MACROSEISMIC STUDIES OF RECENT EARTHQUAKES IN NORTHWEST HIMALAYA – A REVIEW

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ABSTRACT – *The authors have reviewed the results of macroseismic studies carried out for 5 major earthquakes which have visited the northwest Himalaya in the last one and a half decade. The intensity decay as well as accentuation in certain reaches and the isoseismal trends have been analysed with reference to focal mechanism and the prevailing tectonic styles. The main conclusion drawn from these studies is that the eastwest boundaries of the possible source of underthrusting crustal blocks along the detachment surface in the outer Himalaya could be constrained by transverse fundamental fractures. These 3-dimensional boundary conditions would help in assigning seismic potential of the crustal blocks.*

INTRODUCTION

The macroseismic field surveys of major earthquakes necessarily include the effects of dynamic forces caused by the earthquakes on men, constructions as well as the terrain on the earth's surface. These surveys are conducted on the basis of well-established intensity gradings like the Rossi-Forel scale, Modified Mercalli Scale (12 degrees), Mercalli-Cancani-Sieberg (MCS) scale 12 degrees; Madvedev-Sponheuer Karnik (MSK) scale which have been progressively improved upon to include the categories of the structures which are damaged so that the intensities could indirectly give the ground motion characteristics. These post-earthquake surveys provide on-the-spot knowledge of actual situations created by the major earthquakes, assessment of problems requiring immediate attention and also response of structures to dynamic forces as well as the source mechanism.

The Geological Survey of India has carried out field investigations of major earthquakes since the pioneering efforts of Thomas Oldham and the classic work on the Great Assam Earthquake of magnitude 8.7 (1897), Oldham[1] which is not only amongst the world's largest earthquake but is also one of those for which most detailed studies were carried out and laid foundations of modern seismology. Since then the officers of Geological Survey of India have investigated most of the damaging earthquakes. The authors in this write-up intend to summarise the findings of those earthquakes which have visited the NW Himalaya in the last one and a half decade. They have attempted to correlate these with the possible sources, depending upon the seismotectonic styles prevailing in the area and the findings of these field surveys. The earthquakes studied are the Kinnaur earthquake of 1975, the Dharamsala earthquake of 1978, the Dharchula-Bajang earthquake of 1980, the Jammu earthquake of 1980 and the Dharamsala earthquake of 1986.

TECTONIC FRAME WORK

The NW Himalaya including parts of Ladakh and Karakoram have been divided into four NW-SE trending linear belts on the basis of their distinctive geological attributes[2]. The boundaries of these tectonic belts are demarcated by thrusts and faults. In these tectonic belts rocks from Palaeozoic to Recent ages are exposed in different belts. The most important belt relevant to the contemporary tectonics being the outer Himalaya Tertiary belt bounded by MBF1, in the north and the Foot Hill thrust in the south wherein evidences of Neotectonic activity along various tectonic surfaces abound. Based on the geological evidences, carbon dating along some of the surfaces and geodetic measurements across some of the tectonic planes as well as episodic measurements in some domains, Narula *et al.*[3] have classified these neotectonic episodes in three categories eg. younger neotectonic episodes, older neotectonic episodes and undifferentiated neotectonic episodes. The first author on the basis of synthesis and interpretation of the data available on the seismicity patterns, tectonic setup, contemporary deformation styles, focal mechanism studies, geophysical attributes and geothermal manifestations has identified discrete crustal blocks which display similar seismic behaviour[4]. These identified seismic domains are the Main Himalayan seismic zone, High Himalaya seismic zone, High Plateau seismic zone, Kashmir syntaxial seismic zone and the Foot Hill seismic zone, (figure 1).

The most important seismic zone, responsible for most of the seismic activity in the Himalayan Region is the Main Himalayan seismic zone which predominently displays thrust type sources in the frontal portion of the Himalaya. The major tectonic surfaces of regional continuity in this zone are the MBF1 and the MCT. It has also been interpreted that even this Main Himalayan seismic zone could be subdivided into discrete crustal blocks by transverse fault system. A conceptual model on these lines has been postulated for Kangra region by the first author[5].

Macro-seismic studies of recent earthquakes

The NW Himalaya has been visited by a number of large-magnitude earthquakes during the last century, the most devastating of which was the Kangra earthquake of 4th. April 1905 which took a toll of 20,000 lives and damaged most of the buildings in the epicentral tract Middlemiss[6]. The recurrence period of such great earthquakes varies from one century to a few centuries according to various authors (Srivastava[8] for Himachal) and Slemmons[7]. Thus rare opportunities are available for macroseismic investigations of such earthquakes in any particular region. However, lesser magnitude earthquakes of damaging nature are more frequent and thus provide much more chances of careful field studies of damage patterns to arrive at prevailing deformation styles and probable source mechanism. In the NW Himalaya the Magnitude 5 earthquake recurrence period is in the order of 2.5 to 3 yrs.[9] and that of magnitude 6 is in the order of 15 yrs[8].

In the last 15 yrs., the NW Himalaya has been the scene of 4 earthquakes of +5M and one of +6M, namely the Kinnaur, Dharamsala, Dharchula, Jammu and Dharamsala. Ground surveys for all these events have been carried out by the officers of the Geological Survey of India. This material has been examined and the salient findings are reproduced in table I and table II followed by description of individual events.

Kinnaur Earthquake of 19th. January 1975

The upper Sutlej valley in Himachal Pradesh was rocked by a magnitude 7 earthquake on the 19th. January 1975, in the midst of severe cold, continued snowfall and at high altitudes of more than 4000 m. The field investigations were commenced from the 26th. January 1975 as a lot of logistic support had to be organised to reach the meisoseismal area because of its being rendered inaccessible because of heavy snowfall and the blockage of the only link road to the area, the Hindustan Tibet Highway because of heavy landslides caused by this earthquake. A team of eight officers headed by a Director undertook the field surveys and reached the spot of the maximum damage by trekking as well as the use of a helicopter and remained in the area for a period of about a month to assess the damage patterns covering an area of about 45000 sq. km. out of a felt area of about 0.25 million sq. km. The data collected was analysed at headquarters and the report finalised in April 1975[10]. This shock was preceded by a 5.1 magnitude earthquake only a few minutes before while a series of aftershocks between M4 and M5 continued even after one year of the main event.

