Goddard Grant

IN-46

63923-CR

P-7

WILSON CYCLE STUDIES

NASA GRANT NAG5-585

Semi-Annual Report

July 15, 1986 - January 15, 1987

Activity concentrated on the study of regional lineaments in continental evolution and an extended abstract (Appendix 1 attached) was prepared that will be presented at a forthcoming US-India workshop on continental lineaments to be held in Bangalore in April 1987 (attendance is at no cost to the project).

(NASA-CR-180353) WILSON CYCLE STUDIES Semiannual Report, 15 Jul. 1986 - 15 Jan. 1987 (Houston Univ.) 7 p CSCL 08G

N87-19824

Unclas

G3/46 43655

REGIONAL LINEAMENTS AND CONTINENTAL EVOLUTION

Kevin Burke, Lunar and Planetary Institute, 3303 Nasa Road 1, Houston, TX 77058 and Department of Geosciences, University of Houston, Houston, TX 77001 and Celâl Sengör, Lunar Planetary Institute and Istanbul Technical University.

1. SUMMARY

Lineaments within continents are attributable to a small number of processes of continent formation and modification, but interactions among these processes may produce complex patterns.

2. FORMATION AND MODIFICATION OF THE CONTINENTAL CRUST

Continents originate by the sweeping together of island arcs (Burke and Sengör, 1986). Continental and island arc crusts are dominated by rocks of comparable compositional and density ranges (SiO_2 50-70%; 2.6-2.9 gm/cc), evidence of the operation of this process is abundant in the geological record, and can be seen in action today in Indonesia. Misgivings have been voiced about the simple idea of assembling continents by colliding arcs, because some arcs do not closely resemble average continental material and because much continental material is very old (> 2.5 Ga) and the world is likely to have operated in a different way in the remote past.

The world must have operated in a different way in the very remote past, but it is increasingly being recognized that the record of the rocks as far back as 3.8 Ga ago, is consistent with the idea "that many processes have apparently not changed at all" (Thompson et al, 1984, p. 404). For this reason, we here employ the hypothesis that as far back as the record goes, continents have been assembled by processes fundamentally comparable to those acting today.

There are within the oceans shallow-water objects distinct from active arcs, extinct arcs and micro-continents which have been suggested capable of contributing to the continental crust. One such population is that formed at intra-oceanic hot-spots, e. g., Hawaii and Iceland, but although small objects representative of oceanic islands have long been reported from mountain belts of all ages, there are no large Iceland or Hawaii like objects with volumes in excess of a thousand cubic kilometers in the mountain belts of the world. We therefore infer that it is the fate of such material to be largely removed from the surface of the earth by either subduction or obduction. The alternative idea, that older oceans did not contain hotspot volcanics seems less likely. A similar argument applies to the oceanic plateaus (e. g., Caribbean, Manihiki, Ontong Java, Shatsky Rise, Hess Rise) which extend over areas of millions of square kilometers. Evidence both from places where slivers have been caught up in accretionary prisms and from their relationship to old spreading centers shows that they do not represent continental fragments (as has been suggested), but are very thick accumulations of basalt interbedded with pelagic sediments. The mountain belts of the world contain slivers of material of this type, but no large volumes, and we therefore conclude that, oceanic plateaus do not contribute significant volumes of material to the continents.

Materials that contribute substantial volumes to the continents are parts of Island arc systems, including sediments of accretionary wedges which in some areas, for example, the Songpan-Ganzi, the Makran and the Barbados wedge may be of enormous volume.

Once a continent is assembled by arc collision, the vicissitudes to which it can be subjected are limited in both number and extent. We distinguish six main processes by which continents are modified and summarize them thus:

(1) **The construction of an Andean arc** at the continental margin involves a variety of phenomena, including: (a) addition of magmatic material from the mantle; (b) partial melting of older continental crust and related vertical fractionation; (c) thickening of crust by up to a factor of 2 (to 70km) and consequent elevation; (d) compressional tectonism (especially on the borders of the arc) with formation of both a forearc and a foreland trough; (e) extensional tectonism (especially at the crest of the arc).

