Mausam, (1979), **30**, 2 & 3, 253-264

550.341.5(235.24)

Spatial prediction of earthquakes in the Kumaon Himalaya by pattern recognition

VARUNODAY, V. K. GAUR and H. R. WASON

Department of Geology and Geophysics, University of Roorkee, Roorke

ABSTRACT. The work presented relates to a pattern recognition study of the Kumaon Himalaya to delineate dangerous and non-dangerous zones using *a priori* knowledge of some strong earthquakes that occurred in the region. The raw data incorporates various geological parameters and processed to extract distinctive dangerous and non-dangerous features.

1. Introduction

The complexities underlying the processes that produce an earthquake still remain a challange to seismologists. Where and when a future event might occur is a question that continues to engage serious consideration. To answer these questions precisely, one must have a tractable physical model of the earthquake processes and adequate information concerning the distribution of elastic parameters and stress fields in space and time. In the absence of such detailed knowledge, however, one can still attempt to provide meaningful answers to some aspects of these questions using a black box approach which only specifies the various input-output relationships.

One such method is the pattern recognition technique which, through an intensive analysis of a body of data, can enable more information to be extracted than other alternative procedures. The method is, particularly, suitable for taking such problems as earthquake prediction which may involve a large number of associated parameters. The technique essentially consists in developing discriminating decision rules based on the known envoironment of a set of samples and using these to classify unknown samples.

The present work attempts to identify future earthquakes in the space domain based on this technique. All important geological parameters which may be expected to cause an earthquake or contribute to its occurrence, were systematically analysed in respect of a few well known earthquakes with a view to discerning meaningful patterns of their associated features which may then be used to identify other similar or dissimilar environments in the region.

TABLE I

Particulars of the earthquakes used in the study

S. No.	Year	Month	Day	Lat. (°N)	Long. (°E)	Mag.
1	1926	VI	27	30·5	80·5	6·0
2	1935	III	5	29·75	80·25	6·0
3	1937	X	20	31·0	78·0	5·5
4	1945	VI	14	30·0	80·0	6·5
5	1964	IX	26	30·1	80·7	6·2
6	1966	VI	27	29·6	80·9	6·0

The basic algorithm used in this study called *clusters* was first developed and used by Gelfand *et al.* (1976) for studying the earthquakes epicentres in California as a part of the joint U.S.A./U.S.S.R. programme on earthquake prediction.

2. The problem

The objective of this study was to predict the location of future earthquakes of magnitude equal to or greater than 5.5 in the Kumaon Himalaya. For this purpose, data pertaining to 6 earthquakes of magnitudes greater than or equal to 5.5, that occurred in this region between 1900 and 1976, were used as a learning material for developing decision rules. Particulars of these earthquakes are given in Table 1.

Fig. 1 shows the map of the area. This is largely based on the map prepared by Gansser (1964) but incorporates tectonic and regional features since delineated by other workers.

3. General approach

The problem of recognition can be stated as follows : let there be a set of 'objects' each being described in terms of a set of answers to a

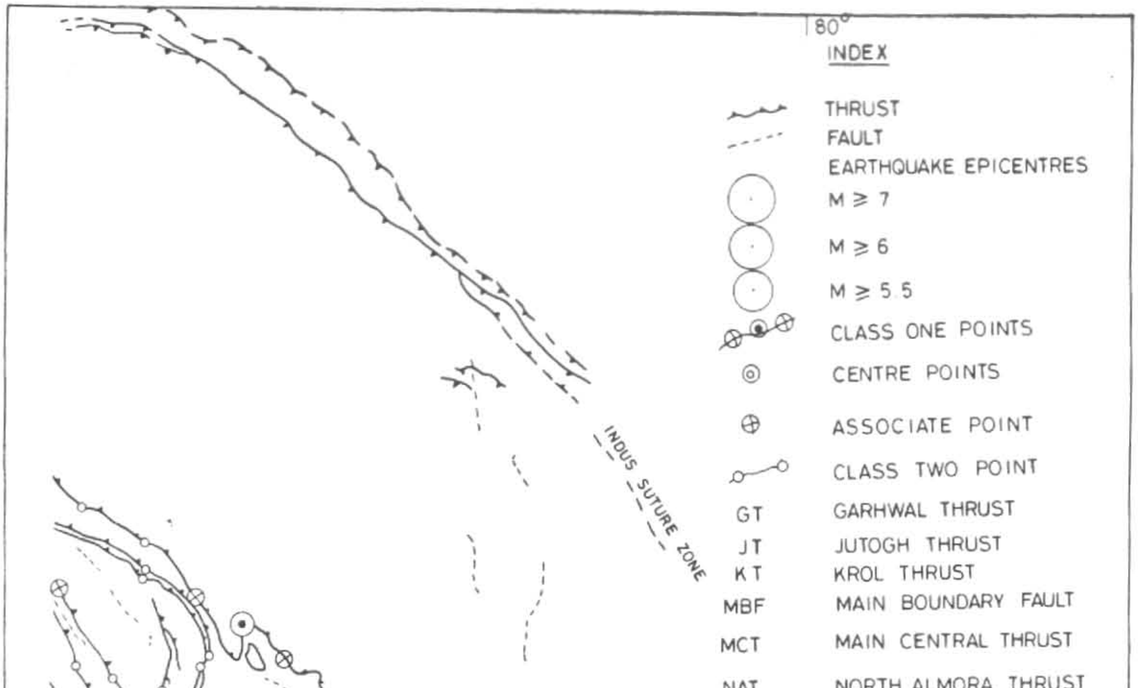

Fig. 1. Tectonic and regional structural map of the Kumaon Himalaya along with identification number of objects of recognition

questionnaire. Furthermore, a classification is drawn up to categorise objects into several groups based on criteria considered to be most plausible for the problem in hand. The aim of the study is to determine as to which class each object belongs. To answer this question we first need to go through a 'learning phase' using *a priori* knowledge provided by the geological features associated with some well known earthquakes.