The isoseismals drawn using comprehensive Modified Mercalli scale indicate that in the meisoseismal area located near Kaurik village an intensity X had been approached in a restricted area of about 89 sq. km. in the Indian Teritory. Because of sparse population in the area the casuality was only 42 dead and 278 houses completely collapsed. The other relevant data about the damages caused is included in table 1 and table II. The assignment of different intensities was done on the basis of the degree of damage caused to different types of constructions and the terrain changes like huge landslides some of which caused temporary blockage of streams like Parachu river between Sumdoh and Kaurik, development of ground fissures in loose deposits, opening preexisting fracture surfaces, dislodgement and rolling of boulders on steep slopes and increase in discharge of hot springs. It was also reported that at about 12.54 hrs. on the 17th. January 1975, i.e. about two days prior to the event a magnetic storm of severe intensity with variations of more than 2000 gamma was recorded at a distance of about 100 km. from the epicentral track and some investigators related this to be a precursor[11] while others interpreted that this could have been caused by Sun spot activity[12]. The isoseismals drawn on the basis of these surveys are reproduced in figure 2. The isoseismals have been

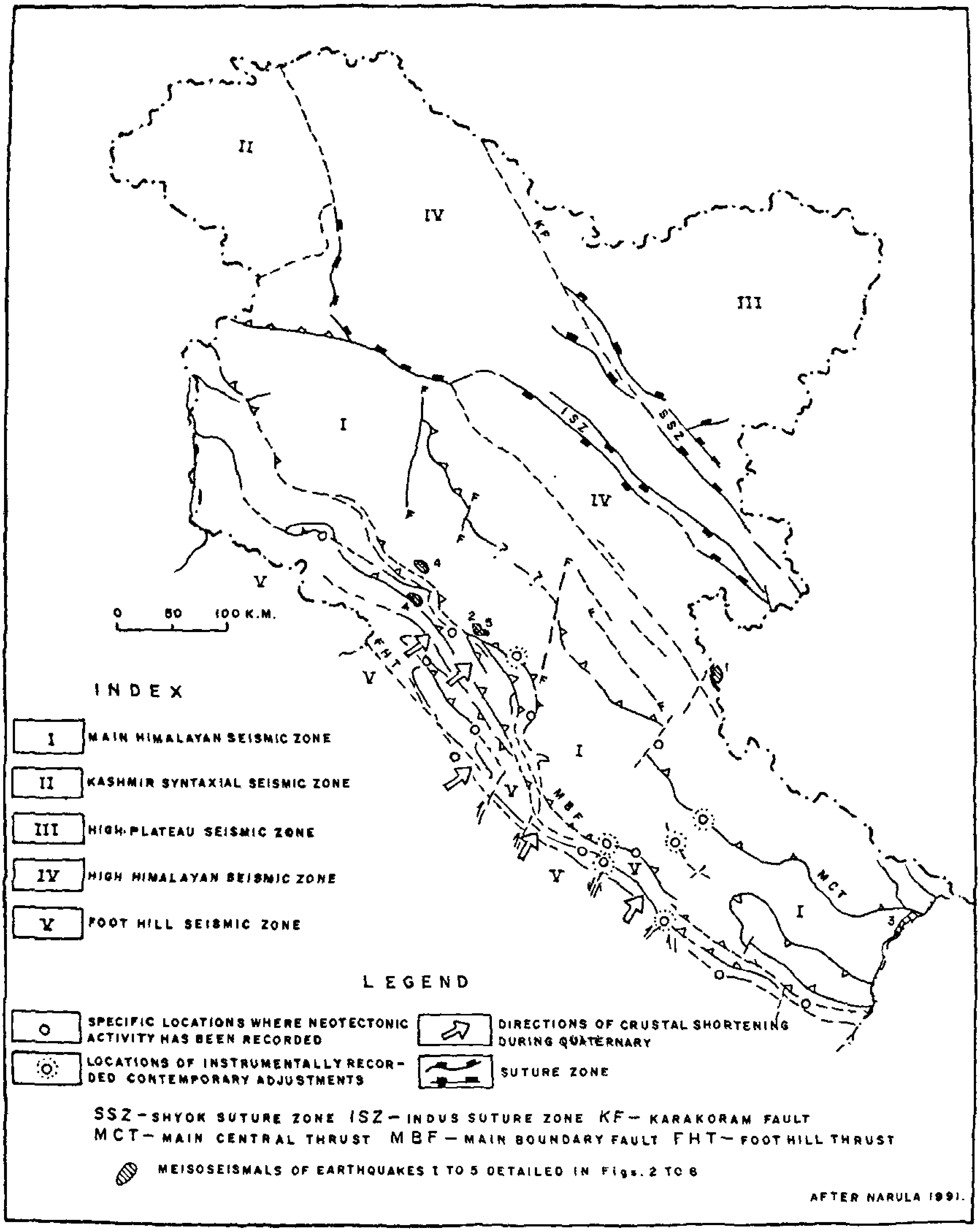

FIGURE 1. Seismotectonic domains of N–W Himalaya (Narula 1991) indicating areas of macroseismic studies for different earthquakes.

