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Published by Elsevier Science Ltd 1996
Paper No. 1765. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

MACROSEISMIC SURVEYS AND SOURCE MECHANISM OF LATUR EARTHQUAKE OF 30 SEPTEMBER 1993, PENINSULAR INDIA

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ABSTRACT

Macroseismic surveys have been conducted for Mb-6.3 intraplate Latur earthquake and an intensity of IX on MSK Scale has been assigned to the meizoseist. The isoseismals are aligned in the N55°E-S55°W direction though the fault plane solutions have given nodal planes aligned in the N60°W-S60°E direction. This event took place in an area occupied by Deccan Volcanics which has concealed the basement tectonic elements. The authors have constrained the basement tectonics by geophysical means and have interpreted that this earthquake is related to intersecting tectonic surfaces. The initial fault break took place along NW-SE trending reverse fault while the propagation was along NE-SW trending strike slip fault.

KEYWORDS

Intraplate earthquake, damage patterns, isoseismals, intersection tectonics.

INTRODUCTION

An intraplate earthquake of magnitude 6.4 (Mb 6.3 USGS) struck the Marathwada region of Peninsular India in the early hours of 30 September 1993 taking a toll of over 7,500 human lives, injuring about 15,000 people and inflicting various degrees of damage to 34,000 houses. The main shock was followed by a number of aftershocks, a few of which were of magnitude upto 5.2 and most of these were located within an area of 500 sq km around the epicentral tract of the main event.

The occurrence of this earthquake acquired greater significance since it jolted a region where such events were least expected. The 650 year old seismic history of the entire Peninsular India has only 9 earthquakes of magnitude greater than 6, including the Kutch earthquake of 1819 (Mag. 7.8) which produced a spectacular fault scarp in the form of "Allah Bund" and the present one which is the deadliest of all the Indian intraplate events. The number of seismic events of magnitude ≥5 in the region is 55.

The low seismicity of entire Peninsular India indicates quite a few tectonic lineaments to be seismogenic in nature. A number of such fundamental faults and shears delimit many tectonic units of the region including Dharwar, Bundelkhand, Aravali and Singhbhum cratons, Pandhyan and East Coast mobile belts, West Coast and Sahayadri tectonic trends, the SONATA (Son - Narmada - Tapti) Rift zone and the Mahanadi, Godavari, Cambay and Kutch grabens of Mesozoic Gondwana age. Out of these, only the Cambay Graben, the West

Coast Tectonic trend, the SONATA Rift zone and the Mahanadi, Godavari Mesozoic Gondwana Grabens have been assigned relatively higher seismic hazard in the contemporary Seismic Zoning map of India on the basis of seismic incidence patterns. Besides this, Umesh Chandra (1977) has identified a number of seismic zones namely the Panvel zone, Narmada zone, Cambay zone, Rann of Kutch, Gimar, Singhbhum, Kakinada-Midnapur, Bhadrachalam, Ongole Kerala-Tamil Nadu and Bellary-Malabar zones based primarily on seismicity pattern and fault plane solutions. The event under study, with the exception of only Bellary earthquake of 1843 has defied all the identified seismic domains and has occurred in the Deccan Trap province wherein well defined seismogenic lineaments are not present. The only major tectonic element in this province, the Kurudwadi fault, has been interpreted on the basis of geophysical attributes. The other lineaments demarcated from remote-sensing techniques are wanting in ground truth. In such a continental domain where a thick pile of Deccan Volcanics is concealing the basement tectonics the constraining of source mechanism has been a difficult exercise and a lot of indirect evidences have to be pooled in to propose a seismotectonic model.

The authors of this paper have synthesized the data generated by macroseismic surveys and geophysical studies and utilised them to constrain the most probable source model which effectively explains various geological and geophysical attributes.

MACROSEISMIC SURVEYS

Extensive macroseismic surveys of about 20,000 sq km area covering more than 200 villages were conducted in the region to constrain the isoseismals of this event based on the degrees of damage suffered by various types of constructions including a few well engineered ones and on the basis of terrain changes brought about by this event. The isoseismals have been delineated by utilising the Madvedev-Sponheuer-Karnik (MSK) Intensity scale and a maximum intensity IX has been assigned to the meizoseist (Fig. 1). In the epicentral and neighbouring area the poor type structures, constituting about 90% of the total constructions have suffered almost complete collapse, corresponding to Grade 4 and 5 of MSK scale. Hence, for the delineation of higher intensity isoseismals greater emphasis has been given to the damage patterns observed in a limited number of brick-cement houses and a few RCC structures.

