Gravity, Crustal Tectonics and Mantle Structure in the Central Asian Syntaxis

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Abstract: An attempt is made to interpret the gravity field in the zone of the Tien Shan-Hindu Kush-Kun Lun-Karakorum-Kashmir Himalaya Syntaxis, considering the local features of the field generated by density anomalies in the Lithosphere separately from the regional geoidal features generated by anomalous density distributions in the Mantle as obtained by satellite geodetic methods.

The local isostatic anomalies show a marked dichotomy astride of a line representing the prolongation of the Chaman Fault lineament. Remarkably, the nest of intermediate Hindu Kush earthquakes is to be found at the intersection between the same line with the Herat Fault lineament. Strong negative anomalies unrelated to either the topography or the geology prevail NW of such line, whereas SE of the line the field is characterized by stripes of alternating negative and positive anomalies all having the Himalayan trend.

Both the Himalayan and the Chaman Fault trends are to be recognized in the geoidal features of GEM 10. The Himalayan trend is here related to the upheaval of the geoid that accompanies all along the Alpine-Himalayan geosyncline, and the Chaman Fault trend to the geoidal downwarping that follows the northern continuation of the tensional zone of the Arabian Sea crossing the syntaxial zone and continuing in the Balkash-Baykal Rift Zone in Central Asia.

A tentative hypothesis is made to interpret the relationship between mantle structure and the crustal tectonics by the mechanism of gravity sliding.

DISCUSSION OF RESULTS

1. A complete review of the gravity measurements carried out up to the year 1960 in the area of the Tien Shan-Hindu Kush-Kun Lun-Karakorum and Kashmir Himalaya Syntaxis, is to be found in Geophysics of Karakorum (Marussi, 1964).

Since 1960, a number of gravity profiles have been observed in Afghanistan by A. Marussi in 1961 and by L.D. McGinnis in 1966 and 1967 and in the Northern Area of Pakistan, in cooperation with the Geological Survey of Pakistan, by C. Ebblin in 1974, by G. Poretti and by S.M. Rahim in 1978.

Extensive gravity surveys have been furthermore performed in the Indus Plain and at the foothills of the Kashmir Himalaya and Hindu Kush by the Geological Survey of Pakistan and other Agencies.

The following sketch map (Figure 1) shows the profiles observed so far in the mountain area.

