of southern Africa rifts, done partly under the support of this grant, were most productive and enlightening on the nature of tectonic activity in the later Archean and the condition of the continental lithosphere at that time. The Pongola structure appears to be the earliest ($\sim$3.0 Ga) rift, with properties like those of younger ones, preserved on this planet (Burke et al 1985a - see attachment). Similarly, the Ventersdorp rift system, of latest Archean age, also has properties like those of modern rifts, and can plausibly be linked to the effects of collisional tectonics in the Limpopo orogenic belt. (Burke et al. 1985b - see attachment). The third supposed rift investigated in southern Africa, the Witwatersrand structure, turned out from our assessment not to be a rift at all (Burke et al. in press, Tectonics - see attachment). However, its' identification as a foreland basin (of an age older than 2.6 Ga) is of considerable significance in the understanding of the nature of continental lithosphere in the later Archean and the tectonic regime operating at that time. As its properties are much like well-studied young foreland basins, the implications of the operation at that time of plate-tectonic processes, and the existence of continental lithosphere of thickness not substantially different from now, are important conclusions.

Studies of along-strike variations in modern rifts were not so fruitful. Unless additional new data is obtained, unambiguous conclusions will be difficult to reach on the causes of the observed variations.

5. Hot-spot studies

A previous compilation of the global hot-spot distribution by us did not include any that might occur within convergent plate boundary zones since alkalic vulcanism within those zones could not unambiguously be attributed to other than shallow mantle or crustal processes. A study of some of the occurrences within convergent zones to see if such an attribution could be made was one of the purposes of these Wilson cycle studies, together with a review and revision of the overall hot-spot list. No unambiguous criteria were found that would enable discrimination on a routine basis of hot-spot-like alkalic volcanism from that unrelated to hot-spots. Major element geochemical and petrographic data readily available for most or all occurrences shows no single one or combination of factors that might be used. While it is possible that isotopic or rare earth data could be helpful, this is not available for enough examples to make a meaningful judgment. The only criterion that showed a possibility for application is the identification of a "hot-spot track", or systematic progression of vulcanism crosscutting the convergent zone on some consistent trend, the same feature that enables identification of many hot-spot tracks outside such zones. However, it is difficult to pick out the compositionally distinctive volcanics of the hot-spot from the background convergent plate boundary vulcanism except when the volcanics are young and fresh. There are two reasons why this is so: first, because erosion or burial in these tectonically active zones readily obscures the older record of the track, and second because alteration of volcanics, ubiquitous in arc terrains, makes it much more difficult to recognize the different hot-spot lavas in the first instance. Thus, they may be present, but unreported, in many places. There is also the problem that no preexisting identifiable base level usually exists in the tectonically active regions of convergent plate boundaries to allow detection of the characteristic domal uplift that is seen to accompany hot-spots in intra-plate regions and along divergent plate boundary systems. Thus, even the detection of active hot-spot centers within convergent boundaries is problematical, and is likely to remain so until much more systematic field-based investigations are made. It is apparent that with detailed knowledge, hot-spot tracks can probably be identified in these zones; one example that may be connected with passage of the Yellowstone hot-spot across the California-Oregon border region is the existence there of kimberlite and related features (C. Blake, pers. comm.). These, however, are at present too poorly dated to be tied with confidence to the hot-spot track.

The two examples proposed for investigation in the original proposal, the Rhine Graben spot, and the French Massif Central, yielded less than expected. No identifiable trace of the Rhine Graben vulcanism is known south of the Alpine foreland basin; the conclusion of Sengor et al. (1976) that the Graben was generated by the Alpine collision is most consistent with this observation. In the case of the Massif Central, Miocene rifting and dispersal of the crustal pieces that used to lie in the general direction of the projected hot-spot track make any identification of it troublesome. While it is entirely possible that the rifting could be connected with hot-spot passage, it is hard to establish this with confidence, and the former possible position of the hot-spot is very poorly constrained. The problem of young isotopic ages within the old part of the Massif Central track, and rather old ages as well as recent ones at the young end of the Rhine Graben track, remains a problem. Since all the ages are determined by the K-Ar technique, some a long time ago, the possibility of excess Argon, loss of argon by subsequent thermal events, and analytical inadequacies all exist, but cannot be identified from the original data. New precise ages are clearly needed to resolve this problem and this fell outside the scope of this research.

A revised global hot-spot list was generated through selective literature search (Table 2). Even though areas of convergent tectonism could not be included, the list is significantly improved over the previous list, because of better understanding of the variability in size of different hot-spots. The previous list had been constructed with criteria that minimized the variation. Similarly, better understanding now exists of the tectonics of secondary extension structures associated with large strike-slip fault systems, allowing a number of items to be placed in the category where magmatism appears to be a secondary effect, or <u>passive</u> response to lithospheric extension. Consequently, the list of presumed <u>active</u> mantle hot-spots is better established. Preparation of a manuscript documenting the list is in its early stages.