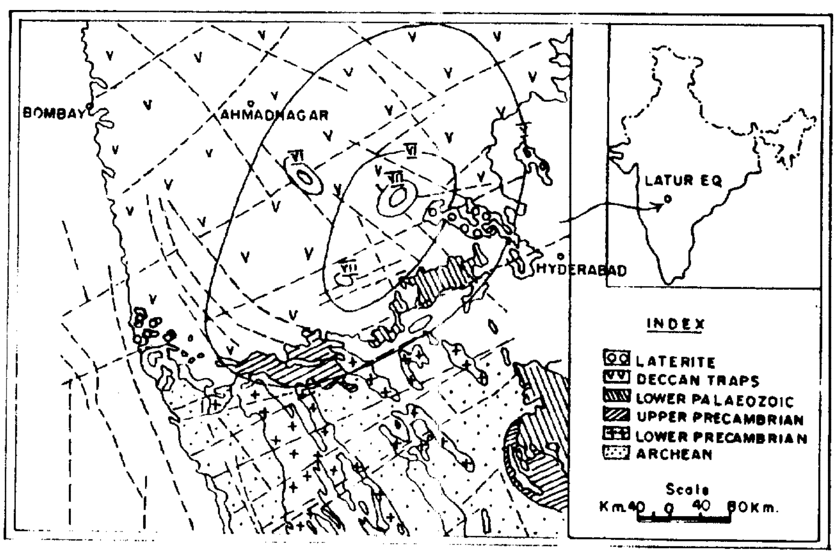

Fig. 1. Isoseismal map of Latur earthquake

The majority of conventional houses in the region are inward looking enclosed constructions having thick and voluminous masonry walls with poor mortar, single outlet and without proper inter-spacing. The damage to such constructions caused the blocking of entries and, hence, trapped the people inside the collapsed houses in choking and suffocating conditions which resulted in very high casualties in and around the epicentral tract. Twenty five villages on both sides of the easterly flowing Tirna river were reduced to rubble and fifty eight others suffered heavy damage. The catastrophe, besides taking a heavy toll of human life caused immense loss of livestock and above all infused a sense of fear psychosis and an endless agony in the minds of the survivors, unmeasurable over any intensity scale.

Meizoseist

A. Damage To Constructions. Six villages namely Killari, Killariwadi, Gubal, Mangrul, Talni and Ganjankhed to the north of Tirna river and eleven villages including Rajegaon, Chincholi, Sastur and Hulli on the southern bank of the river became absolutely uninhabitable. In these villages 14.34% of the total population was killed and another 14.6% was seriously injured, and 91.8% of the houses were completely damaged (Pande *et al.* 1995a). Killari being the largest and most prosperous locality in the meizoseismal zone exhibited almost 100% local type constructions razed to the ground and varied damage in well built brick-cement or RCC column structures. In the Water Tank Complex, heavy damage in the form of shear cracks and fall of small portions of walls occurred in the Post Office, 'Sehkari' Bank and the Hospital buildings. While similar damage occurred in the School building outside Rajegaon, the Grain Godown at Talni and 'Panchayat' office at Sastur showed minor collapses as well. In old and well built structures like the 'Neelkantheshwar' temple at Killari there was heavy damage and a northerly displacement of a large stone idol. The ancient temple of Lord 'Shiva' at Gubal suffered heavily and the 450 year old "Kala Gumbaj" of Sastur completely collapsed.

The damage to the engineered structures has been low to moderate. The RCC Water-Tank at Chincholi village was severely damaged by the earthquake and was later pulled down for fear of its impending collapse. A 62 m long and 4.5 m high irrigation barrage (under construction) across Tirna river at Rajegaon developed cracks in 14 out of 18 piers founded on basalt (Fig. 2). There was minor fall of masonry from some of the piers. In the aqueduct of Lower Tirna Project near Talni, the bearing plates of end piers got jammed due to the vibration of the structure. In an RCC bridge near Mangrul, longitudinal cracks, trending in N50°W-S50°E direction appeared in both the abutments and the deck also cracked. The southern masonry parapet of a culvert, located 2 km west of Killari, was completely dislodged by the strong shaking and shear cracks appeared in the culvert masonry, besides development of slump cracks in the rivulet bank (Fig. 3).