(2) **Continental collision**, as now in Tibet and the Himalayas, produces effects similar to those of Andean collision, but over a much larger area. Indian workers have long described the Himalaya and, thanks to recent pioneering efforts by Chinese geologists and their French and British colleagues, we are beginning to appreciate some of the ways in which continental crust is modified at collision in Tibet.

Tremendous thrusting of the kind first described from the Alps, Scandinavia, the Himalaya and from the North of Scotland about 100 years ago, has accommodated the extensive doubling of continental thickness that characterizes both Andean and collisional mountain belts. Partial melting of the thickened crust at collision produces compositional differentiation with shallow "minimal-melt" granites and deep anhydrous residues. Thickened continents, are unstable being subject to rapid erosion as well as to gravitational collapse, two processes that restore continental thicknesses to normal values (30-40 km) in a few tens of millions of years after the cessation of convergence.

(3) **Flooding of the continents** by the waters of the ocean produces a sediment thickness typically of a few hundred meters and reflects sea level changes dominated by the varying average age of the ocean floor and the volume of ice-caps.

(4) The mature continent records **bombardment from outer space**, but since the beginning

of the rock record (at 3.8 Ga), the flux has been low, and the most complete record is on the oldest continents with Vredefort in South Africa and Sudbury on the Canadian Shield.
(5) Sporadic non-plate margin (or hot-spot) volcanism will modify the continental crust from time to time, but these effects generally produce only local modification.
(6) Rifting (the formation of elongate depressions related to rupture of the lithosphere in extension) is one of the dominant ways in which continents are modified. Rifts form in diverse tectonic environments: Andean arcs may split along their crestal volcanoes to form marginal basins; continents like Africa now and about 200 Ma ago may come to rest over the convective circulation of the mantle and rupture. Rifts also form in association with continental collision (as in the Rhine and Baikal).

Continental assembly from island arcs, Andean arc formation, continental collision and rifting are the dominant processes of continental evolution which leave their mark in the deep structure of the continents. Continental regional geophysical lineaments can be related to one or other of all of these processes.

3. REGIONAL LINEAMENTS WITHIN THE CONTINENTS

Lineaments related to the various processes that generate and modify continental crust are widespread, and I here describe a few examples:
(1) The almost North-South trend of the greenstone belts of Southern India (Fig. 1) is now widely attributed to Archean suturing of arc systems.

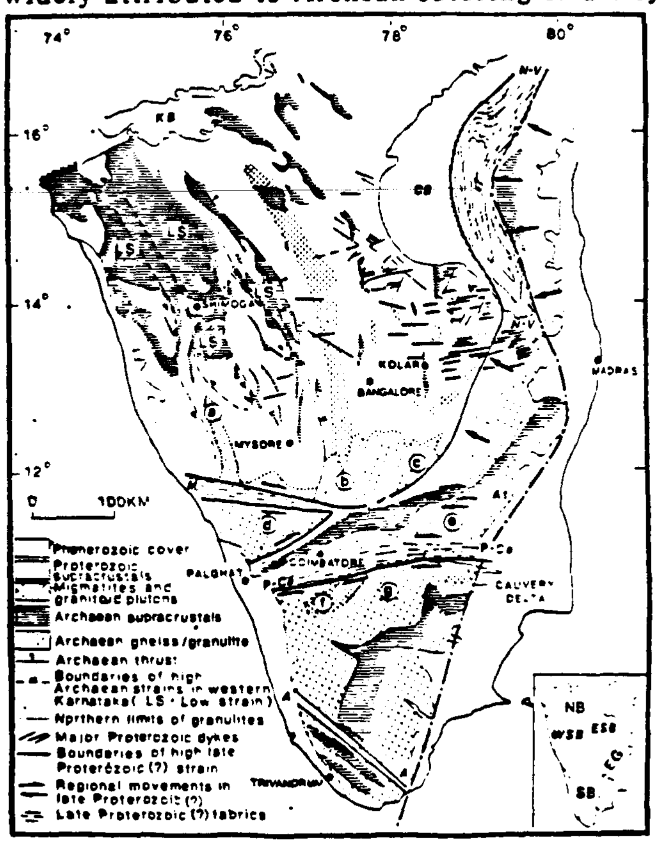

Figure 1. Numerous Archean arc-collisions are suggested responsible for the Greenstone belt trends (horizontal lines) north of a line through Kolar, Bangalore and Mysore. The dash-dot line close to the East coast is a lineament marking the site of a possible Late Proterozoic collision to which the Cuddapah Basin is a foreland-basin. Late Proterozoic strike-slip faults are perhaps associated with this collision. From Drury and others, Journal of Geology, 1984.