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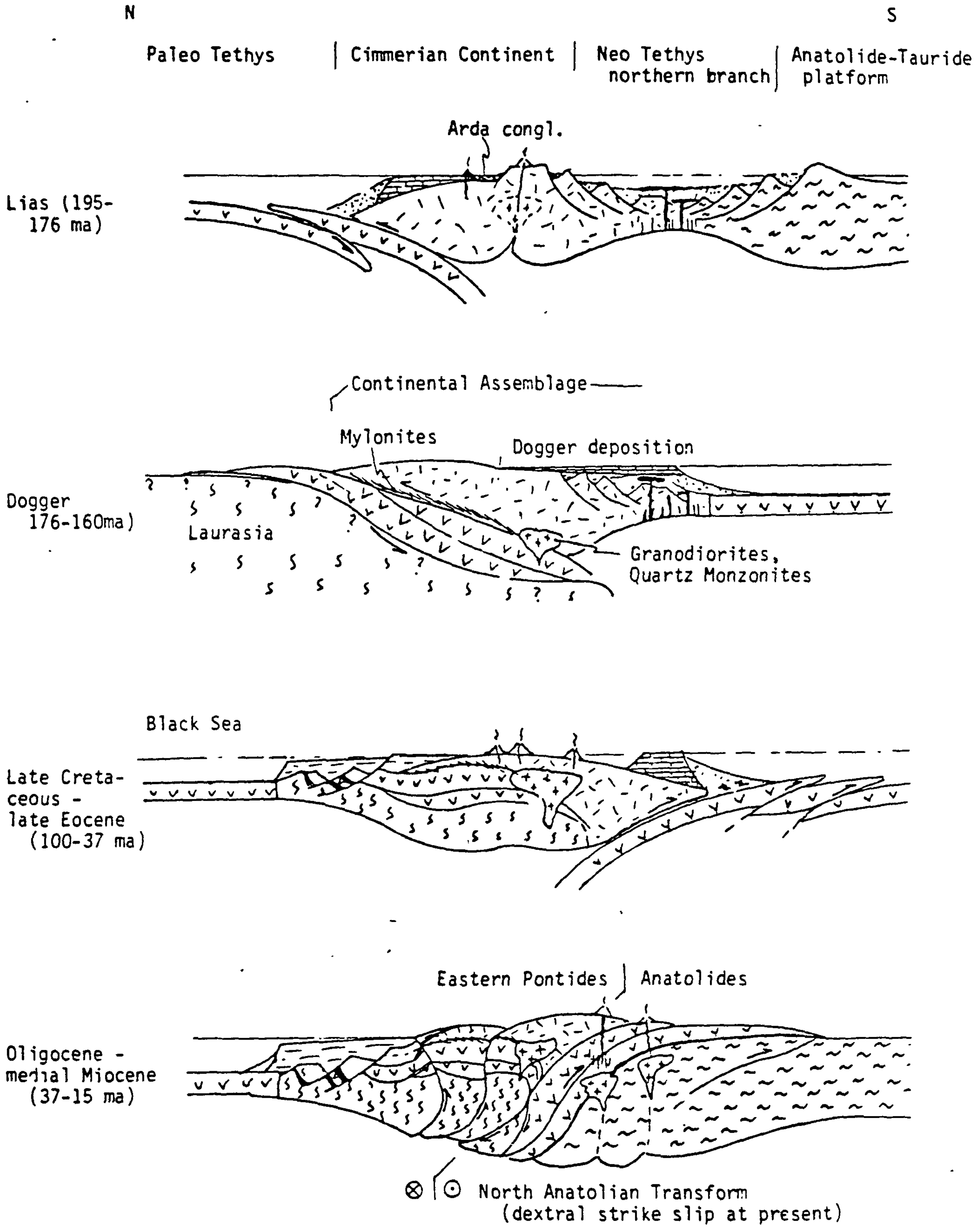
Burke, K.C., Kidd, W.S.F., and Kusky, T.M., in press. Archean foreland basin tectonics in the Witwatersrand, South Africa. Tectonics.

In Preparation

Burke, K. Bradley, L. and Kidd, W.S.F., Do Altantic-type margins convert directly to Andean margins?

