Megatsunamis as a possible means of long distance transport of palynomorphs

Mehrotra *et al.*[1] reported reworked Carboniferous terrestrial palynomorphs (spores and pollen) in the Panna Formation (Palaeocene–Early Eocene) of Mumbai Offshore Basin. This was a puzzling report because Carboniferous sediments are not known from peninsular India. Although Carboniferous sediments are present in the Himalaya, they are marine and their palynomorph yield is known to be extremely poor, which has little in common with the reworked assemblage. Two explanations for this puzzle are: (i) speculated presence of Carboniferous sediments under the Deccan Traps, which were supposedly eroded and redeposited in the Panna Formation, and (ii) reworked palynomorphs might have come from Carboniferous sediments of Africa–Arabia by waves. So far, there is no proof of Carboniferous sediments under the Deccan Traps and the authors did not suggest any mechanism of wave transportation of Carboniferous palynomorphs from Africa–Arabia to Mumbai Offshore Basin.

This communication offers a viable explanation for this puzzle. During the KT transition, 65 Ma ago, an ~40 km diameter bolide hit the western shelf of India that created a giant and complex multi-ring crater with highs and basins, named the Shiva crater[2]. This catastrophic event generated megatsunamis that travelled in all directions severely impacting coastlines of western India, eastern Africa and southern Arabian Peninsula. Northwestward travelling megatsunamis impacted the Arabian continental shelf, coastal regions and moved on land till they hit the eastern and southern margins of the Arabian Shield. These waves were reflected back in the northeastern, eastern and southeastern directions. The effect of these waves on land severely eroded outcropping Carboniferous strata (Berwath Formation, C Member of the Unayzah Formation, the Al Khlata Formation and Khusayyayan and Juwayl Member of the Wajid Sandstone Formation). These Carboniferous stratigraphic units are known to contain terrestrial palynomorphs and all reworked taxa reported from the Panna Formation occur in these formations. It is argued that reflected tsunami waves from the Arabian Shield reached Mumbai Offshore Basin and carried along with them, eroded Carboniferous sediments and associated palynomorphs which were deposited in the sediments of the Panna Formation.

The Mumbai Offshore Basin is located on the western shelf of India which is a composite of several basins, highs and other geologic features under the Arabian Sea. This is a 7 km thick Tertiary basin with five major seismic horizons, H1 through H5. Sediments between H4 and H5 belong to the Panna Formation, which is the oldest stratigraphic unit that unconformably overlies the Deccan Traps (Zutshi *et al.*[2], unpublished). Chatterjee *et al.*[3] report a thick layer of breccia embedded in reddish claystone and siltstone, called the 'Deccan Trap breccia', present between the Panna Formation and the Deccan Traps. The age of the Panna Formation was considered to be Late Palaeocene–Early Eocene, based on foraminifers[2]. However, recent biostratigraphic analysis suggests that the lower part of the Panna Formation may extend to the Early Palaeocene Danian Stage (P. L. Zutshi *et al.*, unpublished).

Carboniferous sediments occur both in subsurface and outcrops in the Arabian Peninsula[4]. These include Early Carboniferous (Tournaisian) to Early–Late Carboniferous (Naumurian) Berwath Formation; Late Carboniferous C member of the Unayzah Formation (dated as Late Carboniferous (Stephanian) Oman–Saudi Arabia Palynozone (OSPZ)-1)[5], Al Khlata Formation[6]; and Juwayl and Khusayyayn Members of the Wajid Sandstone Formation (dated palynologically as Late Carboniferous (Stephanian) to Early Permian (Sakmarian)[7]. Pertinent literature[8–10] on Carboniferous palynology of Arabia was used to locate the source of reworked palynomorphs of the Panna Formation.

Chatterjee *et al.*[3] described a possible Cretaceous–Tertiary (KT) boundary impact called the Shiva Crater. It was created by a bolide of ~ 40 km diameter, which obliquely hit the Western Continental Shelf of India about 65 Ma ago. This impact created a complex peak ring crater with multi-ring basins. The possible role of megatsunamis generated by this event in erosion and transportation of Carboniferous sediments and associated palynomorphs from Arabia–Africa to Mumbai Offshore Basin is investigated.

