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Second Workshop on Non-Linear Dynamics
and Earthquake Prediction

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Active Lineaments and Dynamics of Seismicity

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ACTIVE LINEAMENTS and DYNAMICS OF SEISMICITY

Hierarchy of lineaments

Formal definitions [1].
Examples [2-4].
Applications to platforms [5].

Pattern recognition of earthquake-prone areas [2-4].

System of lineaments and dynamics of seismicity

Kinematic and geometric instabilities in the system of lineaments [6].
Premonitory and post-earthquake activation. Landers earthquake, California, 1992.
Confirmed and false alarms [7].
Migration along lineaments [8,9].

References

1. Alekseevskaya, M.A., Gabrielov, A.M., Gvishiani, A.D., Gelfand, I.M., and Ranzman, E.Ya., 1977. Formal morphostructural zoning of mountain territories. J.Geophys., 43, pp.227-233.

2. 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 epicenters in California. Phys.Earth Planet.Int., 11, pp.227-283. Elsevier Science Publishers B.V , Amsterdam.

3. Caputo, M., Keilis-Borok, V., Oficerova, E., Ranzman, E., Rotwain, I., Solovieff, A., 1980. Pattern recognition of earthquake-prone areas in Italy. Phys.Earth Planet.Int., 21, pp.305-320. Elsevier Science Publishers B.V., Amsterdam.

4. Series of papers on recognition of earthquake-prone areas in the regions of Circumpacific belt, Eurasian Alpine belt (from Pyrenees to Anatolia, Central Asia and Hymalaya). Computational seismology, issues 6 - 25. Available on request.

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7. Rundkvist, D., and Rotwain, I. Interaction of crustal blocks and premonitory seismicity patterns (in print).

8. Vilkovich, E.V., Shnirman, M.G., 1980. On migration of earthquake sources along major faults and Benioff zones. Computational seismology, 13, pp.19-24 (in Russian).

9. Vilkovich, E.V., Shnirman, M.G., 1982. Waves of migration of epicenters (examples and models). Computational seismology, 14, pp.27-37 (in Russian).

Explanations to figures

Page 5.
Zones of discontinous displacements in the lithosphere: "Faults" (right) and "lineaments" (left). After [2].

Page 20.
Areas, where epicenters of earthqukaes with M>6.5 may be located. After [3].
For similar analysis in other regions worlwide see [2,4].

Page 25.
Big Bend segment of San Andreas fault system, after Feigel et al.
Kinematic and geometric incompatibilities of displacements are tested on p.27.

Page 26.
Eastern part of Garlock fault and adjacent faults of San Andreas fault system. After Jackson et al., report for Southern California Earthquake Center.
Kinematic and geometric incompatibilities of displacements are tested on p.27.

Page 28.
Activity after Landers, California, earthquake 1992 continues northward of precursory activity.
Dashed line is the envelope of major precursory activity few years before Landers earthquake (after Knopoff et al).

Page 29.
Zone of lineaments interseation is quiet (after [7]).

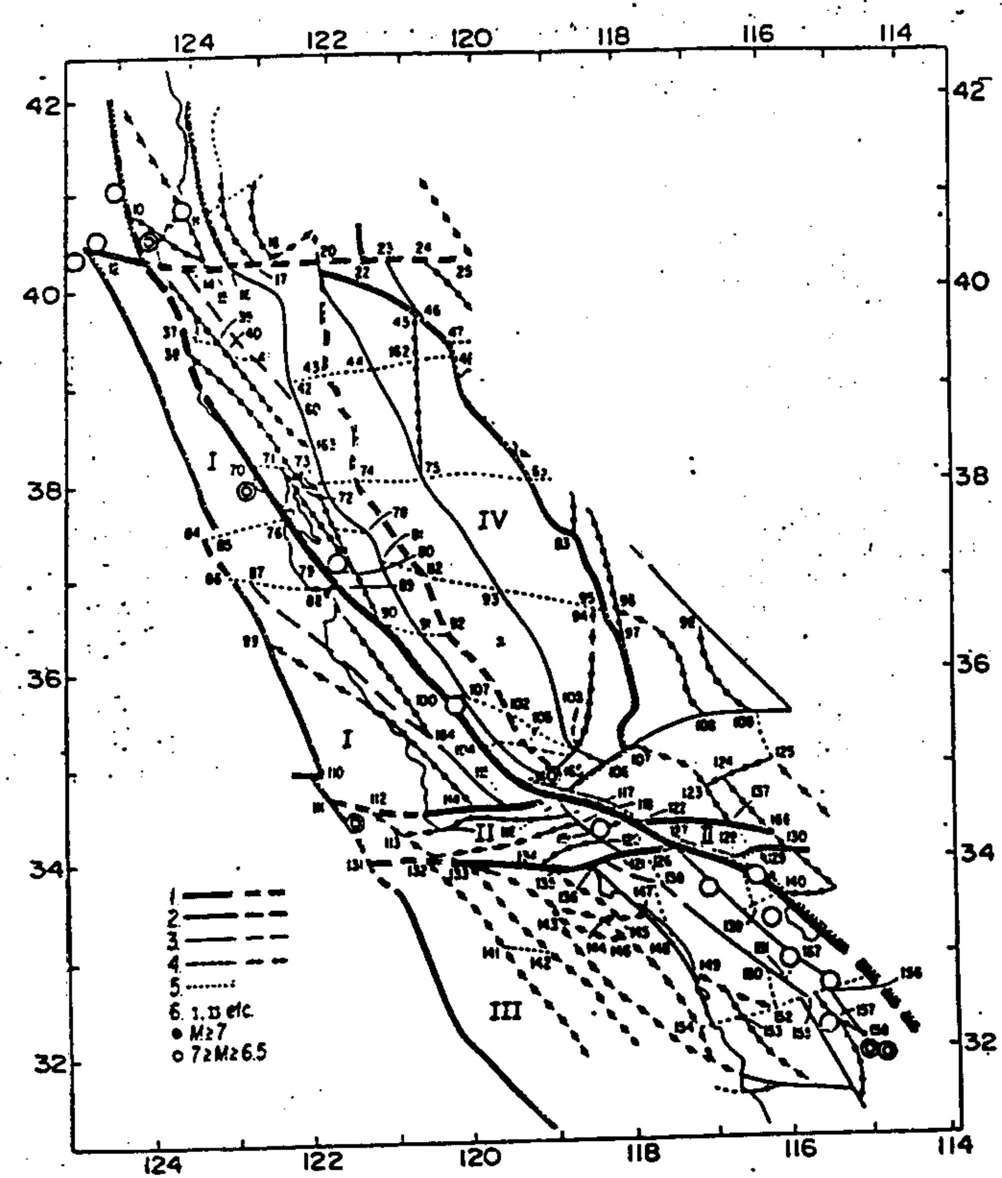
Page 30.
Zone of lineaments intersection is active (after [7]).

Page 31.
Migration of epicenters.
Algorithm and analysis for other regions are given in [8,9].