In the context of the present problem, 'objects' are defined as points on a map lying on the main lineaments of the region. The specific object is to identify regions where 'strong earthquakes' would be likely to occur in the future, that is to delineate the most seismically dangerous zones along the lineaments. All those points which fall in the category of being dangerous are labelled as 'D' objects and the remaining points

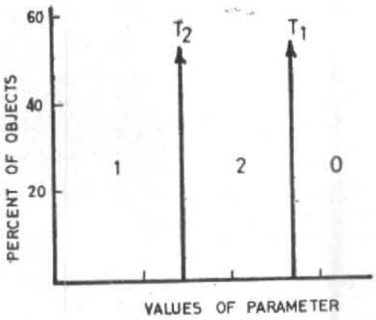

Fig. 2. Representation of the ternary code with respect to threshold values

as 'N' objects.

4. The objects

As stated earlier, an 'object' refers to some point on the thrust. In order to make sense, however, they must be specified such that objects of different classes may not overlap in any zone. Accordingly, four kinds of objects have been distinguished.

The first kind of points are called 'centres' where a 'centre' is just the projection of each epicentre on the thrust closest to it. These constitute a set of six objects with ordinal numbers 1 to 6 in chronological order (Fig. 1).

The second kind of points are those situated on the same thrust on either side of centres at a radial distance of 25 km. These points have ordinal numbers 7 to 18 (Fig. 1). They are called 'associates of corresponding centres'. Ordinarily each centre will have two associates.

The third kind of points constitute a set located at intervals of 50 km along the thrusts provided that they do not lie on the segments already occupied by centres and their associates. Their ordinal numbers are 19 to 48.

Additionally, a few points are also located on some portions of minor thrusts, not included in the third kind, but which exhibit some marked geological features calling for a special sudy. These points, say, of the 4th kind have ordinal numbers 49 to 51.

The objects thus defined are classified into three in the first phase of the recognition process, *i.e.*,

(*i*) Clusters

(*ii*) Single objects inside the clusters and

(*iii*) Single objects outside the clusters.

Each of the centres together with its associates forms a cluster. Six clusters are thus formed and 18 objects lie in the second category. The remaining 33 objects are single objects outside the clusters.

Attributes of all the objects in the three categories constitute the learning material.

5. Defining an object

An object is defined by row vector whose components constitute the answers to a questionnaire. The answers themselves are presented in a ternary code (0 ,1 ,2), with respect to two threshold values selected independently for each parameter. For example,

$$A = (A_1, A_2, \; \dots \; A_n)$$

The component A_j is the answer to the j^{th} question in the questionnaire expressed respectively as 0, 2 or 1 corresponding to values lying above, between and below the two thresholds (Fig. 2).

6. Traits

Traits of an object are also defined by row vectors consisting of $(2n-m)$ components, the first n digits representing the serial number of the question and the remaining representing their answers expressed by a digit of the ternary code, m representing the number of redundant questions. Thus the i^{th} trait is expressed by

$$T_i = p, \; q, \; r, \;\; .. \;..\;\; n, P, Q, R, \; .. \;..\;\; N.$$

In the present study 3 questions were combined at a time to yield the corresponding trait. Accordingly :

$$T_i = p, \; q, \; r, \;\; P, \; Q, \; R$$

If N related geological parameters are used for the study then the objects can be defined in terms of answers to N questions and $p = 1, 2, \dots N$, $q = p, \; p+1, .. N$ and $r = q, \; q+1, .. N$ and so on.

These traits generated from raw data constitute the basic learning material which is used throughout the recognition process.

In general the recognition algorithm consists of 3 phases :

(*i*) Learning

(*ii*) Voting

(*iii*) Control Experiments

7. Learning

In the first phase each object and traits of objects are defined. Thereafter, traits are analysed and on the basis of their frequency of occurrence in different pre-defined categories, dangerous and non-dangerous features are abstracted. Next, all equivalent and weak features are eliminated to extract the distinctive features.

8. Voting

Voting is carried out to determine the numbers nD and Nn of distinctive dangerous and non-dangerous features, characterising each object.