TABLE-I

S NO.	EARTHQUAKE	EPICENTRE	ISOSEISTS AREA IN Sq.K.m					MEIZOSEISMAL MAJOR AXIS		MEIZOSEISMAL MINOR AXIS		REMARKS
			VIII	VII	VI	V	IV	LENGTH	DISPOSITION	LENGTH	DISPOSITION	
1.	KINNAUR 19th JAN 1975 M-7.0	32·45°N 78·43°E	615	2315				8·5	N10°W-S10°E	2K.m.	N80°E-S80°W	ISOSEIST AREA NOT CALCULATED AS PART OF THE AREA IS SNOW BOUND & PART FALLS IN NEPAL
2	DHARCHULA BAJANG 29th JULY 1980 M-6·1	29 56°N 87·07°E	200	1000	6600	32600		35 K.m.	N55°E-S55°W	10 K.m.	N35°W-S35°E	INDIAN TERITORY-ONLY
3	CHARAMSALA 14th JUNE 1976 M 5·0	32·17°N 76·33°E			52	612		14 K.m.	N10°E-S10°W	6 K m.	N80°W-S80°E	
4.	JAMMU-KATHUA 24th AUG.1980 M 5·5 & 5·4	32·89°N 75·55°E 32·62°N 75·32°E	A 28 B	81 16	271·5 153·5	2925		13·25 K.m. 7·5 K.m.	N55°W-S55°E N60°W-S60°E	2 5 K.m. 2·5 K.m.	N35°E-S35°W N30°E-S30°W	BIFOCAL WITH TWO MEIZOSEISMAL TRACTS
5.	DHARAMSALA 26th APRIL 1986 M 5·7	32·10°N 76·30°E		81	1100	4411	17063	14 K m.	N60°W-S60°E	6 K m.	N30°E-S30°W	

TABLE-II

S NO	EARTHQUAKE	CASUALTIES	BUILDINGS DAMAGED		FELT AREA	TERRAIN EFECTS
			PARTLY	FULLY		
1	KINNAUR, 1975	42 DEAD + 40 SEVERLY INJURED	2000	278	0·25M K.m.	DEVELOPMENT OF CRACKS, INCREASE IN TEMPERATURE AND DISCHARGE OF HOT SPRINGS, MAGNETIC STORM 2 DAYS PRIOR TO EARTHQUAKE.
2	DHARAMSALA, 1978	NIL	OLD BUILDINGS IN DHARAMSALA AND MACLEOD-GANJ	–	–	–
3.	DHARCHULA, 1980	NIL	DHARCHULA, PITHORAGARH, BALWAKOTE EXTENSIVELY DAMAGED	MOST OF BUILDINGS IN VILLAGES KALIKA AND GOTHI	–	NIL
4.	JAMMU, 1980	12 DEAD	2887	1312	–	GROUND FISSURES IN BED-ROCK LANDSLIDES AND INCREASE IN DISCHARGE OF SPRINGS
5.	DHARAMSALA, 1986	3 DEAD	3500 + 13000 HOUSES DEVELOPED MINOR CRACKS	137	–	GROUND CRACKS IN SLOPES COVERED BY OVERBURDEN MATERIAL.