(2) The characteristic trend of an Andean arc can be recognized in the Gangdise intrusive and volcanic belt of Tibet (Fig. 2) which represents the arc system associated with northward subduction of Neotethyan ocean floor that preceded the collision of India with the rest of Asia in Paleogene times. Ancient examples of arcs of this kind probably exist within the Indian Shield, perhaps, for example, in the Aravallis.

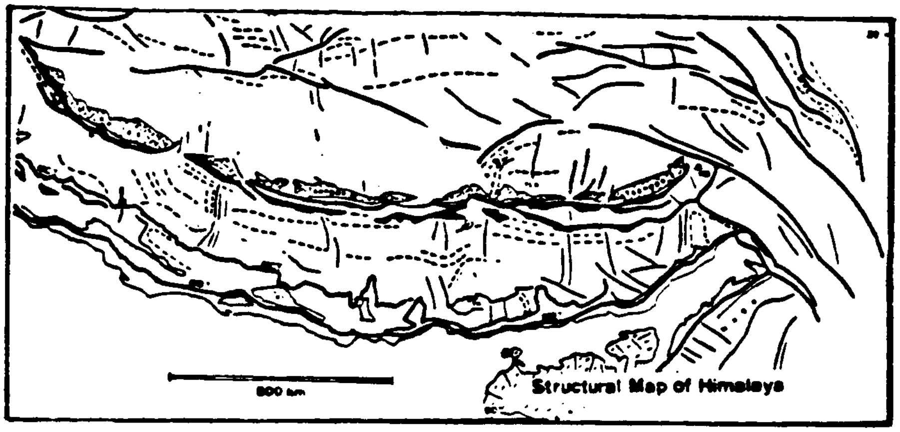

Figure 2. Structural map of the Eastern Himalaya modified from Gansser (1980) showing parallel lineaments attributable to the Indus-Yarlung Tsangpo suture (black) and the Gangdise intrusives (short dashes) representing the roots of an Andean arc.

(3) The Indus-Yarlung Tsangpo suture zone is a familiar feature (Fig. 2) marking the site of the collision between India and the rest of Asia. Similar lineaments are recognized in many parts of the world as recording collisions between continental and arc blocks and fragments. A map of such suture zones in Asia forms Figure 3.

