CONTINENTAL OVERFLOW AND ARCHEAN TECTONICS

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Whether Archean tectonics can be fully understood by application of plate tectonic principles has been a matter of some controversy (de Wit, 1998; Hamilton, 1998). Two complementary approaches exist for resolving this problem. The first is to attempt to explain everything that is seen in the preserved remnants of Archean crust, using the principles of plate tectonics and modern analogues, and to see if unresolved paradoxes and problems remain. This approach faces the difficulties of interpreting rocks whose enormous age implies that Archean events are seen with difficulty through a mask of Proterozoic and Phanerozoic events. An alternate approach is to deduce the differences that marked the Archean by analyzing the underlying physics.

The higher heat output during the Archean implies a steeper geothermal gradient, in continents as well as in oceanic crust. A hot crust is associated with a very weak lower crust which is capable of easy ductile flow (Wernicke, 1990). Gravitational collapse of elevated continental crust with a lower crustal ductile layer is accepted as tectonically plausible (Dewey, 1988). An interesting question is whether an entire continent in Archean times might be gravitationally unstable against such collapse onto adjacent ocean basins; a summary of such a stability analysis is given in Bailey (1999). In such collapse (overflow), the gravitational drive must provide sufficient power to supply losses incurred by friction on upper crustal normal faulting, ductile Couette flow in the lower crust, thrust faulting at the continental margins, and flow in the mantle required to accommodate vertical movements at the Mohorovicic discontinuity. Figure 1 illustrates these mechanisms very schematically.

Reasonable estimates can be made for all these dissipation mechanisms. A striking result is that lower crustal dissipation is unlikely to be significant if recent estimates of lower crustal effective viscosity (Klein et al, 1997) are correct, nor is mantle dissipation. The energy budget is then dominated by the absorption of gravitational power in fault friction. If one further assumes that recent studies of friction on active subduction thrusts (Wang et al,????) are a good guide to the continental margin friction during Archean continental overflow, then thrust fault frictional losses are likely to be dominated by normal fault friction losses. Since normal faults are believed to be reasonably described by the classical theory of faulting (Anderson, 1951) with known laboratory values of rock friction (Byerlee, 1978), it is possible to make a quantitative estimate of the continental elevation required for continental overflow to take place. This leads to the conclusion that the elevation must exceed between 1/3 and 1/2 of the thickness of the brittle layer of the continental crust.

This criterion can be translated into a mean geothermal gradient above which a continent of a given elevation cannot be stable, assuming a particular brittle-ductile transition temperature, as shown in Figure 2 for possible brittle-ductile transition temperatures of 400 and 500 degrees Celsius. It is tempting to associate the close of the Archean with the time at which the maximum stable continental elevation rose above sea level; at this time, continental overflow would cease being easy because of the difficulty of building higher continents against the obstacle of vigorous subaerial erosion. As figure 2 shows, this would correspond to mean continental geothermal gradients dropping below about 30 degrees Celsius per kilometer.

Many peculiarities of the Archean can then be attributed to this pervasive and ongoing gravitational collapse: the absence of modern passive margins, TTG rock suites characteristic of the melting of oceanic crust shallowly submerged by continental overflow, and continental mafic magmatism associated with rapid extensional episodes. It seems likely that such extensions would be rapid. Plausible models of the subsidence associated with such collapse (Figure 3; Pearse, 1999) suggests extensional events would take of the order of 10 million years.

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Figures:

Figure 1: Schematic illustration of dissipation processes in continental overflow.