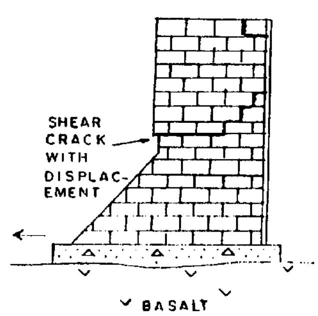

Fig. 2. Damage to a masonry pier of a barrage across Tirna river.

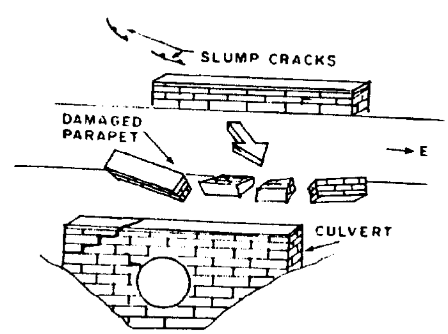

Fig. 3. Collapse of a low parapet, shear cracks in the masonry culvert and cracks in rivulet bank.

B. Terrain Changes. The terrain changes, occurring mainly in the meizoseismal zone, are of a subdued nature primarily because of a low relief topography in association with a limited thickness of soil cover. These are mostly in the form of minor slump cracks and slump failures in and around the epicentral tract. The most important terrain change has been witnessed 2.5 km northwest of Killari in an area of 1600 sq m where the ground has upheaved by 20-25 cm in a length of 135 m. Associated with this feature, N-S and NNE-SSW trending ground fissures have been formed. Along one such fissure trending in NNE-SSW direction, evidence of left lateral strike-slip movement of the order of 20-25 cm is discernible (Pande *et al.* 1995b).

Isoseist VIII

In the 350 sq km cumulative area of this Isoseist, 2.49% of the population has been killed and 70.85% houses badly damaged. There has been development of large and open shear as well as tensional cracks in brick-masonry houses and near total to partial collapses of Type A structures. Yelvat, Kawtha and Makni villages within this Isoseist have shown maximum damage. In Makni village many houses have shown partial collapses and in the well built Irrigation Colony, the brick-cement constructions have got extensively cracked. The Water Tank at Makni has developed wide open cracks along masonry block joints. A longitudinal crack running for over 100 m has appeared in the crest portion of the earthen section of the dam possibly because of the settlement of the earthen fill material (Fig. 4). At Kawtha most of the houses on the northern half of the village collapsed. An eight metre high RCC overhead Water Tank at Kawtha village suffered total collapse under the influence of the strong motions.

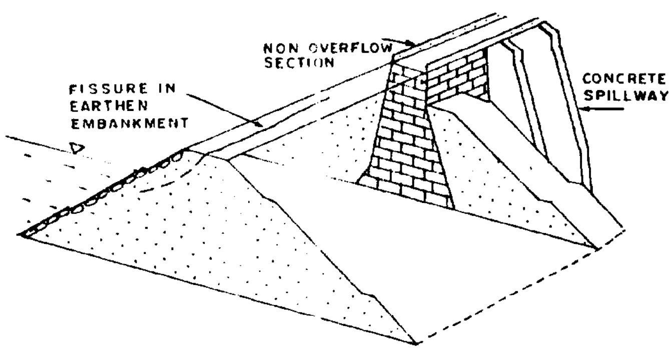

Fig. 4. Longitudinal crack in earthen embankment of Makni Dam and slight separation of earthen-masonry section

Isoseist VII

A total of 30-40 % of adobe and mud rubble constructions in this Isoseist suffered development of wide open shear cracks, tilting, bulging and in a few cases, partial collapse. In Kharosa village nearly 100 dwellings had partial collapse. The old 'Renuka Devi' temple situated on a laterite hillock also suffered similar damage but the famous Kharosa caves adorned with ancient wall paintings and sculptures escaped. The isoseist has a cumulative area of 1250 sq km.

