Evidence of liquefaction near Baramulla (Jammu and Kashmir, India) due to the 2005 Kashmir earthquake

We report here the liquefaction caused near Baramulla in Jammu and Kashmir, India due to the 8 October 2005 Kashmir earthquake (*Mw* 7.6). Study of the liquefaction phenomenon and features caused due to earthquakes is vital for earthquake hazard assessment and palaeoseismology. From the analysis of worldwide earthquake and liquefaction data, it has been observed that an earthquake of magnitude as low as of 5, but more commonly of magnitude higher than 5.5 can produce liquefaction[1]. Also, liquefaction occurs under favourable geological and groundwater conditions and is generally widespread due to large and great earthquakes[2]. Liquefaction occurs when the water saturated sandy layer is overlain by confining medium like clay or silt. During an earthquake, shear stress built-up pore water pressure results in the cohesionless sediments and this leads to liquefaction. Liquefaction during earthquake shaking[3] most commonly originates at a depth ranging from a few metres to about 10 m. Water and sediment mixture erupts suddenly and violently to the surface through pre-existing cracks and fissures or through fractures opened in the capping material in response to seismic shaking. Detailed description and mechanism is described by Obermeier[3].

The 26 January 2001 Bhuj earthquake (*Mw* 7.6) produced liquefaction features not only in the areas close to the epicentre but even as far as about 450 km from the epicentre region near Jambusar[4], where the conditions were favourable for liquefaction. Similarly, the 1950 Upper Assam earthquake, the 1934 Bihar Nepal earthquake[5] and the 1897 Great Assam earthquake[2] whose meizoseismal area was in the alluvial region produced extensive liquefaction. On the other hand, earthquakes like those of the 1993 Latur[6] (*M* 6.1), and the 1999 Jabalpur[7] (*M* 6.1) with their meizoseismal areas in hard rocks, have not produced any liquefaction features. Thus it implies that all the earthquakes may not produce liquefaction unless and until favourable geological and water-table conditions are available at the site.

Here, we report the liquefaction and other related deformation features observed due to the 8 October 2005 Kashmir earthquake (*Mw* 7.6). The earthquake struck at 09:20:38 IST, and had its epicentre in Kishan Ganga (Neelum) valley, a tributary of River Jhelum in Pakistan Occupied Kashmir (POK; Figure 1). The epicentre lies 19 km NE of Muzaffarabad and 125 km WNW of Srinagar (lat. 34.432°N and long. 73.537°E)[8], located in the Frontal Himalayan belt bounded in the northeast by the Main Boundary Thrust (MBT) and in the west by the Jhelum and Shinkiari Fault. The area is covered with rocks of the Frontal Belt affected by fold-thrust movement during the terminal phase of Himalayan orogeny[9]. One of the nodal planes of the USGS fault plane solution showed almost N–S strike, paralleling the Jhelum–Shinkiari fault system[9] gently dipping in the NE direction lying in Indus–Kohistan Seismic Zone (IKSZ) with a focal depth of 20 km, attributing the thrust mechanism to this earthquake. However, Gahalaut[10] cautioned that this earthquake is not to be considered to be located in the Kashmir-Himalaya Seismic Gap and thus threat due to expected future major earthquakes in the Kashmir gap region still remains.

We observed the liquefaction features at Kichama-Shala Teng village, about 9 km from Baramulla town on the Baramulla–Muzaffarabad road on the left bank of Jhelum river (Figure 1). This location is about 80 km ESE from the epicentre. This area falls within the isoseismal of VIII intensity (MSK-64 scale)[9]. The coseismic features observed are in the form of sand dykes and blows, localized subsidence of ground surface, ground cracks, and lateral spreading at a single site stretching out to an areal extension of 800 × 300 sq. m (Figure 2). The elongation of cracks on the ground varies from 30 to 50 m in length, in the NE–SW direction, showing parallel to sub-parallel relationship between the separated individual blocks and also the river bank (Figure 2). It is observed that lateral spread-ground cracking is seen to be confined within a small area comprising river terrace bounded by large boulders and cobble strata in the upstream (Figure 2) and thick vegetation covering hard rocks in the downstream side. The width of cracks varies from 3 to 4.5 cm and the depth varies from 60 to 130 cm. Just at the water edge, the ground had overhanging features (about to fall) with wide cracks. The overall lateral spread on the area conformed to the topography but was in an arc-shaped geometry with respect to water edge line. Liquefaction features are found in the form of sand blows/sand volcanoes in clusters (eight features in number) and also one in solitary form associated with lateral spread. The distance between the solitary feature and the cluster is about 200 m in the upstream direction. In general, the surfacial observations show that there was a local ground subsidence due to liquefaction. There is one prominent feature showing a ground crack cutting across the sand blow (Figure 3) striking N40°, conforming well to the overall attitude (NE–SW) of all other external cracks in the area. Further, a sand

