

COMMENT ON "DYNAMIC SURFACE TOPOGRAPHY: A NEW INTERPRETATION  
BASED UPON MANTLE FLOW MODELS DERIVED FROM SEISMIC TOMOGRAPHY"  
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In a recent paper in this journal, Forte *et al.* [1993] have proposed a model of global dynamic topography with an amplitude of three kilometers (six kilometers peak to peak). If North America, Australia, and other continents were dynamically depressed by the one to two kilometers predicted, then these continents would today be below sea-level and nearly covered by epeiric seas. Since the continents are nearly entirely exposed and have become progressively exposed since the Late Mesozoic the amplitude of the Forte *et al.* model is clearly much too large.

Forte *et al.* have predicted dynamic topography of the Earth's surface up to and including spherical harmonic degree eight in two ways. First, they removed a modeled isostatic component of topography from observed topography which they termed "dynamic topography". Second, they have computed topography on the surface of a viscous mantle with driving loads constrained via a tomographic inversion of mantle seismic heterogeneity. In their isostatic topography model, they have assumed a single crustal column for all continental crust and a single column for all oceanic crust; these two types of isostatically balanced columns are arranged on the Earth's surface using the continent-ocean function. Forte *et al.* assume there are no crustal thickness variations within continents, not necessarily a bad assumption at long wavelengths, and that a single global parameter characterizes the offset between all continental and all oceanic crust. Both predictions of dynamic topography are close in terms of pattern and amplitude.

The dynamic topography presented by Forte, *et al.* has nearly a three kilometer amplitude and all continents are located in dynamic topography depressions: North America and Australia are in the deepest depressions each of about two kilometers maximum and Africa is depressed by up to one kilometer. I will show that North America, Australia, and Africa cannot possibly have such extremely depressed dynamic topographies. First, these continents, like all continents, have been repeatedly inundated by shallow seas over the Phanerozoic and this inundation can be accomplished by global and regional sea-level changes of a few hundred meters -- certainly less than one kilometer. Second, if the continents were dynamically depressed by two kilometers, most of their area would be covered by shallow seas.

Let me review some of the basics of Phanerozoic sea-level change and what they imply for Earth dynamics. In major platform areas, like North America or Australia, flat lying marine rocks of constant age can cover up to about fifty percent of the surface and/or sub-surface area of platforms

[Schuchert, 1916]. It has been known since the first few decades of this century that sea-level rises and falls of about 100 meters could explain these observed marine deposits [Kuenen, 1939; Hallam, 1992]. Wise [1974] argued that the surface of the Earth is in a long-term quasi-equilibrium in which freeboard remains approximately constant with the oceans periodically flooding the continents. Significantly, Phanerozoic transgressions and regressions can be accomplished by eustatic and regional sea-level changes and although the magnitude of these fluctuations are debated, it does not seem that estimates fall below 100 meters [Bond, 1978] or exceed 700 meters [Hallam, 1984]. Many climatic and geologic factors effect sea level, including epeirogeny, which has long been known to be an important regional factor [eg. Bond, 1978]. Fluctuations in dynamic topography are probably a major control on epeirogeny and regional sea-level change [Gurnis, 1992].

Gurnis [1990] showed how continents would become flooded and exposed as they moved with respect to a large-scale, larger than continental scale, pattern of dynamic topography -- much like the pattern now predicted by Forte *et al.* Flooding is dependent on the ratio of geoid to dynamic topography, or admittance, but when admittance is as small as predicted in the Forte *et al.* model,  $\sim 0.03$ , then dynamic topography is by far the most important control on marine inundation. When the admittance is small and the continents are located in dynamic topography lows, as they are in the Forte *et al.* predictions, then inundation reaches its maximum. Since we know from the stratigraphic record that sea-level has oscillated by  $\sim 200$  meter around a mean, then when continents are in dynamic topography lows, continents must experience a sea-level rise proportional to the dynamic topography. Clearly, the relative sea-level rise would be at least one kilometer for North America and Australia in the Forte *et al.* model. The actual rise would probably be significantly higher since about half of the ocean basins are on dynamic topography highs of at least 500 meters. The estimate of relative sea level rise of one kilometer (Figure 1) is an approximate minimum. The intersection of a relative sea-level rise with present day hypsometry (Figure 1) gives the fraction of a continent which would be covered by ocean water. From the Forte *et al.* predictions we expect N. America should be flooded by about 80 percent and Australia by about 98 percent. Since North America and Australia, like nearly all continents, are mostly exposed, the amplitude of dynamic topography and the positioning of continents in lows predicted by Forte *et al.* is at odds with these simple observations.