Isoseist VI

In this Isoseist spanning over an area of 15,000 sq km, the poor Type A constructions showed development of fine to open shear cracks, fall of plaster and occasional minor collapse. Latur and Osmanabad district headquarters fall within this Isoseist.

ANALYSIS OF DAMAGE PATTERNS

A. Conventional Houses. The conventional houses are built of thick mud-masonry walls which have dressed "wythes" of single stones of 20 cm dimensions while the inner portion of the wall is made of random boulder and mud fill. There are no through stones to bind the inner and outer "wythes". In many cases these thick walls are the load bearing ones whereas in the older constructions the inner portion of the houses is made of timber framework. This practice of using timber framework had been dispensed with in newish constructions. In fact, the houses which have timber framework, have escaped total collapse although the outer walls have been razed to the ground (Fig. 5). The roofs of these constructions are made of thick pile of earth which has made the buildings very heavy thereby adding to the seismic loads. Such buildings have suffered maximum damage.

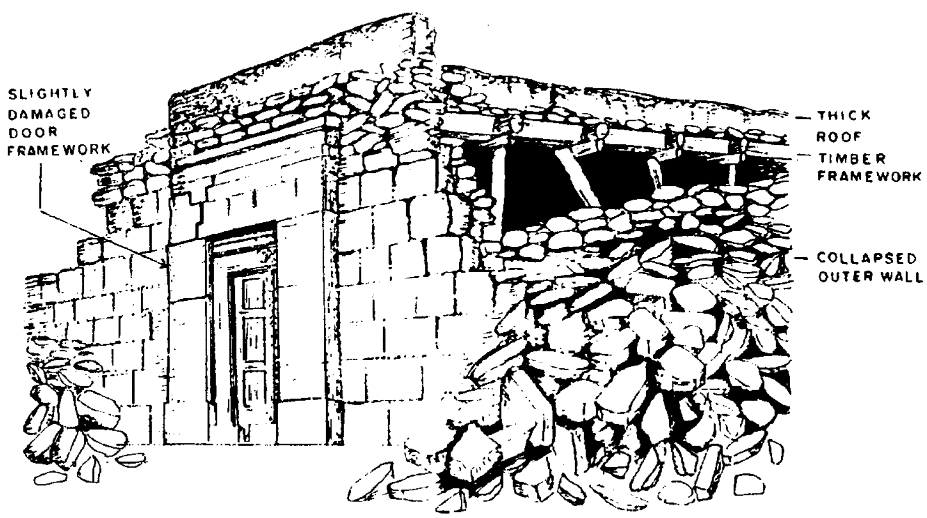

Fig. 5. Damage to a conventional house in the meizoseist. Provision of timber columns and beams has prevented total collapse of the structure.

There was no strong motion recorder in the area and thus the spectral analyses of the main shock are not available but the aftershocks indicate that maximum of the response spectrum is obtained in the frequency range of 5 to 10 Hz which is close to the eigen frequencies of thick walled conventional constructions in the region (Baumbach et al, 1994). This might have accentuated the damage and collapse of the buildings under resonance.

Many scientists have attributed the extensive damage to the poor foundation material- the block cotton soil with low load bearing capability. The authors during the damage surveys have not recorded any foundation related failures, except in stray cases. As such, the physical characteristics of the foundation materials have not played any significant role in the damaging effects.

In the lower intensities, the thick outer walls show typical "wythe" failure in the absence of through stones and in some isolated cases, such damage was noticed even in intensity VI of MSK scale. In the intensities VIII and IX such houses show complete or partial collapses. In many cases the houses were built back to back with common or touching walls on 2 or 3 sides. This caused accentuation of the damage by interactive dynamic loading.

In many villages, extensions have been provided either in constructing new portions adjacent to the existing ones or one or two storeys have been added on the existing conventional constructions. Naturally, these houses have also collapsed along with the conventional ones.

