Recent microseismicity in Nellore district of Andhra Pradesh

The Nellore district in the Southeastern part of Andhra Pradesh is one of the nine coastal districts of the state. The microtremor activity in the district started in October 2015 and continued up to July 2016. During this period, a few hundred tremors were recorded by the temporary seismic network installed locally by the CSIR-NGRI. Apart from the data recorded by this network, those from the semi-permanent seismic stations at Racherla, Addanki, Cuddapah, Srikalahasti and Srisailam were used in the study[1].

The Nellore Green Schist Belt (NSB) in the southern peninsular shield consists of several geological and geochemically distinct tracts of deformed volcano sedimentary successions: the Vinjamur group, Kandra ophiolite complex, the Kanigiri ophiolitic melange and the Udayagiri group. The NSB has been traditionally divided into the western Udayagiri group dominated by a low grade metasedimentary succession and the eastern Vinjamur group with amphibolites (metabasalts) and magmatic gneisses[2,3]. The NSB hosts a number of younger felsic to alkaline-mafic intrusives in its northern part (Prakasam district) constituting the Prakasam Alkaline province[4]. Recently, NSB has received attention in terms of reports of supra-subduction zone ophiolitic melange, deformed alkaline rift complexes and records of deformation indicating possible multiple crustal convergences[5–9].

The microtremor activity in Nellore district is confined to a very narrow area bound by villages Chakalakonda and Kothapeta. In this study, a total of 231 tremors were located in the region, using the velocity model inferred from controlled source seismic experiment[10]. Similar microtremor activity was also reported in Hyderabad during 1994, 1995, 1998 and 2000, from the Jubilee hills area located in the western part of the city. The largest event in this sequence was of magnitude 2.8. During October 2010 localized microtremor activity, accompanied with subterranean sounds, was reported in the Vanastalipuram area in the eastern part of Hyderabad. Sporadic microearthquake activity was also observed during 2007–2009 in Nanded (Maharashtra) with the largest magnitude being 2.9 (ref. 11).

The waveform data of microtremors in Nellore were collated from all the network stations to obtain hypocentral parameters. Well-located epicentres were plotted to examine the spatial distribution. It was noticed that all these tremors occurred at shallow depths in the upper most crust, down to a depth of 9 km. The largest magnitude earth tremor in this sequence was 3.5, corresponding to an event on 28 May 2016. Analysis of the seismicity pattern indicates that they align with the Nellore–Badvel Fault oriented in the NW–SE direction and Terrane Boundary Shear Zone (TBSZ)[12], which is marked by several major lineaments parallel to the Cuddapah Eastern Margin Thrust/Shear (CEMT)[12].

Taking cognizance of the maximum felt earth tremor reports from this region, we attempted to examine the amplification level of seismic signals using the spectral ratio of horizontal to vertical (H/V) components. The amplification depends on layer thickness, degree of compactness and age of the formation. The damage during an earthquake is generally larger over soft sediments due to the large amplification of ground motion compared to that on rigid outcrops. Estimation of amplifications shows high amplification particularly in the study region, because most settlements are along river banks comprising soft sediments. The technique of ambient noise measurement and analysis has been successful in characterizing the spatial variation of amplifications. In this case, we studied the site response at the Vinjamur village seismic station using the