This crater is covered under Cenozoic sediments and the petroliferous Mumbai Offshore Basin sits on top of it. The age of the Crater is based on: (i) Deccan Trap breccia and the overlying Danian sediments; (ii) radiometric dating of the presumed proximal ejecta melts, and (iii) the magnetic anomaly of the Carlsberg Ridge which was also created by the same impact. Since age estimates[11,12] of Deccan Traps are around 65 Ma, Chatterjee *et al.*[3] suggest that the Deccan Trap Breccia underlying the Panna Formation indicates impact-related sedimentary deposit at the KT boundary.

According to Ida and Iwasaki[13], tsunamis in the open ocean are not high but they grow in height as they approach coastal zones. As the depth of water decreases, their wavelength and velocity also decreases, but the wave energy remains nearly constant. The level of wave energy determines the level of sediment disturbance on the continental shelf, coral reefs, beaches, estuaries and deltas. Tsunamis can travel at high speeds for a long period of time and lose little energy in the process. One of the consequences of tsunami impacts on the coastal regions is that palaeosols like marshy and peaty soil get buried under thin layer of tsunami sand. Coastal erosion, sediment erosion and re-deposition, and deformation of coastal sediments are other important impacts of tsunamis[14,15].

During the KT transition, India was an island in the Indian Ocean located east of present-day East Africa and approximately 1500–2000 km southeast of the Arabian Peninsula. The Shiva bolide impact created gigantic megatsunamis that travelled in circular waves in all directions. The closest coastal regions hit by these waves were located on the west coast of India. On the other side, waves travelling in westerly and southwesterly direction moved to the coast of East Africa. Some of these waves were refracted or reflected back in the ocean in the southeastern direction after impacting the African coast. Thus there is no possibility of any sediment transport from East Africa to Mumbai Offshore Basin.

Megatsunamis travelling northwestward hit the southern coast of the Arabian Peninsula and gigantic waves moved along the low-lying Arabian coastal regions and further inland till they reached the southern and eastern margins of the Arabian Shield. This rigid high of crystalline rocks reflected back most of the waves in the northeast, east and southeastern directions. Waves travelling in the southeastern direction came back to the region of their origin, i.e. the Mumbai Offshore Basin. It is envisaged that megatsunamis that crossed over the lowlands of the Arabian Peninsula severely eroded outcrops of Carboniferous strata. The reflected returning waves carried fine Carboniferous sediments and associated palynomorphs to Mumbai Offshore Basin and deposited them in sediments of the Panna Formation. This interpretation follows the well-known phenomenon of coastal destruction, shelf and coast erosion and re-deposition by tsunamis[14,15]. According to Frank Gonzalez (US National Oceanographic and Atmospheric Administration), 'the dynamics of reflected tsunami waves are more or less identical to incident waves, including those wave properties that affect sediment deposition'. Lawton *et al.*[16] provide evidence of tsunami-induced sediment movement carrying debris from collision that spread back and forth across the Gulf of Mexico region following the Chicxulub Impact. The tsunami mixed the debris and sloshed it around, settling some and carrying sediments and fossils from the coast back into the ocean depths.

Since tsunamis hit the coastal regions of East Africa and Arabia, it is logical to expect tsunami deposits at the KT boundary in these regions. Since the KT boundary throughout East Africa is a regional hiatus[17], no basal Danian tsunami deposits are expected. Likewise, in the Arabian region also, there is widespread unconformity at the KT boundary. This was a period of widespread regression and most of the Arabian region was emergent, thus exposed to erosion[4]. Megatsunamis must have been extremely effective in eroding such an emergent surface. In the Khaimas sub-basin of northern United Arab Emirates, sedimentation continued through the KT boundary. There is a report of sandy anhydritic unit at the base of Paleocene in this basin[4]. This is the only report on the presence of sand in the otherwise shallow marine carbonate environment. This sand could possibly be a remanent of megatsunamis that impacted the Arabian Peninsula during the KT boundary. All these observations indicate that reworked Carboniferous palynomorphs from the Panna Formation were most likely sourced from Carboniferous sediments of the Arabian Peninsula.

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