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ESTIMATION AND ANALYSIS Mmax OF THE EARTHQUAKES OF CARIBBEAN AND MIDDLE AMERICA REGION WITH THE HELP OF THE GEO EXPERT SYSTEM

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ABSTRACT

The GEO expert system is designed for solving problems of complex prognosis and analysis of geophysical fields. The principal part of the system can be used to solve research problems of parameter prognosis and to recognize physical structure elements from a set of features which indirectly reflect structure peculiarities and processes occurring within the structure. The system ensures: expert knowledge acquisition: input, editing, mapping, and analysis of feature fields, calculation of secondary feature fields which can be considered as functions of linear structures, geophisical events, functions of single feature fields or sets of feature fields; revealing of empirical regularities from data and knowledge, including explanation and argumentation facilities; geological object recognition; geophysical field prognosis and analysis; dialogue with the user employing scientific map processor and intellegence interface. The GEO system is implemented on personal computers of an *IBM PC/XT/AT/386* -and compatible types.

The GEO system was used for analysis of lateral regularities of seismicity and Mmax prediction of Caribbean and Middle America region. This one consists of very high tectonic activity structures and includes heterogeneous sites with heterochronous continental, primary-and secondary oceanic and intermediate crusts.

The most informative features are: geological environment (substantion, structure, origin and history of development of the crust as a whole, according to Case and Holcombe, 1980); the very major active faults (interplate and intraplate subdivided according to kinematic and morphology type, i.e. upthrusts, lateral slips and tensional ones); the thickness of the crust, gravity anomalies, seismic activity and recent volcanismus.

INTRODUCTION

The Mmax value at a certain point of the map defines the limiting energy earthquake among all probable foci, the projections of which on the Earth surface contain the given point. The region prognosis methods are based on assumption that relationship between Mmax value and features, which describe intensity of tectonic processes, strength properties of medium and maximum sizes of structure heterogeneities at the vicinity of given point is available. The idea to the solution of the problem is to find the relationship and to use it as estimation of Mmax value for any point of a map. Another way it can be said that initially on a basis of data and expert knowledge the pattern of Mmax map in the feature space is found and then obtained relationship is mapped on the geographical co-ordinates.

The problems of finding the relationships between limiting energy of earthquakes and geological and geophysical features are very complicated and hardly formulated task in the field of data analysis. The solution of the problem requires to examine influence of many factors, to check various models of the region seismicity, to create and to analyse a lot of prognosis map.

One of the most promising ways of solving the problems of such type is based on the application of artificial intelligence methods developed during last years in connection with creating of expert systems. It is known about tens expert systems in the Earth sciences fields, such as PROSPECTOR, LITO, HIDRO, DRILLING ADVISOR etc [1]. Verbal and well structural expert knowledge are used in such systems to provide the solution. In the case of Mmax prediction, as in the most practical problems of regional geological and geophysical prediction, expert knowledge are not verbal, moreover, they contain uncertainty and contradictions.

GEO [2] is the professional-oriented expert system designed for solution of wide class problems of geological and geophysical prognosis. System accumulated fifteen-years experience of collaboration between specialists on the computer science, seismology and geology [3,4]. System is designed for personal computers of an IBM PC/XT/AT/386 - and compatible types. The principal part of the system can be used to solve researh problems of parameter prognosis and to recognize physical structure elements from a set of feature which indirectly reflected structure peculiarities and processes occuring within the structure.

The system ensures expert knowledge acquisition, revealing of empirical regularities from data and knowledge including explanation and argumentation facilities, intelligence interface and processing, analysis and displaying of the geological and geophisical fields employing advanced scientific map processor. In order to find the regularity the system integrates different types of data - catalogues of geophisical events or geological objects, patterns of linear and circular structures, initial and generated by the system fields of features - and expert knowledge - a region seismicity conception and knowledge of prognosis values at sample points of the region under study obtained through independent questioning of experts and presented as interval expert evaluations.