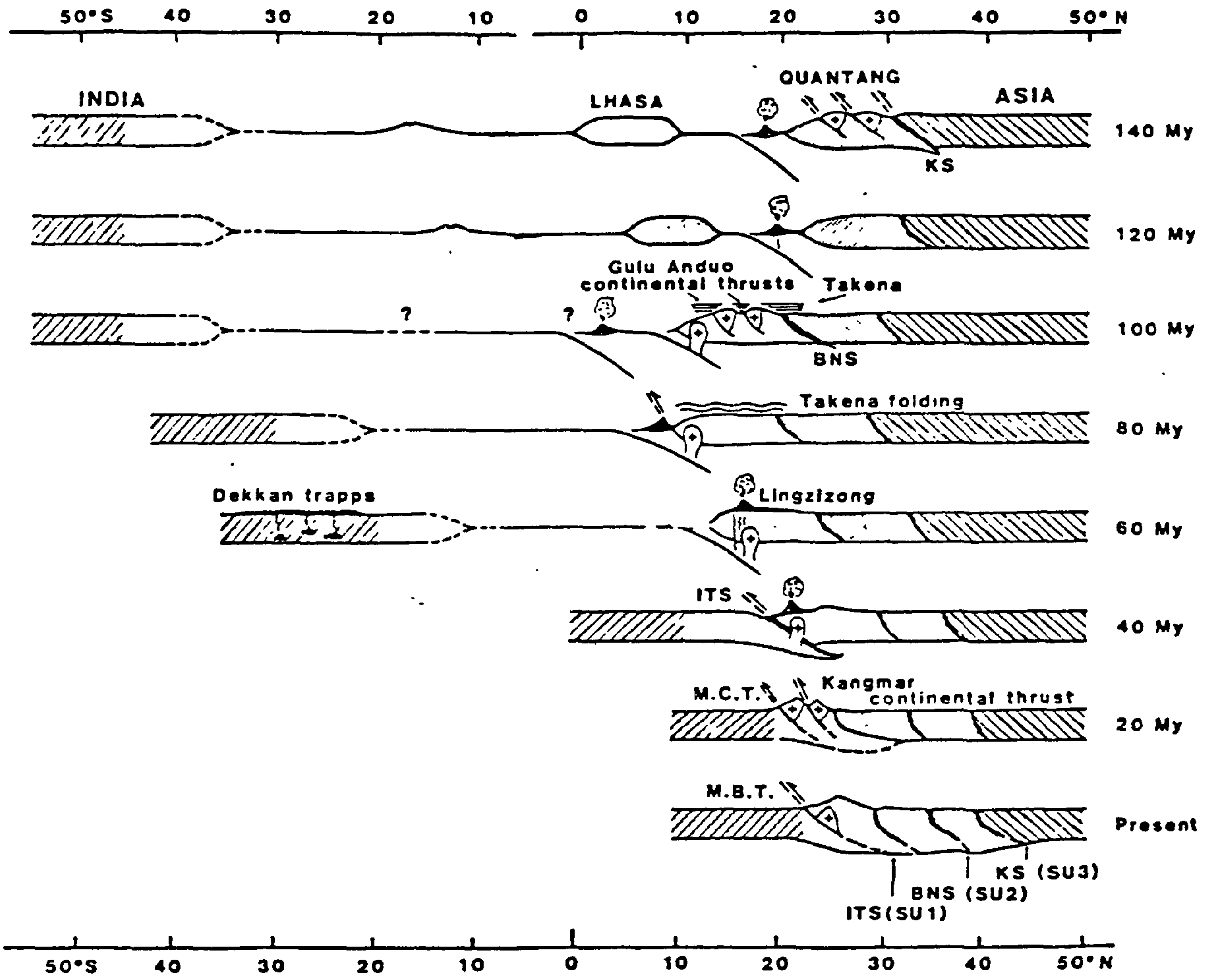
Collision Zone	Atlantic-Type Side	Approximate Age of Rifting	Convergent Side	Age of Collision in Ma	Duration of Rifted Margin
Timor	Australia	150	Banda Arc	Now	160
Taiwan	China	30	Phillipines	Now	30
Zagros	Saudi Arabia	290	Iran	Now	210
Bitlis	Arabia	450	Taurides	10	590
Carpathian	Poland, Ukraine	180	Hungary	10	170
Himalayan	*Southern Tibet*	600	*Southern Tibet*	40	560
Pontide	*S. Cimmeria*	180	*S. Cimmeria*	40	140
Cuba	Florida	160	Cuba	50	80
Oman	Arabia	600	Buried Arc	80	520
Brooks Range	North Slope Alaska	350	Yukon-Koyukuk Terrane	120	250
Chirsky	Siberia	370	Omolon	170	230
Venezuelan coast	S. America	150	Off Shore Islands	80	70
Ouachita	N. America	600	Yucatan (?)	300	300
Antler (Nevada, Utah)	N. America	800	Buried Arc	350	450
Taconic	N. America	600	Bronson Hill, Miramichi	450	150
Franklinian	N. America	600	N. Ellesmere Island	370	230
Dahomeyan	West African Craton	1100	Dahomides	600	500
Coronation	Slave Province	2100	Bear Province	1700	400
Cape Smith/Lab Trough	Superior Province	2000	Churchill Province	1875	125
Caledonides (Scand.)	Baltic Shield	650	East Greenland	425	225
Urals	Russian Platform	650	Siberia	290	360

NAG-5333 Final Rept. Table 1.