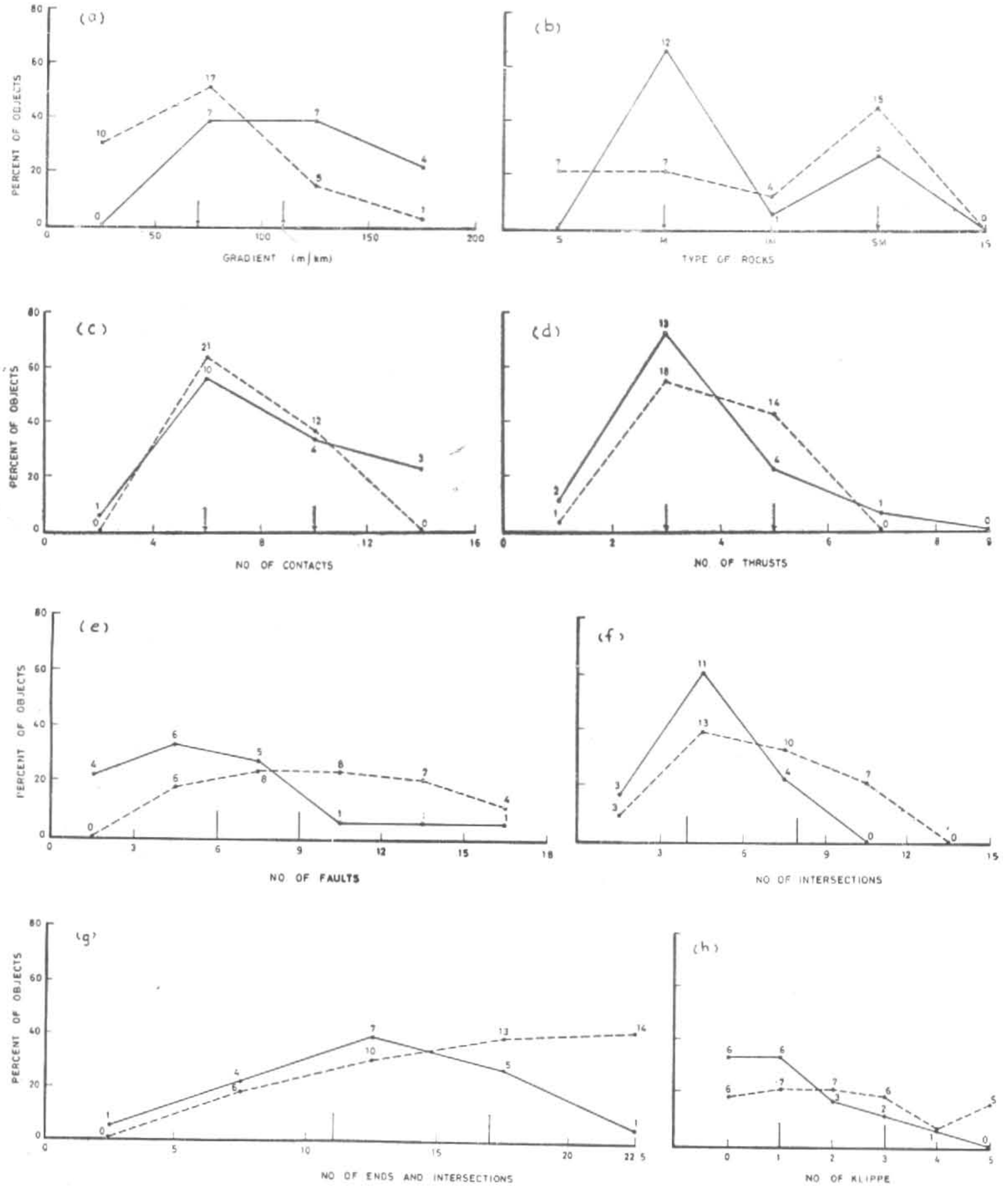

Fig. 3. One dimensional distribution of parameters for points on major thrusts of the Kumaon Himalaya. Values of parameters are indicated on the horizontal axis; the solid line is the histogram for class I objects; dashed line is the histogram for Class II objects; the assigned thresholds are shown by arrows; the number near each point implies the number of objects falling in that category and the same is expressed in percentage of objects on vertical axis.

Recognition is based on the diffrence $\triangle=(nD - Nn)$. The object is recognised as dangerous if $\triangle \geqslant \bar{\triangle}$ where $\bar{\triangle}$ is some threshold value.

9. Control experiments

These expeiments are needed to ensure that recognition algorithm has produced stable and reliable results. They include suitably formulated logical experiments.

The recognition algorithm 'clusters' is discussed in detail by Gelfand *et al.* (1976). The stability of

TABLE 2

Characterisation of objects, list of parameters considered (Kumaon Region)

No.	Parameter Name
1**	Gradient, Gr
2*	Area of soft sediments A
3*	Type of Rocks (I,M,S)
4**	No. of Contacts, NC
5**	No. of thrusts, NT
6***	No. of faults, nf
7***	No. of Closed thrusts, nk
8***	No. of intersections, ni
9***	Total no. of ends and intersections, ne
10	Distance from nearest intersection or sharp bend, R

Note : Measured inside the circle of radii *12·5 km, ** 25 km ***50 km

TABLE 3

List of parameters used for recognition

S. No.	Name of parameter	Thresholds
1**	Gradient, Gr	$\leqslant 70$ $70 < Gr \leqslant 110$
2*	Type of rock	Presence of M Presence of SM
3**	Number of contracts, NC	$\leqslant 6$ $6 < NC \leqslant 10$
4**	Number of thrusts, NT	$\leqslant 3$ $3 < NT \leqslant 5$
5†	Number of faults, nf	$\leqslant 6$ $6 \leqslant nf \leqslant 9$
6*	Number of intersections, ni	$\leqslant 4$ $4 < ni \leqslant 8$
7*	Total number of ends and intersections, ne	$\leqslant 11$ $11 < ne \leqslant 17$
8†	Number of Klippe, nk	$\leqslant 1$ $1 < nk \leqslant 3$

Note : Measured inside a circle of radii *12·5 km, **25 km, †50 km

TABLE 4

Feature of object	Should be found in		
	Clusters	Single objects inside clusters	Single objects outside clusters
D	$\geqslant 4$	$\geqslant 2$	$\leqslant 2$
N		$\leqslant 1$	$\geqslant 7$

the results established by their control experiments was considered to be adequately reliable for the present work also for which no control experiments could be performed seperately for want of computer facilities.

10. Parameters

Recognition has been carried out on the basis of important geological parameters, which are listed in Table 2.

Several parameters were *a priori* chosen on the basis of their possible associations with earthquake occurrences, directly or indirectly, and their frequency distributions studied. Of these only the above eight showed significant discrimination. The questionnaire was accordingly prepared on the basis of these, the respective thresholds being chosen in such a way that neither the range between them becomes too narrow nor the number of objects falling in any interval becomes too small. These parameters along with the threshold values are listed in Table 3 and their one dimensional distribution are shown in Fig. 3.

Using these parameters all the 51 objects were defined and subsequently the dangerous and the non-dangerous features, according to the rules given in Table 4.

11. Discussion of results

Learning through clusters alone, 202 dangerous features were obtained, 384 dangerous and 804 non-dangerous features were obtained from single objects inside the clusters and 496 dangerous and 102 non-dangerous features were obtained in respect of the single objects outside the clusters. Finally distinctive dangerous and non-dangerous features were obtained by eliminating all equivalent and weak features.

Gathering all the features so abstracted, a further shortlisting was carried out by identifying those that appear dangerous or non-dangerous in more than one of the groups investigated. 82 distinctive dangerous and 29 distinctive non-dangerous features were thus obtained. These features and their equivalents are shown in Tables 5 and 6.

