Large Igneous Provinces, Mantle Plumes and Uplift: A Case Study from the Dhanjori Formation, India

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Introduction

Significant pre-volcanic uplift of the lithosphere is one of the expected consequences of mantle plume upwelling (*Campbell & Griffiths*, 1990; *Farnetani & Richards*, 1994). Many major mafic/ultramafic lavas have been attributed to mantle plumes that are expected to produce crustal uplift (doming) preceding the major phase of volcanism. Such pre-volcanic uplift would have significant consequences on the regional sedimentation pattern. These include

1. progressive palaeogeographic shallowing and thinning of strata,
2. the abrupt appearance of erosional unconformities (“sequence boundaries” in sequence stratigraphic terminology), and
3. radial drainage and palaeocurrent patterns.

Subsequent erosion may remove much of the volcano-sedimentary record of domal uplift. However, sedimentologists can identify progressive shallowing of palaeogeography prior to volcanism and distinctive palaeocurrent patterns if these exist, and this may provide constraints on plume interpretations of the volcanic episode. So far, the emphasis in large igneous province (LIP) research has been on geochemistry, geochronology, petrology, geophysics and physical volcanology. However, the sedimentology and stratigraphy of adjoining lithological units are of paramount importance in constraining the sequence, timing and magnitude of vertical motions accompanying volcanism and should not be neglected (*Rainbird*, 1993; *Williams & Gostin*, 2000; *Rainbird & Ernst*, 2001; *He et al.*, 2003).

LIPs may or may not be related to mantle plumes. It is difficult to defend a LIP–mantle plume connection where pre-volcanic lithospheric uplift is absent. This is particularly true for continental flood basalts (CFB; see *Czamanske et al.*, 1998; *Sheth*, 1999; also the Siberia page and the Deccan page). Also, not all oceanic LIPs are associated with pre-volcanic crustal uplift (*e.g.*, *Neal et al*., 1997). LIPs without evidence for pre-volcanic uplift invite reconsideration of both the plume-impact and the plume-incubation models (*Sheth*, 1999). Recently, *He et al.* (2003) reported rapid, kilometer-scale crustal doming prior to the eruption of the Emeishan flood basalts, a LIP that formed close to the Permo-Triassic boundary in southwest China. This postualted plume-induced uplift was correlated with the sudden change from carbonate-platform to terrestrial-clastic facies in the western Yangtze Craton at the transition between the Middle and Upper Permian. *He et al.* (2003) relied on local published accounts not easily accessible to international readers on the generalized Permian stratigraphy and inferred palaeogeography (*He et al.*, 2003; their Figure 2) without presenting any field photographs. However, their stratigraphic-thickness data (*He et al.*, 2003; their Figure 3) clearly indicates crustal doming. Nevertheless, *He et al.* (2003) do not comment on any associated change in palaeocurrent pattern, which is an expected consequence since the Emeishan flood basalts are overlain by terrestrial sedimentary rocks.

An important question related to plume models for LIPs is whether uplift and extensional deformation precede magmatism in the manner predicted by experimental and numerical models (*Griffiths & Campbell*, 1991; *Farnetani & Richards*, 1994; *He et al.*, 2003). A plume-induced radial drainage/palaeocurrent pattern (*Cox*, 1989; *Kent*, 1991) is expected in both terrestrial and marine settings. *Cox* (1989) reported such a drainage pattern on peninsular India and postulated that it was a consequence of pre-volcanic uplift prior to Deccan volcanism. However, the drainage pattern of peninsular India is much older than the Deccan volcanism (*Sheth,* 2003a,b). Also, the uplift of the Western Ghats is recent and ongoing. If this is the case, a plume model for Deccan volcanism is not supported (*Sheth*, 2003a,b).

The sedimentological and stratigraphic criteria proposed for tracing LIP-plume connections are somewhat generalized, and will not all be useful at a given location. For example, progressive shallowing of palaeogeography as a consequence of plume-induced lithospheric uplift should be clear in a marine depositional setting (*e.g.*, in the transition from deep to shallow marine, or marine to terrestrial palaeogeography; see *Richards et al.*, 1991; *Rainbird*, 1993; *Rainbird & Ernst*, 2001; *He et al.*, 2003 for various case studies). In a continental depositional setting, such evidence is less likely to be found, however. This is because the depositional surface is already well above mean sea level (the base level of erosion) and its preservation potential is small. Unlike the case of marine depositional settings, an erosional unconformity/sequence boundary will thus not develop because the depositional surface is already subaerially exposed.

In addition, various soft sediment/pre-lithification deformation structures are expected within underlying sediments that have suffered uplift, irrespective of palaeogeographic setting. This is because mass-flow processes would have operated because of large changes in palaeoslope. *Rainbird* (1993) documented clear evidence of penecontemporaneous volcanism from the sediment-lava contact from the Neoproterozoic Shaler Group, Victoria Island, Canada (Figure 1). Careful sedimentological investigations thus have the potential to provide valuable insights relevant to evaluating possible plume-LIP genetic linkages, that cannot be investigated by other means.