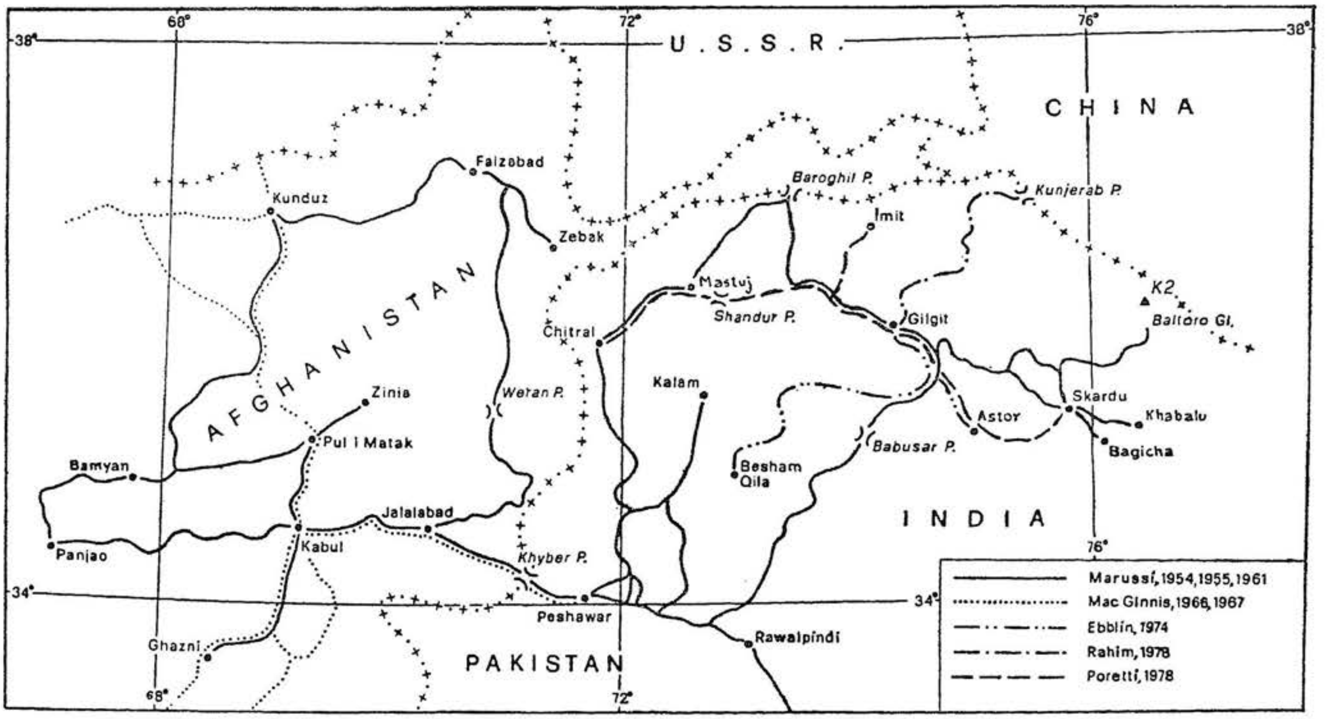

Fig. 1. Gravimetric profiles observed in the Northern Area of Pakistan and NE Afghanistan.

Proc. Intern. Commit. Geodynamics, Grp. 6, Mtg. Peshawar, Nov. 23-29, 1979: Spec. Issue, Geol. Bull. Univ. Peshawar, Vol. 13, 1980.

It should be reminded that all gravity data observed prior to 1971 are based on the Old Potsdam Gravity System, and that an appropriate reduction is necessary to bring them in agreement with the New Potsdam System as defined by the International Association of Geodesy and incorporated in the International Gravity Standardization Net 1971 — IGSN71.

A reduction of −13.20 mGal must therefore be applied to the values observed in Pakistan by the Italian Expeditions of 1954 and 1955, and of −17.39 mGal to those observed in Afghanistan in 1961. As far as the values observed by L.D. McGinnis in Afghanistan in 1966-67 are concerned, the reduction to be applied amounts to −14.72 mGal.

Furthermore, in the computation of gravity anomalies, the Standard Gravity Formula based on the Madrid Ellipsoid of 1924 and the International Gravity Formula adopted in Stockholm in 1930 has been used throughout for the computation of the gravity anomalies published up to the present time, whereas the International Association of Geodesy has adopted simultanoeusly with the change of the Old Potsdam System, a new Reference Field based on the Lucerne Ellipsoid (Geodetic Reference System 1967). As a consequence of the simultaneous change of the gravity standard and of the reference field, the gravity anomalies published up to now will suffer only minor changes.

Major changes are instead to be expected from the improved knowledge of elevations in some cases. Especially after the construction of modern roads in the Northern Area of Pakistan new spirit levelling profiles have been made possible, leading to a substantial improvement in our knowledge of geophysical fields in this exceptionally interesting region.

2. As far as the interpretation of gravity anomalies is concerned, one must distinguish between the effects generated by anomalous density distributions deep in the mantle (long-wavelength anomalies), and those due to density anomalies in the lithosphere (short-wavelength anomalies) and in the uppermost layers of the crust.

Modern satellite techniques have supplied a worldwide pattern of gravity anomalies that permits the separation of the two effects. The latest available map of anomalies is incorporated in the GEM 10 geoid published in 1977 by NASA — Goddard Space Flight Center, based on satellite observations and 1° x 1° surface gravity data (Fig. 2).