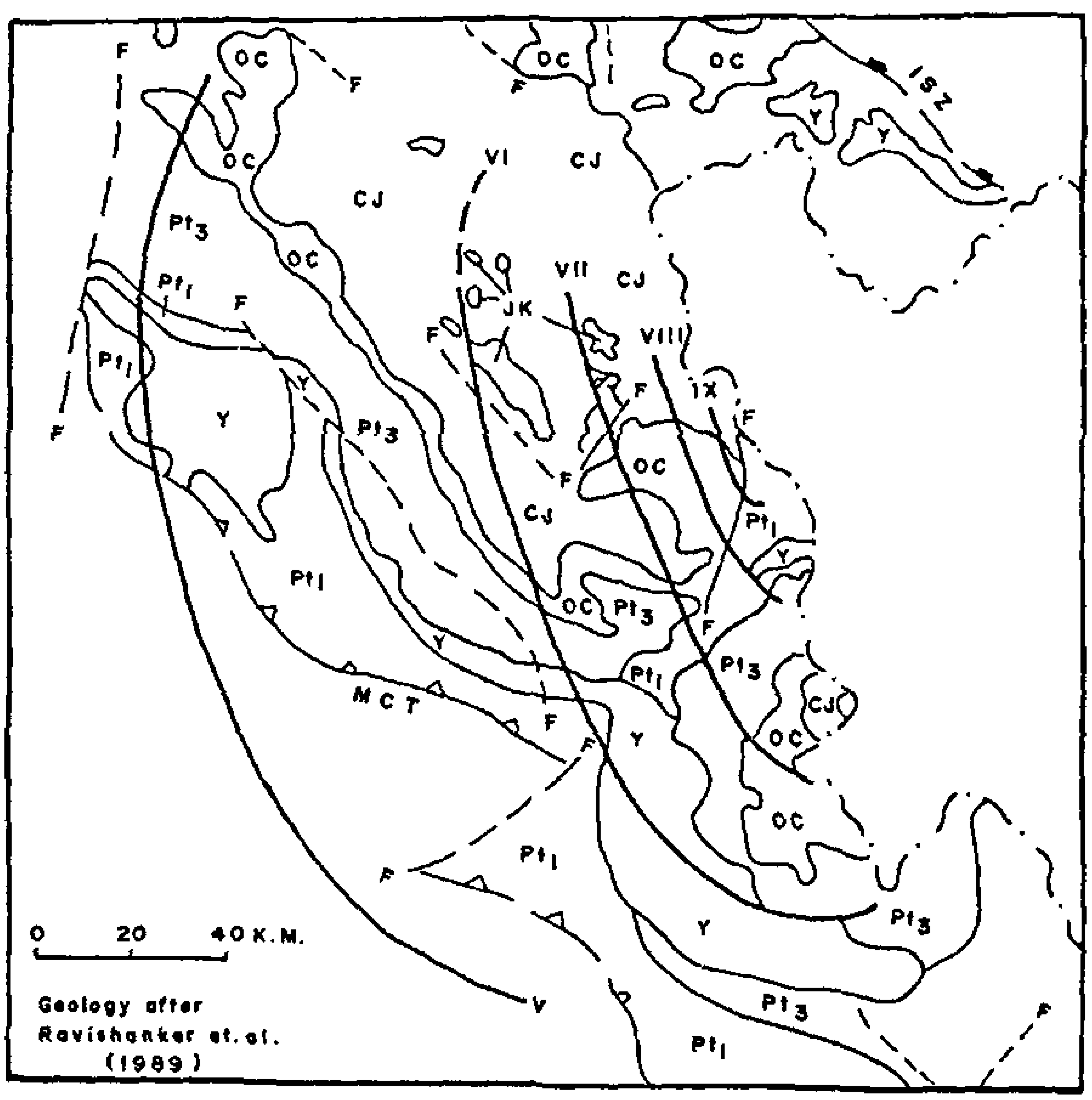

FIGURE 2. Isoseismals of Kinnaur earthquake of 19th Jan. 1975 (Hukku-*et. al.* 1975) on Geological Base. JK-Jurassic-Cretaceous, CJ-Carboniferous-Jurassic, OC-Ordovician-Devonian Pt2$_3$-Vendian, Pt1$_3$-Proterozoic, Y-Granites ISZ-Indus Suture Zone, MCT-Main Central Thrust FF-Faults.

restricted to Indian territory though Bhargava (1979) has tried to extrapolate and close the isoseismals VIII and IX for interpreting the possible source mechanism. According to them the intensity attenuation on eastern side is much more rapid than that on the western side. The pattern has been attributed to the down-thrown blocks of the Kaurik fault (possible source fault) to be more active. However, the authors are of the opinion that such an attenuation could be the result of a combination of two factors namely ■ contrasting lithologies i.e. more competent crystallines and meta-sedimentaries exposed on the eastern side than the shales and limestones on the downthrown side of the Kaurik-change fault ■ down dip fault propogation of the source.

Fault-plane solutions of this earthquake and its aftershocks have demonstrated normal faulting along N-S or NNW-SSE oriented nodal planes. (Chaudhary and Srivastava, 1976 and Molnar and Tapponnier, 1978 in Verma *et al.*[13]. These fault-plane solutions conform to the isoseismal trends obtained by field surveys. On geological conditions the nodal plane heading westwards could be the possible source fault of this earthquake and Kaurik-change fault is its surface trace (figure 2).

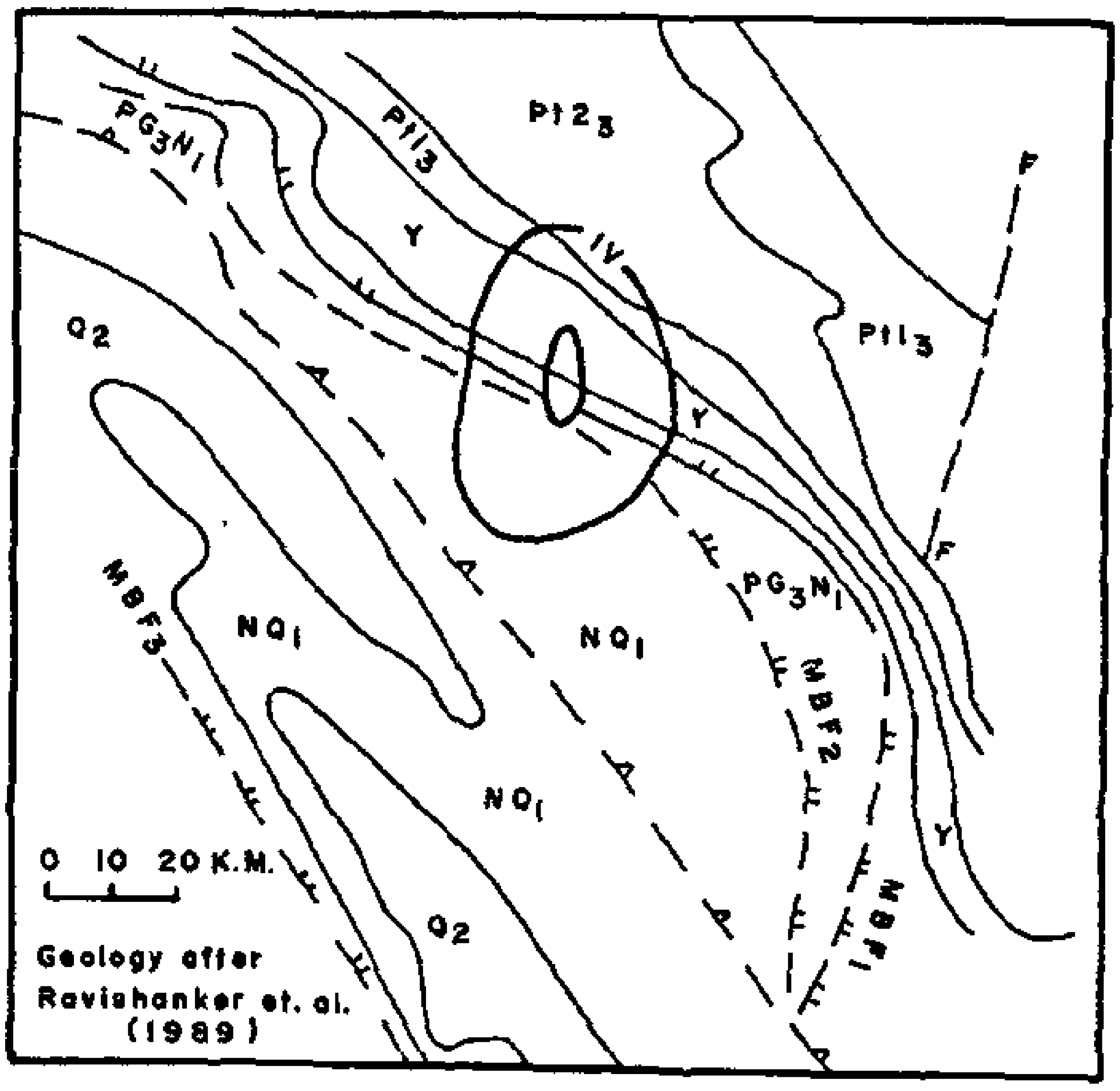

FIGURE 3. Isoseismals of Dharamsala Earthquake 14th June 1978 (Kumar *et al.* 1981) on Geological Base. Q_2-Holocene, NQ_1-Mio-Pliocene, PG_3N_1-Oligo-Miocene, $Pt1_3$ $Pt2_3$-Proterozoic, Y-Granites, F F-Fault, MBF_{1-3}-Main Boundary Faults.