Figure 1: Cross-sectional view of longitudinal projections developed at the interface between a gabbro sill and quartz-arenite of the Kuujjua Formation, Canyon Creek area (Canada). The base of the silll has loaded down into the underlying sediment, indicating that the sand was soft when the sill was injected (from Rainbird, 1998; Figure 8c).

The Dhanjori Formation

There is a strong correlation between CFB provinces and cratonic margins (*Anderson*, 1994; *King & Anderson*, 1995). Also a majority of CFBs have apparently erupted through deep rifts containing thick sedimentary sequences (*e.g.*, *Sheth*, 1999). Best studied are Phanerozoic CFB, although mantle plumes have been invoked to explain Precambrian mafic volcanism as well. Recently I studied the Late Palaeoproterozoic siliciclastic Dhanjori Formation, Singhbhum province, India (*Mazumder*, 2002; *Mazumder & Sarkar*, 2004; Fig. 2a,b). The Dhanjori Formation comprises Late Palaeoproterozoic terrestrial (alluvial fan-fluvial) continental deposits along with interbedded mafic and ultramafic (minor felsic) magmatic rocks formed in an intracontinental rift setting (*Mazumder & Sarkar*, 2004). The magmatic episode is unrelated to normal plate boundary processes (*Mazumder & Sarkar*, 2004) and thus the magmatic component of the Dhanjori Formation represents a LIP (*Coffin & Eldholm*, 1994; *Prokoph et al.*, 2004).

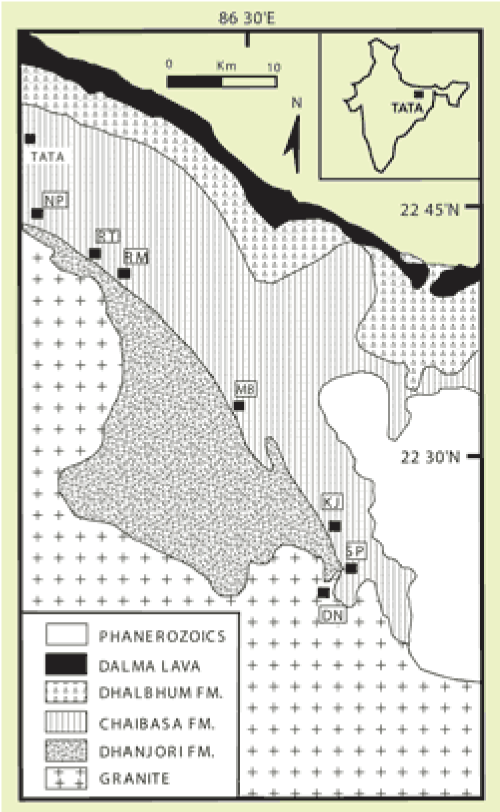

Figure 2a: Simplified geological map of the Dhanjori basin study locations: DN, Dongadaha; KJ, Khejurdari; SP, Singpura; MB, Mosaboni; RM, Rakha Mines; RK, Rukmini Temple (Jadugorah); NP, Narwa Pahar. Nearest city (Tata) shown on the map of India.

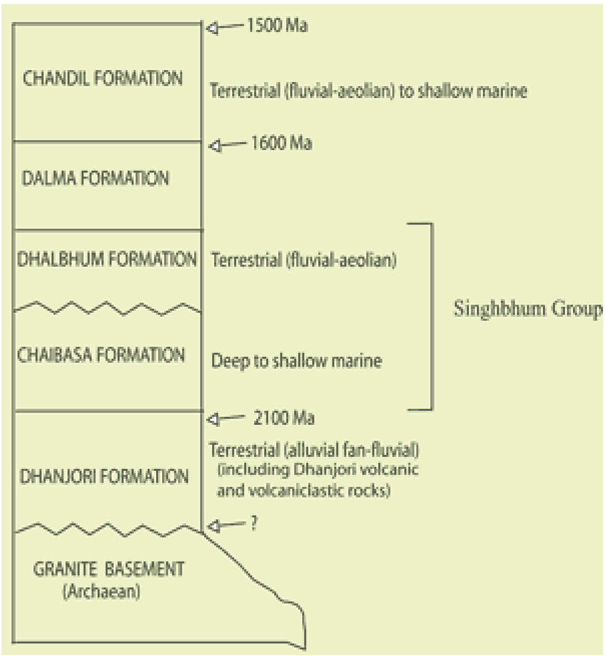

Figure 2b: Proterozoic stratigraphic succession of the Singhbhum crustal province, India (after [Mazumder, 2003]).

