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Comment on "On Orogeny and Epeirogeny in the Study of Phanerozoic and Archean Rocks"

The Concept of Epeirogeny is Re-emphasized

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Contrary to recent discussions (Hermes and Borradaile, 1987; Thurston and Easton, 1987; Miall, 1987) the concept of epeirogeny is today more important than when Gilbert (1890) first introduced this term. In the past, epeirogeny was commonly explained in terms of glacial rebound. More recent interest in episodes of crustal epeirogeny relates to vertical movements of the crust in continental platform regimes and intracratonic basins at sites like the Appalachian Basin (Friedman and Sanders, 1982, 1983; Johnson, 1986; Friedman, 1987a, b), Arbuckle Mountains (Harrison *et al.*, *in prep.*; Glash and Friedman, 1988), Michigan Basin (Fisher and Barratt, 1985), Ozark Dome (Friedman, 1987a), Adirondacks (Isachsen, 1985), Nashville Dome (Stearns and Reesman, 1986), Athabasca Basin of Saskatchewan (Pagel, 1975; Hoeve, 1984; Fred Langford, *pers. comm.*, 1987), Orcadian Basin of Scotland (Das *et al.*, *in prep.*), basins in Africa (Openshaw *et al.*, 1978; Fred Langford, *pers. comm.*, 1987), and elsewhere.

Various techniques of study of strata exposed at the surface in underformed areas of continental platform regimes and intracratonic basins (fluid-homogenization temperatures, $\delta^{18}\text{O}$, vitrinite reflectance, diagenetic minerals, fission-track analyses, argon-loss, conodont-alteration data, and mathematical geodynamic models) imply that these strata have been heated to temperatures that suggest a great depth of burial, much greater than previously thought, and subsequent uplift. Unexpectedly, large amounts of uplift and erosion, ranging from 4.3 to 7.0 km, for example, for the northern Appalachian Basin, have re-exposed these formerly deeply buried rocks. Therefore, the lithosphere, in its isostatic unroofing of thick sequences of sedimentary strata, has undergone much larger vertical motions than geologists had estimated. It has been claimed that vertical movements of the crust are not important and that lateral motion of plates is the driving mechanism that activates tectonic changes. Yet the data imply deep uplift and erosion of former covering strata. Such former great depth of burial of undeformed strata, which are now exposed at the surface, reflect large-scale vertical movements of the crust and uplift of the lithosphere. These drastic changes represent unroofing with widespread implications for paleogeography of a kind unrecognized at present (Friedman, 1987b). As an example for the Appalachian Basin, surface-exposed Silurian strata are interpreted to have reached maximum burial depth of 5.0 km; Devonian strata in the Catskill Mountains had former burial depth of about 6.5 km; Lower Ordovician carbonate sequences were buried to more than 7.0 km; Middle Ordovician strata had paleodepth of approximately 5.0 km. (Brockerhoff and Friedman, 1987; Friedman, 1987a, b; Friedman and Sanders, 1982; Gurney and Friedman, 1987; Urschel and Friedman, 1984). Beaumont *et al.* (*in prep.*), using a mathematical geodynamic model computed for sedimentary basins in North America in undisturbed areas, removal by erosion of in excess of 15 km of strata. Whitney and Davin (1987) hypothesized that a thick wedge of Taconic rocks overrode Lower Ordovician carbonates. If so, this wedge was removed by erosion. Crough (1981) interpreted that southeastern Canada and New England have been elevated at least 4 km relative to the central Appalachian region and have subsequently been eroded.

When I wrote the chapter on sedimentary tectonics ("Sedimentary Strata and Tectonic Movements") of my co-authored textbook *Principles of Sedimentology* (Friedman and Sanders, 1978) unnamed structural geologists, serving as reviewers, asserted that all tectonic movements relate to laterally driven plates and heretic views expressing vertical movements should be abandoned. Now I recognize how blind these reviewers were. The usage of concepts of plate tectonics reminds me of the bible "Search And Thou Shalt Find". Epeirogenic movements in continental platform regimes and intracratonic margins can be explained by reference to plate margin processes. However, whether or not these vertical movements ultimately are genetically related to plate margins is certainly not known, and indeed is less relevant than to recognize the distinction between tectonic deformation at plate margins resulting in deformed strata and the vertical motion of undeformed strata in continental platform regimes and intracratonic basins. The recognition of these two kinds, deformation in mobile belt areas at plate margins and the yoyo motion of undeformed strata on stable platforms, are both tectonic features. Recently the importance of vertical movements has been re-emphasized in platform and intracratonic settings (Friedman and Sanders, 1982; Johnsson, 1986; Friedman, 1987a). Thus, epeirogeny has retained its importance.

For the Appalachian Basin, three ages of vertical uplift for undeformed strata may be proposed: (1) Late Pennsylvanian to Permian coinciding with the Allegheny orogeny based on (a) recrystallization of authigenic feldspars and their Ar-age spectra in Cambro-Ordovician carbonates (Hearn and Sutter, 1985), (b) fission-track data on fluorite in Silurian carbonates (V. Harder and G.M. Friedman, unpublished data), (c) paleomagnetic ages (Levine, 1986), (d) illitization (Elliot and Aronson, 1987), (e) mathematic geodynamic model (Beaumont, Quinlan, and Hamilton, *in prep.*) and, (f) an absence of Pennsylvanian strata beneath Mesozoic basins of the eastern United States; (2) a Cretaceous age has been proposed based on (a) structural-geochemical approach (Tillman and Barnes, 1983) and (b) apatite fission-track analyses (Duddy *et al.*, 1987); and a Tertiary age based on structural and tectonic studies (Isachsen, 1985). These three inferred ages suggest that the Appalachian Basin may have undergone several episodes of uplift with its original strata remaining undeformed.

Authigenic feldspar in Cambro-Ordovician carbonates of the kind inferred as Late Pennsylvanian to Permian occurs along the proto-Atlantic shelf from New York to Newfoundland, Scotland, and Greenland paralleling the Taconic belt suggesting active crustal epeirogeny at this time along this entire belt. Whether this event may ultimately be explained by plate tectonics or not is a secondary matter. Epeirogeny, as a concept expressing the vertical motion of undeformed strata, is very much alive. From an economic point of view, rocks that are now exposed at the surface or occur at shallow depth may have lain within the window of maturity for hydrocarbon source rocks before the removal of thick sequences of strata, although the present depth of burial may be too shallow.

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