The geological environment most prone to earthquakes can not ordinarily be identified owing to complex situations. Significance of individual parameters for defining a dangerous environment could not be fairly interpreted because each parameter, under different combinations, may lie between different threshold values. Moreover, comparing Tables 5 and 6 we find that some features are identified as dangerous as well as non-dangerous. This reflects the fact that some ambiguities cannot be resolved if the study is confirmed to the single objects inside the clusters.

Voting has been carried out for all objects individually and dangerous and non-dangerous

TABLE 5

Distinctive dangerous features and their equivalents

Distinctive dangerous features No. (1)	Gradient (Gr) (2)	Type of rock (3)	Number of Contacts (NC) (4)	Number of Thrusts (NT) (5)	Number of faults (6)	Number of intersection (ni) (7)	Total No. of ends and inter-sections (ne) (8)	No. of Klippe (nk) (9)
1	—	—	—	—	—	—	—	≤1
	—	—	—	—	—	—	11<ne≤17	—
	—	—	—	—	—	—	11<n2≤17	—
2	—	—	—	3<NT<5	—	—	—	—
3	—	—	—	—	≤6	—	—	—
4	—	—	—	—	—	4<ni≤8	—	—
5	—	—	—	—	—	—	11<ne≤17	—
6	>110	—	—	—	—	—	—	—
7	—	—	6<NC≤10	—	—	—	—	—
8	—	—	—	≤3	—	—	—	—
9	—	M	—	—	—	—	—	—
10	70<Gr≤110	—	—	—	—	—	—	—
11	≤70	—	6<NC≤10	—	6<nf<9	—	—	—
12	≤ 70	—	—	3 NT 5	—	—	≤11	—
	≤ 70	—	6<NC≤10	—	—	—	≤11	—
13	—	SM	—	3<NT<5	6<nf≤9	—	—	—
	70	SM	—	—	6<nf≤9	—	—	—
14	—	—	—	3<NT≤5	6<nf≤9	—	—	≤1
15	—	—	—	—	6<nf≤9	—	≤11	≤1
	—	—	—	—	6<nf≤9	—	≤11	—
	—	—	—	—	6<nf≤9	≤4	≤11	—
	—	—	6<NC≤10	—	6<nf≤9	—	≤11	—
	—	SM	—	—	6<nf≤9	—	—	≤1
	—	SM	—	—	6<nf≤9	—	≤11	—
	—	SM	—	—	6<nf≤9	≤4	—	—
	—	SM	6<NC≤10	—	6<nf≤9	—	—	—
16	70	—	≤6	—	—	4<ni≤8	—	—
17	—	NOT M or SM	—	3<NT≤5	—	—	>17	—
18	—	NOT M or SM	—	—	6<nf≤9	—	—	≤1
19	—	—	≤6	3<NT≤5	—	4<ni≤8	—	—
	—	NOT M or SM	—	3<NT≤5	—	4<ni≤8	—	—
20	—	—	—	3<NT≤5	6<nf≤9	4<ni≤8	—	—
21	—	—	—	3<NT≤5	—	4<ni≤8	>17	—
22	—	—	—	3<NT≤5	—	—	>17	≤1
23	—	—	—	—	6<nf≤9	—	>17	≤1
	—	—	—	—	6<nf≤9	—	>17	—
	—	—	—	—	6<nf≤9	4<ni≤8	—	≤1
	—	—	—	—	6<nf≤9	4<ni≤8	>17	—
24	—	SM	—	3<NT≤5	—	>8	—	—
25	—	—	6<NC≤10	—	—	—	—	≤3
	—	—	6<NC≤10	—	—	—	>17	≤3
	—	—	6<NC≤10	—	>9	—	—	≤3
	—	—	6<NC≤10	3<NT≤5	—	—	—	≤3
	—	—	6<NC≤10	3<NT≤5	—	—	>17	—
	—	SM	—	—	—	—	>17	≤3
	—	SM	—	—	6<nf≤9	—	—	≤3
	—	SM	6<NC≤10	—	—	—	—	>3
	—	SM	6<NC≤10	—	—	—	>17	—
26	—	—	—	—	—	>8	—	>3
	—	—	—	—	—	>8	>17	>3
	—	—	—	—	—	>8	—	>3
	—	—	—	3<NT≤5	—	>8	—	>3
27	≤70	SM	—	—	—	—	11<ne≤17	—
28	≤70	—	—	3<NT≤5	—	—	11<ne≤17	—
29	≤70	—	—	—	—	4<ni≤8	11<ne≤17	—
30	—	SM	—	3<NT≤5	—	—	11<ne≤17	—
31	—	—	—	—	6<nf≤9	—	11<ne≤17	—
32	—	—	—	—	—	4<ni≤8	—	>3
	—	—	—	3<NT≤5	—	4<ni≤8	—	>3
	—	SM	—	—	—	4<ni≤8	—	>3
	≤70	—	—	—	—	4<ni≤8	—	>3
	≤70	SM	—	—	—	4<ni≤8	—	—
33	—	SM	≤6	3<NT≤5	—	—	—	—
34	—	—	≤6	3<NT≤5	—	4<ni≤8	—	—