In the paper the application of GEO for estimation and analysis of Mmax of tectonic shallow earthquakes for the Caribbean and Middle-America region is considered.

MODEL

Seismicity of the Caribbean and Middle America as a whole was generalized by B.Gutenberg and Ch.Richter (1954) and then by L.Sykes and Ewing (1965) and P.Molnar, L.Sykes (1969). They gethered data about the earthquakes of the region, determined the belts of high seismic activity and with the help of them set up schemes of tectonic structure of the region. It was done in the terms of the plate tectonic theory and confirmed that theory. The investigation of earthquake focal mechanism solutions let them to determine directions of the lithosphere plates recent movements and to get other important geodynamic data about active structure.

The region under study consist of the very high recent tectonic-magmatic and seismic activity zones. There are interaction of the very different blocks and plates of the lithosphere. We suppose that Mmax values depend on rheology of the geological environment and on peculiarities of the recent geodynamics, that is: 1) on substantial compositions and structures of lithospheric blocks; 2)on characters of neotectonic and recent tectonic processes which determine interaction of those blocks.

The main parts of the neotectonic model of the region are (see Fig.1):

1)the Caribbean plate which is moving eastward relative to the Americas at a rate of 2-4 cm/yr and has a crust of mainly oceanic type and partly (along its boundary) continental and transitional types;

2)North-American and South-American continents, which are moving westward and have a very heterogeneous and heterohronous basement, crust and differently neotectonically and and recently deformed;

3)deep-water oceanic basins -Atlantic one on the east and Pacific one on the west (Cocos and Nazca plates).

The boundaries of the above mentioned blocks are active subduction zones (the Middle American on the west, the Lesser Antilles on the east, the North Panama and South Caribbean ones on the south-western) and strike-slip faults zones (on the north and on the south). Recent development of the crustal structures are in the conditions of sub-horizontal compression. Active vertical movements are also possible and they are due to transference of substance in the Upper Mantle or in the lower crust as well as gravitational leveling.

DATA

The next fundamental materials were in consideration:

1.The Earthquakes Catalogue NOAA 1904 - IV/1983;

2.The Schematic Map of Bouge Anomalies (seal 1:2 000 000), compiled in 1976 (V.A.Levchenko as the editor);

3.The Schematic Map of the Mochorovichich Discontinuities relief according to geophysical data (scale 1:5 000 000), compiled in 1976 by V.A.Levchenko a.o.

4.Geologic-Tectonic Map of Caribbean Region by J.E.Case and T.L.Holcombe (U.S.G.S.,1980)[6].

FEATURES

Fields of features are presented in coordinate net $0.4^{\circ} \times 0.4^{\circ}$ .About 20 fields, based on data we had, were analysed.

The feature fields could be divided in the groups: a)structural (fields of the largest active faults, graded according to their value and morphology, as well as fields of density of faults with different smoothing windows, the field of Mochorovichich discontinuities relief, the field of local peculiarities Mochorovichich discontinuities relief; b)substantial (Fields of Bouge gravity anomalies. of modulus of the gradient and other modifications of the Bouge anomalies field; types of crust, graded according to the age of its creation, particularities of the sections and neotectonic and recent tectonic deformations); c)Geodynamical (the fields of seismic activity, of the distance from the faults graded to the type of movements along them).

Some versions of presentation of the data on faults tectonics and types of the crust were analysed. When coding the data on types of the crust we should like to take into account information from [6] on historical differences of the blocks, on peculiarities of their inner structure, on differences of the neotectonic and recent tectonic activity , on the types and directions of recent movements and on other properties which determine tense state of the crust.

The principle of coding consisted of two elements: 1)dividing of all the blocks of the region on three types (continental, oceanic and transitional) and 2)subdividing of them according to the time of creation and to the degree of the activity of neotectonic and recent tectonic deformations. Each subtype was numbered. As a rųsult the following classification was taken:

1.Platform areas under-lain by Cretaceous and Cenozoic sedimentary rocks upon dislocated Paleozoic or Upper Precambrian basement (Yucatan and Bahamas(?) platforms).