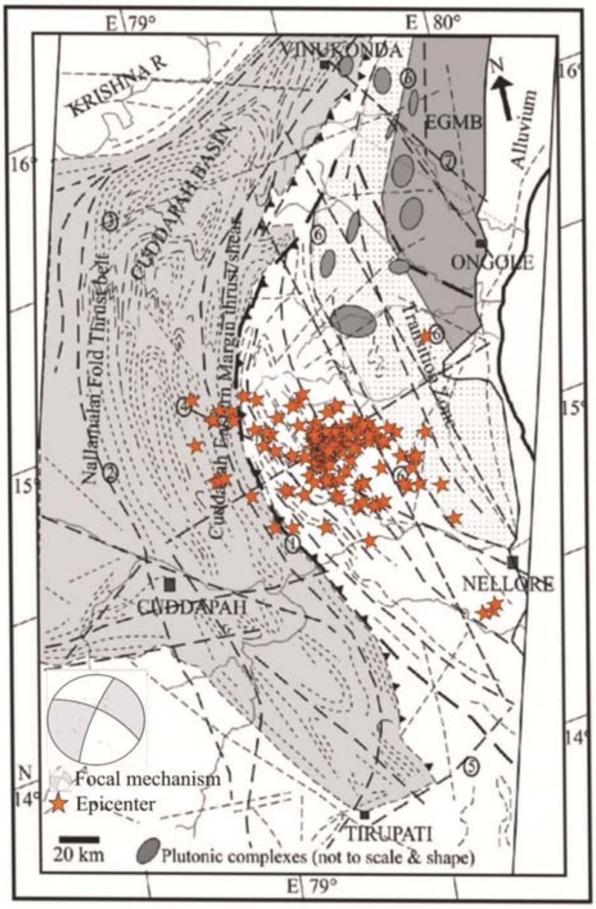

Figure 1. Plot of epicentres on image interpretation of landsat TM[11]. Some of the major lineaments (shown with numbers) are: (1) Cuddapah Boundary Thrust, (2) Nallamalai/Rudravaram Line, (3) Gani-Kalva Fault, (4) Nellore-Badvel Fault, (5) Karakambadi Fault, (6) Terrane Boundary Shear Zone (TBSZ) and (7) Gundlakamma Fault.

H/V ratio of the Fourier spectrum of recorded ground motion, in terms of dominant frequencies and amplifications. Lermo and Chávez-García[13] found that the estimated dominant period of the site response and the overall amplification factor varies with geology. The method gave a good estimate of frequency and amplitude for the first resonant mode of the site. At Vinjamur, a significant amplification, up to four times, was observed in the predominant frequency range of 6–8 Hz, implying that input signal in this frequency range is amplified, due to soft soils in the uppermost layers of the terrain. High amplification also suggests a high impedance contrast between soft soils and basement rocks on which these are deposited.

Fault plane solution from observations of seismic waves is important to characterize the earthquake source or nature of faulting. In the present study, a focal mechanism is obtained for a M 2.8 microtremor, using the first motion polarities recorded at 9 seismic stations. The obtained strike–slip solution is in conformity with existing tectonic environment in the region. The NW–SE trending nodal plane is considered the primary plane of faulting.

Fluctuations in the depth to the water table accompanied by changes in river flows transmit pore-fluid pressure transients to hypocentral depths. This mechanism can trigger earthquakes in a brittle medium already stressed and close to failure[14]. However, in regions with pre-existing fractures, conducive hydrological conditions can trigger earthquakes due to excessive rainfall, termed as hydroseismicity. A good rainfall occurred in Nellore during 2015–16 compared to 2014–15 and previous years (source: Revenue Divisional Offices of Nellore district). The rainfall data during 2015–16 at Udayagiri, Varikuntapadu and Vinjamur mandals in Nellore district were plotted against the number of earthquake events located by our study. A visual inspection reveals a good correlation between heavy rainfall and increased seismicity (Figure 3).