The Dhanjori Formation overlies Archaean Singhbhum Granite and represents terrestrial (alluvial fan-fluvial) deposits interbedded with mafic-ultramafic and minor felsic volcanic and volcaniclastic rocks. It is overlain by the deep-to-shallow marine Chaibasa Formation (*Bose et al.*, 1997; *Mazumder et al.*, 2000; Mazumder & Arima, 2005; Mazumder, 2004; Mazumder, 2005a; Mazumder, 2005b; Mazumder et al., 2006; Figures 2a,b). Cooling of the voluminous Archaean Singhbhum granite possibly induced isostatic readjustment. The associated extensional regime and deep-seated fractures controlled the formation of the Proterozoic Dhanjori basin (*Mazumder*, 2002; *Mazumder & Sarkar*, 2004; *Roy et al.*, 2002).

The Dhanjori Formation comprises two members: the lower member includes phyllites, quartzites and thin conglomerates, whereas the upper member has volcanic and volcaniclastic rocks along with some quartzites and phyllites (Figure 3). Basin tilting and volcanic eruption intervened and resulted in the second phase of Dhanjori sedimentation, although the general fluvial depositional setting remained unaltered. The different palaeocurrent trends displayed by the two members are a consequence of fluvial response to basin tilting. The volcanic and volcaniclastic rocks might have blocked river courses resulting in short-lived lacustrine deposition (*Mazumder & Sarkar* , 2004).

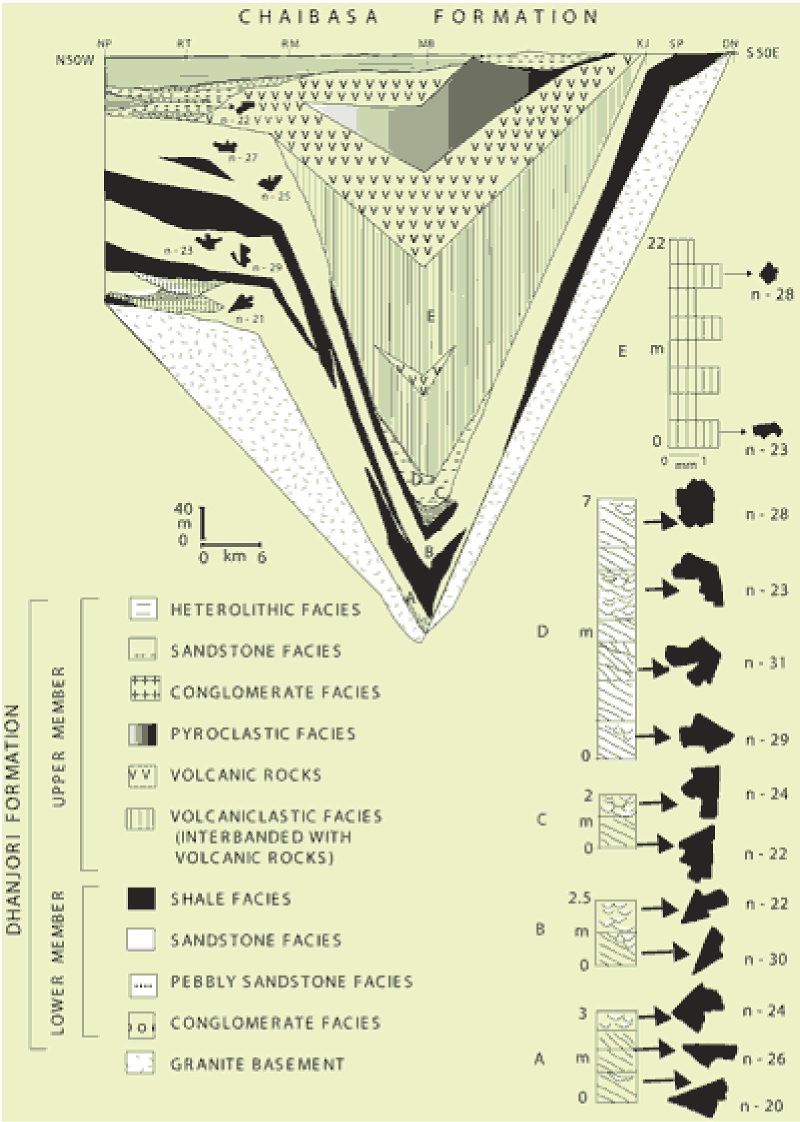

Figure 3: Lateral and vertical facies transition during Dhanjori sedimentation. Short sections showing interrelationship between various sandstone facies and temporal change in palaeocurrent direction are also shown (after Mazumder & Sarkar, 2004; their Figure 2; n represents number of palaeocurrent measurements). Study locations are marked in Figure 2a. Lithofacies constituents of the lower and upper members of the Dhanjori Formation are also marked. See Mazumder & Sarkar (2004) for detailed sedimentary facies analysis.