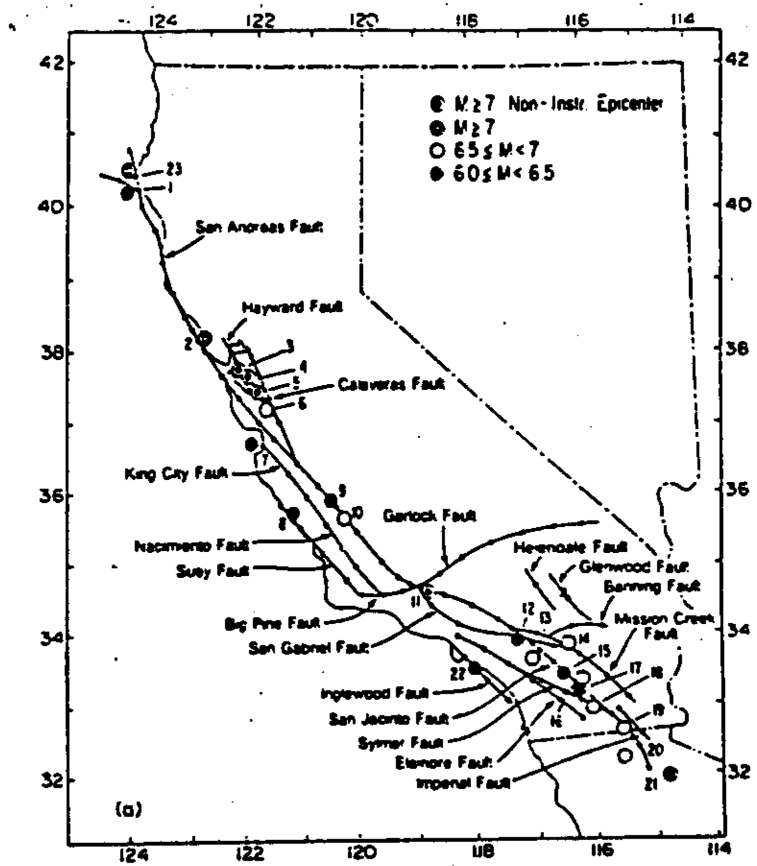
FORMAL MORPHOSTRUCTURAL ZONING

A.M. GABRIELOV

V.I. KEILIS-BOROK



MORPHOSTRUCTURAL SCHEME



SCHEME OF MAIN FAULTS

LINEAMENT - A SURFACE TRACE OF ACTIVE FAULT.

IS OUTLINED BY JOINT ANALYSIS OF:

- GEOLOGICAL DATA
- GEOMORPHOLOGICAL DATA
- GEOPHYSICAL DATA ON THE STRUCTURE OF LITHOSPHERE
- SATELLITE PHOTOS

DIFFERENT PARTS OF A LINEAMENT MAY BE EXPRESSED IN DIFFERENT SETS OF DATA.

"TECTONIC FAULT" ON TECTONIC MAPS USUALLY REPRESENTS THOSE PARTS OF A LINEAMENT WHICH ARE EXPRESSED IN GEOLOGICAL DATA. FOR YOUNG FAULTS THESE DATA, AS WELL AS ANY OTHER KIND OF DATA SEPARATELY, ARE OFTEN INSUFFICIENT.

SATELLITE PHOTOS SHOW TOO MANY LINES. THEIR NEOTECTONIC SIGNIFICANCE SHOULD BE ESTIMATED, ALLOWING FOR OTHER DATA.

METHOD OF SOLUTION:

FORMALIZED MORPHOSTRUCTURAL ZONING

FORMALIZATION IS ORIENTED TO MAKE REPRODUCIBLE THE CONCLUSIONS OF AN EXPERT. IT IS NOT SUFFICIENT FOR AUTOMATION, SINCE MANY ELEMENTARY DEFINITIONS REMAIN INTUITIVE, SUCH AS "VALLEY" OR "OROGENESIS".

BASIC DEFINITIONS

MORPHOSTRUCTURE

THE STRUCTURE IN THE LITHOSPHERE (OR ITS UPPER PART) EXPRESSED IN TECTONICS AND/OR MODERN TOPOGRAPHY.

MORPHOSTRUCTURAL ZONING

DIVISION OF A TERRITORY INTO HIERARHICALLY ORDERED SET OF MORPHOSTRUCTURES. THEY ARE OF THREE DIFFERENT TYPES:

AREA - A PART OF LITHOSPHERE WITH COMMON FEATURES, INDICATING COMMON HISTORY - IT DEVELOPED FOR SOME TIME AS AN ENTITY AND IN DIFFERENT WAY THAN SURROUNDING VOLUMES.

LINEAMENT - LINEAR ZONE SEPARATING AREAS.

KNOT - A ZONE OF INTENSIVE AND CONTRAST DEVELOPMENT AROUND INTERSECTION OF LINEAMENTS.

AREAS

FOLLOWING DIVISION WAS INTRODUCED FOR REGIONS OF HIGH NEOTECTONIC AND SEISMIC ACTIVITY:

MOUNTAIN COUNTRY (1st RANK) CONSISTS OF MEGABLOCKS (2nd RANK) WHICH CONSIST OF BLOCKS (3d RANK)

BLOCK : A COMPLEX OF LARGE ELEMENTS OF TOPOGRAPHY (MOUNTAIN RIDGES AND MASSIVES; INTER-FORE- OR INTRAMOUNTAIN BASINS; VALLEYS; PLATEAUS; HIGHLANDS; WATER BASINS).

THEY ARE MERGED INTO A BLOCK IF ELEMENTS OF THE SAME TYPE HAVE SIMILAR QUANTITATIVE CHARACTERISTICS, SUCH AS:

- AGE OF OROGENESIS
- AVERAGE ALTITUDE (OF AXIS OR BOTTOM)
- WIDTH
- STRIKE OF AXIS
- THICKNESS OF SOFT SEDIMENTS

HERE "SIMILAR" MEANS - WITHIN GIVEN LIMITS (6 GRADES FOR OROGENESIS; 10% FOR ALTITUDES, ETC.)

THIS INDICATES A COMMON NEOTECTONIC HISTORY.

BOUNDARY OF A BLOCK IS MARKED BY THE CHANGE OF THESE CHARACTERISTICS.

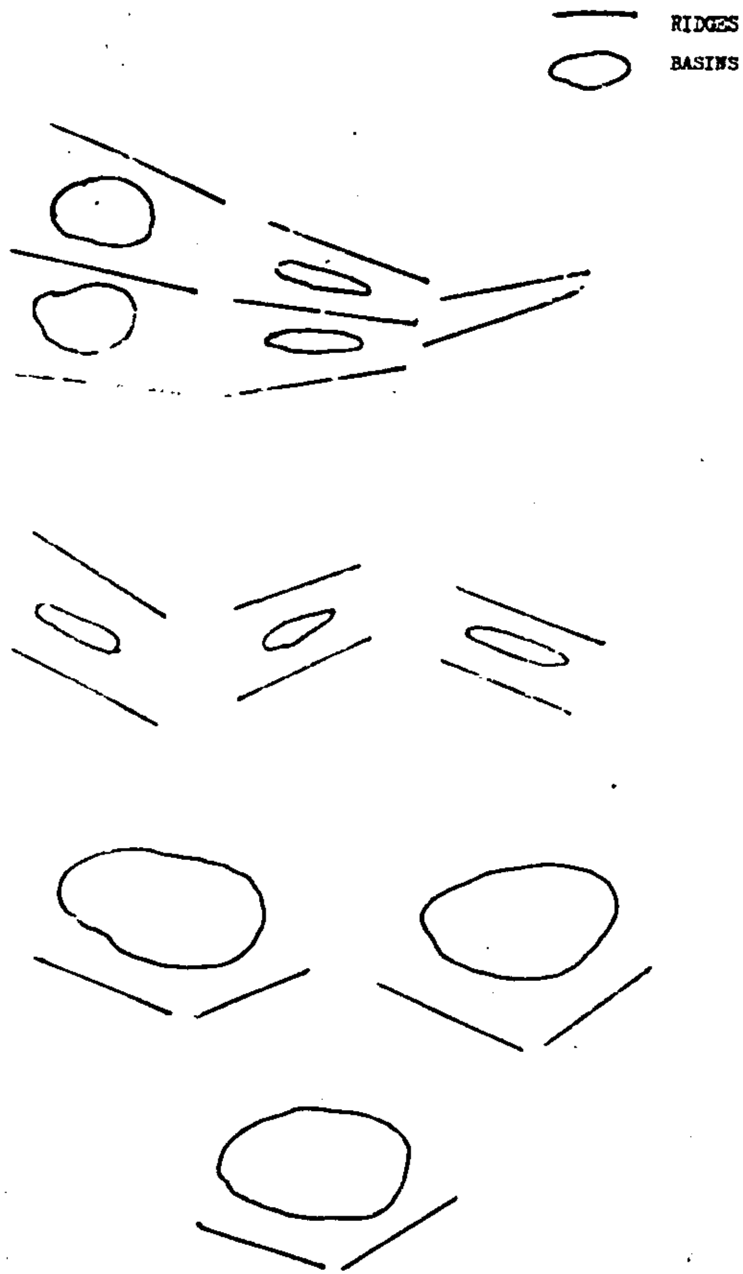
MEGABLOCK: A COMPLEX OF BLOCKS WITH COMMON DEVELOPMENT SINCE OROGENESIS AND REGULAR AND GRADUAL CHANGE OF QUANTITATIVE CHARACTERISTICS.