ATLANTIC MARGIN IN PONTIDES CONVERTS TO ANDEAN IN LATE CRETACEOUS (BASED ON SENGOR)

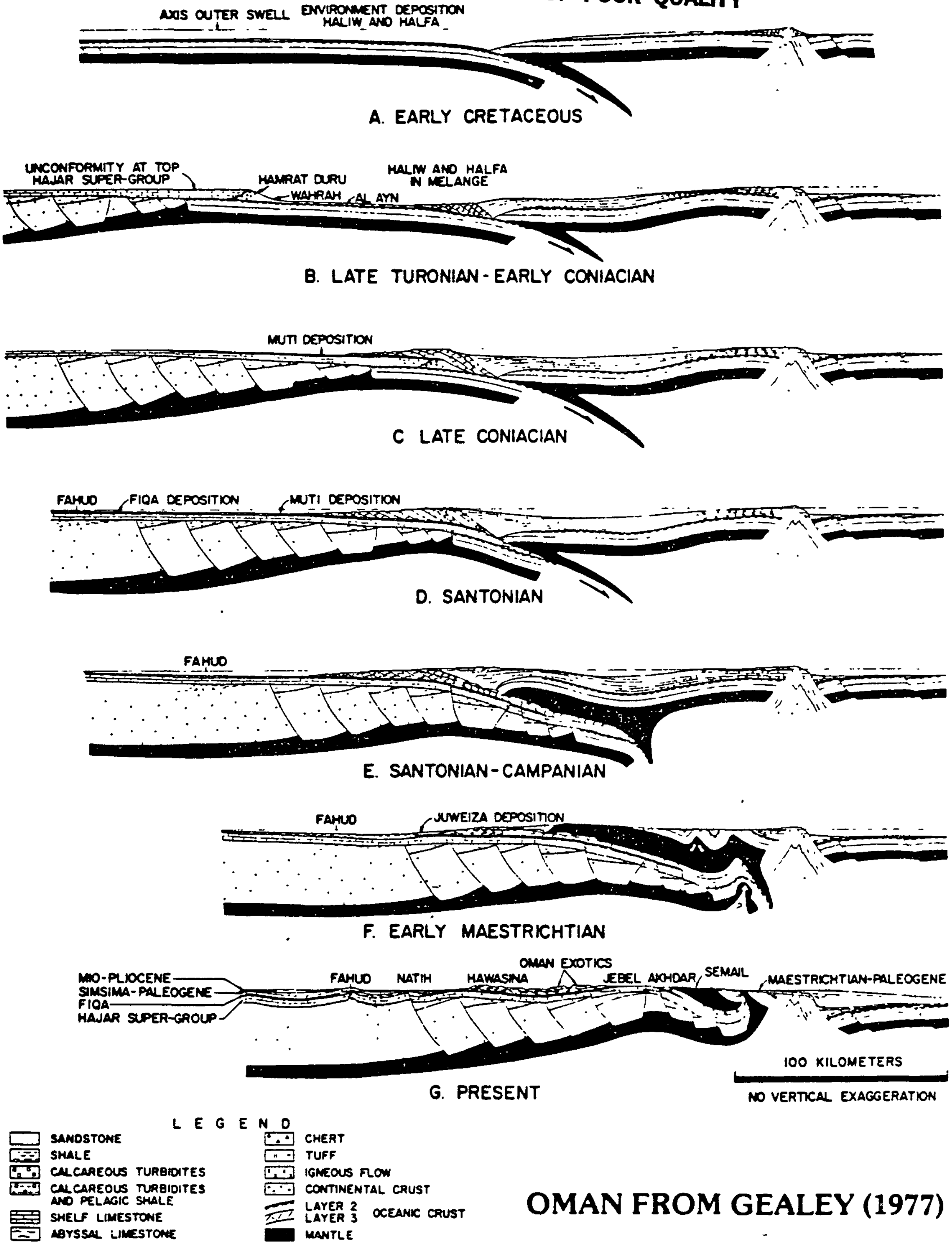
NAG-5333 Final Rept. Fig. 1



AN INTERPRETATION OF THE EVOLUTION OF