In summary, well-located microtremors define a narrow epicentral zone aligned along Nellore–Badvel Fault oriented in the NW–SE direction and TBSZ, which is marked by several major lineaments parallel to CEMT[12]. These are responsible for the recent ongoing swarm activity in Chakalakonda–Kothapeta areas situated in the NSB. The seismogenic depth is found to be shallow (<9 km). Focal mechanism studies reveal strike–slip faulting. Interestingly, correlation of rainfall data with the timing of

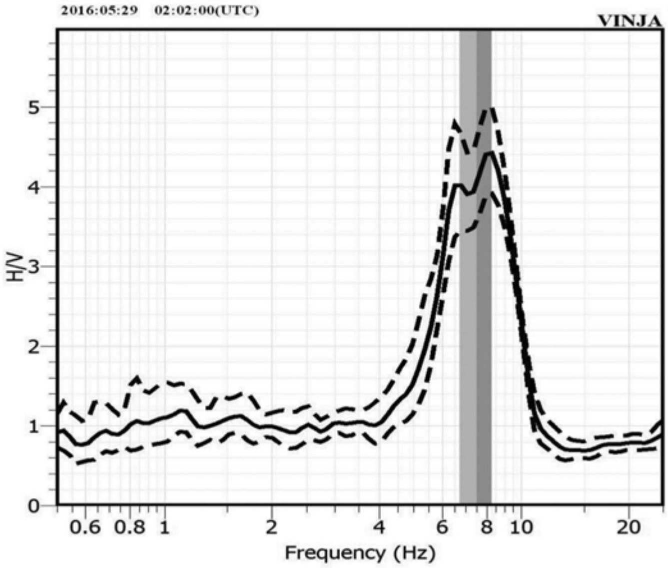

Figure 2. H/V spectral ratio plot for ambient noise recorded at Vinjamur Seismic Station.

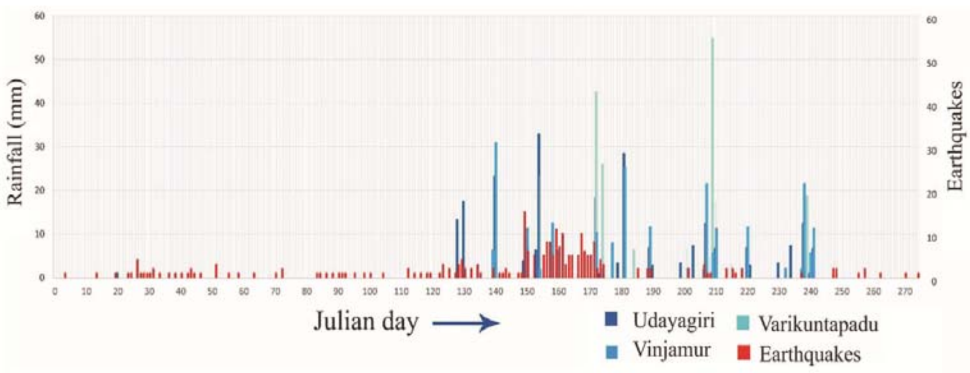

Figure 3. Histogram showing rainfall data versus number of earthquakes per day located in the study region.

seismicity, causally supports the hypothesis of hydroseismicity. Pore pressure diffusion guided by a permeable fracture zone in this region, is a plausible mechanism for this swarm type hydroseismicity. A comprehensive analysis leads to the inference that earthquake swarm nucleation is a result of time-dependent stress changes induced by water infiltration due to excess rainfall in areas straddling the seismic zone, like Varikuntapadu Mandal in Nellore, in addition to the constant tectonic stress prevailing in the region.