EXAMPLES OF ALLOWED CHANGES:

MONOTONOUS CHANGE OF ALTITUDES ALONG OR ACROSS THE STRIKE OF PARALLEL RIDGES.

MONOTONOUS CHANGE OF THE WIDTH OF DEPRESSIONS - ALONG THEIR CHAIN OR ACROSS THE STRIKE OF PARALLEL ELONGATED BASINS.

GRADUAL CHANGE OF STRIKE OF ELONGATED ELEMENTS LEADING TO SPECIFIC REGULAR PATTERNS - "FANS", "ZIGZAGS", ETC.



MAIN PATTERNS OF MEGABLOCK GEOMETRY

MOUNTAIN COUNTRY: A SET OF MEGABLOCKS WITH COMMON TYPE OF OROGENESIS AND PATTERN OF TOPOGRAPHY.

TYPES OF OROGENESIS:

- VOLCANIC;
- EPIPLATFORMAL,
- EPIGEOSINCLINAL,
- CONTINENTAL RIFTS.

PATTERNS OF TOPOGRAPHY:

RANGE OF ALTITUDES: LOW (<1.5km), AVERAGE (1.5-3.5km), HIGH (3.5-5.5km), OR HIGHEST.

ALTERNATION OF CERTAIN ELEMENTS OF RELIEF: RIDGES AND VALLEYS; PLATEAUS AND MASSIVES, ETC.

TYPE OF MOUNTAINS, USUALLY CORRELATED WITH THE TYPE AND AGE OF OROGENESIS AND WITH CORRESPONDING CONSOLIDATION OF ROCKS. FOR EXAMPLE, FOLDED MOUNTAINS ARE TYPICAL FOR EPIGEOSINCLINAL OROGENESIS, AND MONOLITIC ("BOX-LIKE") MOUNTAINS FOR EPIPLATFORMAL.

DOMINANT STRIKE - WITHIN 90° INTERVALS.

NOTE: ALL DIVISIONS AND THRESHOLDS ARE INDICATED AS AN EXAMPLE; IT MAY BE NECESSARY TO CHANGE THEM IN OTHER REGIONS.

LINEAMENT - A BOUNDARY ZONE BETWEEN AREAS.

RANK = MAXIMAL RANK OF AREAS IT SEPARATES.

WIDTH - FROM 10 TO 40 km, LARGER FOR HIGHER RANKS.

LONGITUDINAL LINEAMENTS - APPROXIMATELY PARALLEL TO DOMINANT STRIKE OF TECTONIC STRUCTURES AND TOPOGRAPHY.

VERTICAL MOVEMENTS ARE CLEARLY EXPRESSED WITHIN. CONSIDERABLE PART IS USUALLY INDICATED AS FAULTS ON TECTONIC MAPS.

UNDIRECT EVIDENCES:

CONTACT OF ELEVATIONS AND DEPRESSIONS,

PERIPHERY OF LARGE ELEMENTS OF TOPOGRAPHY,

CONTACT OF CONTRAST FORMS OF TOPOGRAPHY - SUCH AS STEEP RIDGE AND FLAT BOTTOM OF A VALLEY WITHOUT INTERMEDIATE FOREHILLS,

INTENSIVE FAULTING AND FOLDING ALONG THE SAME STRIKE.

TRANSVERSE LINEAMENTS - EXPRESSED DISCONTINUOUSLY (EXCEPT SOMETIMES ON SATELLITE PHOTOS). NOT ALWAYS SHOWN ON TECTONIC MAPS.

UNDIRECT EVIDENCES:

STRAIGHT VALLEYS

VALLEYS NOT FOLLOWING THE STEEPEST DESCENT

ELONGATED INTRUSIVE BODIES

SHARP TERMINATION OF LONGITUDINAL STRUCTURES (GEOLOGICAL OR TOPOGRAPHICAL)

SHARP CHANGE OF THEIR CHARACTERISTICS - AGE, STRIKE, THICKNESS, ELEVATION, ETC.

LINEAR OR EN ECHELON PATTERN OF SUCH CHANGES

LINEAR OR EN ECHELON PATTERN OF SPECIFIC FEATURES - VOLCANOES, PEAKS OR SADDLEPOINTS, IN PARALLEL RIDGES, ETC.

USUALLY (BUT NOT NECESSARILY) FORM A LARGE ANGLE WITH DOMINANT STRIKE OF TECTONICS AND TOPOGRAPHY.

MAJOR STRIKE-SLIP FAULTS - SUCH AS SAN-ANDREAS OR NORTH-ANATOLIAN.

ARE TRACED BY:

OFFSETS OF PERPENDICULAR STRUCTURES - THEY ALWAYS TERMINATE AT SUCH FAULTS AND NEVER CROSS THEM CONTINUOUSLY.

GRADUAL ROTATION OF PERPENDICULAR RIDGES, ETC.

KNOTS - SPECIFIC STRUCTURES AROUND INTERSECTIONS OF LINEAMENTS CHARACTERIZED BY ESPECIALLY INTENSIVE AND CONTRAST MOVEMENTS.

EVIDENCES:
- MOSAIC PATTERN OF TOPOGRAPHY;
- DIVERSE ELEMENTS OF RELIEF;
- BROKEN-LINE FORM OF THEIR BOUNDARIES;
- MANY CONTACTS OF CONTRAST ELEMENTS OF RELIEF;
- MOSAIC PATTERN OF GEOLOGICAL MAP;
- MANY CONTACTS OF ROCKS OF DIFFERENT AGE (e.g. PZ and Q_2)

A KNOT HAS WELL DEFINED BOUNDARIES. THEIR DETERMINATION REQUIRES, HOWEVER, SPECIAL FIELD STUDIES OR MAYBE DETAILED SATELLITE PHOTOS.