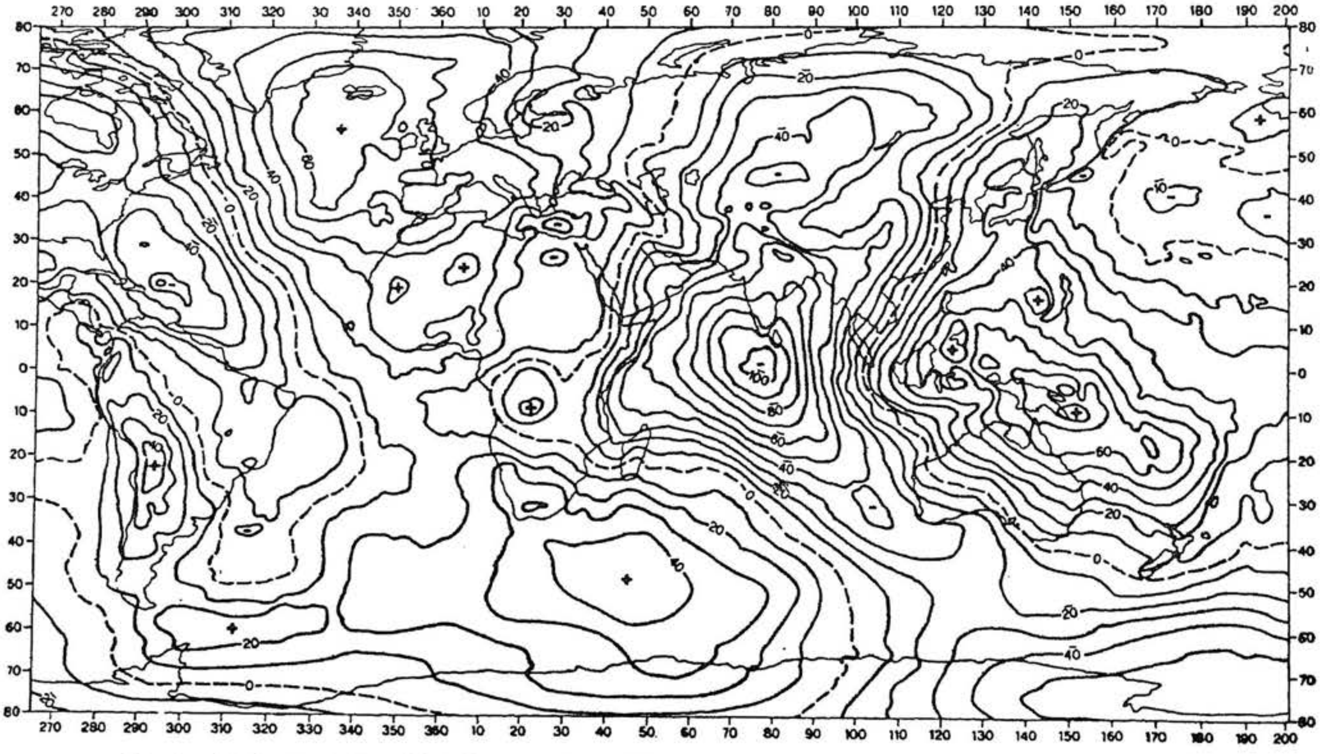

Fig. 2. GEM 10 Geoid published by NASA-Goddard Space Flight Center, 1977 — Contours at 10 m intervals.

A marked depression of the geoid is apparent in the Indian Ocean immediately south of Cape Comorin, which is responsible for the negative gravity anomalies that predominate in the southern part of the Indian Peninsula. Such depression extends attenuated toward the north, crosses the Tien Shan-Hindu Kush-Karakorum-Kashmir Himalaya Syntaxis and proceeds toward NE in the regions of Ferghana, Lakes Issik Kul, Balkash, Ala Kol, Ebi Nur, Ubsa Nor, Baykal and the valley of the River Lena.

It is remarkable that in the area of the syntaxis the low negative anomalies (depression of the geoid) intersects the high of positive anomalies (upheaval of the geoid) that characterizes the Alpine Belt and extends onto Tibet and Eastern Asia. The area of the syntaxis is therefore located at the saddle of the geoidal undulation.

The residual isostatic anomalies of lithospheric origin show in the syntaxial zone two strikingly dis-