TABLE 5—(*contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
35	—	—	—	—	—	>8	—	≤1
	—	—	—	—	—	>8	>17	≤1
	—	—	—	—	>9	>8	—	≤1
	—	—	≤6	—	—	>8	—	≤1
	≤70	—	—	—	—	>8	—	≤1
36	70<Gr≤110	SM	—	—	—	—	>17	—
	70<Gr≤110	SM	—	—	>9	—	—	—
37	70<Gr≤110	—	—	—	—	—	>17	≤1
38	—	SM	—	—	—	4<ni≤8	>17	—
	—	SM	—	—	>9	4<ni≤8	—	—
39	≤70	—	6<NC≤10	≤3	—	—	—	—
40	≤70	—	6<NC≤10	—	—	—	11<ne≤17	—
41	—	SM	—	≤3	—	—	11<ne≤17	—
42	—	—	6<NC≤10	≤3	>9	—	—	—
43	—	—	6<NC≤10	—	>9	—	11<ne≤17	—
44	≤70	SM	—	—	≤6	—	—	—
45	—	SM	≤6	—	—	—	≤11	—
	—	SM	≤6	—	—	≤4	—	—
	—	SM	≤6	—	≤6	—	—	—
46	—	—	≤6	≤3	—	—	≤11	—
	—	—	≤6	≤3	≤6	—	—	—
47	>110	—	—	—	≤6	—	—	≤1
	>110	—	—	—	≤6	—	—	—
	>110	—	—	3<NT≤5	—	—	—	≤1
	>110	—	—	3<NT≤5	≤6	—	—	—
	>110	—	—	3<NT≤5	—	—	—	—
	>110	—	6<NC≤10	—	≤6	—	—	—
	>110	—	6<NC≤10	3<NT≤5	—	—	—	—
	>110	SM	—	—	≤6	—	—	—
	>110	SM	—	3<NT≤5	—	—	—	—
48	>110	—	—	—	—	—	≤11	≤1
	>110	—	—	—	—	—	≤11	—
	>110	—	—	—	—	≤4	—	≤1
	>110	—	—	—	—	≤4	≤11	—
	>110	—	—	—	—	≤4	—	—
	>110	—	6<NC≤10	—	—	—	≤11	—
	>110	—	6<NC≤10	—	—	≤4	—	—
	>110	SM	—	—	—	—	≤11	—
	>110	SM	—	—	—	≤4	—	—
49	—	—	6<NC≤10	≤3	—	—	≤11	—
	70<Gr≤110	—	—	≤3	—	—	≤11	—
50	—	—	—	≤3	≤6	4<ni≤8	—	—
	70<Gr≤110	—	6<NC≤10	—	—	4<ni≤8	—	—
51	70<Gr≤110	—	—	≤3	—	—	11<ne≤17	—
52	70<Gr≤110	—	—	—	—	4<ni≤8	11<ne≤17	—
53	—	—	—	≤3	—	4<ni≤8	11<ne≤17	—
54	—	—	—	—	≤6	4<ni≤8	11<ne≤17	—
	—	—	6<NC≤10	—	—	4<ni≤8	11<ne≤17	—
	—	SM	—	—	≤6	—	11<ne≤17	—
55	70<Gr≤110	—	—	≤3	—	≤4	—	—
56	≤70	NOT M OR SM	—	—	—	—	11<ne≤17	—
57	—	NOT M OR SM	≤6	—	—	—	11<ne≤17	—
58	—	NOT M OR SM	—	≤3	—	—	11<ne≤17	—
59	—	—	≤6	≤3	—	—	11<ne≤17	—
	≤70	—	≤6	—	—	—	11<ne≤17	—
60	—	—	≤6	—	>9	≤4	—	—
61	—	NOT M OR SM	—	≤3	—	4<ni≤8	—	—
	70<Gr≤110	NOT M OR SM	—	—	—	—	>17	—

TABLE 5 *(contd)*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
62	—	—	—	—	—	—	—	1<nk≤3
	—	—	—	—	—	—	>17	1<nk≤3
	—	—	—	—	>9	—	—	1<nk≤3
	—	—	—	—	>9	—	>17	1<nk≤3
	—	—	—	≤3	—	—	—	1<nk≤3
	—	—	—	≤3	—	—	>17	1<nk≤3
	—	—	—	≤3	>9	—	—	1<nk≤3
	—	—	≤6	—	—	—	—	1<nk≤3
	—	—	≤6	—	—	—	>17	1<nk≤3
	—	—	≤6	—	>9	—	—	1<nk≤3
	—	—	≤6	≤3	—	—	—	1<nk≤3
	70<Gr≤110	—	—	—	—	—	—	1<nk≤3
	70<Gr≤110	—	—	—	—	—	>17	1<nk≤3
	70<Gr≤110	—	—	—	>9	—	—	1<nk≤3
	70<Gr≤110	—	—	≤3	—	—	—	1<nk≤3
	70<Gr≤110	—	≤6	—	—	—	—	1<nk≤3
63	≤70	—	—	≤3	—	4<ni≤8	—	—
	≤70	M	—	—	—	—	—	≤1
	≤70	M	—	—	—	4<ni≤8	—	—
	≤70	M	—	≤3	—	—	—	—
	≤70	M	—	—	—	—	—	—
64	≤70	—	—	—	>9	4<ni≤8	—	—
65	—	M	—	—	>9	—	—	≤1
	—	M	—	—	>9	4<ni≤8	—	—
	—	M	—	—	>9	—	—	—
	—	M	—	≤3	>9	—	—	—
66	—	—	—	—	>9	4<ni≤8	11<ne≤17	—
67	—	≤70	6<NC≤10	—	—	4<ni≤8	—	—
68	—	6<NC≤10	—	—	—	—	>17	≤1
	—	—	6<NC≤10	≤3	—	—	>17	—
	—	M	—	—	—	—	>17	—
	—	M	—	—	≤4	4<ni≤8	>17	—
	—	M	—	3<NT≤5	—	—	>17	—
	—	M	6<NC≤10	—	—	—	—	≤1
	—	M	6<NC≤10	—	—	—	>17	—
	—	M	6<NC≤10	—	4<ni≤8	—	—	—
	—	M	6<NC≤10	≤3	—	—	—	—
	—	M	6<NC≤10	—	—	—	—	—
69	—	—	—	≤3	6<nf≤9	—	—	≤1
	—	—	—	≤3	6<nf≤9	—	—	—
	—	—	6<NC≤10	≤3	6<nf≤9	—	—	—
70	—	—	6<NC≤10	3<NT≤5	—	4<ni≤8	—	—
71	—	—	6<NC≤10	—	>9	4<ni<≤8	—	—
72	—	—	—	3<NT≤5	>9	4<ni≤8	—	—
73	—	—	—	≤3	—	>8	>17	—
	—	—	—	≤3	—	>8	—	—
	—	—	—	≤3	>9	>8	—	—
	—	—	≤6	≤3	—	>8	—	—
	—	SM	—	≤3	—	>8	—	—
74	>110	—	—	—	—	4<ni≤8	—	≤1
	>110	—	—	—	—	4<ni≤8	—	—
	>110	—	6<NC≤10	—	—	4<ni≤8	—	—
75	70<Gr≤110	—	—	—	—	≤4	11<ne≤17	—
	70<Gr≤110	NOT M OR SM	—	—	—	≤4	—	—
	70<Gr≤110	NOT M OR SM	6<NC≤10	—	—	—	—	—
76	≤70	—	—	3<NT≤5	≤6	—	—	—
	≤70	—	6<NC≤10	—	≤6	—	—	—
77	—	NOT M OR SM	—	—	≤6	—	—	≤1
	—	NOT M OR SM	—	—	≤6	≤4	—	—
	—	NOT M OR SM	—	—	≤6	—	—	—
	≤70	NOT M OR SM	—	—	≤6	—	—	—
78	—	—	—	3<NT≤5	≤6	—	11<ne≤17	—