DHARAMSALA EARTHQUAKE OF 14TH. JUNE 1978

Dharamsala and its vicinity was shaken violently at 21 h. 42 min. 9s. Indian Standard Time on the 14th. June, 1978 and was felt in the whole of Kangra valley. This shock of magnitude 5 on Richter scale was preceeded by a smaller shock. There was no casuality caused by this shock but the damages caused in the form of cracks in the buildings in and around Dharamsala town were reported and in order to assess the damage patterns and possible source mechanism, field surveys were conducted by the officers of Geological Survey of India and the data analysed to draw isoseismals. The information obtained has been published[14]. Most of the damage was caused to the old buildings and one wall in the police lines collapsed while others developed gaping cracks. Cracks also developed in many buildings, constructed stone masonry in cement mortar like the seismological laboratory and the civil hospital at Dharamsala. The well-constructed R.C.C. frame structures with reinforced pillars displayed cracks only in the partition walls. Maximum intensity assigned to this earthquake is +VI and the isoseismals drawn are reproduced in figure 3. On the basis of the isoseismal trends Kumar *et al.*[14] have interpreted that a N-S tear exposed west of Dharamsala which has displaced even the MBF-2 could have been the source fault, a strike slip fault across the Himalayan trend.

Source Mechanism studies conducted by Das Gupta *et al.*[15] have however indicated a thrust type of mechanism though the strike of the nodal planes conforms to the isoseismal trends. Interestingly the nodal planes are disposed across the regional trends of the thrusts in this area and thus direct correlation of the event with mapped geological structures has not been possible. The authors are of the view that the intersection of the detachment surface with the transverse fault could have provided a locale for anomalous stress buildup in response to the plate tectonic forces. This anomalous stress build up with compressional forces aligned across the general stress fields caused by plate motion could have resulted in the reverse fault type movement along the preexisting transverse faults on the similar lines of the intersection model suggested by Talwani[16]. Implications of this model on the earthquake patterns in the region are further discussed in the next chapter.

DHARCHULA-BAJANG EARTHQUAKE OF 29TH. JULY, 1980

An earthquake of Mag. 6.1 rocked the border town of Dharchula and Bajang in Nepal in the afternoon of 29th. July, 1980 and according to media, extensive damage was reported. A team of seven officers from

Geological Survey of India fanned out in the area between 8th. and 20th. August 1980 to collect information of damage patterns with an aim of drawing the isoseismals. These surveys revealed extensive damage to the poorly constructed masonry structures in the villages between Kalika and Gothi and heavy damage to masonry structures with cement mortar like the PWD rest house and some higher structures supported on wooden pillars in Dharchula town This meisoseismal area demonstrated maximum damage and the MM scale assigned to this was VIII. The isoseismal drawn on the basis of damage pattern studies are included in unpublished GSI report by Srivastava *et al.* 1980 and reproduced in figure 4. An interesting finding in these surveys was heavy damage to masonry structures built in cement mortar along two linear ridges on rock foundations while the main market area, though, of poorer construction and located on overburden material escaped major damage. It is possible that there was a considerable accentuation of accelerations on the ridges and that too in buildings located close to the major change in slope on these ridges. Because of topographic reasons these ridges have 60 m. of level difference from general levels in the area and are unconfined in the sides. The long axis of the isoseismals is aligned in NE-SW direction (table-I). It was interpreted by Srivastava *et al.*[17] that this trend coincides with that of the Moradabad fault and thus could have a genetic relationship with that tectonic surface aligned oblique to the Himalaya trend.

The focal mechanism studies conducted by Ni and Barazangi (1984) in Verma and Kumar (1987) for this earthquake have indicated a thrust type of deformation with nodal planes oriented in 193° and 16°. Both these