2.Platform areas consisted of sedimentary, metamorphic, and igneous rocks of Precambrian age (Guyana Shield).

3.Platform areas with Precambrian basement and locally distributed Phanerozoic sedimentary cover (Sub-Andean basins and platform areas of Colombia and Venezuela).

4Thrust-and-folded areas of Cretaceous to Eocene age with minor neotectonic deformations (The Peten "laramide" deformed belt in the Middle America).

5.Areas under-lain by metamorphic and igneous rocks of Prepensylvanian age with Mesozoic and Cenozoic deformations of variable style and degree (Nuclear Central America).

6.Neotectonic orogenic areas (Andean deformed belt).

7.Areas with sub-oceanic secondary-ocean and reformed initially oceanic crust with sedimentary and volcanic cover of Upper Paleozoic-Cenozoic age (Gult of Mexico, Columbian, Venezuelan and Yucatan basins, southern step of the Nicaraguan submarine rise, Beata and Aves submarine Ridges, Cayman Trough).

8.Deep-water oceanic basins with the crust of initially-oceanic nature (Pacific and Atlantic oceans).

9.Thrust-and-folded areas of Cretaceous to Eocene age with moderately and active neotectonic movements (The Great Antilles deformed belt).

10.Areas of thrust-and-strike-slip origin, superimposed on an older subduction zone (Puerto Rico Trench).

11.Areas of Latecretaceous-Cenozoic deformations of subduction style.

12.Areas of Neogene and Quaternary deformation above recent subduction zones (Middle America and Northern Costal part of Souther America).

13.Neogene and Quaternary volcanic arcs (Lesser Antilles island arc).

14.Areas under-lain by carbonate and inter-bedded clastic strata of Cretaceous and Cenozoic age with block-faulting and minor folding (Central Nicaraguan and Cayman submarine rises, Jmaica).

15.Tertiary volcanic and sedimentary province with block-faulting and open folding (Middle America).

16.Areas of active recent volcanism upon recent subduction zone (Middle America).

The feature values from 1 to 6 are given to blocks with the crust of continental type, from 7 to 13 - to blocks with oceanic crust, and from 14 to 16 - to areas with transitional type of the crust. It was supposed that in the limits of each type the more was the feature value the more was Mmax.

Data on fault tectonic represent only those faults which are of the same order as the crust blocks under consideration. Faults of the first order are those boundarying lithosphere plates, faults of the second order are the major intra-plate ones, dividing heterogeneous blocks of the crust. Seismic potency of faults zones is conneced with their morphology and cinematics. Therefore three types of the faults of each ordered were examined: 1)thrust faults, 2)Strike-slip faults, 3)normal faults. As a result six schemes of the faults were composed and analysed. Fields of minimum distances till the faults were calculated for each of those schemes. Besides the width of dynamic influence zone of the steeply dipping faults were chosen 100 km toward both sides of fault. The influence of asymmetric subduction zones was spread as far as 200 km towards only up-thrusting blocks.

Besides that the fields of faults density and fields of summary length of the faults were calculated (smoothing windows radiuses were equal 50 and 100 km).

PREDICTION FUNCTION

For finding the empirical regularity we used 490 sample points with Mmax estimates over the range M=5.0 to M=8.5. Estimates were given by one expert.

The feature fields get from the map of the Mochorovichich discontinuities relief and from the schematic map of Bouge anomalies had considerable gaps, so two prediction functions were found : $F^{(1)}(x)$ - for the part of the region where all feature were known (zone 1 on Fig.2), and $F^{(2)}(x)$ - for all region.

The average error value of the expert evaluation approximation was equal 0.2. For 21 points of the sample set the error values of approximation were more then 0.5.