TABLE 5 (*contd*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
79	—	—	—	$3<NT\leq 5$	—	≤ 4	$11<ne\leq 17$	—
	—	NOT M OR SM	—	$3<NT\leq 5$	—	≤ 4	—	—
	—	NOT M OR SM	$6<NC\leq 10$	$3<NT\leq 5$	—	—	—	—
80	≤ 70	—	$6<NC\leq 10$	$3<NT\leq 5$	—	—	—	—
81	—	—	—	$3<NT\leq 5$	>9	—	$11<ne\leq 17$	—
	$70<Gr\leq 110$	—	—	—	>9	—	$11<ne\leq 17$	—
	$70<Gr\leq 110$	—	—	$3<NT\leq 5$	—	—	$11\leq ne<17$	—
	$70<Gr\leq 110$	—	—	$3<NT\leq 5$	>9	—	—	—
	$70<Gr\leq 110$	NOT M OR SM	—	$3<NT\leq 5$	—	—	—	—
82	$70<Gr\leq 110$	—	≤ 6	$3<NT\leq 5$	—	—	—	—

Number of parameters (*vide* Table 3)

TABLE 6

Distinctive non-dangerous features

Distinctive non-dangerous features No. (1)	Gradient (Gr) (2)	Type of rock (3)	No. of Contacts (NC) (4)	No. of Thrusts (NT) (5)	No. of faults (Nf) (6)	No. of Intersection (ni) (7)	Total No. of ends and intersections (ne) (8)	No. of Klippe (nk) (9)
	$70<Gr\leq 110$	—	—	—	—	—	—	—
2	—	—	—	≤ 3	—	—	—	≤ 1
3*	—	—	—	—	≤ 6	—	—	—
4	—	—	—	—	—	—	—	$1<nk\leq 3$
5*	—	—	—	$3<NT\leq 5$	—	—	—	—
6	—	—	—	—	—	—	>17	—
7	—	—	—	—	—	$4<ni\leq 8$	—	≤ 1
8	—	SM	—	—	—	$4<ni\leq 8$	—	—
9*	—	M	—	—	—	—	—	—
10*	—	—	$6<NC\leq 10$	—	—	—	—	—
11*	—	—	—	—	—	—	$11<ne\leq 17$	—
12	—	—	≤ 6	—	—	$4<ni\leq 8$	—	—
13*	>110	—	—	—	—	—	—	—
15	—	SM	—	—	—	—	—	—
16	—	—	—	—	—	—	—	≤ 1
17	—	Not M or SM	—	—	—	—	—	—
18	—	—	≤ 6	—	—	—	—	—
19	—	—	—	—	—	$4<ni\leq 8$	—	—
20	—	—	—	—	>9	—	—	—

Number of parameters (*see* Table 3)