Application to *active platforms*

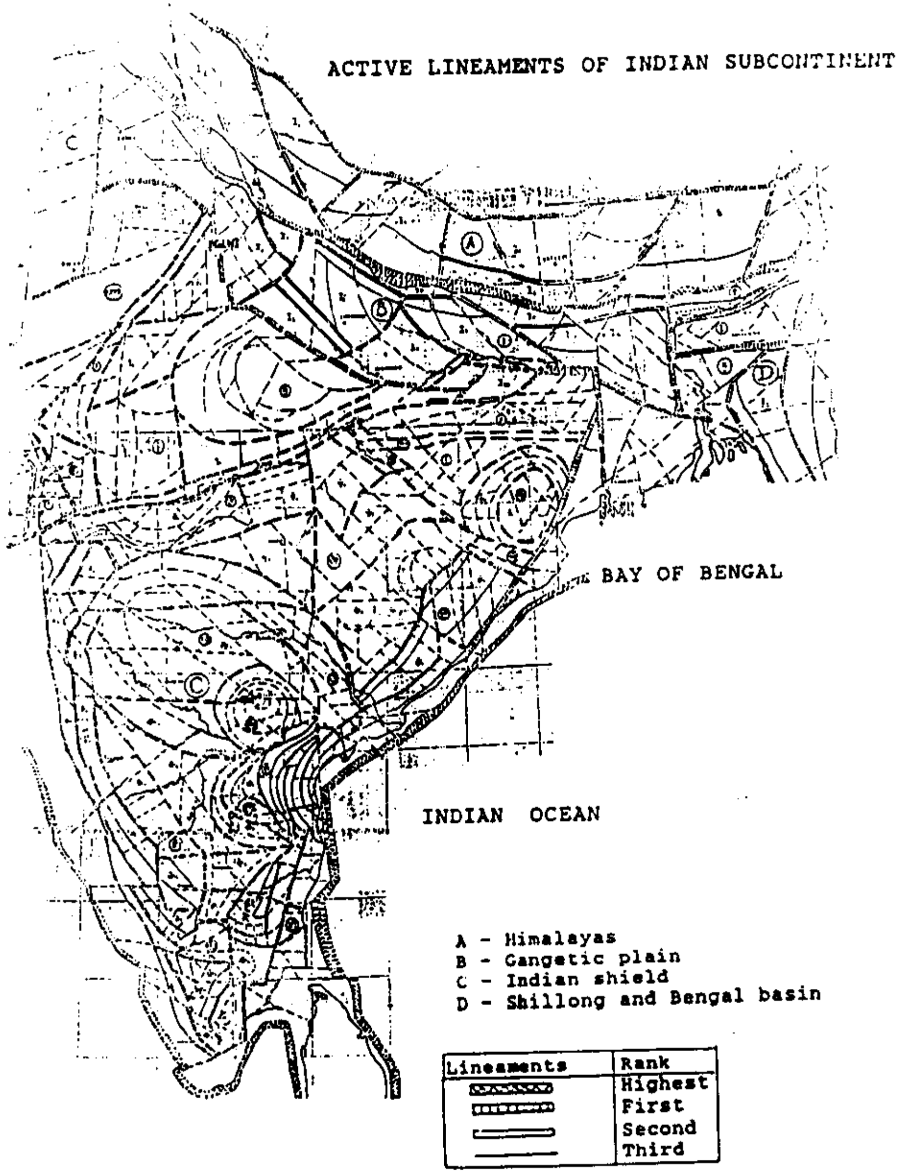
is based on:

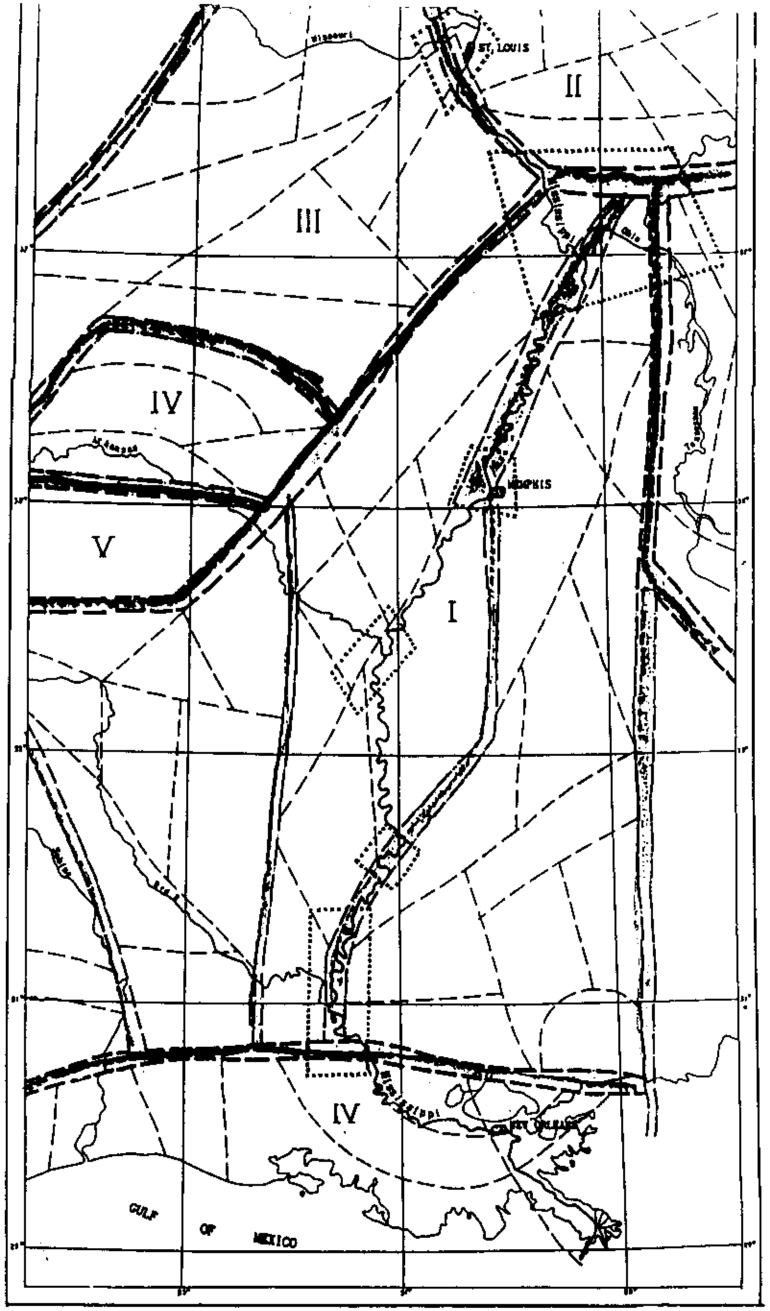
elevation (reflects the total sum of neotectonic vertical movements)

linear elements of relief
(their abnormally high length and density reflect fracturing of crustal fundament)

pattern of landscape,
particularly of river network

nodes are also prominent by mosaic structure. They attract population centers (e.g. all 17 province capitals in SW Russian platform)