Furthermore, contemporaneous positioning of the continents in dynamic topography lows of large amplitude, as proposed by Forte *et al.*, is at odds with the withdrawal of shallow seas from the continents since the end of the Mesozoic. Much of this withdrawal of seas from platforms was probably eustatic but with some important, regional or

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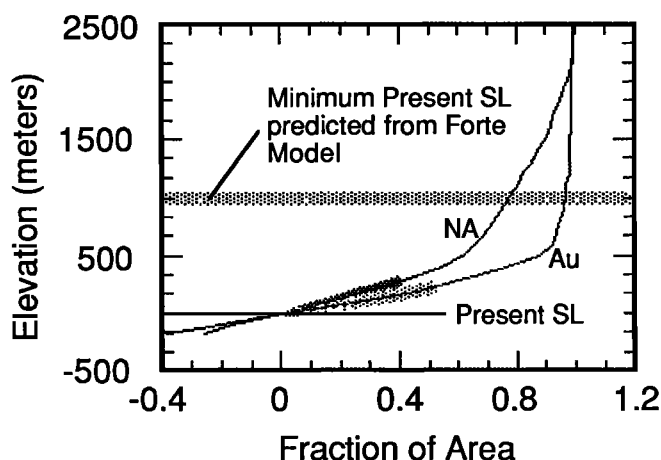


Fig. 1. Hypsometric curves for North America, NA, and Australia, Au, from Harrison *et al.* [1983]. The area has been normalized by area presently above sea-level. Shown by light shading overlying hypsometries are the fractional areas covered by Cretaceous and younger marine deposits. N. American flooding is from Wise [1974] and Australian flooding is from Struckmeyer and Brown [1990].

epeirogenic motions [Bond, 1978]. In particular, a 93 Ma shoreline deposit in Minnesota, USA, shows that sea-level has fallen 280 m [McDonough and Cross, 1991] but Forte *et al.* predict that this mid continental area is dynamically depressed by ~2 km. The results for Africa are even more extreme: Mid-Cretaceous shoreline deposits have been elevated to one kilometer, after sediment unloading, above present sea-levels [Sahagian, 1988] and this demonstrates that Africa has been actively uplifting in addition to the general eustatic sea-level fall since the Cretaceous [Bond, 1978]. If Africa is clearly being uplifted, how can it be in a 500 m to one kilometer dynamic topography low as predicted by Forte *et al.*?

Despite these fundamental problems with the Forte *et al.* models, other predictions of dynamic topography are more consistent with geologic observations. The tomography-constrained viscous flow model of Hager, *et al.* [1985] predicts a dynamic topography amplitude of about one kilometer, but, first, most continents only straddle dynamic topography highs and lows and, second, Africa is on a dominant 600 meter dynamic topography high. The former is not inconsistent with stratigraphic observations, but the latter is very much consistent with geologic observations of the Cenozoic uplift of Africa. Significantly, the pattern of dynamic topography predicted by Hager *et al.* [1985] is in phase with the long wavelength residual oceanic topography obtained by subtracting the cooling of a simple half-space from observed bathymetry [Cazenave and Lago, 1991; Pribac, 1991], although there is a factor of two difference between them. The low amplitude, ~ 300 meter, residual topography results of Cazenave and Lago [1991] and Pribac [1991] imply long wavelength dynamic topographies which are most consistent with geologic observations [Gurnis, 1990].

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