The 24 August 2021 M_w 5.1 earthquake, 320 km northeast of Chennai, India: brittle rupture of a fault line

On 24 August 2021 at 12:35:50 IST, an undersea earthquake of magnitude M_w 5.1 on the Richter scale occurred at a depth of around 10 km and shook some parts of the southeast coast of India (source: USGS). The epicentre of the quake lay in the Bay of Bengal (BoB) at 14.440°N lat. and 82.991°E long., about 296 km southeast of Kakinada, Andhra Pradesh and 320 km northeast of Chennai (Figure 1). A few coastal parts of Tamil Nadu and Andhra Pradesh felt mild tremors, but there was no reported destruction, tsunami warning and aftershocks. Although the eastern BoB has witnessed a few earthquakes in the historical past (see figure 1 of Krishna *et al.*[1]), the western BoB has remained relatively stable. The last activity was noticed more than a century ago on 19 May 1918 at a location of 15.9°N, 83.7°E (Figure 1). In the recent past, on 21 May 2014, the eastern BoB had witnessed a 6.0 magnitude earthquake at 18.3°N, 87.9°E. These quakes are situated in the far interior away from active seismic zones such as divergent/convergent/transform plate boundaries, and also from diffusive plate boundary in the Indian Ocean. Therefore, the present earthquake event has drawn our attention to examine available geophysical data around the earthquake location to discern possible causes that may have generated this unusual, shallow-depth earthquake.

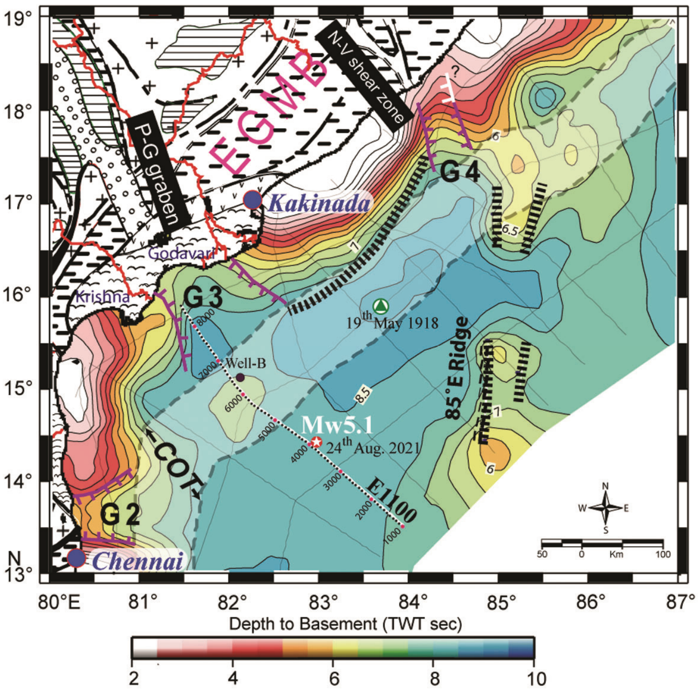

Figure 1. Map showing depth to the basement in the Bay of Bengal and adjacent onshore geology of India (after Krishna *et al.*[1]). White star within red circle represents the location of the 24 August 2021 earthquake (https://earthquake.usgs.gov/earthquakes/eventpage/us7000f2x8/executive) and green triangle in white circle shows the past earthquake event in the same area which occurred on 19 May 1918 (ref. 5). White line with black dots shows the seismic profile used to investigate the fault fabric and its past activity in the vicinity of the earthquake event. Solid black circle shows the location of ONGC drill hole 'B' (ref. 1) and thin lines are the network of the ION/GXT multichannel seismic reflection profiles. G2, G3 and G4 are continuity of onshore grabens. COT represents the continent–ocean transition separating the continental rocks from the oceanic rocks.

Deep seismic reflection data available in close proximity (~10 km from the epicentre) of the earthquake were examined to decipher the structural fabric and activity prior to the occurrence of the present event. The high-quality seismic image shows a mound-like structure with a rise of approximately one kilometre from the surrounding basement level and a number of faults fracturing the upper oceanic crust (Figure 2). The oceanic basement is overlain by approximately 5 km thick sediments and 3.24 km water column. The sedimentary strata over the structural mound are deformed in response to past tectonic activity in the area. The sedimentary horizons are correlated to chrono-stratigraphic results of ONGC drill well B for assigning age to the cessation of the last activity[2]. It was found that the faults on flanks of the structural mound were active up to 0.3 Ma (Figure 2). This observation suggests that the last tectonic event took place in the present

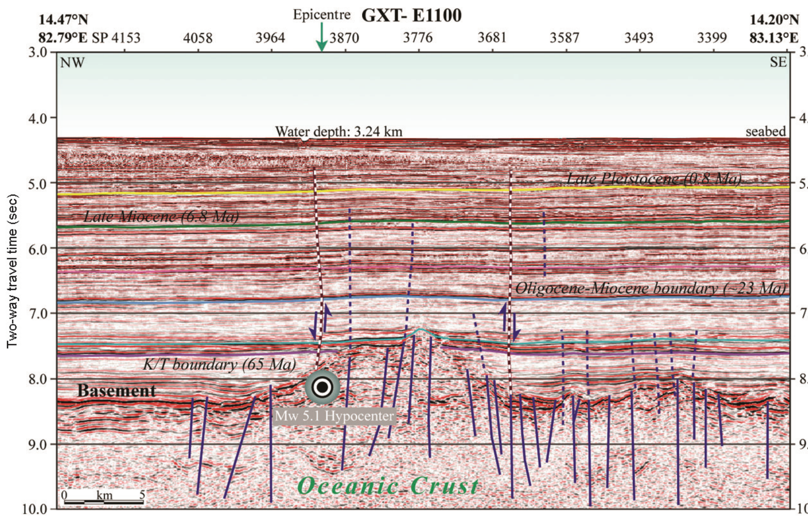

Figure 2. Seismic image in the immediate vicinity of the earthquake location. Epicentre and hypocentre are projected on the seismic section. Series of small-scale faults around the structural mound and their continuity into the overlying sediment strata are shown. Location of the seismic profile is shown in Figure 1.