SOUTHERN TIBET BY ALLEGRE AND MANY OTHERS

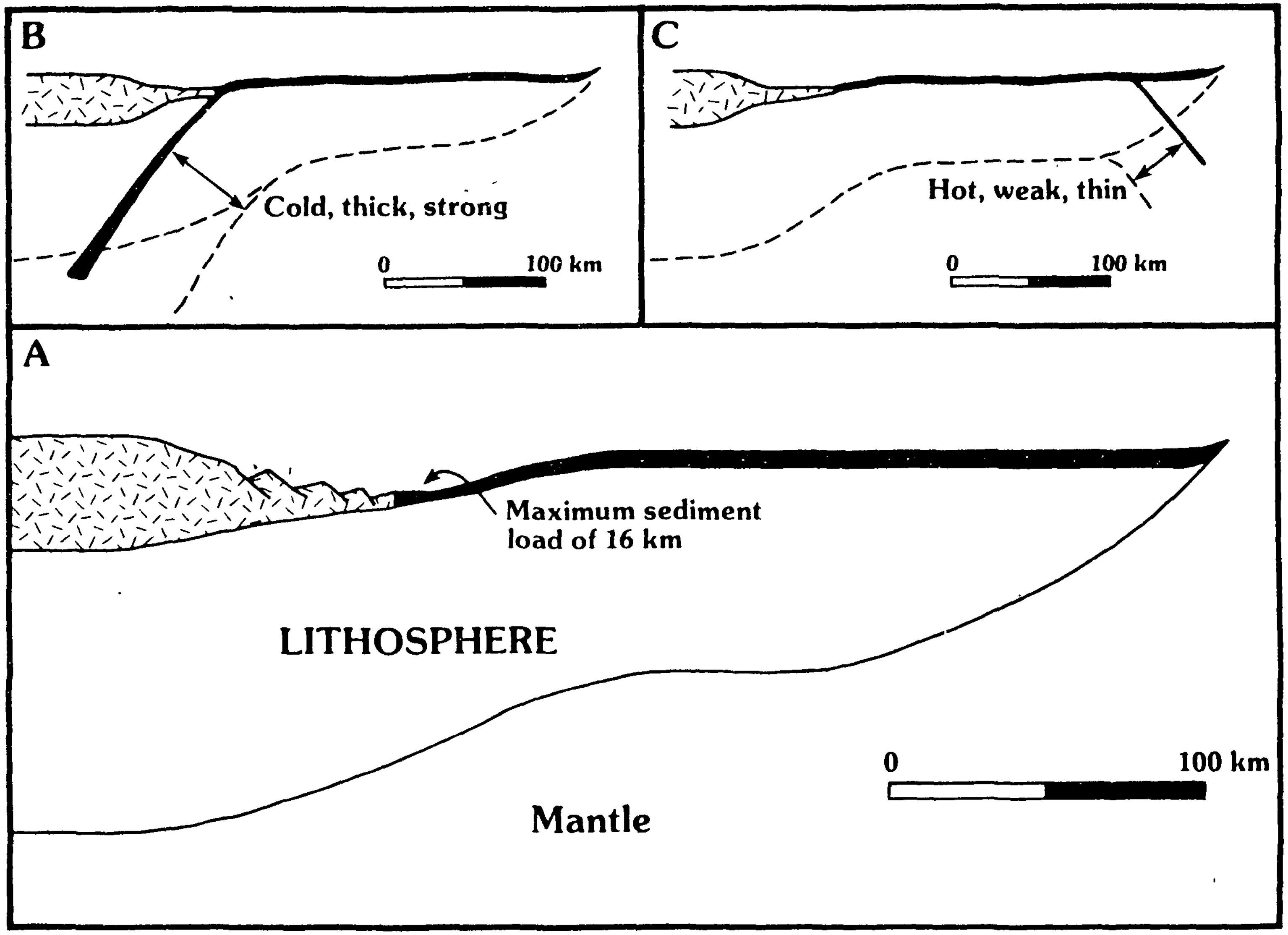
NATURE JANURY 1984

NAG-5333 Final Rept. Fig. 2



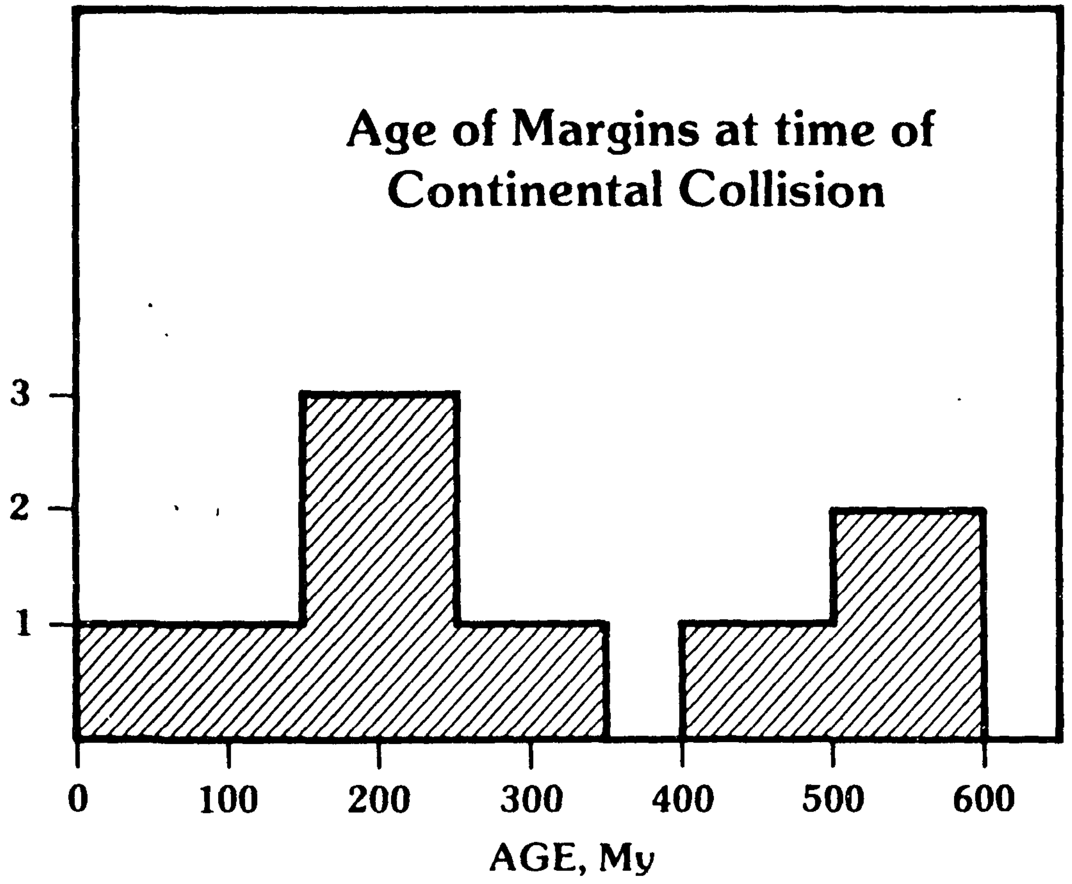
OMAN FROM GEALEY (1977)