1. Srinagesh, D. *et al.*, *J. Geol. Soc. India*, 2015, **85,** 419–430.
2. Ramam, P. K. and Murthy, V. N., *Geol. Soc. India*, 1997, 245.
3. Saha, D., *Gondwana Res*., 2002, **5**, 701–719.
4. Kaila, K. L. *et al.*, *J. Geol. Soc. India*, 1979, **20**, 307–333.
5. Saha, D., *J. Asian. Earth Sci*., 2011, **42**, 158–175.
6. Upadhyay, D., *Precambrian Res*., 2008, **162**, 59–69.
7. Vijaya Kumar, K., Ernst, W. G., Leelanandam, C., Wooden, J. L. and Grove, M. J., *Tectonophysics*, 2010, **487**, 22–32.
8. Dharma Rao, C. V., Santosh, M. and Yuan-Bao, W., *Gondwana Res*., 2011, **19**, 384–401.
9. Ratnakar, J. and Leelanandam, C., *Geol. Soc. India, Mem*., 1989, **15**, 145–176.
10. Chandrakala, K., Mall, D. M., Dipankar Sarkar and Pandey, O. P., *Precambrian Res*., 2013, **231**, 277–289.
11. Srinagesh, D. *et al.*, *Curr. Sci*., 2012, **103**, 366–369.
12. Nagaraju, J. and Chetty, T. R. K., *J. Indian Geophys. Union*, 2014, **18**, 165–182.
13. Lermo, J. and Chávez-García, F. J., *Bull. Seismol. Soc. Am.*, 1993, **83**(5), 1574–1594.
14. Vasudevan, D. and Rao, T. M., *Indian Miner*., 1975, **16**, 43–47.

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Parasitic nematode in dead stranded dugong on Mithapur coast, Okha, Gujarat, India

The dugong is a herbivorous marine mammal and the only extant species of family Dugongidae. It has a large distribution range, which includes subtropical and tropical countries in world. In India, the mammal is distributed in the Andaman and Nicobar Islands, Gulf of Mannar and Palk Bay, Tamil Nadu and Gulf of Kachchh, Gujarat[1–4]. In Gujarat, the current population status of dugong is unknown and its sighting is rare. Here we report the presence of parasites in a dead dugong stranded at Mithapur (22°25′14.5″N, 68°59′34.8″E), Okha, Gujarat on 3 January 2013.

Dugongs are susceptible to a wide range of diseases, including parasitic and infectious diseases[5]. This marine mammal serves as an ideal host to diverse forms of parasites that thrive in the internal organs and also external parasites on its body surface[5]. Blair[6] lists an array of parasitic infestations from the species of order Sirenia (Dugong and Manatee). Over the years, at least 19 species of trematodes and one species of nematode have been described from dugongs[5]. Barnacles and copepods were observed residing as unusual parasites on dugong[7]. Major internal parasites are commensal organisms, but few parasites have also been related with disease[5].

The internal parasitic nematode, *Paradujardinia halicoris* is the only species found in the dugong stomach, reported from several countries, including Australia, the Philippines Red Sea, Papua New Guinea, India, Sri Lanka, Madagascar, Malaysia, Palau and Japan[6,8]. One species of nematode (*P. halicoris*) and three species of trematode parasites have been observed from dugongs in the Gulf of Mannar, but external parasites have not been reported[9].

Nematodes were observed in the stomach of the dead stranded dugong during post-mortem. The sample was collected and preserved. Scanning electron microscope (SEM) was used with the standard protocol. The images were captured on a SEM CARL ZEISS (model no. EVO-18) at the Gujarat Ecological Education and Research (GEER) Foundation, Gandhinagar. SEM revealed more accurate details of morphological structures of the specimen[10]. Identification of specimens was done in consultation with the relevant literature[11–14]. For further confirmation, the photographs were sent to David Blair, James Cook University, Australia.

From morphological details of the sample (Figure 1) and SEM observations (dead sample – dried) (Figure 2), the species was identified as *Paradujardinia halicoris* (Owen, 1833)[15]. Blair also approved and confirmed the species. SEM revealed certain distinct features of this species, specifically three lips at the anterior end of the specimen (Figure 2). This helped validate our observations.

A total of around 18 individuals of the species were observed, which were about 80–100 mm in length. The external morphological characteristics of species are as follows[11–14]. A well-marked constriction separates the head from the neck. Mouth with three well-defined rounded lips. Male is slightly smaller than female.

Although over the years several dead stranded dugongs have been recorded[2] and necropsied, there was no record of this parasite from their body. To the best of our knowledge, there seem to be no previous records on endoparasitic infestation in dugongs in Gujarat.

Several decades earlier, a study had described a dugong infection by 540