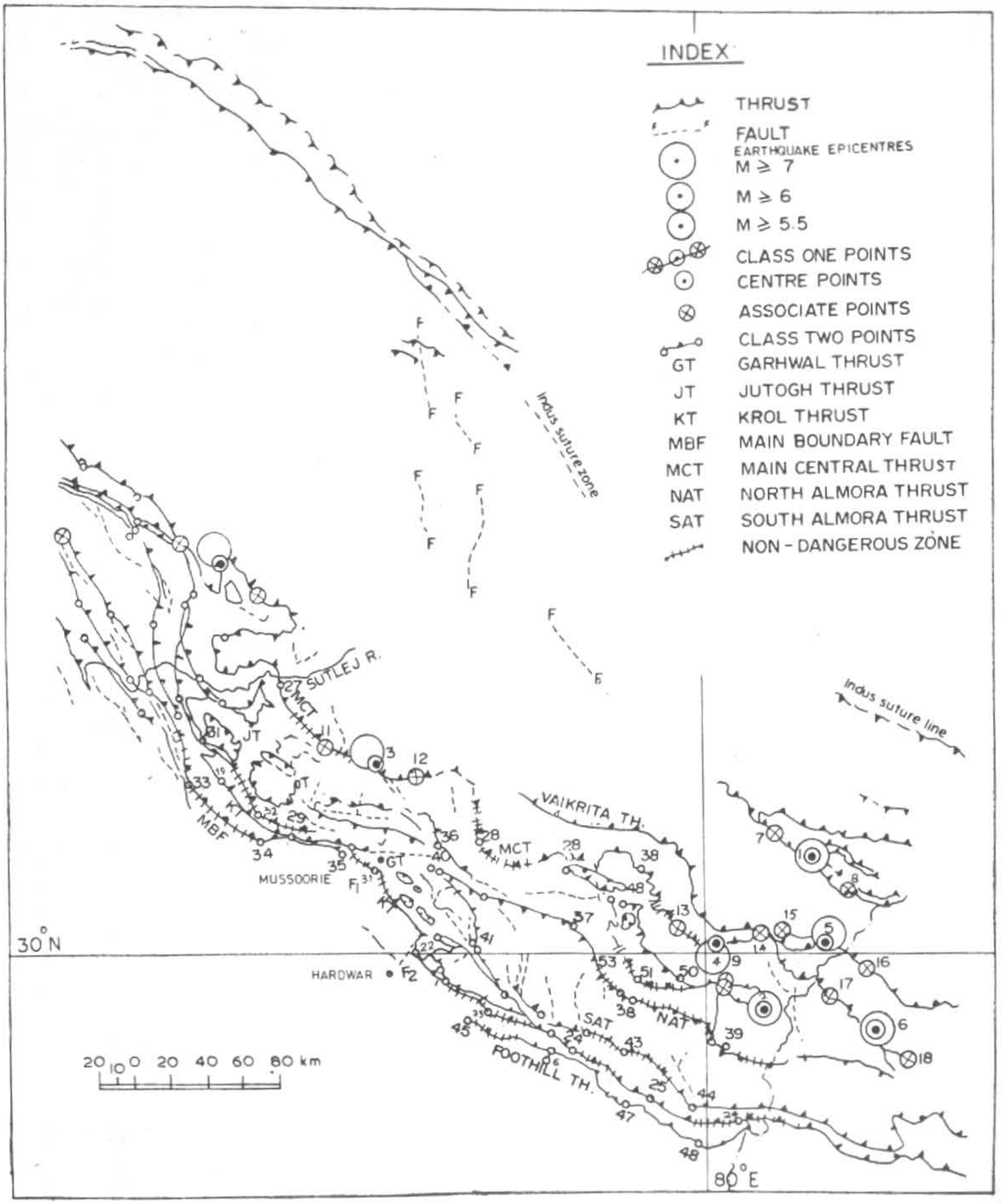

Fig. 4. Tectonic and regional structural map of the Kumoan Himalaya along with identification number of objects of recognition and distribution of dangerous and non-dangerous zones

objects are identified. Out of the 51 objects considered, 33 appear as dangerous and 18 as non-dangerous. An interesting result of voting appears in clusters 3 and 4, where it is found that these centres and one of their associates turn out to be non-dangerous. The result is quite unexpected but can be explained in terms of three possibilities :

(*i*) Complex and non-uniform geological conditions that appear in the Himalaya, *i.e.*, the regions in which these two earthquakes have occurred may be attended by geological conditions that are remarkably different from those for the rest of the clusters.

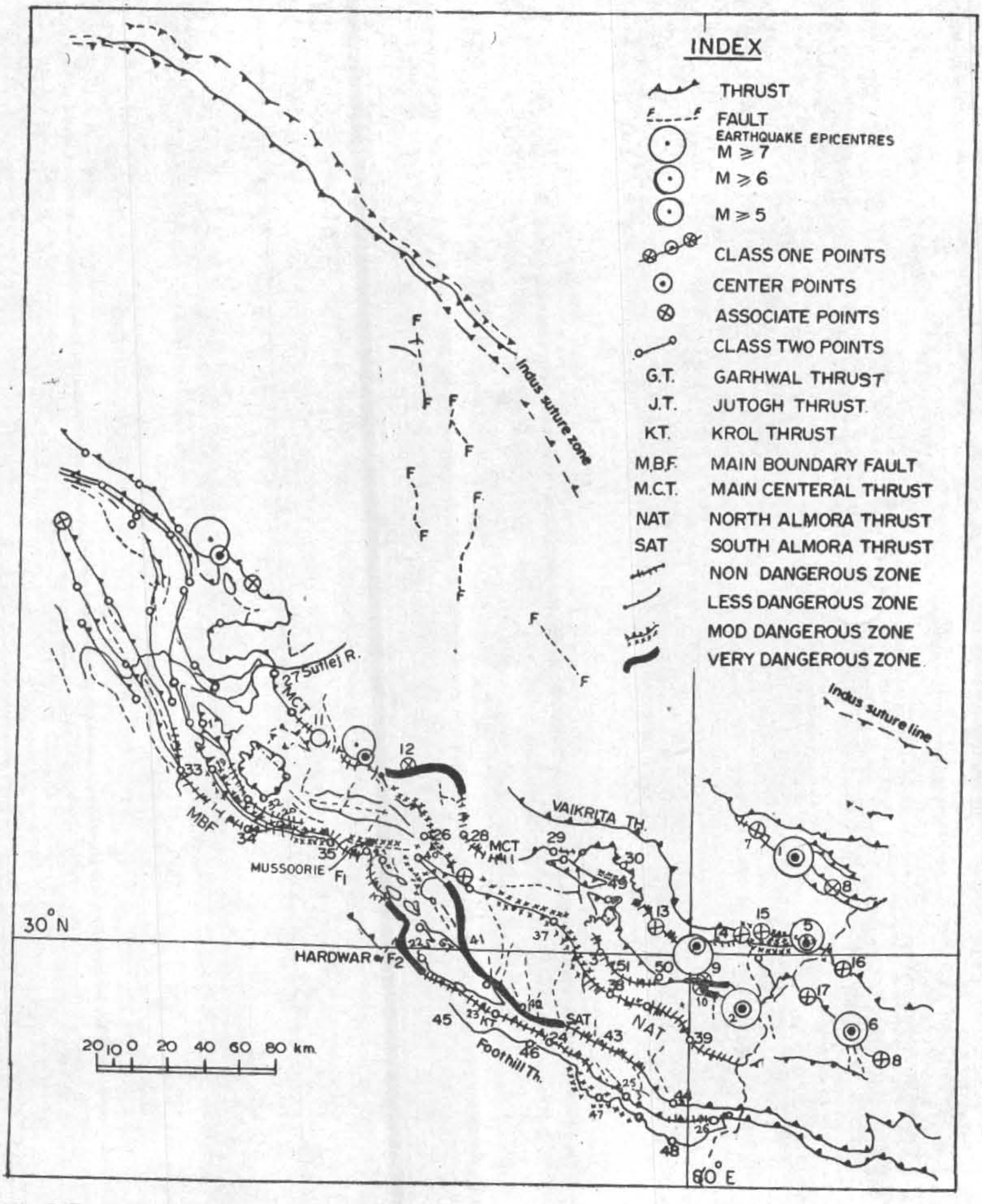

Fig. 5. Tectonic and regional structural map of the Kumaon Himalaya along with identification number of objects of recognition and microzoning map with respect to $\triangle$ values

(*ii*) Different source mechanism in respect of these earthquakes from those in respect of the other four, although this question must await the solution for the fault plane dislocations.