earthquake region about 0.3 Ma and was reactivated on 24 August 2021. The sediments deposited in the adjoining parts of the mound structure were thicker by more than 1 km compared to those lying over the mound. This led to a notable differential sediment loading and vertical stresses on fault planes lying on the mound structure and in the adjoining oceanic basement. Therefore, it is considered that differential loading of sediments on the mound structure may possibly have triggered this moderate earthquake in BoB.

The earthquake that struck in the western BoB on 24 August 2021 is an unusual one compared to the previous event that occurred on 21 May 2014 in the eastern BoB with reference to both depth of origin and mechanism. The 2014 earthquake nucleated at 50–60 km depth within the upper mantle, while the present one has occurred at a shallow depth of 10 km immediately below the basement. The processes that led to the triggering of both earthquakes seem to be different. The 2014 earthquake originated at a greater depth within the oceanic mantle, where brittle failure may not have been a possible mechanism for its occurrence. Therefore, several non-brittle failure mechanisms were proposed for the generation of the 2014 earthquake in the eastern BoB[3–5]. Interpretation of seismic section reveals that weak fault zones exist within the upper oceanic crust in the vicinity of the 2021 earthquake location that got reactivated at 0.3 Ma (Figure 2). Earlier, Krishna *et al.*[1] had analysed the behaviour of a 300 km-long palaeo-fault system that exists on the central eastern margin of India. They inferred that rift-related normal fault was reactivated during the Early Miocene (~16 Ma) and continued its activity until 0.3 Ma before cessation. The plausible mechanism suggested for this episodic activity is due to the vertical loading of the sedimentary column exerted on underlying weak zones within the crust. Thus, we conclude that the differential sediment loading on both sides of the structural mound may be responsible for developing a vertical stress field and triggering the brittle failure of pre-existing weak zone/fault planes within the oceanic crust. In our view, large parts of the western BoB are mostly free from tectonic influence, but are experiencing differential stresses caused by variable sediment loading. This note presents some initial observations, and the focal mechanism is not constrained yet. Therefore, we cannot completely rule out other possibilities for the occurrence of this 2021 intraplate earthquake in the western BoB.

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Accomplishments in edible seaweed domain in India and the way forward

Seaweeds have been commonly utilized as a component of oriental diet, especially in Japan, China and Korea since ancient times owing to the presence of beneficial nutrients. Although there is little tradition of using seaweed in Western cuisine, at present there is renewed interest in India to use seaweeds as sea vegetables. They possess not only nutritional value, but also pharmaceutical properties like anticoagulant, anti-mutagenic, antioxidant, anti-cancerous and antibacterial activity. Thus, seaweeds have enormous commercial importance for human food, nutraceuticals and pharmaceuticals production. The commercial seaweeds market was estimated to account for USD 13.3 billion in 2018. It is projected to reach USD 21.11 billion by 2023, at a compound annual growth rate of 8.4% in terms of value, 85% of which will be comprised of food products for human consumption[1].

Further, Global Hunger Index (GHI) 2020 puts India much lower in ranking (94) than some of the neighbouring countries[2]. It may be noted that India has a more calorie-deficient or undernourished population. Besides, the prevalence of underweight children and associated mortality is alarming. Based on the available statistics, an overwhelming 31% of the country's population follows strict vegetarian diet. This provides a perfect opportunity for introducing seaweed-based diet into the Indian culinary sector, especially in popular programmes like the 'Midday Meal Scheme' to enhance nutritional quality. This note highlights the major accomplishments carried out in the edible seaweed sector during the last few decades, and the way forward.

Taxonomy and utilization

The earlier taxonomic works have enlisted 8 species of *Ulva* and 13 species of *Enteromorpha* along the Indian coast[3,4]. Two species of *Monostroma*, namely *M. latissimum* and *M. oxyspermum* were reported from the west coast of India[5]. Seven species of *Porphyra* were reported from the country[6]. The interest in the edible aspects of seaweeds has been generated primarily due to their medicinal properties rather than nutrition benefits. Two projects were sponsored by the Department of Ocean Development, Government of India, to study antibacterial (especially anti-tuberculosis) activities from *Enteromorpha* and iodine content of seaweeds from India – with special reference to Gujarat. The initial work by Parekh and his team at CSIR-Central Salt and Marine Chemicals Research Institute (CSMCRI) (1983–85) covered biochemical analysis of several components of seaweeds, especially amino acids, minerals, proteins, pigments and lipids. Mention should also be made of the critical work on proteins, amino acids and peptides from seaweeds by Lewis at CSIR-CSMCRI (1962–80). The overall work can