NAG-5333 Final Rept. Fig. 3



CROSS SECTION THROUGH ATLANTIC TYPE MARGIN A) UNDEFORMED B) FAILING AT MARGIN IN COLD, STRONG LITHOSPHERE C) FAILING OF OCEANIC LITHOSPHERE AWAY

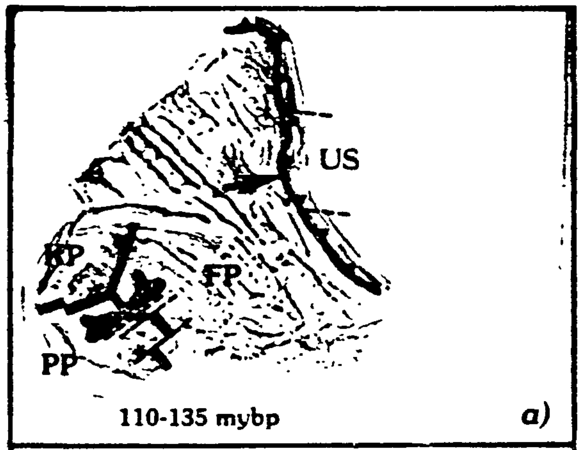
NAG-5333 Final Rept. Fig. 4



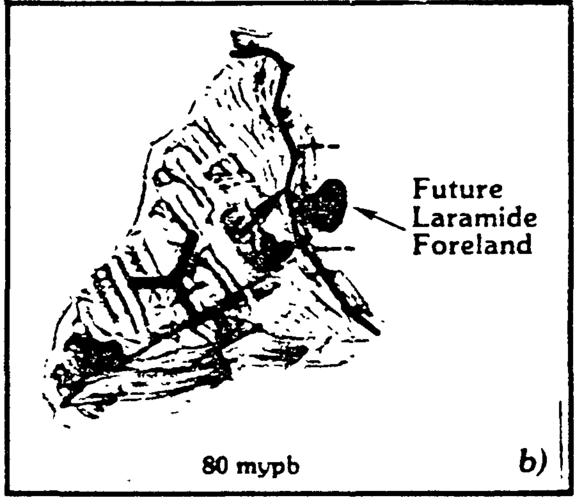
HISTOGRAM OF AGE OF MARGINS AT TIME OF CONTINENTAL COLLISION SUGGESTING NO CORRELATION BETWEEN AGE OF MARGIN AND STABILITY OF MARGIN

NAG-5333 Final Rept. Fig. 5

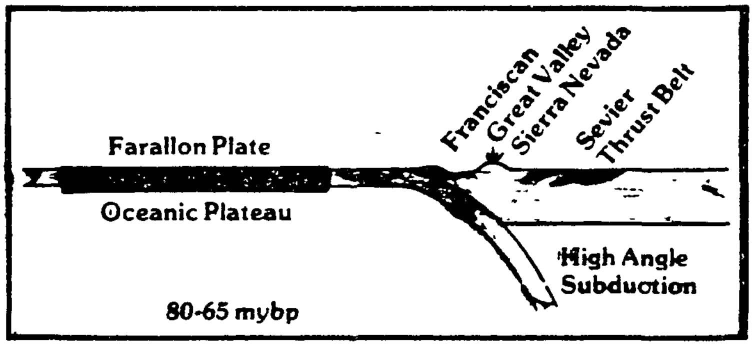
NAG-5333 Final Rept. Fig. 6



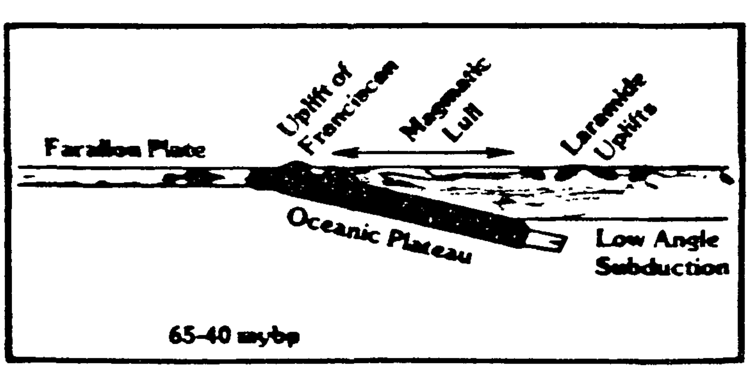
a) HESS RISE AND ITS TWIN FORMED AT KULA-PACIFIC SPREADING CENTER DURING THE EARLY CRETACEOUS.



b) HESS RISE TWIN APPROACHING NORTH AMERICA DURING THE LATE CRETACEOUS.



