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A RUPTURE MODEL FOR LARGE EARTHQUAKES OF THE HIMALAYAN COLLISION ZONE

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ABSTRACT

A review of the available literature for the 1897 Assam, 1905 Kangra, 1934 Bihar-Nepal and 1950 Assam earthquakes permits a rupture model for large (magnitude greater than 8) earthquakes of the Himalayan Collision Zone to be proposed within the framework of the plate tectonics paradigm. The rupture responsible for such an earthquake should occur on an entirely concealed fault surface with a gentle dip in the northerly direction normal to the local strike of the Himalaya. The rupture should occur mainly under the Lesser Himalaya with its southern limit close to the surface trace of the Main Boundary Thrust except in the Shillong Plateau region where it may be close to the southern of edge of the plateau. Its length parallel to the strike of the Himalaya should be about 300 km and the rupture propagation should be predominantly from the eastern to the western end. The sense of relative slip across the fault surface should be of the thrust type mainly.

INTRODUCTION

Four earthquakes of magnitude greater than 8, viz., the 1897 and 1950 Assam, 1905 Kangra and 1934 Bihar-Nepal, have occurred in the last 100 years alone along the seismic belt associated with the Himalayan Collision Zone. It is now established that such earthquakes are caused by ruptures, i.e., failures by relative slip along segments of pre-existing major faults. Estimates regarding the rupture locations, extents, orientations as well as directions of relative slip and rupture progation for the above earthquakes would be useful in formulating seismic risk mitigation measures for future large earthquakes of the Himalayan Collision Zone. Most of the available estimates of rupture parameters for these earthquakes have been obtained during the twenty five years of ISET's (Indian Society of Earthquake Technology's) existence. The reason is partly that the early years of ISET coincided with the period in which the plate tectonics hypothesis was propounded and recognized as a revolutionary new paradigm in earth sciences. The earthquake rupture concept, which came into focus with the elastic rebound theory put forward by Reid following the San Francisco earthquake of 1906 (Richter, 1958), gained in importance greatly with the attempts to model earthquake source processes within the framework of this paradigm. Also the twenty five years of ISET have witnessed important advances in the tools for earthquake source processes investigations, namely, improvements in seismograph design, increase in number of seismograph stations, progress in theoretical seismology, strides in the methodology for interpretation of seismological data and phenomenal growth in the capabilities and reach of computers. We summarize in this note the latest available results regarding the ruptures responsible for the above four large earthquakes of the Himalayan Collision Zone.

RUPTURES ON A CONCEALED FAULT SURFACE

Although these earthquakes caused great havoc and spectacular surface effects, the geologists investigating the field evidence (Oldham, 1899; Middlemiss, 1910; Dunn, et al., 1939; Krishnaswamy, et al., 1970) found no indications that the causative ruptures had outcropped at the surface. Seeber, et al., (1981) and Seeber and Armbruster, (1981) proposed a seismotectonic model according to which large earthquakes of the Himalayan Collision Zone occur near the upper surface of the Indian shield as it subducts under the Himalaya. Lyon-Caen and Molnar (1983) using gravity data estimated a dip of 3° for this detachment fault surface. Ni and Barazangi, (1984) concluded from the estimated hypocentral locations for medium and small magnitude earthquakes of the Himalayan seismic Belt that the seismically active part of the detachment lies under the Lesser Himalaya at a depth varying systematically between 10 to 20 kms. Chander's, (1988a) interpretation of geodetic data for the 1905 earthquake yielded for this surface a depth estimate of about 10 km under Dehra Dun and a dip estimate of about 5° to the northeast locally.

ESTIMATES OF RUPTURE SIZE AND GEOGRAPHIC LOCATION

Evidence about the 1897 rupture

During the 1897 Assam earthquake, the area falling within the Mercalli X isoseismal covered the Shillong Plateau and parts of the Brahmaputra valley to its north (Oldham, 1899). This implied to Seeber and Armbruster, (1981) that the rupture extended beyond this area and they estimated its extent as about 300 and 550 km in the north-south and east-west directions respectively. Khattri and Tyagi, (1983) estimated the rupture length as about 400 km. Molnar, (1987b) deduced from Oldham's, (1899) data that the rupture was limited in the east-west direction to about 200 km length beneath the Shillong Plateau. He put the southern limit of rupture along the southern edge of the plateau and suggested that the rupture could have extended under the Himalaya north of the Brahmaputra valley but this was not provable from the available macroseismic observations. We feel that since the earthquake effects are often accentuated in alluvial regions and since such areas lie north, west and south of the Shillong Plateau, Molnar's, (1987b) estimates of rupture extent although conservative may not be far off the mark.