MORPHOSTRUCTURAL ZONATION OF CENTRAL USA
Compiled by E. Rantsman

I–VI MACROBLOCKS

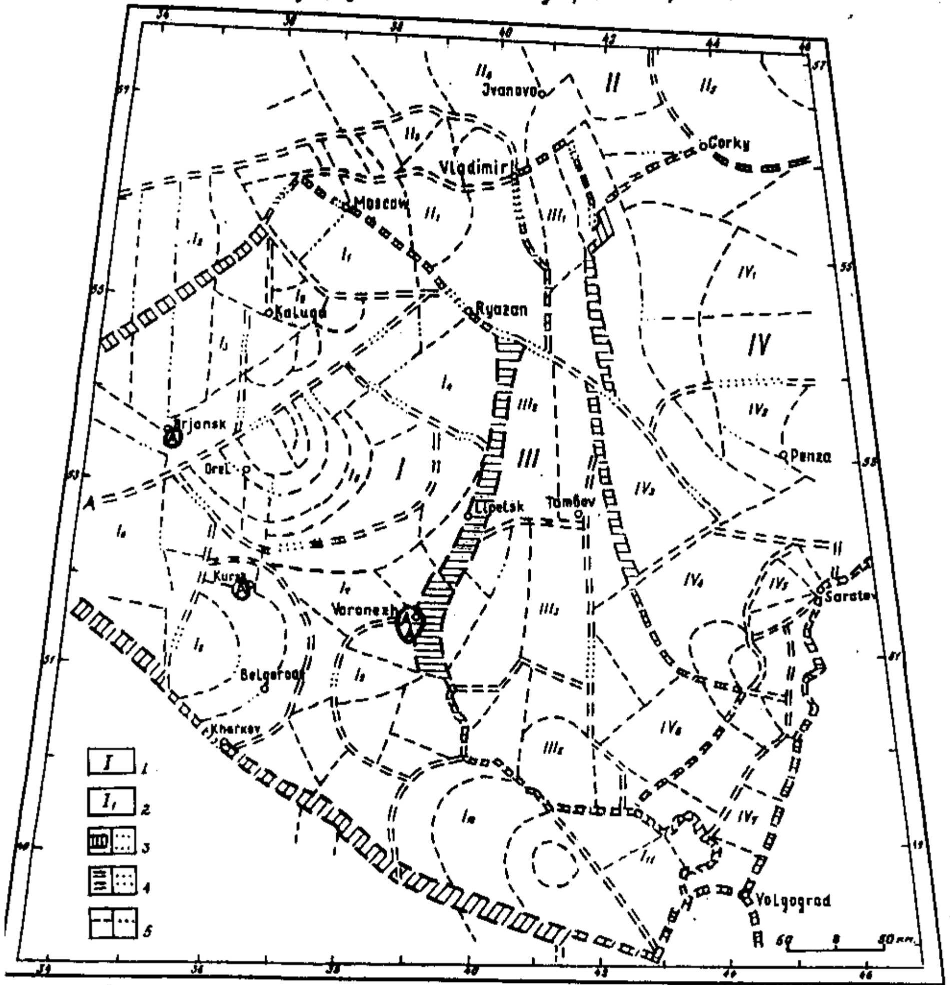
MORPHOSTRUCTURAL LINEAMENTS
FIRST RANK
SECOND RANK
THIRD RANK

BOUNDARIES OF KNOTS

MORPHOSTRUCTURAL ZONATION
MAP OF THE CENTRAL RUSSIAN PLAIN

Compiled by M. Glasko, E. Rantsman.

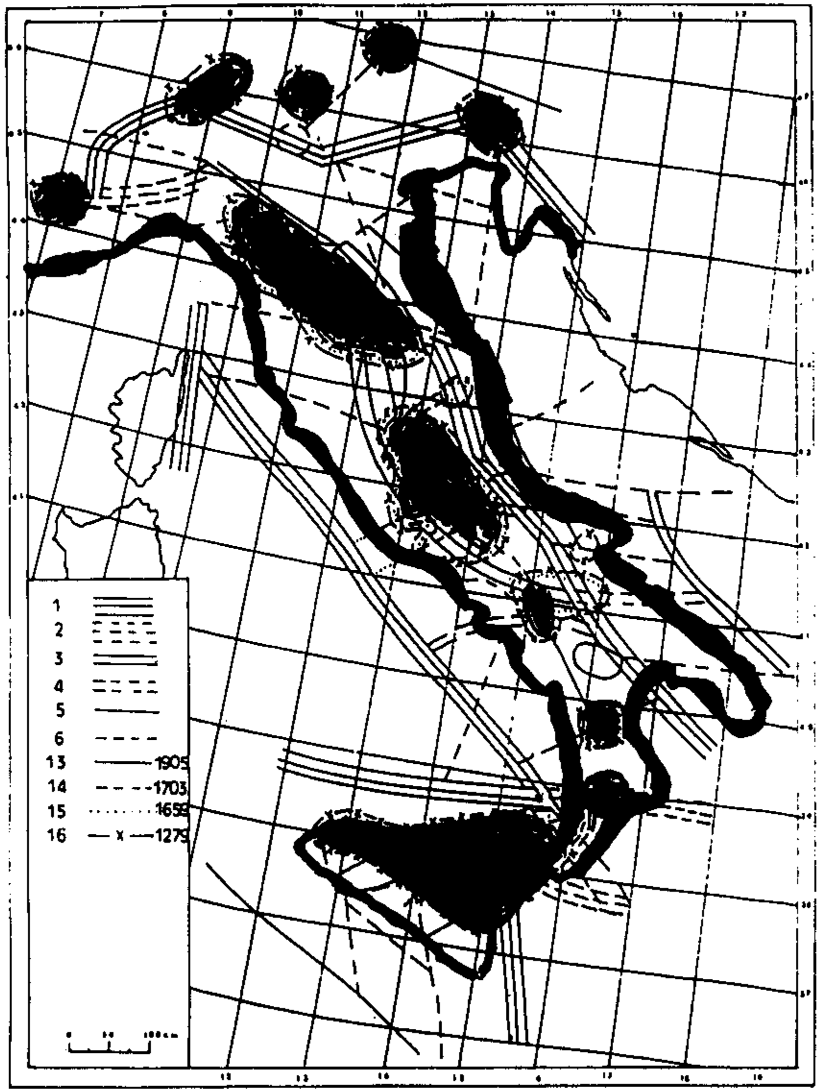
(Institute of Geography Russian Academy of Siences) 1991 г.



1 – makrobloks; 2 – megabloks; 3 – first rank; 4 – second rank; 5 – third rank; A – nuclear power plants; 3,4,5 – morphostructural lineaments.

An earthquake may be triggered only in specific structures, probably the same for 10^6 years (around some intersections of the faults) [2-4]

Triggering mechanism migrates between these structures $10 - 10^2$ km/year [8-9]



THE RESULTS ARE CONFIRMED BY SUBSEQUENT OCCURRENCE OF THE STRONG EA-S.

FINDINGS:

- STRONG EA-S OCCUR NEAR SOME INTERSECTIONS OF THE FAULTS, MARKED BY LOCAL TENSION (ATTRACTING THE FLUIDS) ON THE BACKGROUND OF INTENSE NG-Q UPLIFT
- THIS CRITERION IS QUALITATIVELY SIMILAR WORLDWIDE
- IT MEANS THAT LARGE CITIES, NUCLEAR POWER PLANTS ETC ARE ATTRACTED TO EA-KE PRONE AREAS: TENSION MEANS FERTILE PLANE, ACTIVE MEANS FAST RIVER.
- IN PRACTICAL ASPECT - POSSIBILITY OF THE RECONNAISSANCE, FAST AND INEXPENSIVE (\$$10^4$ VRS 10^6 TO 10^7), OF ABOUT 200 SUPERCRITICAL SITES.

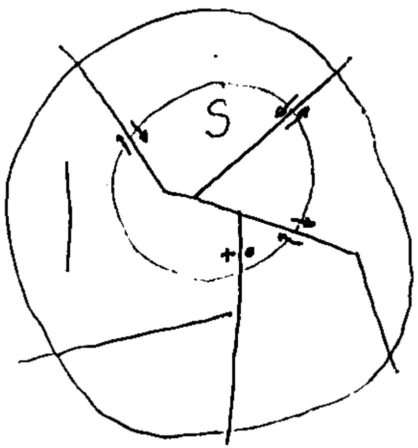
SYSTEM OF LINEAMENTS AND DYNAMICS OF SEISMICITY

Kinematic (Saint-Venant) incompatibility after [6].
of the movements on lineaments is the integral measure of stress and strain accumulation.