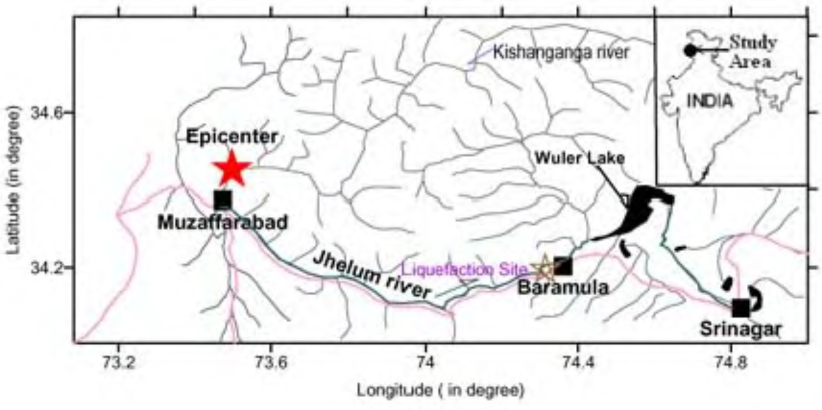

Figure 1. Location map of observed liquefaction near Baramulla and epicentre of the 8 October 2005 Kashmir earthquake.

Figure 2. A view of the lateral spread and ground cracks (30–50 m length) at Kichama-Shala Teng village 9 km from Baramulla, on the left bank of the Jhelum river located 80 km ESE of the epicentre of the 8 October 2005 Kashmir earthquake.

Figure 3. A view of the elliptical liquefaction feature (measuring about 2.3 m in longer axis and 1.6 m in smaller axis) observed as a solitary feature near Baramulla. Subsidence and ground cracks cutting across the sand blow are seen.

dyke with a surface expression of 14 m length is also observed. Though USGS mentioned about the liquefaction and sand blows[8] in the western part of the valley of Kashmir and near Jammu, no details are available. Though the earthquake magnitude is equal to that of the 2001 Bhuj earthquake, there are not many reports of liquefaction in the region except that by USGS (as mentioned above) and Thakur *et al.*[11], who reported liquefaction at the Simbal camp, Jammu. They observed that the feature extended in NE–SW for a distance of 250 m. However, severe landslides were reported by GSI, EERI[9,12,13].

The liquefaction features located by us lie along the left bank deposits of the Jhelum river. The right bank constitutes rocky outcrop of phyllite with thick hill slope wash materials like pebbly-boulder deposits on the flange. The left bank consists of unconsolidated fluvial deposits in a limited stretch of 800 × 300 sq. m with a levelled topography having gentle slope of maximum 10° towards the river in the form of terrace. The terrace has a 10 cm thick, well-sorted, medium grain-sized sand layer sandwiched between two impermeable silty-clay beds, which serve as a capping layer (maximum thickness of 2.1 m) and the silty clay layer below the sand bed has a maximum exposed thickness of ~ 4 m. River water level lies at 1–5 m from the natural surface along the upstream direction of the left bank terrace and depth to water table is about 3 m. Due to seismic shaking, pore water pressure in the sand layer increases but the shear strength of the granular strata at depth decreases. These strata can then fail in shear[14] even where the ground surface is inclined as gently as 0.1 to 5%. Due to geological and geohydrological conditions explained above, overlying confined material shifted horizontally in the form of laterally moving landslides (lateral spread). Sand is vented to the surface through some fissures. Conditions which caused lateral spread and liquefaction are similar to those explained by Obermeier[3]. Attempts are under way to study palaeoliquefaction and test the hypothesis of direct dating of liquefaction by optically stimulated luminesence dating technique in the area.

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Was Yangtze Craton, South China attached to the Trans-Aravalli block of the NW Indian shield during Late Proterozoic?