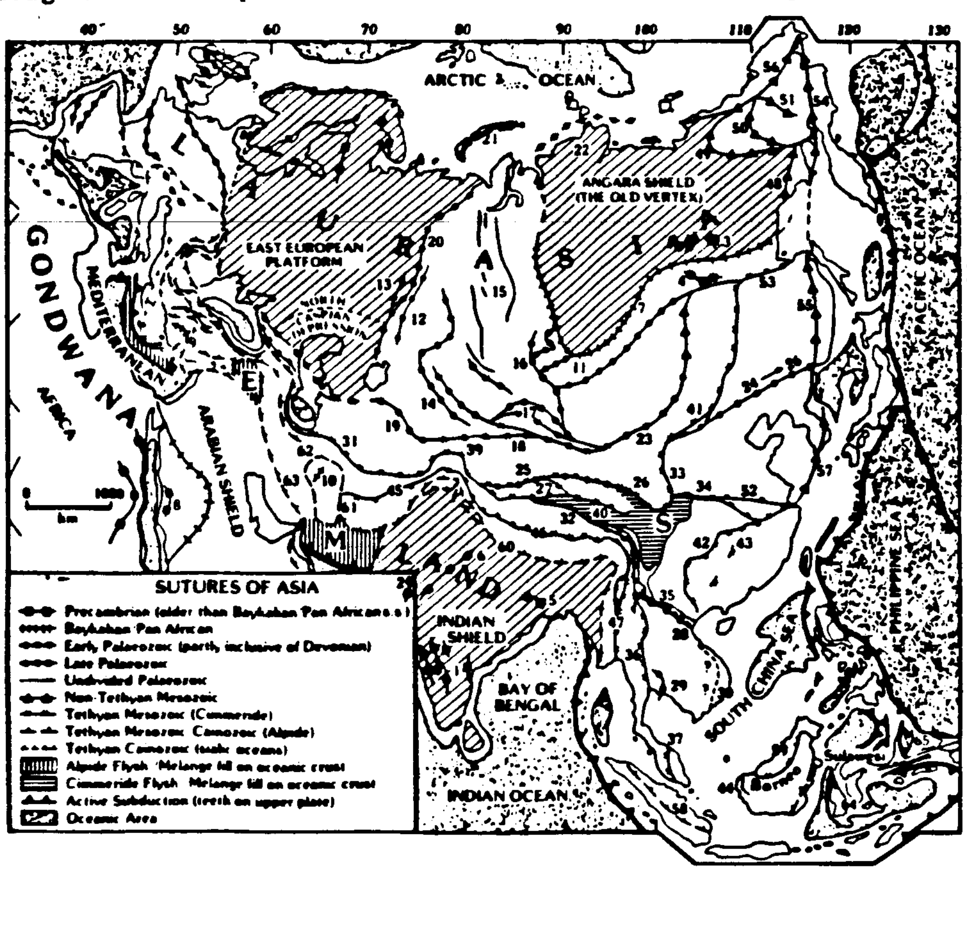

Figure 3. Sutures of Asia along which blocks and fragments (sometimes confusingly called terranes) have been joined, mainly during the Phanerozoic.

(4) Many of the world's most spectacular lineaments mark the sites of major strike-slip fault-zones and some of the most prominent of these faults are related to continental collision. New understanding of these features has followed from appreciation of their role in the process of "tectonic escape" by which material caught in a collision attempts to escape toward an oceanic "free-face". Faults in China and southeast Asia, such as the Altyn Tagh fault (Fig. 4) are the best examples of active faults of this kind, although more ancient features, such as the New York to Alabama lineament, have also been associated with collisional events.

Examples of strike-slip related linear features shown in Figure 1 are possibly associated with a late Proterozoic collisional event roughly along the site of the present East Coast of India. The Cuddapah basin may be a Precambrian foreland basin related to such a collision.

(5) Although rifts occur in a variety of different tectonic environments, many of the most familiar are related to collision. For example, in Figure 4 the Baikal and Shansi rifts inferred from their ages to be associated with the current Indian-Asian collision.

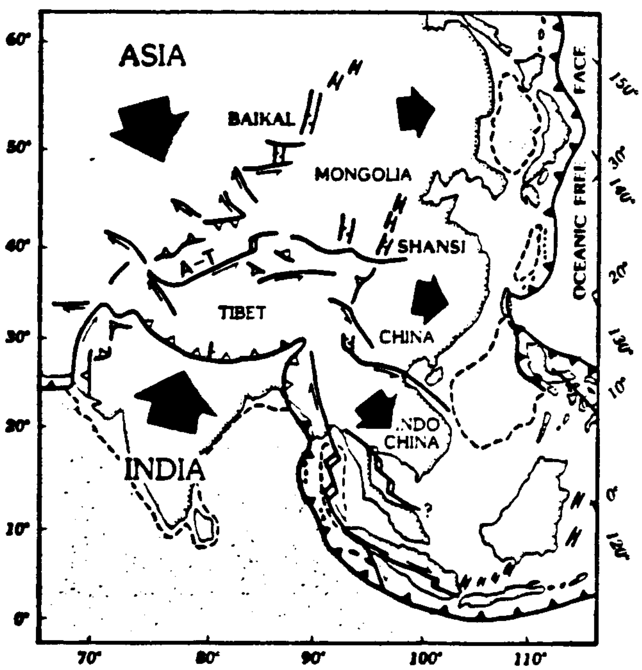

Figure 4. Tectonic escape in South-East Asia. Modified and simplified from Tapponnier et al. Note that evidence of timing indicates an association with the Himalayan collision for rifts as far apart as Baikal and the Sumatran coal basins (at 103°E, 3°S). A-T is the Altyn Tagh fault zone 1200 km in length.