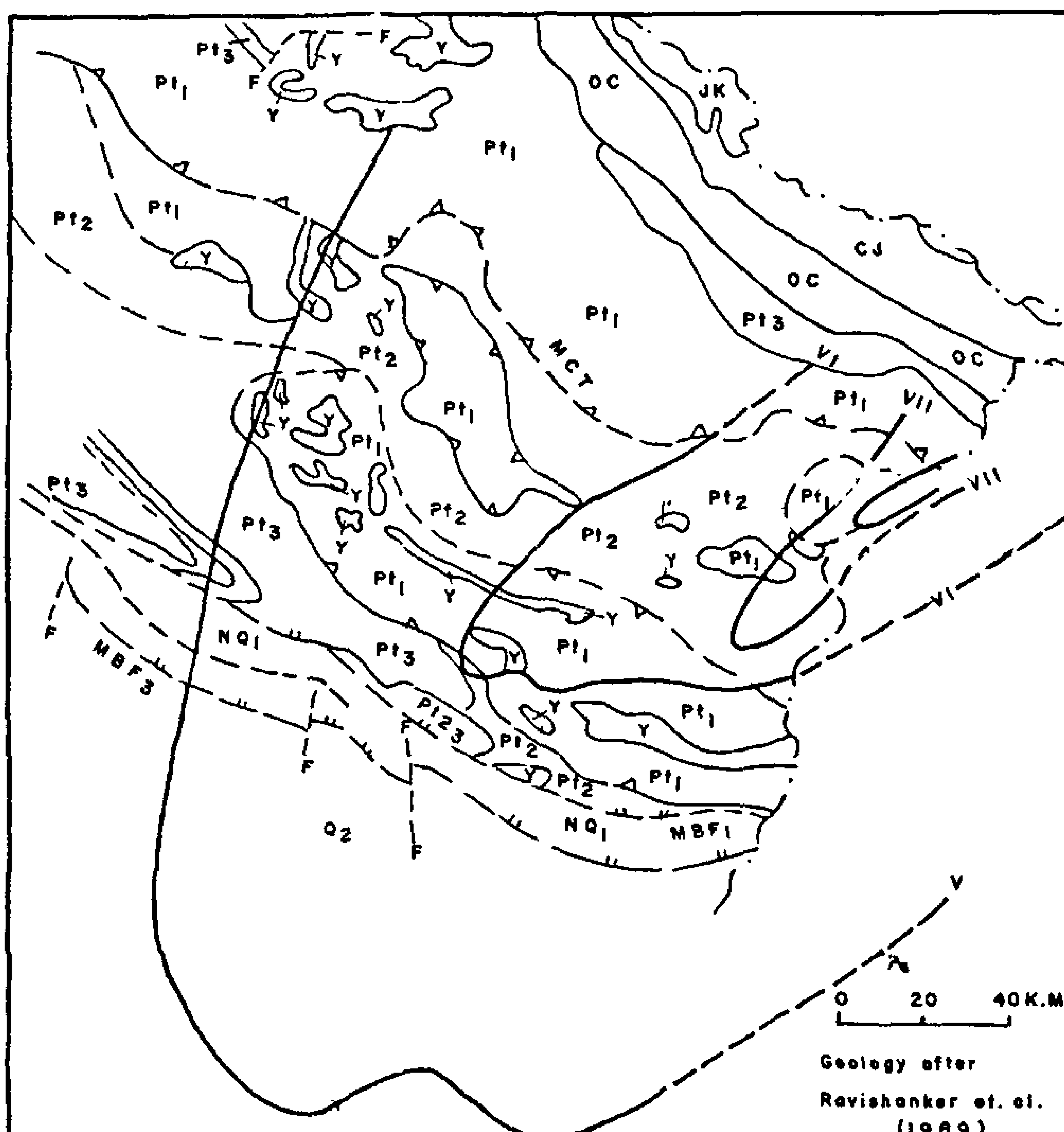

FIGURE 4. Isoseismals of Dharchula Earthquake, 29th July 1980 (Srivastava *et. al.*, 1980) on geological base Q_2-Holocene, NQ_1-Mio-Pliocene, JK-Jurassic Cretaceous, CJ-Carboniferous Jurassic, OC-Ordovician-Devonian, Y-Granites, Pt_{1-3}-Proterozoic, MCT-Main Central Thrust, MBF_{1-3}-Main Boundary Faults, FF-Fault.

nodal planes do not tally with the trend of the isoseismals and cannot be correlated with Moradabad (strike slip) fault.

JAMMU-KATHUA EARTHQUAKE OF 24TH. AUGUST. 1980

A bifocal earthquake of magnitude 5.5 and 5.4 rocked Jammu, Kathua, Udhampur and Doda districts of Jammu and Kashmir in the early hours of 24th. August 1980 causing considerable damage to poorly-constructed buildings while well-designed stone masonry houses with cement mortar and wooden-framed structures suffered only partial damage in two epicentral tracts one in Bhaddu-Dudwara area and the other in Lohai Malar area. The macroseismic surveys conducted by the officers of Geological Survey of India have indicated that the maximum intensity attained by the bifocal event in both the epicentral tracts is in the order of VII on the MM scale[18]. The salient features of various isoseismals and the total damage caused by this earthquake are tabulated in table-I and table II and figure 5.

Ground fissures have been recorded in Trimbli and Ramkote villages in the sandrock exposed along a spur as well as in the areas covered by overburden material in Buddu and alluvial cover on the bank of Bhini river near village Dudwara. A number of ground fissures were reported in Chuchali, Bani and Dhagoar villages. Most of these fissures trend in the WNW-ESE. Landslides and rockfall were also caused by this quake near Najot village and Daggar village respectively. Two separate sources for these events have been visualised, the main shock assigned to the down dip extension of the MBF1 and the second shock to a basement fault in the extension of Suruin-Mastagarh anticlinal axis. The authors are of the view that the twin sources could be the asperities at the intersection of MBF1 and the basement fault in extension of surface trace of Suruin-Mastagarh anticlinal axis with the detachment surface[19]. If it is accepted to be a bifocal event and the first shock has triggered the second one, the time lag of 12 minutes between the two events is anomalously high because the distance between two epicentres is only 21 km, and fault propagation/energy transmission would have been of the order of 10 seconds only. It is, therefore probable that instead of a bifocal event we are dealing with two discrete shocks located on the detachment surface with a timelag of 12 minutes being incidental.

The isoseismal patterns not only reflect a rapid attenuation on the eastern side of isoseismal V but an apparent termination along the projected trace of the Ravi tear.