The solution confirmed the geodynamic model, which explained the Mmax field basically as simultaneous action of two factors - the intencity of strain accumulation and the type of geological media. The following feature fields are the most informative for zone 1: seismic activity field, types of Earth crust and the field the field of local peculiarities Mochorovichich discontinuities relief. When the prediction function was found for all region only two feature were selected by the system: seismic activity and types of Earth crust.

Conclusively selected versions of the prediction functions take the form

$$F^{(1)}(x) = 5.5 + \varphi^{(1)}(x_1) + \varphi^{(1)}(x_2) + \varphi^{(1)}(x_3),$$

$$F^{(2)}(x) = 5.6 + \varphi^{(2)}(x_1) + \varphi^{(2)}(x_2),$$

where:

x_1 - seismic activity (on Ju.V.Riznichenko method),

x_2 - types of Earth crust,

x_3 - the values of local peculiarities Mochorovichich discontinuities relief, which are equal difference between deep of Mochorovichich discontinuities relief and the result of its smoothing by the window with radius 100 km.

The graphics of the functions are given in Fig.3a and 3b. The graphics show that seismic activity has the most considerable influence on the Mmax forecast. The relationship between seismic activity and Mmax has logarithmic behavior. The relationship between Mmax and types of the Earth crust are shown that the Mmax values are connected more with intensity of the crust then with the types of the crust. A small contribution of all subtypes of the continental crust in Fig.3a can be explained basically that the main part of the continental crust of the region is located outside the zone 1, for which prediction function $F^{(1)}$ was found. It is easily seen in Fig 3a that for zone 1 the Mmax values are decreased on the places with local heights of the Earth crust foot. This fact can be explained by the influence of the appropriate processes in the upper mantle.

PROGNOSIS

The prognosis Mmax field is shown in Fig. 4. For the areas 1 the Mmax values were calculated according to $F^{(1)}(x)$, the values for the rest territory were calculated according to $F^{(2)}(x)$. A juxtaposition of the Fig.4, 1 and 2 shows that awaited earthquake zones are associated with deep-seated linear anisotropy of the crust and determined by block movements character and by intensity of the earth crust deformations.

The first area of the very high values Mmax>7.5 along the Pacific ocean is connected genetically with the Middle America subduction zone and with the crust mainly of transitional type. Considerable decreasing Mmax at Panama territory is connected with sharp dropping of seismic activity. It may be explained by decreasing of undethrusting component of the Nazca plate in comparison to transverse moving of the Cocos plate under the Middle America. Decreasing of Mmax at the boundary between the Cocos and the Nazca plates in spite of high seismic activity may be explained that this zone belongs to deep-water basin with the oceanic crust (see 8 on Fig.2). Moreover this zone of deformations can be of strike-slip and tensional type, which does not contribute to accumulation of tectonic overstrains. Similar values of Mmax in western Colombia and in the Middle America are determined by similar geological and geodynamic conditions.

The second area or the increased values of Mmax>7.5 is connected with the Lesser Antilles subduction zone. But here both converged plates have oceanic crust. In the northern part of Lesser Antilles arc there are three disconnected areas with Mmax>7.5. The location of them can be connected : 1)with differences of the subduction zone inclination; 2)with rheology properties of the crust in the northern part of the Lesser Antilles zone, where the arc consists of two heterochronous branches; 3)with the circumstance, that several aseismic rises of the crust of the Atlantic ocean, which are striking obliquely to the subduction zone.

Along the northern and southern strike-slip boundaries of the Caribbean plate the Mmax values drops till 6.5-7.0. In the Northern Caribbean it can be explained by the development of the structure in the zone of deep-seated strike-slip fault which reasons the considerable tension of the Earth Crust and opening of the Cayman deep-water through with oceanic crust. In the Souther Caribbean, including the Northwestern South America, the highest values of Mmax (≥7.1)are associated with Bocono and El-Pilar strike-slip faults zones, which are developing in continental crust in compressing conditions.