We highlight here the similarities between the Yangtze Craton (YC) of South China and the Trans-Aravalli block (TAB) of the NW Indian shield in terms of anorogenic, bimodal, 'within plate' magmatism, Strutian glaciation and position of palaeo-poles during Late Proterozoic. The study has implications for plume tectonics and assembly of the Malani supercontinent.

The Indian shield is composed of three main geotectonically different blocks or terranes, the South Indian Block (SIB), the Bundelkhand block (BB) and the Trans-Aravalli block (TAB), which were juxtaposed and sutured during different periods of earth's history. The TAB (west of the Aravalli Mountain) is unique in the geological evolution of the Indian shield as it marks a major period of anorogenic (A-type), bimodal, high heat-producing, 'within plate' magmatism represented by the Malani igneous suite. The Malani magmatism (50,000 sq. km; 732 Ma) comprising peralkaline (Siwana), metaluminous to mildly peralkaline (Jalor) and peraluminous (Tusham and Jhunjhunu) granites with carapace of acid volcanics (welded tuff, rhyolite, perlite, explosion breccia, etc.) is characterized by volcano-plutonic ring structures – Siwana, Jalor, Tusham and radial dykes (Jhunjhunu) (Figure 1). The suite is bimodal in nature with minor amounts of basalt flows, gabbro and dolerite dykes[1]. The Siwana ring structure (25.6 km NS and 31 km EW) is the most spectacular feature of the Thar Desert and it coincides with low-velocity anomaly centred around Sarnu–Dandali and Mer-Mundwara, Rajasthan, representing fossil plume head[2]. The Malani magmatism is controlled by NE–SW trending lineaments of fundamental (mantle) nature and owes its origin to the Malani plume[3,4]. Representatives of Malani magmatism also occur in Kirana Hills, and at Nagarparkar in Pakistan.

South China comprises the YC to the northeast and the Precambrian Cathysia block to the southeast. The YC has a Late Archaean–Proterozoic nucleus surrounded mostly by younger orogenic belts. Both the blocks were sutured during collision of Grenville age[5] (Figure 2).

Neoproterozoic anorogenic magmatism and coeval mafic magmatism are widespread around the YC of South China. The magmatism coincides with NS-trending Kangdian rift and NE-trending Nanhua rift. The first one at ca. 830–795 Ma (pre-rift) and the second one at 780–745 Ma (syn-rift), the Chengjian magmatism. The later granites are younger than 1.0 Ga Siban orogeny and intrude the rift sequence. Both the pre- and syn-rift magmatism have been attributed to superplume because of its intraplate setting, peralkaline to alkaline affinity and association with coeval swarms of mafic dykes. Emplacement of the dyke swarm initiated the break-up of Rodinia. The superplume may represent two normal plumes to account for these two episodes of magmatism[6].

According to Wong and Li[7], at places the ca. 780–750 Ma granites are unconformabaly overlain by Upper Sinian sequence (750 Ma), which is interpreted to have formed a rift cover. Li *et al.*[6] have correlated the syn-rift (780–745 Ma) magmatism with the Malani magmatism besides those of Laurentia, South Africa and Australia.

The APWP palaeomagnetic poles at ca. 800 Ma place South China at 55–70°N at par with high paleolatitudes of India during Malani rhyolite period (ca. 750 Ma)[8,9]. The migration of India to higher paleolatitudes could be the cause of Precambrian glaciation as exemplified by the Pokhran boulder in Rajasthan which is of

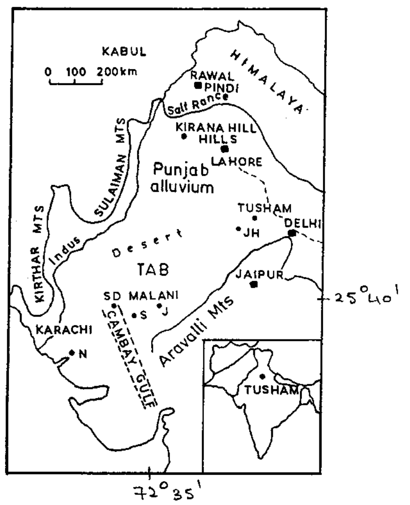

Figure 1. Location map of the Malani igneous suite. SD, Sarnu-Dandali; J, Jalor; S, Siwana; JH, Jhunjhunu; N, Nagarparkar.