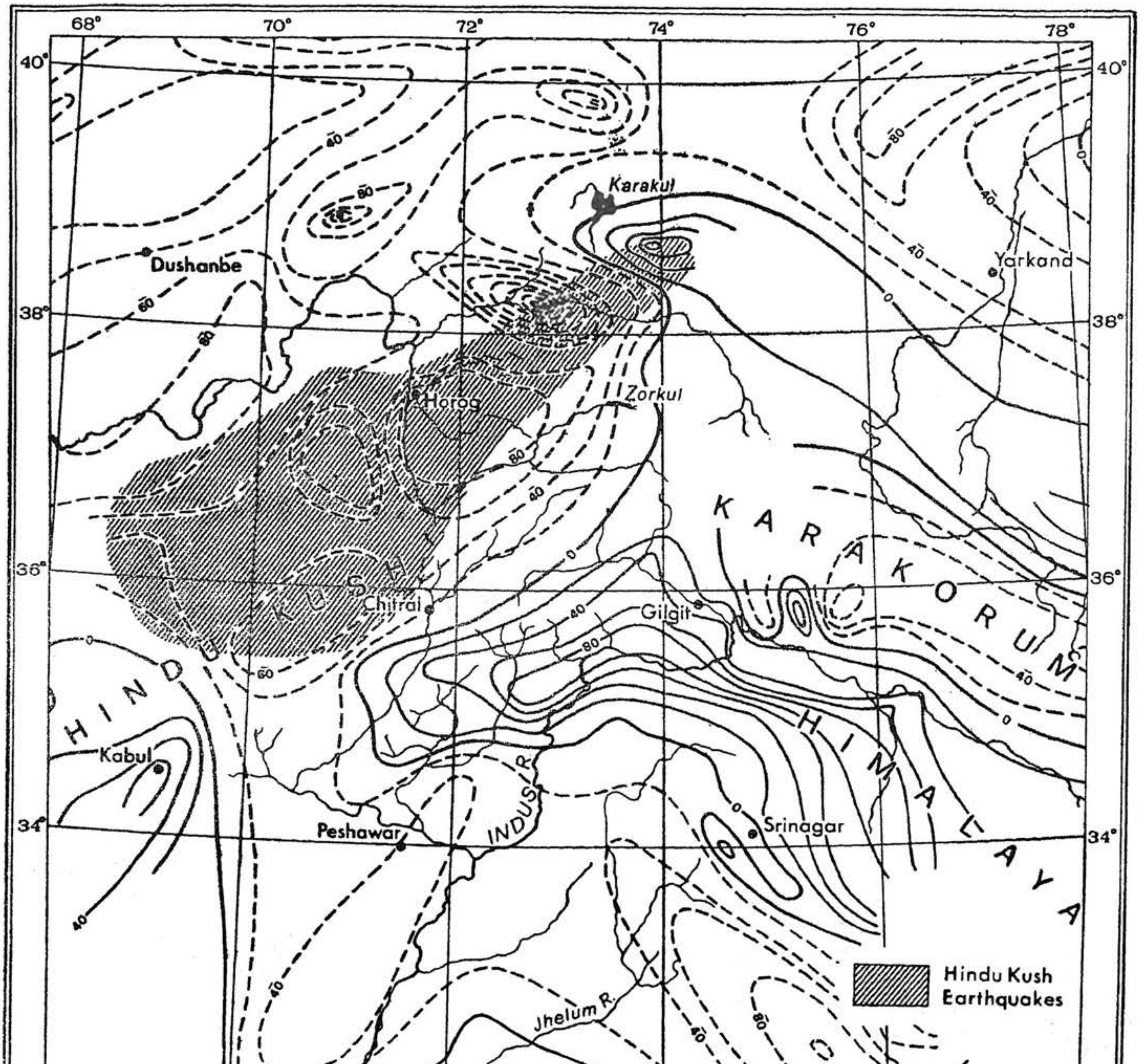

Fig. 3. Airy isostatic anomalies for a normal crust 30 km thick in the Northern Area of Pakistan, Pamir and NE Afghanistan and seismic area of Hindu Kush earthquakes.

tinct patterns separated by a line joining approximately the city of Kabul with Lake Karakul, and having therefore the trend of the Chaman Fault of which it appears to be the prolongation (Fig. 3).

The gravimetric pattern SE of the line shows a central core of marked negative anomalies related to the Axial Granitic Batholith of the Great Karakorum bordered by two bands of positive anomalies related to the surrounding metamorphic and the ophiolitic outcrops. Both the central core of negative anomalies and the bordering bands of positive anomalies follow the Himalayan trend. Negative anomalies appear again at the foothills, related to the Tarim and the Indo-gangetic foredeeps.

The gravimetric pattern NW of the Chaman line shows instead a predominance of strong negative anomalies that do not appear correlated either with the topography or the geology.

The Chaman Fault lineament possibly continues in the fault system of Northern Tien Shan which will be discussed later; it is possibly related to the nest of intermediate Hindu Kush earthquakes which is to be found at the intersection of the Chaman and the Herat Fault systems.

3. Reverting to the general trends of the geoid obtained by satellite geodetic methods, it is remarkable that generally speaking, the upheaval of the geoid that corresponds to positive density anomalies in the mantle, appears correlated to regions of crustal compression; whereas the downwarping of the geoid, corresponding to negative density anomalies, appears related to regions of crustal extension. Consequently, upheavals of the geoid in the Asiatic continent are associated with epigeosyncline mountain-building processes, and downwarpings with epiplateform activation that took place mainly in the late Cenozoic times continuing in the Quaternary up to the present (Schlesinger, 1978; Kailasam, 1978).