Condition $K=\sum v_i = O$

ensures that relative movements along lineaments can be realized through our reconstruction of the absolute movements of the blocks.

Saint-Venant incompatibility may indicate: internal inconsistency in our reconstruction of the fault system (its geometry and rates of movement); and/or accumulation of strain and stress; and/or rotation of the blocks; and/or the change of K after each earthquake.

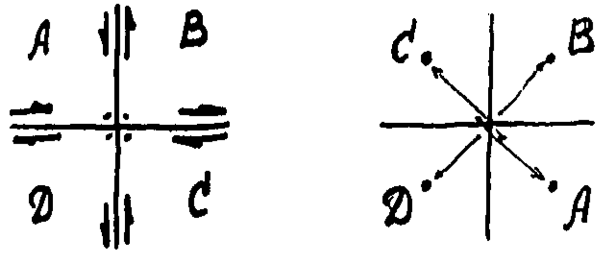


"Geometric" incompatibility, after [6].

Even if K=O, the movements may be not possible without the change of geometry of lineaments near intersection zones.

Geometric incompatibility measures the tendency of the nodes (faults intersection zones) to hierarchical fracturing and expansion.

Example:



(First introduced by McKenzie and Morgan, 1969 for triple junctions).

King, 1989 suggested, that accumulation of stress/strain near an intersection will transmit incompatibility down the hierarchy: new faults will be formed to accomodate incompatibility; it will grow on their intersections; yet new faults will be formed etc.

Quantitative measure of geometric incompatibility after [6]:

Consider system of lineaments inside some contour L;
S is the area within L.

$$G = \frac{d^2 S}{dt^2},$$

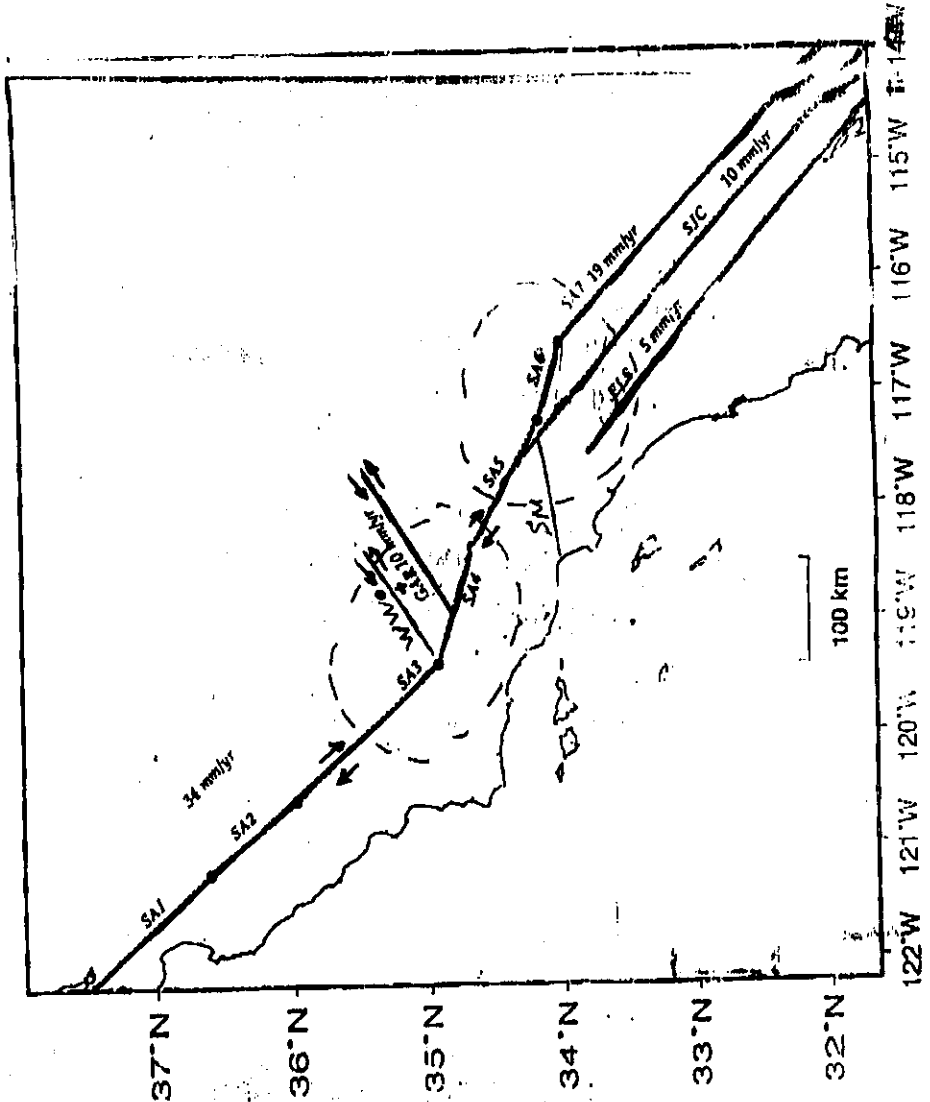
Analog of Stokes formula (G may be determined by movements on L)

$$G = \frac{1}{n}\Big((n-2)([v_1,v_2]+[v_2,v_3]+\ldots+[v_n,v_1])+ (n-4)([v_1,v_3]+[v_2,v_4]+\ldots+[v_n,v_2])+\ldots +2([v_1,v_{n/2}]+[v_2,v_{n/2+1}]+\ldots+[v_n,v_{n/2-1}])\Big),$$

for even n, and

$$G = \frac{1}{n}\Big((n-2)([v_1,v_2]+[v_2,v_3]+\ldots+[v_n,v_1])+ (n-4)([v_1,v_3]+[v_2,v_4]+\ldots+[v_n,v_2])+\ldots+ ([v_1,v_{(n+1)/2}]+[v_2,v_{(n+3)/2}]+\ldots+[v_n,v_{(n-1)/2}])\Big),$$

for odd n.



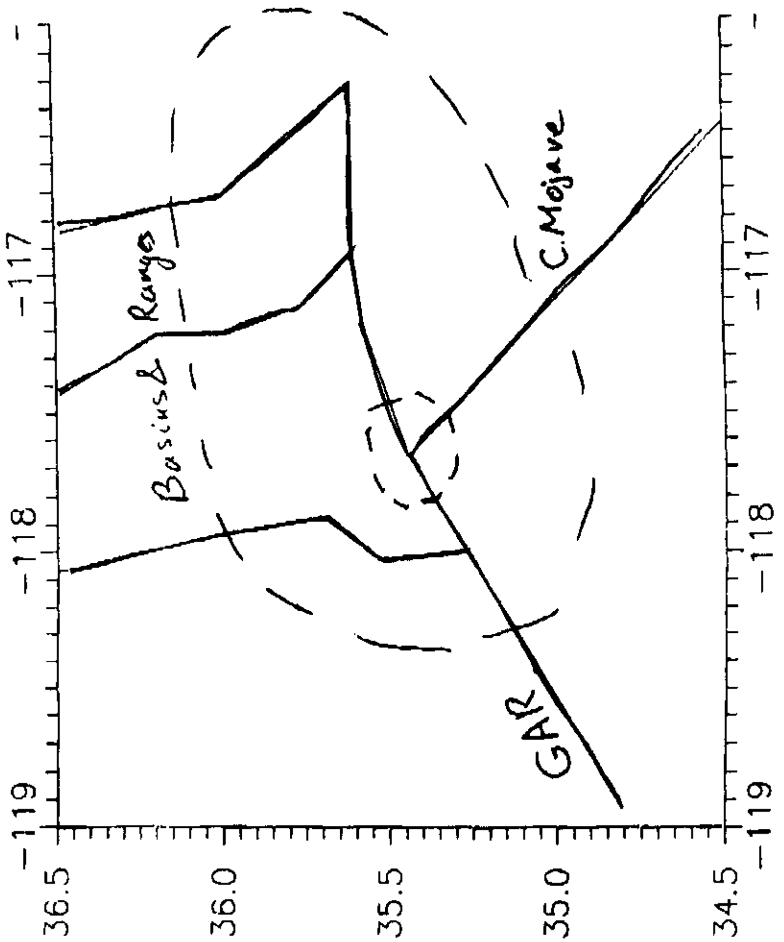


TABLE 1

Saint-Venant (K) and geometric (G) incompatibilities in the Big Bend and Garlock nodes