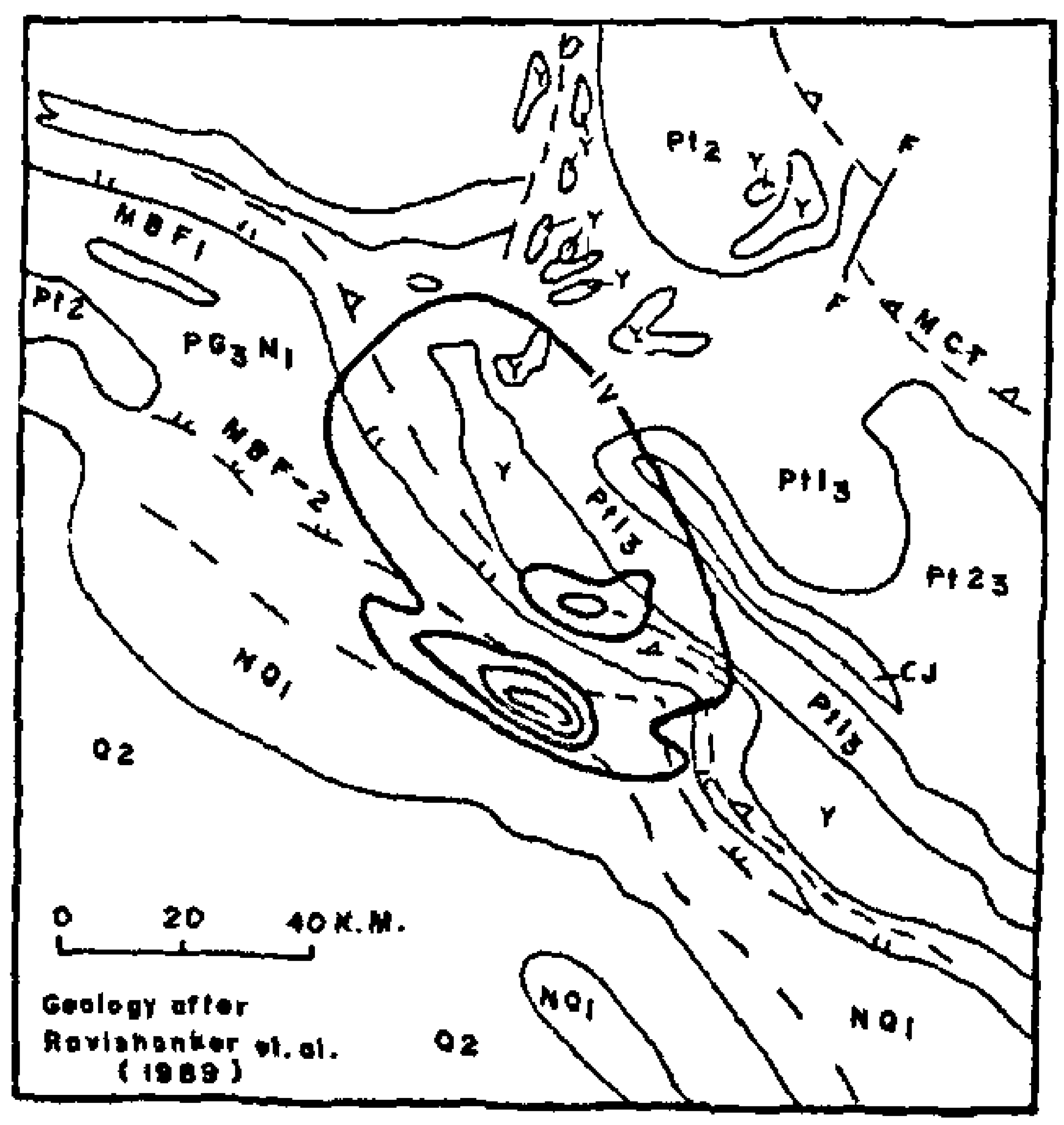

FIGURE 5. Isoseismals of Jammu-Kathua Earthquake 24th August 1980 (Krishnamurthy *et al.* 1980) on geological base. Q_2-Holocene, NQ_1-Mio-Pliocene, PG_3N_1-Oligo-Miocene, CJ-Carboniferous Jurassic, Y-Granites, Pt_{1-3}-Proterozoic, MCT-Main Central Thrust, MB-F_{1-2}-Main Boundary Faults, FF-Fault.

DHARAMSALA EARTHQUAKE OF 26TH. APRIL, 1986

The Kangra valley of Himachal Pradhesh, where ±5 magnitude earthquakes are quite frequent, was rocked by an earthquake of Mag. 5.7 in the afternoon of 26th. April, 1986 and on the basis of media reports on the extent of damages caused, a team of five officers was deputed from the Geological Survey of India to carry out the macroseismic studies of the damage patterns and the job was accomplished between the 4th. May, 1986 and 19th. May, 1986. The maximum damage was caused in the Nadeli village where almost all the houses built in masonry with mud mortar collapsed while almost all the houses with brick masonry in cement mortar were badly damaged or partly collapsed. Ground cracks trending in N70W-S70 E were observed in a slope inclined at 15° and covered by overburden material. Gupta *et al.*[20] assigned intensity VIII on MM in a restricted area while intensity VII covers an area of about 100 sq. km. enclosing important townships like Macleodganj, Dharamsala Cantt., Dharamsala depending upon the damage pattern studied. The general tectonic set up and the isoseismals are incorporated in figure 6. Interesting findings from the isoseismal patterns are that:

- The epicentral tract is oriented across the general trend of the isoseismal in the lower intensity ranges.