CONCLUSION

The forecasting map of Mmax supports the known regularities of spatial distribution of earthquakes of the Caribbean and the Middle America. The priority of geodynamic peculiarities of the recent development of the areas, of types of interaction of plates and blocks of the crust is established quite well. The influence structural-and-formation as well as historical peculiarities of the plates and blocks is noticeable less. So it can be supposed that when working out similar problems the first thing is to estimate closely neotectonic and recent geodynamic situation and appropriate classification of territories investigated according to their substantial and structural peculiarities of the crust.

The solution could be more correct if initial data were more complete. In particular it is desirable to include in the analysis data about velocities and vectors of displacements of crust blocks as well as about changing of these parameters in time.

The result of using of the GEO expert system show that it is an effective instrument to compose and analyse forecasting maps Mmax.

REFERENCES

1.Waterman A.D. A Guide to Expert Systems. Addison-Wesley Publ. Comp., 1985.

2.Гитис В.Г., Деарт Д.А., Руденко С.Л., Омер Б.Г. ГЕО - экспертная система для геолого-геофизическеого прогноза.- В сб. "Экспертные системы: состояние и перспективы", Москва, Наука, 1989.

3.Gitis V.G., Mironov M.A., Bune V.I., Kalenik V.N., Shchukin Yu.K. Mmax Earthquake Prediction Map Development: Method, Software, Results.- Proc. of the 2nd Intern. Symp.on the Analysis of Seismicity and on Seismic Hazard, Liblice, Czechoslovakia, May 18-23,1981.p.437-466.

4.Гитис В.Г., Миронов М.А., Буне В.И., Каленик В.Н., Шукин Ю.К. Прогноз Ммах землетрясений на основе аппроксимации интервальных экспертных оценок. - Изв. АН СССР, Физика Земли, 1986, N4, с.24-31.

5.Mann P., Burke K. Neotectonics of the Caribbean. Reviews of Geoph. and Space Physics, Vol. 22, No.4, p.309-362, 1984.

6.Case J.E., Holcombe T.L. Geologic-Tectonic Map of the Caribbean Region, USGS, 1980.