B. Engineered Buildings. A few newish constructions made either in brick masonry with cement mortar with or without lintel bands, or RCC frame structures had come up in the area, particularly, in the bigger villages. These structures like the "Neelkantha Kripa Nivas", a new house with lintel band, the Gramin Hospital complex, the Maharashtra Bank building - a frame structure, and the newly constructed shopping complex opposite to this bank, have not collapsed and the damage has been restricted to shear cracks in the vicinity of the openings or the partition walls in frame structures. A well designed Water Tank on RCC pillars has escaped any damage in Killari village. However, a few new constructions like the Cooperative Bank building with RCC roof slab and brick masonry walls located in a housing complex, have collapsed along with other conventional houses. The newly constructed "Mandap" made of RCC pillars and concrete slab has also escaped damage though the outer walls (old, conventional type construction) and older constructions in the "Neelkantheshwar" temple have collapsed.

An engineered construction, the Kawtha overhead tank of 100 kilolitre capacity has, however, collapsed. The possible reasons for the failure of this structure could be fullness of the tank thereby, adding to inertia forces, as well as inadequate and improperly tied reinforcement in the pillars. Some workers have, however, attributed the failure of this structure to the spiral staircase which might have added torsion because the structure had become eccentric.

Many brick-masonry constructions like the ones in Killariwadi have collapsed. These buildings had not been provided with any defensive measures against dynamic loading. Another factor which has contributed towards the failure of these houses is the poor quality of the bricks used. In many cases the shear cracks have cut through the bricks rather than the sand-cement mortar used as binding material.

SOURCE MECHANISM

The region is occupied by Deccan Volcanics which have covered various rock groups including the basement and have thus concealed the tectonic surfaces, some of which could be of fundamental nature. A few lineaments have, however, been recognised in the area though most of them do not display evidence of tectonic adjustments. It is possible that some of these lineaments are tectonic surfaces as their continuation in the coastal areas as well as in the Son-Narmada rift zone have displayed tectonic adjustments and a few of them are neotectonically active surfaces (Ravi Shanker, 1987, Vardarajan & Ganju, 1989). On the basis of these evidences it is inferred that some of these basement features could be related to the source mechanism.

The utilisation of indirect methods like gravity surveys, modelling of gravity residuals and deep resistivity surveys have helped greatly in constraining the disposition of important features like the NW-SE trending lineament along Ganjankheda stream, ENE-WSW fault located close to Killari village and another along the Tirna river. (Appa Rao *et al.*,1995). These dispositions are similar to the ones identified by Remote Sensing techniques.

The source parameters of this event have indicated focal depth in the range of 6.8 to 10 km. Considering the thickness of the Deccan Volcanics which is of the order of 250 - 550 m in the area of study, it is definite that the basement fracture/fractures are involved as the source fault/faults. The focal mechanism studies have indicated that this event was caused by a reverse type fault with a disposition of N60°W-S60°E and dip towards the southern quadrant. The Ganjankheda lineament coincides with this trend and, as such, a few workers have related the event with this lineament. The modelling from the gravity and deep resistivity data has also indicated a fault conforming to this trend albeit the sense of movement along this fault conforms with the tensional regime and not the compressional one as indicated by focal mechanism studies. Possible explanation for this anomalous style of deformation is that during and after the Deccan Volcanic emplacement the tensional regime was operative which resulted in block faulting of considerable throws. In the contemporary times this tensional regime has changed to compressional one and as this is of much subdued nature, the resultant throws, worked out by geophysical modelling, still reflect the normal type of throws.

The macroseismic surveys conducted after this event have given NE-SW isoseismal trends albeit with NW-SE bulge in the higher intensities along Ganjankheda lineament. This NE-SW trend does not conform to the focal mechanism trend and thus warrant explanation. In the source mechanism of this event it is possible that more than one tectonic surfaces are involved and the intersection of these features provided the asperity for strain build up and the initial break took place along the NW-SE trend (Narula, 1995). The existence of such a feature has been brought out by gravity and resistivity surveys and the analysis of aftershock patterns have corroborated the same. The composite fault plane solutions have given both NE-SW as well as NW-SE trending faults as source mechanism albeit of the strike slip type. In the compressional regime prevalent in the Intraplate of Indian Peninsula the intersection tectonics could have been responsible for this event. It will not be out of place to mention that in the intersection tectonics the main shock and aftershocks may give different focal mechanism solutions which may be both reverse fault type and strike slip type (Talwani,1989).