N	K(East)	K(North)	G	
NW node	-1.117	3.858	-342.853	
of Big Bend	0.030	2.220	-340.523	1*
SE node	-4.597	-6.55	- 77.944	
of Big Bend	-4.597	-3.555	-178.446	2*
East	-3.598	5.619	- 19.357	
Garlock	-0.017	2.130	- 35.055	3*
node	1.537	8.723	- 41.462	4*
Garlock-C.Mojave-node	-1.173	-0.939	- 27.835	

1* 2mm/year horizontal shortening across White Wolf fault is allowed for

2* 3mm/year horizontal shortening across the Sierra Madre fault is allowed for

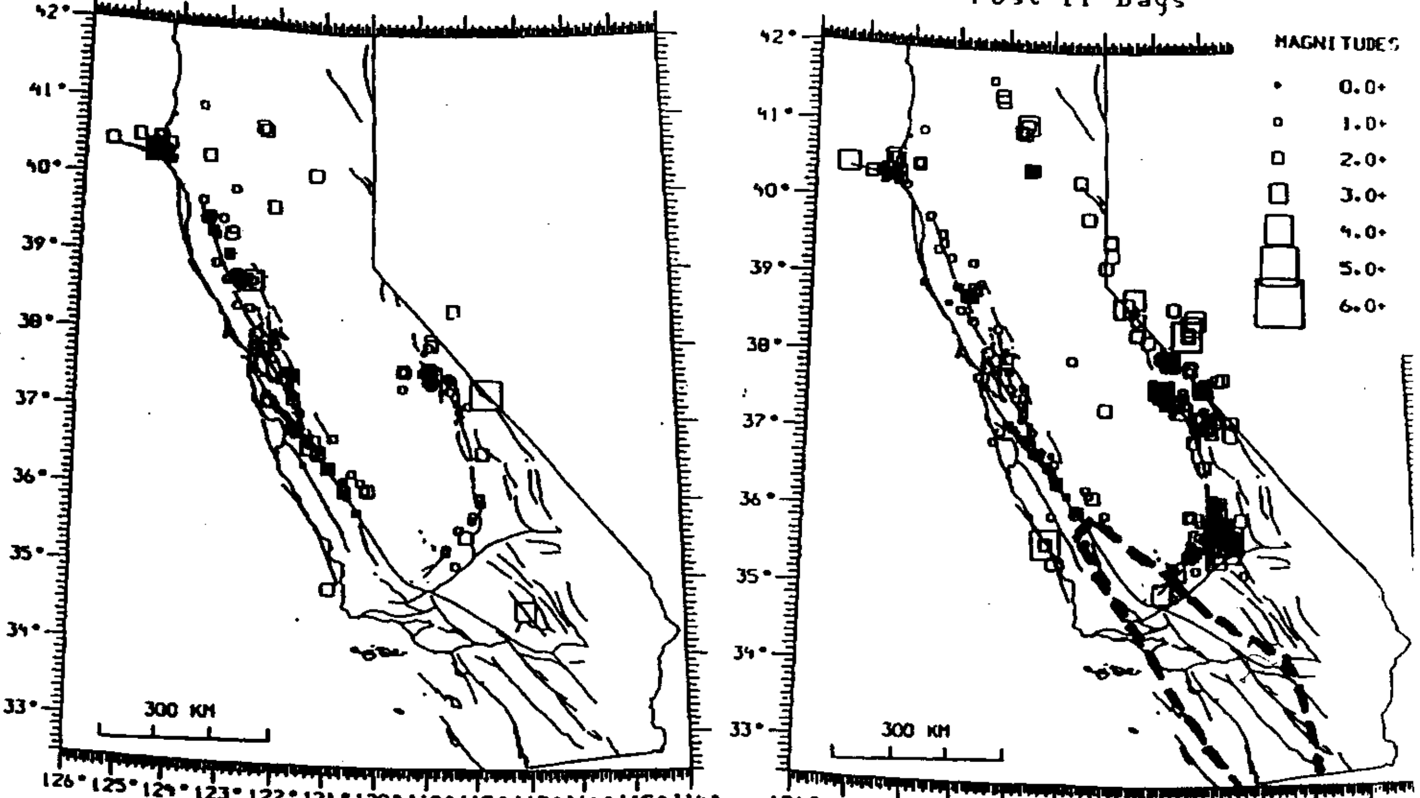
3* Slip rate in Central Mojave is doubled from 5 to 10 mm/year

4* Meridional right-lateral strike-slip deformation is introduced. It continues northward to original Landers faultbreak