PRE-LARAMIDE CONVERGENCE STYLE



SUBDUCTION OF THE HESS RISE TWIN AS A POSSIBLE INFLUENCE ON LARAMIDE OROGENY.

HOT SPOTS -- WORLD LIST
NAG-5333 Final Report -- Table 2

Hot spots defined on the basis of both a structural or topographic uplift (anomaly) and associated vulcanism of alkaline type (distinct from normal spreading ridge vulcanism and from tholeiitic flood basalt). On spreading ridges, excess vulcanism occurs compared with normal segments (e.g. Iceland). Size of hot spot, defined by diameter of uplift or of anomalous vulcanism, is typically about 200 km, but ranges from about 100 km to about 500 km. This finite width requires hot spot tracks to be defined by swaths of the width of the hot spot; a narrow line is not justified by the data and conceals the possible errors in determination of the position. Groups of a few hot spots may be defined by topographic swells in places (e.g. East African Swell), but only a minority can be joined in this way.

Notations

*	Oceanic lithosphere (for within plate hot spot only)
C	Continental lithosphere (for ridge axis hot spots only)
Q	No volcanic evidence - proposed only from ridge axis topography
r	Associated with a live rift
Y	In vicinity of RRR, RRT or RRr triple junction
I	Impactogenal origin proposed (usually with r)
T	In zone of secondary tectonics associated with primary transform plate boundary
1,2 etc	Number of swell hot spot belongs within (1-East African, 2-Ethiopian, 3-Red Sea, 4-Colorado Plateau, 5-Azores)

Plate abbreviations:

AFR = Africa
ANT = Antarctica
ARA = Arabia
COC = Cocos
EUR = Eurasia
GOR = Gorda
IND = Indo-Australian
NAM = North America
NAZ = Nazca
PAC = Pacific
SAM = South America

In divergent boundary hot spot list, if hot spot appears off-axis, plate(s) on which hot spot lies underlined.

A. Hot spots on or near divergent or ridge-transform-ridge plate boundary segments

No.	Notations	Name	Coordinates	Plates
0		Yermak	84N, 0	EUR/NAM
1		Jan Mayen	71N, 09W	EUR/NAM
2		Iceland	65N, 16W	EUR/NAM
3	5	45°N Atlantic	44N, 28W	EUR/NAM
4	Y5	Azores	38N, 27W	EUR/AFR/NAM
5	5	Colorado Smt.	34N, 38W	AFR/NAM
6		Ascension	08S, 14W	SAM/AFR
7		St. Helena	16S, 06W	AFR/SAM
8		Tristan/Gough	38S, 11W	AFR/SAM
9		Discovery Smts.	46S, 08W	AFR/SAM
10	Y	Bouvet	54S, 03E	ANT/AFR/SAM
11		Prince Edward/Marion	47S, 38E	ANT/AFR
12		Rodriguez	20S, 62E	AFR/IND
13		St. Paul/New Amsterdam	39S, 78E	ANT/IND
14	Q	Naturaliste	48S,105E	ANT/IND
15	Q	Kangaroo	49S,135E	ANT/IND
16	(Y)	Balleny	67S,163E	ANT/PAC/IND
17		Easter	27S,109W	NAZ/PAC
18		Galapagos	0, 91W	NAZ/COC
19		Revillagigedo	19N,111W	PAC/NAM/COC
20		Explorer Smt.	49N,132W	PAC/GOR
21		Bowie Smt.	53N,136W	PAC/NAM/GOR
22	(c)3	Harrat Er-Raha	27N, 36E	ARA/AFR
23	YC2	Aden	14N, 46E	ARA/AFR
24	YC2	Danakil	15N, 41E	AFR/ARA
25	YC2	Awash	10N, 41E	AFR/ARA

B. Hot spots within plates

1. Africa

26	r2	S. Wonji	07N, 38E	AFR
27	r1	Nakuru	0, 36E	AFR
28	r1	Kilimanjaro	03S, 36E	AFR
29	r1	Nyiragongo	01S, 29E	AFR
30	r1	Rungwe	09S, 34E	AFR
31	*	Vema Smt.	33S, 08E	AFR
32	*	Madeira	33N, 17W	AFR
33	*	Canary	28N, 15W	AFR
34		Anti-Atlas	31N, 07W	AFR
35	*	Cape Verde	16N, 24W	AFR
36		Dakar	15N, 18W	AFR
37		Air	18N, 09E	AFR
38		Ahaggar	24N, 06E	AFR
39		Tripoli	32N, 13E	AFR
40		Jebel Sawda	29N, 15E	AFR
41		Haroudj	28N, 17E	AFR
42		Ih Ezzane	23N, 11E	AFR
43		Tibesti	23N, 18E	AFR
44		Jebel Uweinat	23N, 25E	AFR
45		Bayuda	18N, 33E	AFR
46		Jebel Marra	14N, 25E	AFR
47		Biu	11N, 12E	AFR
48		Jos Plateau	10N, 09E	AFR
49		Adamawa	06N, 10E	AFR
50		Ngaoundere	06N, 13E	AFR
51		Cameroon	04N, 09E	AFR
52	*	Sao Tome/Annobon	0, 06E	AFR
53	*	Comores	12S, 44E	AFR
54		Cap d'Ambre	14S, 49E	AFR
55		Central Madagascar	20S, 47E	AFR
56	*	Reunion/Mauritius	21S, 56E	AFR
57	*5	Great Meteor Smt.	31N, 29W	AFR
58		Lesotho	29S, 29E	AFR