From the above discussions, it emerges that this earthquake has taken place in the vicinity of intersecting pre-existing fault surfaces, concealed under the Deccan Volcanics and the disposition of these tectonic surfaces make an angle of 120° with each other. Fault mechanics-wise, both reverse and strike slip motions on two discrete faults could take place in such a disposition. Generally, the intraplate events do not show surface manifestations but this event, like the one in Australia has shown these manifestations in the form of upheaval in the WNW-ESE disposition and strike slip in NE-SW direction. Keeping all these parameters in view, the authors have proposed a source model for this event depicted in Fig. 6

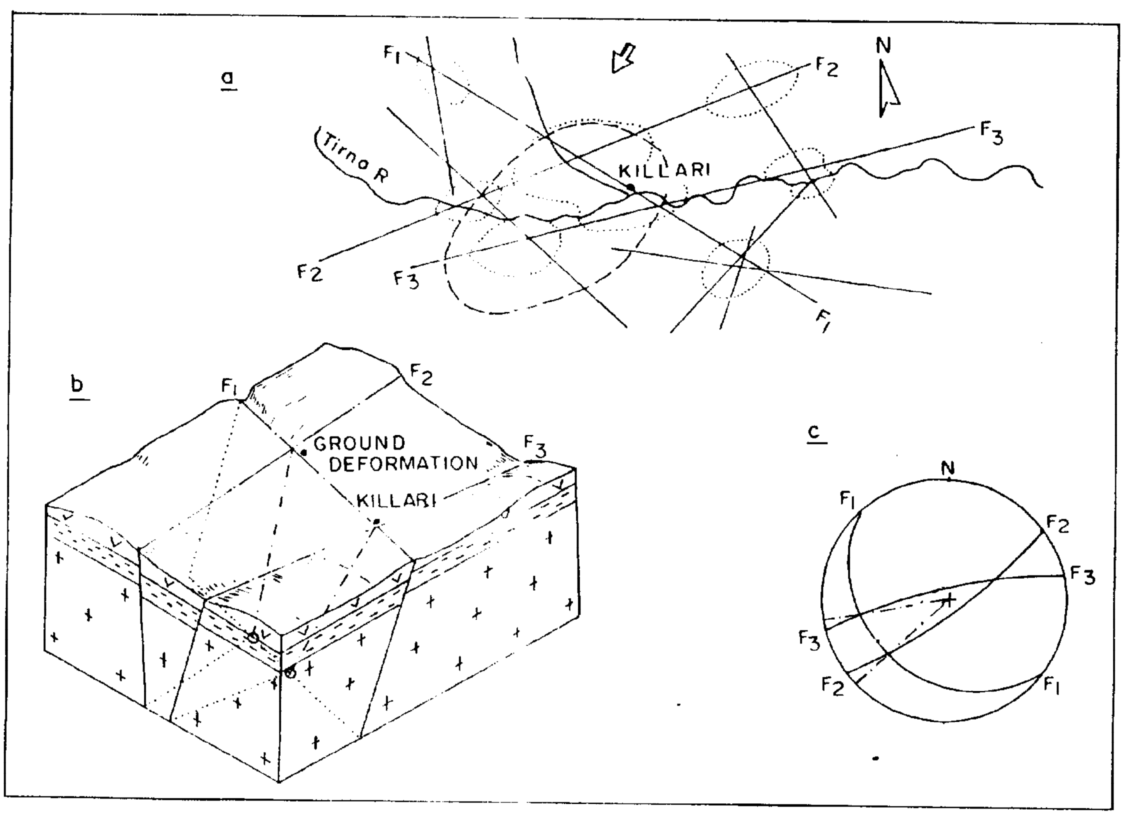

Fig. 6. Source mechanism of Latur earthquake (a.) Plan showing configuration of faults, zones of strain locking and epicentral tract. (b.) Block diagram explaining intersection model. Main rupture occurring at F_1-F_2 intersection in reverse type motion initiating unlocking at other locked segments and left lateral strike slip motion along F_2. (c.) Stereonet plot of intersecting fault planes F_1, F_2 and F_3.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the Director General, Geological Survey of India for according permission to publish this paper. The valuable suggestions made by Mr. Ravi Shanker, Deputy Director General, Northern Region, Geological Survey of India are gratefully acknowledged. The authors are thankful to Ms. Jaya Singh, Assistant Geologist, Geological Survey of India for the help rendered in finalisation of this manuscript.

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