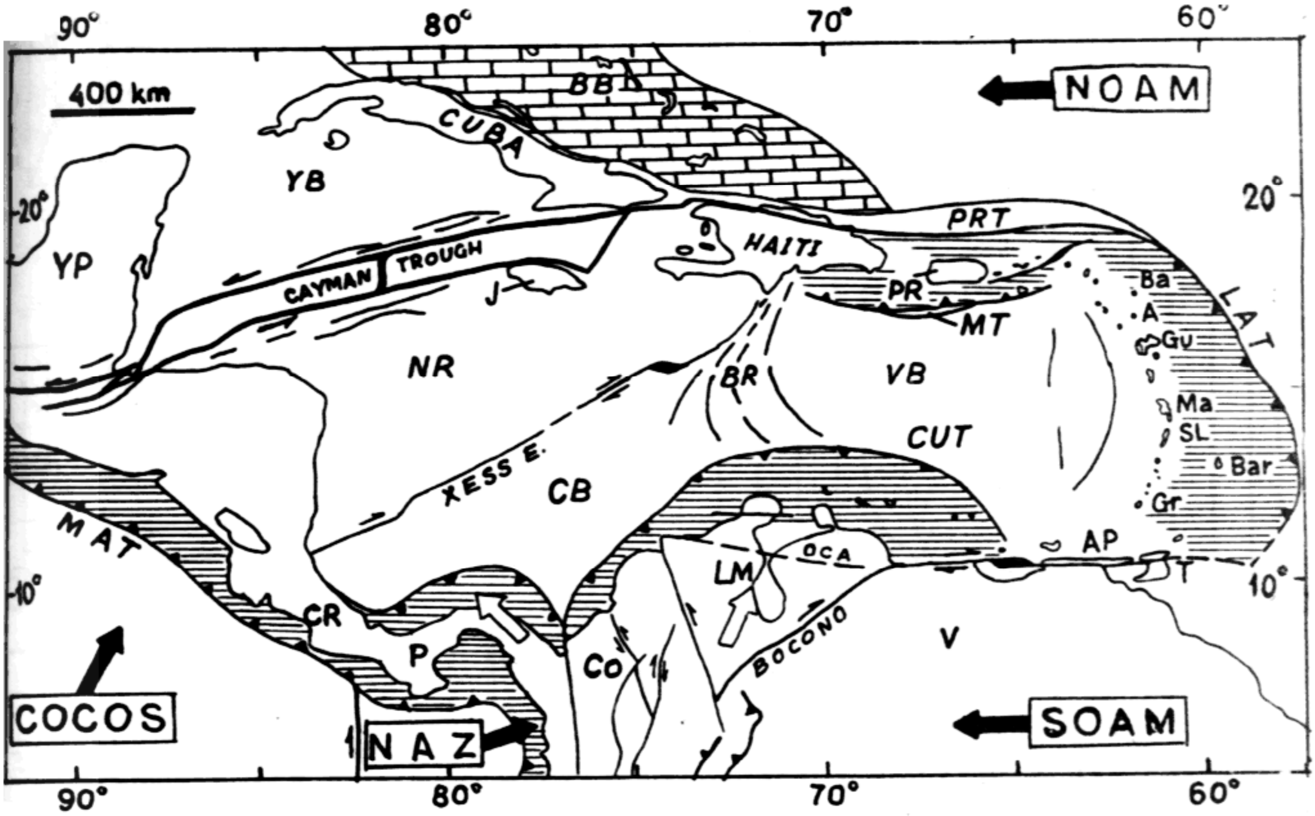

Fig.1. Scheme of major elements of neotectonic structure of the Caribbean and the Middle America (by P.Mann and K.Burke, 1984).

Abbreviations: A - Antigua, BB - Bahama Banks, Bar - Barbados, Ba - Barbuda, BR - Beata Ridge, Co - Colombia, CB - Colombia Basin, CR - Costa Rica, CUT - Curasao Trench, Gr - Grenada, Gu - Guadeloupe, J - Jamaica, LAT - Lesser Antilles Trench, LM - Lake Marakaibo, Ma - Martinica, MAT - Middle America Trench, MT - Muertos Trench, NR - Nicaragua Rise, P -Panama, PR - Puerto Rico, PRT - Puerto Rico Trench, SL-Santa lucia, T - Trinidat, V - Venezuela, VB - Venezuela Basin, YB - Yucatan Basin, YP - Yucatan Peninsula, Xess E - Xess Escarp.

Abbreviations of lithosphere plates: COCOS - Cocos plate, NAZ - Nazca plate, NOAM - North American plate, SOAM - South American plate. General directions of of plate motions relative to the Caribbean are shown by arrows. Lines with triangular mark subduction zones, horizontally ruled areas are accretionary prisms, open arrows indicate approximate direction of movement of the Maracaibo Block relative to cratonic South America and Panama relative to the Colombian Basin.