2. Antarctica -- (most continental hotspots in Antarctica defined only by volcanic occurrences -- uplift information lacking -- identification tentative. Several may be associated with ice-buried rifts.

59	*	Peter 1st Id.	69S, 91W	ANT
60		Merrick Mtns	75S, 72W	ANT
61		Alexander	72S, 70W	ANT
62		Hudson/Jones Mtns.	74S, 97W	ANT
63		Murphy/Crary Mtns.	77S,115W	ANT
64		Mt. Siple	73S,126W	ANT
65		Ames/Flood Ranges	76S,135W	ANT
66		Executive Committee Range	78S,126W	ANT
67		Fosdick Mtns.	77S,144W	ANT
68		Mt. Early	87S,153W	ANT
69		Mt. Erebus	78S,167E	ANT
70		Mt. Melbourne/Adare Pen.	73S,170E	ANT
71		Gaussberg	67S, 89E	ANT
72	*	Heard	53S, 74E	ANT
73	*	Kerguelen	49S, 70E	ANT
74	*	Crozet	47S, 52E	ANT

3. Arabia

75	3	Mecca	22N, 42E	ARA
76	3	Medina	26N, 41E	ARA
77		Damascus	33N, 37E	ARA
78	I	Diyarbakir	37N, 39E	ARA

4. Cocos

79	*	Cocos	05N, 87W	COC

5. Eurasia - a) West of zone affected by India-Asia collision tectonics

80		Massif Central	46N, 03E	EUR
81	Ir	N. Rhine Graben	51N, 08E	EUR

5. Eurasia - b) In zone affected by India-Asia collision tectonics

82	Ir	Baikal/Irkutsk	52N,104E	EUR
83	Ir	NE Ordos Plateau	40N,114E	EUR
84	I(r)	Ara Hangay	48N,100E	EUR
85	I	Vitim Plateau	54N,113E	EUR
86		Nen-Chiang	49N,125E	EUR
87	I	SW Hsing-An	45N,115E	EUR
88	Ir	Soeul/Wonsan	39N,127E	EUR
89		Cheju	33N,126E	EUR

- c) SE China-Indochina block

90		Hainan	21N,110E	EUR
91		SE Laos-Vietnam	14N,108E	EUR
92		Borneo	01N,113E	EUR

6. Gorda - none except on spreading ridge boundary with PAC (see above)

7. Indo-Australia

93		N. Queensland	20S,145E	IND
94		W. Victoria	38S,143E	IND
95	*	Tasmantid Seamounts	39S,155E	IND
96		Lord Howe Rise	36S,160E	IND
97		Norfolk	29S,168E	IND

8. North America

98		Balagan Tas/Indigirsky	67N,144E	NAM-or (NAM/EUR)
99		Anjuisky	67N,165E	NAM
100		St. Lawrence	64N,170W	NAM
101		Nunivak	61N,165W	NAM
102		Seward Peninsula	66N,160W	NAM
103	T	Mt. Edziza	58N,131W	NAM
104	r	Yellowstone/Snake River	44N,112W	NAM
105	4	Flagstaff	35N,112W	NAM
106	r4	Santa Fe	36N,106W	NAM
107	r4	Rio Grande/Big Bend	30N,105W	NAM

9. Nazca

108	*	Isla San Felix	26S, 80W	NAZ
109	*	Isla Jan Fernandez	34S, 81W	NAZ

10. Pacific

110	T	E. Otago	46S,173E	PAC
111	T	Banks Peninsula	44S,174E	PAC
112	T?	Chatham Id.	44S,176W	PAC
113	T?	Campbell Id.	52S,169E	PAC
114	T?	Antipodes Id.	50S,179E	PAC
115	*r?	Samoa	14S,172W	PAC
116	*	Caroline	05N,164E	PAC
117	*	Hawaii	20N,155W	PAC
118	*	Guadalupe	29N,118W	PAC
119	*	Rarotonga	22S,158W	PAC
120	*	Tahiti	18S,148W	PAC
121	*	Marquesas	11S,138W	PAC
122	*	Macdonald Seamount	29S,140W	PAC
123	*	Pitcairn/Gambier	27S,120W	PAC

11. South America

No.	Notations	Name	Coordinates	Plates
124	*	Fernando de Noronha	04S, 32W	SAM
125	*	Trinidade/Martin Vaz	21S, 28W	SAM