The inspection of the geoidal map of Eurasia indeed shows that the whole of the Alpine Belt is accompanied by a geoidal ridge that in the Far East culminates in the enormous rise of the highly tectonically active region of Melanesia. Conversely, the tensional region of the Afro-Asiatic Rift Zone, that further proceeds along the Owen fracture and the lower Indus Valley possibly crossing the Karakorum Syntaxial zone and continuing in the region of the Lakes Balkash and Baykal, is associated with a marked geoidal downwarping.

The tensional character of the subcontinent south of the Alpine Belt is made clear, east of the lower Indus Valley, by the system of fractures and vents that allowed the outflow of the Deccan Traps (Kailasam, 1978), and West of the Valley by the number of wrench faults, volcanoes, lava flows and quaternary troughs that characterize the tectonics of S.E. Afghanistan and Seistan (Wellman, 1966; Tectonic and Magmatic Maps of Afghanistan, 1977; Stocklin, 1977).

An extensive literature illustrates the Balkash-Baykal zone in which late Cenozoic and Quaternary rifting, formation of troughs and volcanism, and present positive vertical movements all witness its tensional character (Artemjev and Artyushkov, 1971; Schlesinger, 1978; Yanshin, 1978; Zorin and Florensov, 1978; Tapponier and Molnar, 1979). No further comment being therefore necessary in this connection, it should be mentioned instead that according to the opinion expressed by Schlesinger (1978) the epigeosynclinal process, characterized by intense folding of relatively local character, is followed at its end or little later by the epi-platform process characterized by the absence of folding but by powerful vertical mountain building movements over considerably greater areas. Such movements, rather than the epigeosynclinal processes, are accountable for the highest altitudes of the mountain ridges.

Artemjev and Artyushkov (1971), Zorin and Florensov (1978) and Yanshin (1978) express the view that epiplatform processes should be related to lower densities and higher temperatures present in the mantle, and consequently to intense differential vertical movements causing the asthenosphere to rise, thus creating upswells of its roof.

It is therefore not without meaning that both the highest altitudes of the Central Asian mountain system, as well as the only nest of mantle earthquakes existing in the continent, are to be found at the intersection of the described belts of compression and of tension.

4. No hypotheses are advanced at this time as to the mechanism that correlates density anomalies in the mantle with crustal tectonics, although an obvious interpretation would be that greater densities result in sinking of mantle material and consequently in the downwarping of the mantle-asthenosphere boundary. Provided the asthenosphere has a sufficiently low viscosity, gravity sliding of the lithosphere might take place generating accumulation and compression of the lighter crustal material in the resulting geosyncline.

Conversely, lower densities would lead to rising of mantle material and consequently to upwards buckling of the mantle-asthenosphere boundary. Here again the lithosphere might slide apart by gravity, thus originating tensional features in the crust.

REFERENCES

Artemjev, M.E. and Artyushkov, E.V. — *Structure and Isostasy of the Baikal Rift and the Mechanism of Rifting* — Journ. Geoph. Res., v. 76, No. 5; 1971.

Afghan Geological and Mines Survey — *Mineral Resources of Afghanistan* — (With Geological, Tectonic and Magmatic Maps) — Kabul, 1977.

Bartole, R. — *Structural Lineaments of the Central Asian Orogenic Syntaxis from Landsat Imageries* — Rend. Acc. Naz. Lincei, S. VIII, LXIV, fasc. 5 and 6, 1978.

Chinese Acad. Geol. Sc — *Tectonic Map of the People's Republic of China* — Peking, 1975.

Desio, A. ; Marussi, A. — *On the Geotectonics of the Granites in the Karakorum and Hindu Kush Ranges* — Intern. Geol. Congress, Copenhagen, 1960.

Ding Guoyn; Li Yongshan — *Seismicity and the Recent Fracturing Pattern of the Earth Crust in China* — Acta Geologica Sinica, V. 53, No. 1, 1979.

Ebblin, C. — *Tectonic Lineaments in Karakorum, Pamir and Hindu Kush from ERTS imageries* — Rend. Acc. Naz. Lincei, S. VIII, V. LX, fasc. 3, 1976.

Ebblin, C — *Deformations in the Area of the Pamir-Himalayan Syntaxis and Strain Patterns of the Earth's Surface* — Boll. Geo. e. Sc. Affini, XXXVII, N. 2 3.