Evidence about the 1905 rupture

Seeber and Armbruster, (1981) estimated the extent of rupture for the 1905 Kangra earthquake as about 300 km along the NW-SE strike of the Himalaya locally and about 140 km normal to it. Khattri and Tyagi, (1983) estimated the rupture length as about 300 km also. Molnar, (1987a) suggested three alternative models for this rupture : (i) strikewise about 100 km long rupture beneath the Kangra high intensity region; (ii) this and a smaller rupture under the Dehra Dun high intensity region; (iii) a single continuous rupture extending from Kangra to Dehra Dun. Chander, (1988a) interpreted the observations of ground level changes caused by this earthquake and ruled out Molnar's first alternative altogether. Chander's, (1988a) preferred model envisages a rupture extending from the vicinity of Kangra to about 15 km NW of Dehra Dun and about 80 km northeastward under the Lesser Himalaya from the general vicinity of the Main Boundary Thrust.

Evidence about the 1934 rupture

Chen and Molnar, (1977) and Singh and Gupta, (1980) interpreted limited seismic surface wave data for the 1934 Bihar-Nepal earthquake to infer rupture dimensions of 130x50 km^2 and 129x42 km^2 respectively. Seeber, et al., (1981) and Seeber and Armbruster, (1981) estimated the rupture length as about 300 km parallel to the local strike of the Himalaya. Seeber, et al., (1981) suggested that the rupture extended north-south from beneath the Lesser Himalaya 250 km upto the elongated Mercalli IX isoseismal enclosing Monghyr. Seeber and Armbruster, (1981) suggested that the rupture extended only about 150 km from under the Lesser Himalaya upto the axis of the slump belt. Khattri and Tyagi, (1983) put the rupture length at about 300 km also. Chander (1989) argued that this and the 1905 ruptures were comparable in size and location relative to the Main Boundary Thrust.

Evidence about the 1950 rupture

According to Chen and Molnar's, (1977) estimate based on surface wave data, the 1950 Assam earthquake was caused by a rupture of about 260x80 km^2. Seeber and Armbruster, (1981) estimated on the basis of macroseismic data the rupture extent parallel to the locally NE-SW strike of the Himalaya as about 300 km. Khattri and Tyagi, (1983) estimated the rupture length as about 350 km.

Summary about rupture size and geographic location

In short, the estimates of rupture lengths for these earthquakes range from 142 to 550 km parallel to the local strike of the Himalaya with the figures of 300±100 km appearing most frequently. The extent of rupture normal to the strike of the Himalaya is much less constrained. The southern limit of rupture is a more definable concept. The limit was along the southern edge of the Shillong Plateau in the 1897 case and close to the Main Boundary Thrust in the 1905 case. Chander, (1989) argued for a similar location in the 1934 case. The data are vague for the 1950 case but it should not have been too much south-east of the Main Boundary Thrust in any case. The ruptures were definitely mainly under the Lesser Himalaya in the 1905, 1934 and 1950 earthquakes and probably partly so in the case of the 1897 earthquake also.

SENSE OF RELATIVE SLIP ACROSS THE FAULT SURFACE

If the above mentioned seismotectonic moel is accepted then predominantly thrust type motion should occur during large earthquakes of the Himalayan Collision Zone. The vast majority of focal mechanism solutions for the medium magnitude earthquakes of the Himalayan Seismic Belt (Fitch, 1971; Chandra, 1978; Ni and Barazangi, 1984; Baranowski, et al., 1984) have been interpreted as thrusts on low angle faults dipping normal to the strike of the Himalaya. The summary about the above four earthquakes is as follows. Molnar, (1987b) assumed that the 1897 earthquake occurred by northward underthrusting motion of the Indian plate. Chander, (1988a) found the northeastward underthrusting of the Indian plate consistent with the geodetic data for the 1905 earthquake. Chen and Molnar, (1977) assumed a northward underthrusting mechanism for the 1934 earthquake. Singh and Gupta, (1980) deduced from sparse P wave data a combination of reverse and strike slip motion on a south dipping plane. However, Chander, (1989) argued that with two inconsistencies the same data yield a northward underthrusting solution. Chen and Molnar, (1977) deduced from P data northward underthrusting mechanism for the 1950 earthquake.

DIRECTION OF RUPTURE PROPAGATION

Chander, (1988b) has made out a case that rupture propagation in large earthquakes of the Himalayan Collision Zone is from the eastern to the western end predominantly.

CONCLUSION

Sixteen out of the twenty references cited above belong to the period since the inception of ISET. Hence, we conclude that these years have been witness to notable progress in the evolution of a rupture model for devastating earthquakes that visit the northern regions of India all too frequently. The main features of this model are as summarized in the Abstract.

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