Figure 5 is a representation of Gondwana-Land in Late Permian times in which it is indicated, following a suggestion of Peter Lehner, that the "Gondwana" rifts of India, Madagascar and Australia can be attributed to an arc-collision event recorded in the 'Samfrau'.

Although virtually all of the major lineaments of the continents can be ascribed to one or other of the processes outlined here, deciphering exactly how the processes have operated is generally difficult and may not always be possible. An illustrative example of

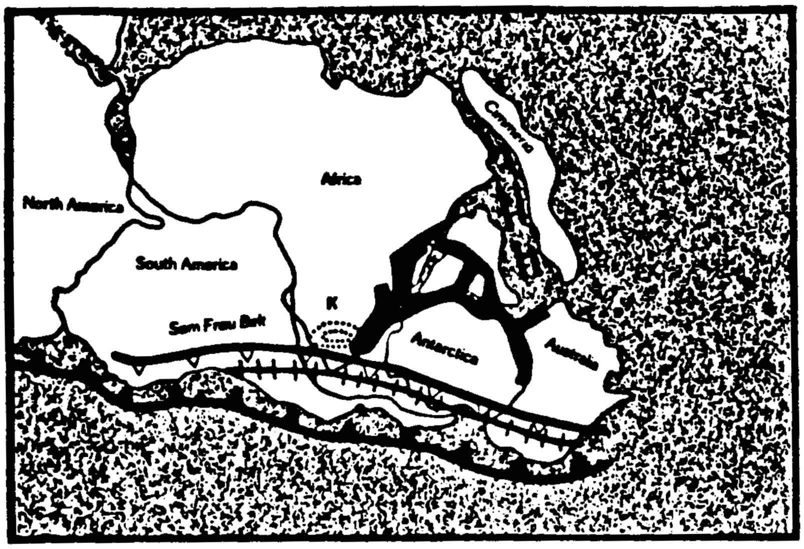

Figure 5. End Paleozoic collision of arc systems with Gondwana induced rifting in Africa, India, Australia and Antarctica. The Cimmerian continent left Gondwana and an extensive foreland basin (K) was filled by Karroo sediments.

how rifting, strike-slip motion and suturing may interact to yield complex geometric patterns is shown in Figure 6.

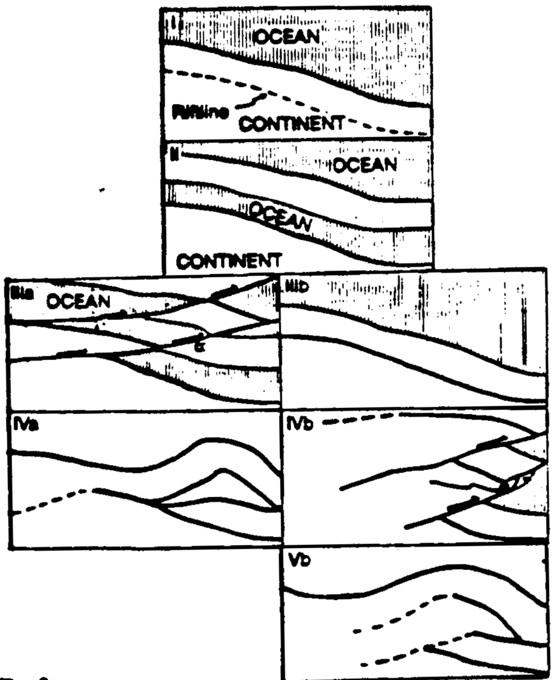

Figure 6. Complex lineament patterns within continents (as in IV and V) may be produced by rifting (I and II) and strike-slip motion (IIIa) before suturing (IVa) or suturing (IIIb) followed by strike-slip motion (IVb).

References

Burke, Kevin and Celâl Sengör, 1986. Tectonic escape in the evolution of the continental crust in Reflection Seismology: The Continental Crust. Geodynamics Series Vol. 14, pp. 41-53, American Geophysical Union.

Thompson, A. B., F. M. Richter, H. Ahrendt, M. J. Bickle, K. Burke, R. F. Dymek, W. Frisch, R. D. Gee, A. Kroner, R. K. O'Nions, E. R. Oxburgh, and K. Weber, 1984. The long-term evolution of the crust and mantle in Patterns of Change of Earth Evolution, edited by Holland and Trendall, pp. 389-406.