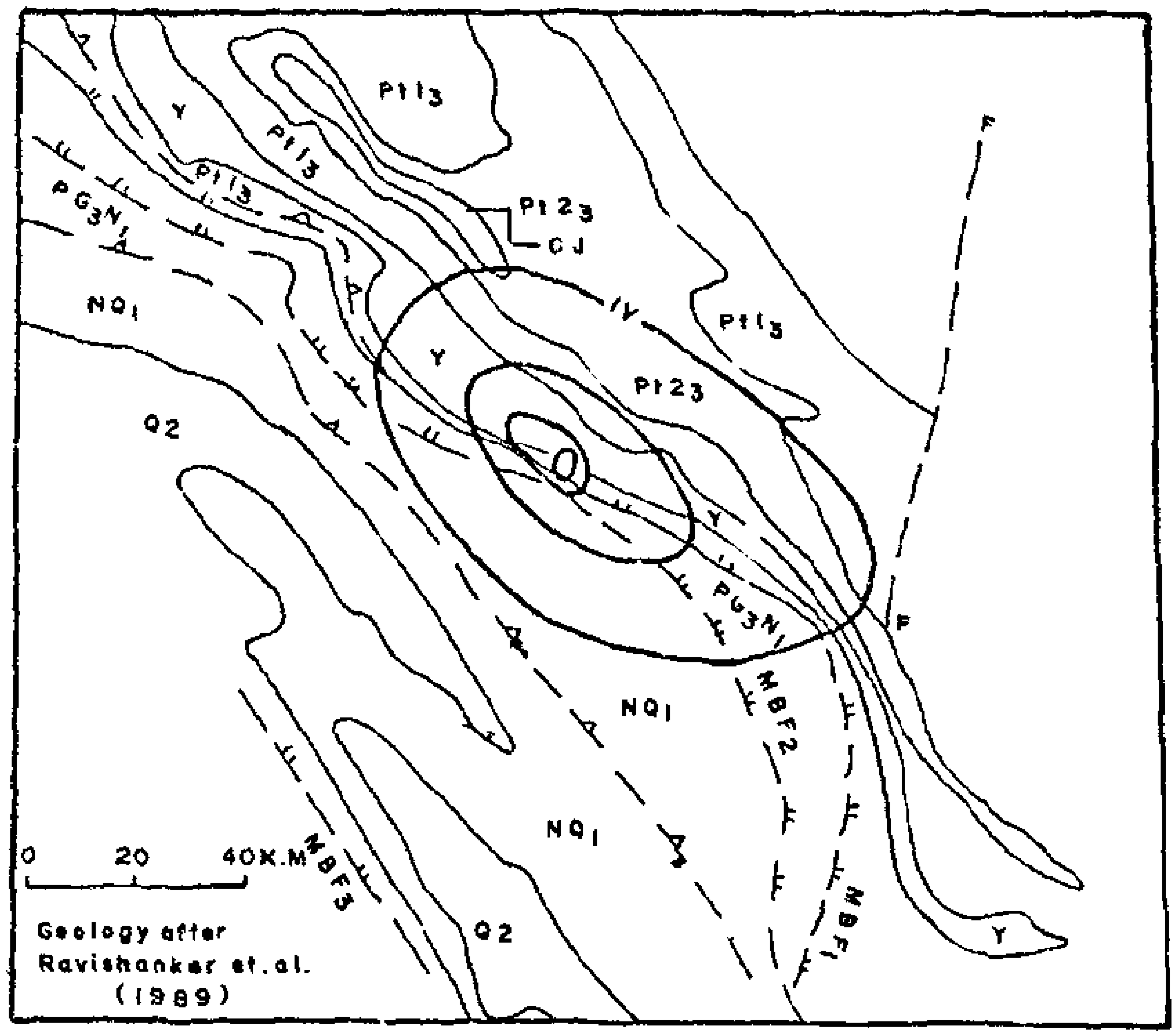

FIGURE 6 Isoseismals of Dharamsala Earthquake, 26th April 1986 (Gupta *et al.*, 1986) on geological base, Q_2-Holocene, NQ_1-Mio-Pliocene, PG_3N_1-Oligo-Miocene, Y-G ites, CJ-Carbo-niferous-Jurassic, Pt-Proterozoic, MBF_{1-3}-Main boundary faults, FF-Fault.

■ The attenuation of intensity VII is quicker on the SE side than on the northwestern side while the reverse is true for intensity VI and V and once again the attenuation of intensity IV has become rapid in the south-easterly direction.

From these intensity decay patterns the following interpretations have been made:

The source fault is aligned in the N55°W–S55°E direction along the general trend of the isoseismals but adjustments might have taken place along the N-S tear located west of Dharamsala township as vertical accentuation caused by topography in the vertical accelerations might not be the only cause of meizoseismal to be aligned in the N-S direction. It has been found from the strong motion records of the earthquake that maximum horizontal ground acceleration has been calculated at Shahpur[21] almost south of the epicentral tract but commensurate damages have not been observed at in this township, may be the vertical accentuation of accelerations have not taken place because of its being located in the valley portion. Another inference drawn by Chandrasekaran[21] is that the empirical formulae available in literature for attenuation do not predict the accelerations correctly and the attenuations are much slower than the ones obtained from the formulae. Thus the macroseismic studies attain importance to qualitatively assess the changes in accelerations observed particularly in the near source areas, in the absence of strong motion array.

DISCUSSIONS

The seismicity in the outer Himalaya has been explained either by the Evolutionary model or by the Steady state model of the collision tectonics hypothesised by various researchers. The steady state model first proposed by Seeber and Armbruster[19] and later supported by Ni and Barazangi (1984) on the basis of well constrained focal depths and fault-plane solutions, is the one which adequately explains the prevailing deformation styles in the Himalayan Front. The main premise of this model is that detachment surface under thrusting Himalayan front, within the crust, is the locale of most of the present day seismic interaction. However, none of the models constrain the crustal blocks in the east west direction and these have mostly been idealised as open ended sources. According to the authors such an idealisation does not result in realistic assessment of the source potential. The first author suggested that the Main Himalayan seismic zone is intersected by the transverse features dividing this zone into discrete blocks of similar seismic behaviour (Narula[3] and Narula[4] (in press).

The analysis of the isoseismal trends as well as their attenuation patterns discussed in this paper reveal that the seismic source(s) in the NW Himalaya are mostly parallel to the Himalayan trend with localised modifications inferred to have been caused by attenuation as well as accentuation of intensities along the geologically well established transverse features. In fact some of the isoseismal trends like that of Dharamsala earthquake of 1978 and that of Dharchula earthquake of 1980 are markedly oblique (transverse) to the Himalayan trend. The fault-plane solutions for these events are thrust type and P-axis not in conformity to the prevailing deformation styles. The authors feel that such modifications in the isoseismal trends and changes in the P-axis orientation might have been caused by intersection of, and by the reactivation of the pre-existing transverse zones of weakness. Such an inference is in conformity with the intersection model of Talwani[16]. The abrupt attenuation and termination of isoseismal V for Jammu-Kathua earthquake along the projected trace of Ravi tear can only be explained by damping along this feature. From the above discussions it can be concluded that the transverse features have a significant role in the generation and modifications of the source parameters. The corollary to this inference is that these transverse features mapped on the ground extend down atleast to the detachment surface and deeper.

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