(*iii*) Uncertainties in location of these earthquake epicentres.

It is found that one associate in both of these clusters turns out to be dangerous and it is possible that the earthquake might actually have occurred towards this associate but was wrongly located.

The distribution of dangerous and non-dangerous zones is shown in Fig. 4. The hatched zones along the thrusts are found to be non-dangerous. The results in respect of main lineaments are discussed below.

11.1. *Main central thrust*

The main central thrust turns out to be one of the most seismically active zones of the area. 4 different dangerous zones are marked along this thrust, while only small stretches totalling a length of about 150 km are identified as non-dangerous.

A remarkable feature that emerges is that most of the dangerous points on the curved sheets appear on the concave side of the bend while the non-dangerous zones appear on the bends convex towards the Indian plate. This can be explained by the fact that since the Indian plate is moving towards the Eurasian one, the stress fields on the concave sides will be more intense than those on the convex thereby increasing the probability of earthquake occurrences there. If this observation would be confirmed generally, one could derive some useful criteria for selecting sites of new engineering projects in such regions.

11.2 *Main boundary fault Krol thrust*

The main boundary fault is characterised as a zone incorporating mainly non-dangerous objects except for a small zone of about 25 km in length lying near its overlap with the Krol thrust, which appears to be generally more active particularly in its western extensions.

A notable observation that may prove significant in the context of geophysical engineering appears on the Krol thrust at its intersections with two transverse faults F1 and F2 lying near Mussoorie and Hardwar, which are recognised respectively as non-dangerous and dangerous.

The north Almora thrust is found to be quite active except for a long belt of non-dangerous zone which lies near western Nepal. The marked trend revealed by the seismicity of this zone is the identification of single continuous dangerous as well as non-dangerous zones, the boundary between the two being marked by an intersecting transverse fault F3.

The south Almora thrust also reveals two long dangerous zones sandwiching a small non-dangerous zone.

An unexpected feature appearing from the studies is the dangerous zone along the lineament south of the Krol thrust. The lineament has emerged out as a long dangerous zone of about 150 km in length leaving aside only a small stretch of 25 km lying to the western side of the thrust.

A comparative study of the delineated dangerous zones has also been carried out by examining the value of $\triangle$, for each object. Objects with $\triangle$ values of $\triangle > 4$ are labelled as very dangerous, those with $2 < \triangle \leqslant 4$ as moderately dangerous and others with $1 \leqslant \triangle \leqslant 2$ as less dangerous ones. These, zones are separately marked in Fig. 5 which have interesting implications to microzoning exercises in complex geological environments.

A remarkable feature that emerges is that the segments in which the main central thrust is dangerous, the main boundary fault is found to be non-dangerous. This result would constitute an interesting mechanism for crustal shortening conjunctively accommodated by two parallel lineaments in a region of continent-continent convergence.

The study presented here was limited both in extent of the region studied as well as in the selection of parameters owing to limited computer time and facilities available. But the study does point out interesting implication of these results to the problems of siting and design of complex engineering projects in the region.

References

Bongard, M. M., Vaintsveig, M.I., Guberman, Sh. A., Izvekova, M.L. and smirnov, M. S., 1966, The use of self learning program in the detection of oil containing layers, *Geol Geofiz.*, **6**, 96-105 (in Russian).

Chaudhury, H.M., Srivastava, H.N. and Subba Rao, J.V. 1974, Seismotectonic Investigations of the Himalya, *Himalayan Geology*, **4**, pp. 481-491.

Fuchs, G., 1975, Contributions to the Geology of the North-Western Himalayas, *Abs. Geol.*, B-A, **32**, 1-59.

Gansser, A., 1964, *Geology of the Himalaya*, Intersci. Publ., 289.

Gelfand, I.M., Guberman, Sh., A., Izvekova, M.L., Keilis. Borok. V.I. and Ranzman, E. Ya., 1972, Criteria of High Seismicity determined by Pattern Recognition, *Tectonopphysics* **13**, 415-422.

Gelfand, I.M.. Guberman. Sh, A., Keilis - Borok, V.I., Knopoff, L., Press, F., Ranzman, E. Ya, Rotwain, I.M. and Sadovsky, A.M., 1976, Pattern, Recognition Applied to Earthquake Epicentres in California, *Physics of the Earth and Planetary Interiors*, **11**, 227-283.

Jhingran, A. G., Thakur, V. C. and Tandon, S. K., 1976, Structure and Tectonics of the Himalaya, *Himalayan Geology Sem.*, Sec. II, Structure, Tectonics. Seismicity and Evolution : 1-39.

Meisel, W. S., 1972, Computer-Oriented Approaches to Pattern, Recognition, *Mathematics in science and Engg. Series*, **83**, Academic Press, Inc. London, p. 250.

Rupke, J., 1974, *Stratigraphic and Structural Evaluation of the Kumaun Lesser Himalaya, Sedimentary Geology*, **11**, 81-265.

Valdiya, K. S., 1976, Himalayan Transverse Faults and Folds and their Parallelism with Subsurface structures of the Northern Indian Plains, *Tectonophysics*, **32**, 353-386.

DISCUSSION

(Paper presented by Varunoday)

J.G. PADALE (CWPRS) : Has any attempt been made to varify the results from geodetic measurements ?

AUTHOR : No. Adequate data is not available for this purpose.