NORTHERN CALIFORNIA NET

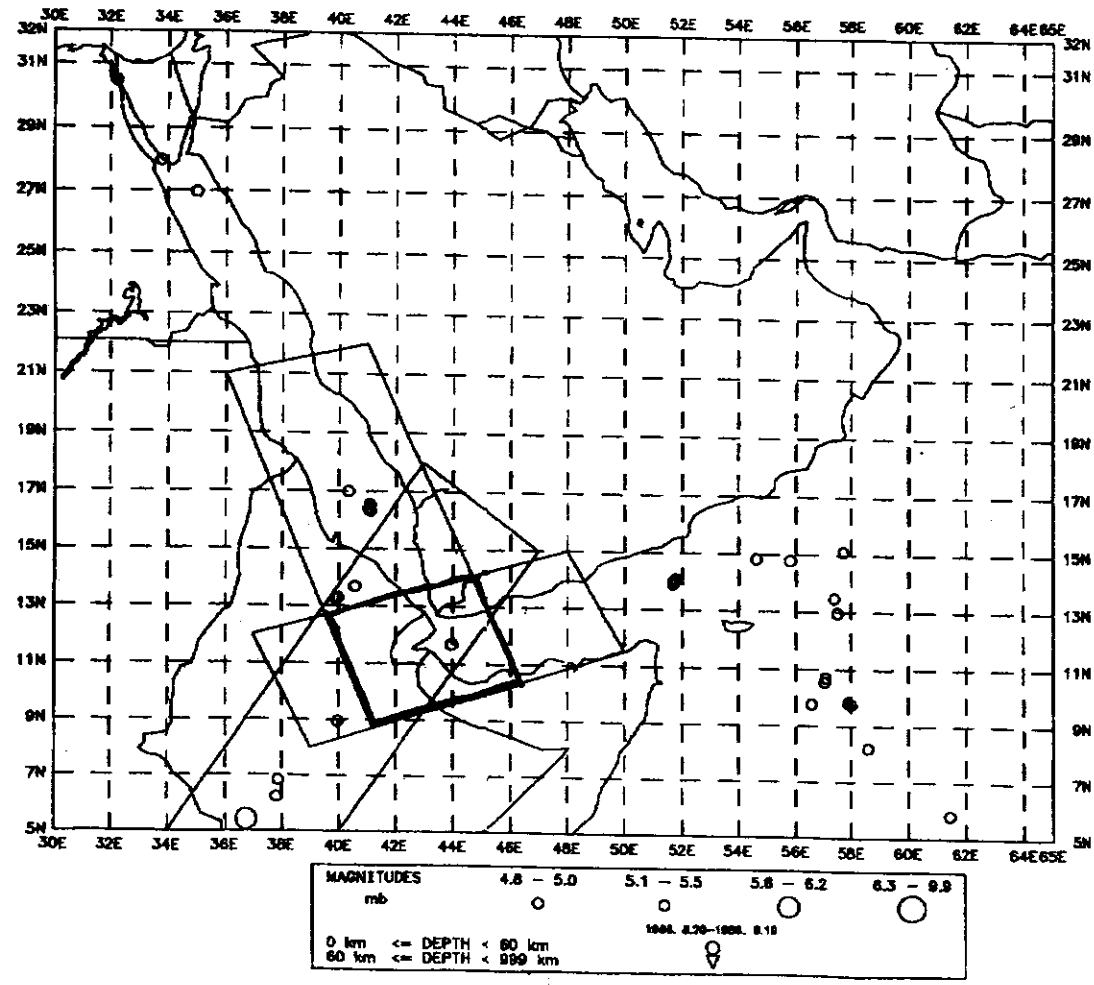
Pre 11 Days

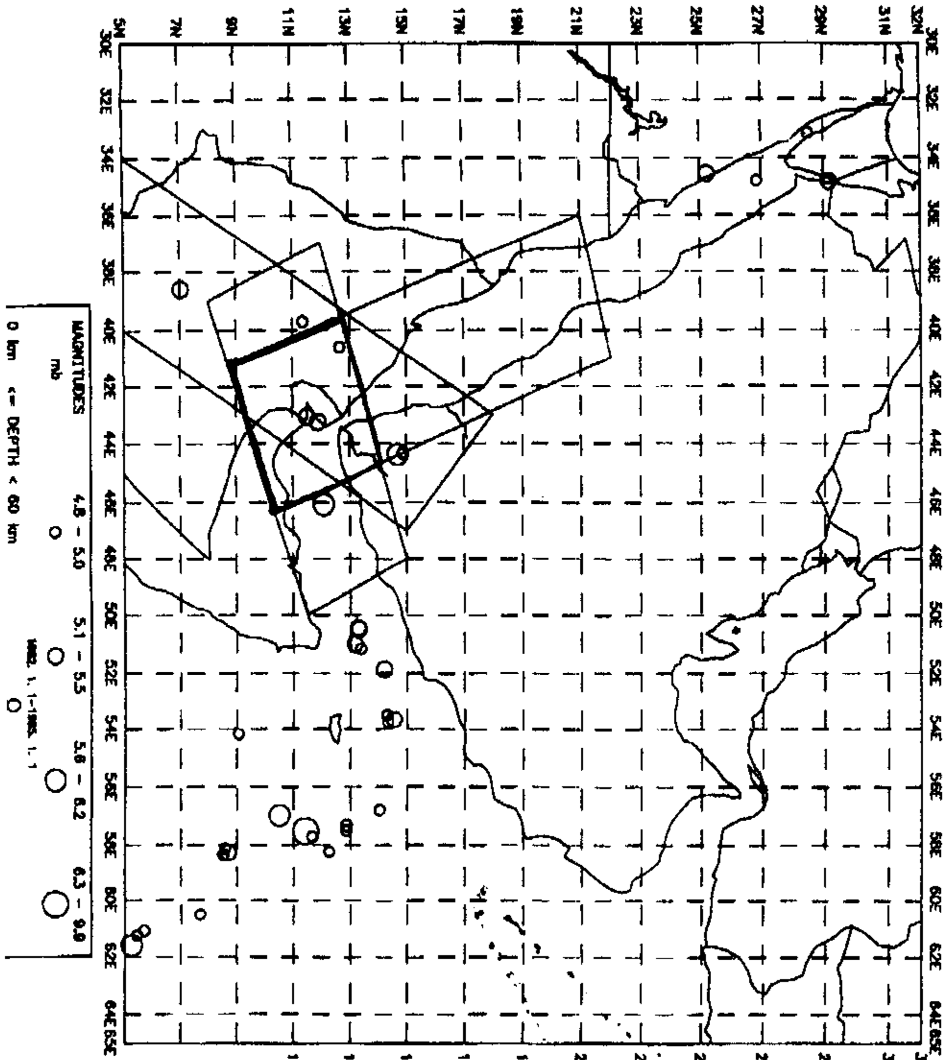
Post 11 Days



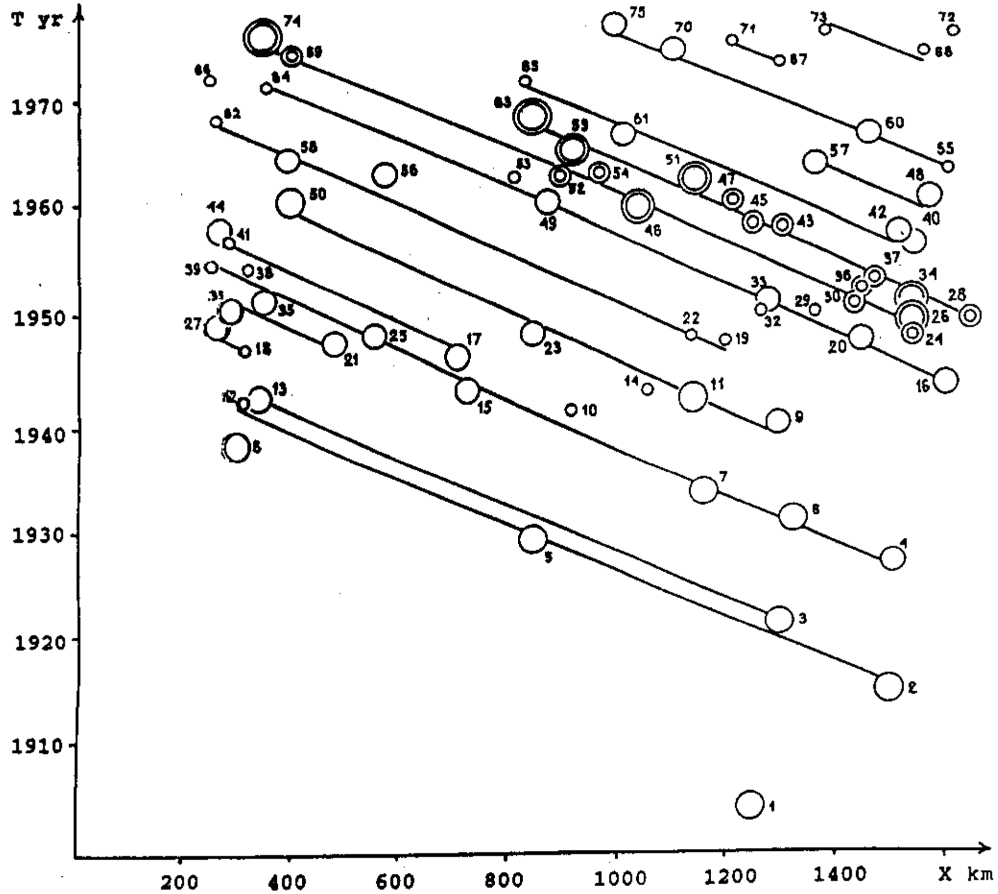
Reasenberg & Hill

The alarm before strong ea-ke 1989





The False alarm 1985



New Zealand

M≥5.6

Velocity 45 km/yr

Confidence level 0.95