Florensov, N. A. — *Rol Riftogeneza v Geologischeskoij Istorii* Zemli — Akademiya Nauk S S.S.R., Inst. Zemnoy Kori, Novosibirsk (1977).

Kaila, K. L. ; Krishna, V. G. ; Roy Chowdhury, K. ; Hari Narain — *Structure of the Kashmir Himalaya from Deep Seismic Sounding* — Journ. Geol. Soc. of India, V. 19, N. 1, 1978; pp. 1-20.

Kailasam, L. N. — *Plateau Uplift in Peninsular India* — Conferenec on Plateau Uplifts, Flagstaff, 1978. Ed. Lunar and Planetary Inst., Houston, Texas.

Lang, J. — *Evolution geodynamique de bassins intramontagneux tertiaires d'Afghanistan Central (Bamyan, Yakwalang, et vallee du Ghorband* — Mem. Hors — Serie N. 8, Soc. Geol. de France, Paris, 1977.

Marussi, A. — *Le anomalie della gravita lungo la catena del Karakorum — Hindu Kush* — Rend. Acc. Naz. Lincei, S. VIII, V. XXXV, fasc. 5, 1963.

Marussi, A. — *Geophysics of the Karakorum* — Italian Expeditions to the Karakorum (K2) and Hindu Kush, II. Geophysics, Vol. I; E. J. Brill, Leiden, 1964.

Marussi, A. — *Introductory Report on Geophysics* — Internat. Colloquium on the Geotectonics of the Kashmir Himalaya-Karakorum-Hindu Kush-Pamir Orogenic Belts; Acc. Naz. Lincei, Rome, 1976.

McGinnis, L. D. — *Gravity Fields and Tectonics in the Hindu Kush* — Journ. Geoph. Res., V. 76, N. 8, 1971.

NASA — *Global Detailed Gravimetric Geoid Based upon a Combination of the G.S.F.C. GEM 10 Earth Model and 1°x1° Surface Gravity Data* — NASA-Goddard Space Flight Center, Greenbelt, Md. 20771, USA (1977).

Saxena, M. N. — *The Himalaya — A modified Arc System and the Gravity Tectonics* — Tectonic Geology of the Himalaya, P. S. Saklani Ed. ; Today and Tomorrow's Printers and Publishers, New Delhi, 1978.

Schlesinger, A. E. — *Relationship between Nongeosyncline and Epigeosyncline Uplifts and Mountain Building* — Conference on Plateau Uplifts, Flagstaff, 1978. Ed. Lunar and Planetary Inst., Houston, Texas.

Shatskii, N. S. — *Tectonic Map of the U.S.S.R. and Neighbouring Regions* — U.S.S.R. Acad. of Sc., Moscow, 1956.

Shih Chen-liang; Huan Wen-lin; Yan Jia-quan; Wang Su-yun; Wang Chih-Kang — *On Recent Tectonics of China and its Vicinity* — Terrestrial and Space Techniques in Earthquake Prediction Research — Fr. Vieweg & Son, Braunschweig-Wiesbaden, 1978.

Stocklin, J. — *Structural Correlation of the Alpine Ranges between Iran and Central Asia* — Mem. Hors Serie N. 8, Soc. Geol. de France, Paris.

Tapponnier, P. ; Molnar, P. — *Active Faulting and Cenozoic Tectonics of the Tien Shan, Mongolia and Baykal Regions* — Journ. Geoph. Res., V. 84, B.7, 1979.

Terman, M. J. — *Tectonic Map of China and Mongolia* — U S. Geol. Survey, Reston, 1973.

Wellman, H. W. — *Active Wrench Faults of Iran, Afghanistan and Pakistan* — Geol. Rundschau, 55, 1966.

Yahnshin, A. L. — *Tectonic Map of Eurasia* — U.S.S.R. Acad. of Sc., Moscow, 1966.

Yahnshin, A. L. — *The Role of Epiplatform Mountain Building in the Development of the Earth's Crust* — Conference on Plateau Uplifts, Flagstaff, 1978. Ed. Lunar and Planetary Inst., Houston, Texas.

Zorin, Yu A. ; Florensov, N. A. — *On Geodynamics of Cenozoic Uplifts in Central Asia* — Conference on Plateau Uplifts, Flagstaff, 1978. Ed. Lunar and Planetary Inst., Houston, Texas.