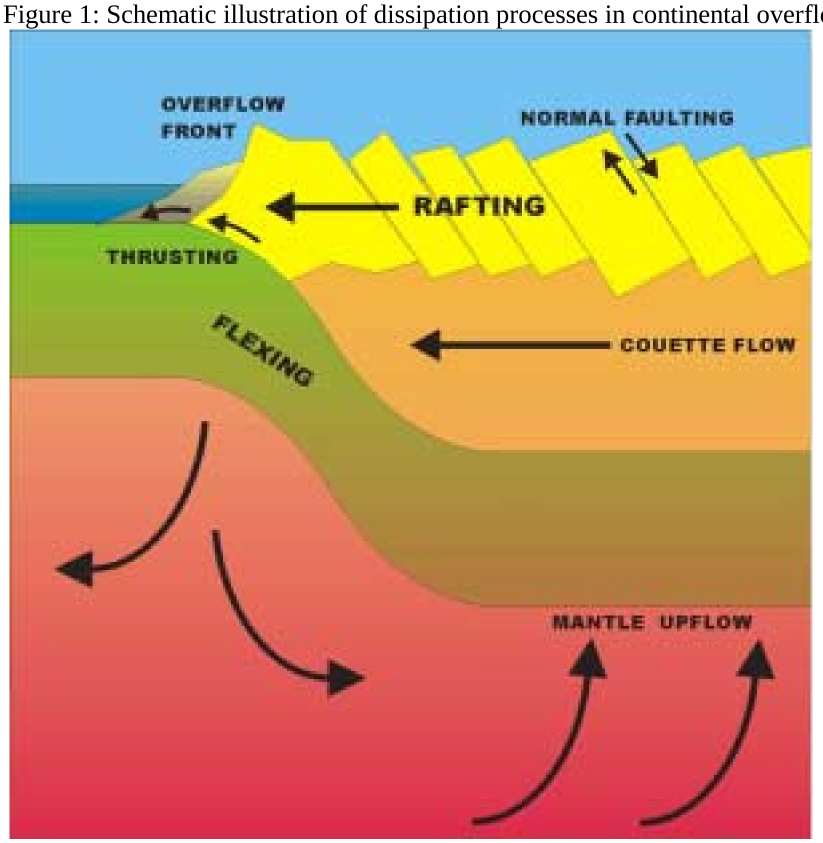

Figure 2: Elevation above which continents are gravitationally unstable, as a function of mean crustal geothermal gradient, for brittle-ductile transition temperatures of 400 and 500 Celsius respectively.

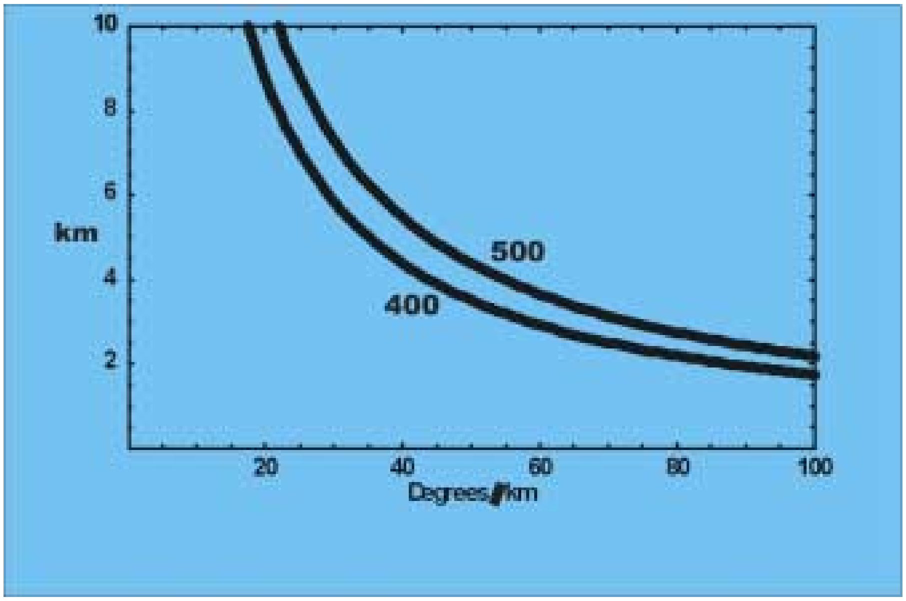

Figure 3: Continental subsidence in modeled overflow event, for a number of fault friction scenarios (after Pearse, 1999).