Dhanjori volcanism took place in an intracontinental rift setting as is evident from the interbedded, compositionally immature terrestrial deposits (*Mazumder & Sarkar*, 2004; Figures 4a,b). Confinement of the volcanic and volcaniclastic rocks within the upper member (Figure 3) implies that initiation of rifting was not a consequence of convective upwelling in the mantle. The presence of basalts (Figure 5), including some ultramafics, within the upper member implies subsequent upwelling of mantle materials and decompressional melting following crustal extension. *Gupta et al.* (1985) (summarized in *Mazumder & Sarkar*, 2004 and references therein) reported komatiitic rocks from the Dhanjori Formation, but typical komatiites with convincing chemistry and texture are absent. Although interbedded volcanics and volcaniclastics at different stratigraphic levels within the upper member indicate episodic volcanic eruption during sedimentation, evidence for pre-volcanic uplift are lacking and so is a radial palaeocurrent pattern (*Cox*, 1989; *Kent*, 1991). If Dhanjori volcanism is related to a mantle plume, then the consequences of this plume are not seen in the sedimentological record. Alternatively, the volcanism may simply represent a CFB unrelated to a mantle plume.

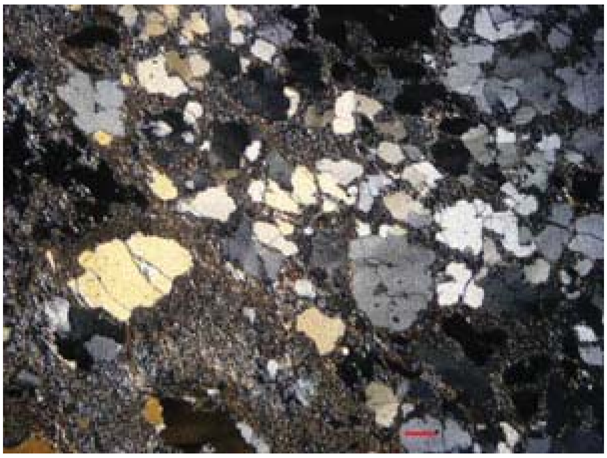

Figure 4a: Poorly sorted and texturally immature Dhanjori sandstone (red bar length 0.2 mm). Note the dominance of angular quartz and rock fragments.

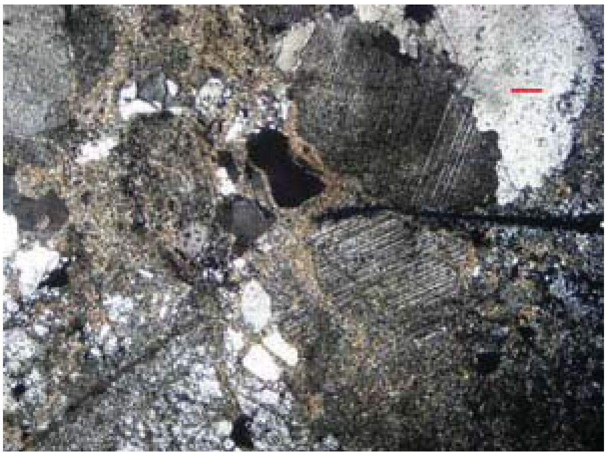

Figure 4b: Coarse-grained, feldspar-rich Dhanjori sandstone (red bar length 0.2 mm).

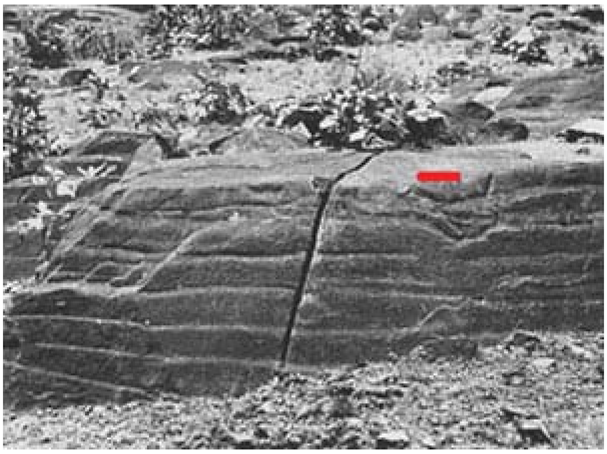

Figure 5: Flow banding within Dhanjori basalt (bar length 14 cm).

Final remarks

The claim that the sedimentary record provides independent supporting evidence for mantle plume influence on the generation of LIPs, is not always true (see also pages on Siberia, the Ontong Java Plateau and Ontong Java Plateau Impact theory). The genetic linkage between CFBs and mantle plumes is at best difficult to establish from sedimentological analysis alone.

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