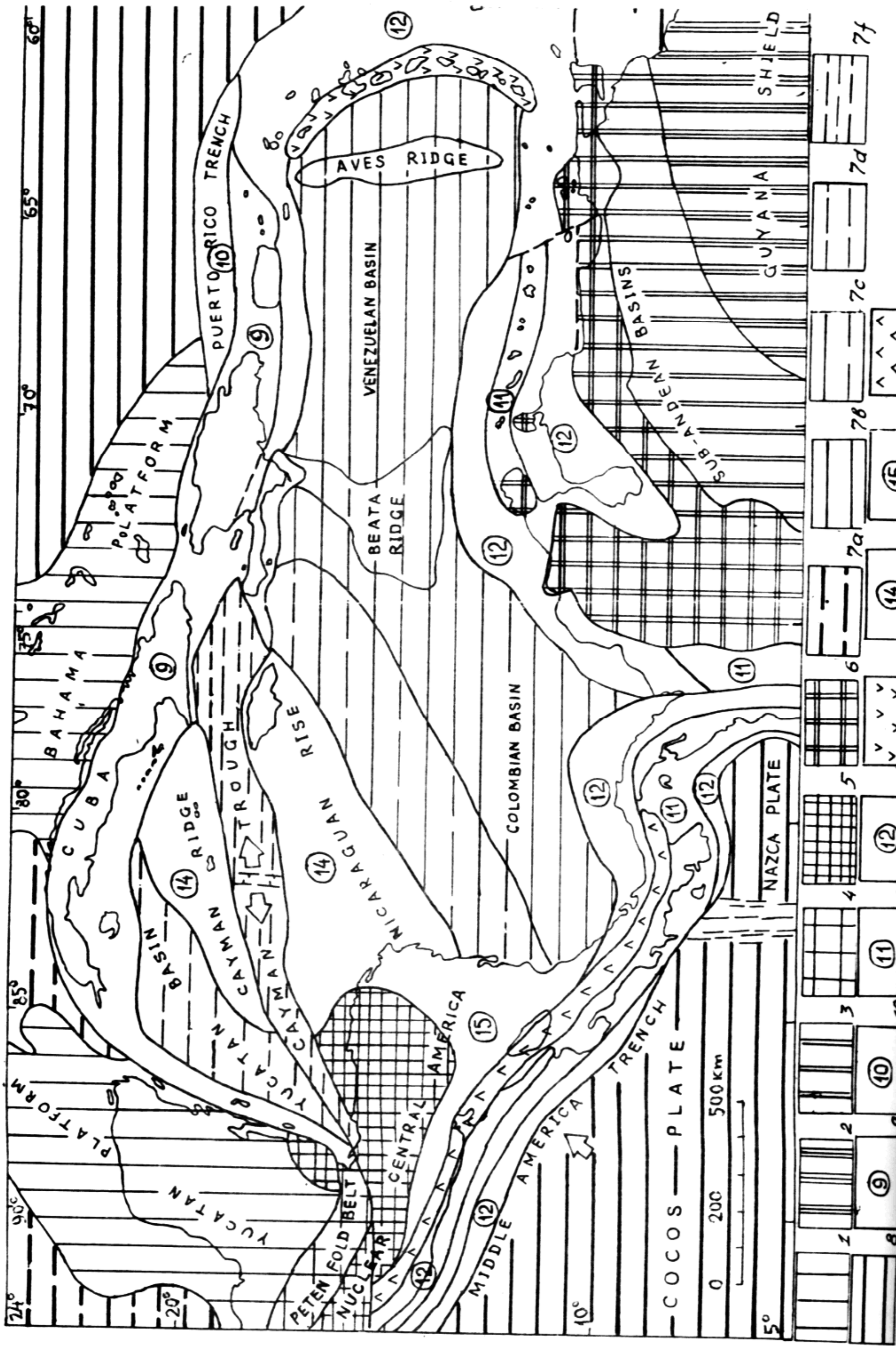
YUCATAN PLATFORM
BAHAMA PLATFORM
CUBA
BASIN
RIDGE
CAYMAN
TROUGH
YUCATAN
CAYMAN
NICARAGUAN RISE
CENTRAL AMERICA
PETEN FOLD BELT
NUCLEAR
MIDDLE AMERICA TRENCH
COCOS PLATE
NAZCA PLATE
COLOMBIAN BASIN
BEATA RIDGE
VENEZUELAN BASIN
AVES RIDGE
PUERTO RICO TRENCH
SUB-ANDEAN BASINS
GUYANA SHIELD
0 200 500 km
24°
20°
10°
5°
90°
85°
80°
75°
70°
65°
60°
1 2 3 4 5 6 7a 7B 7c 7d 7f
8 9 10 11 12 13 14 15 16

Fig 2.

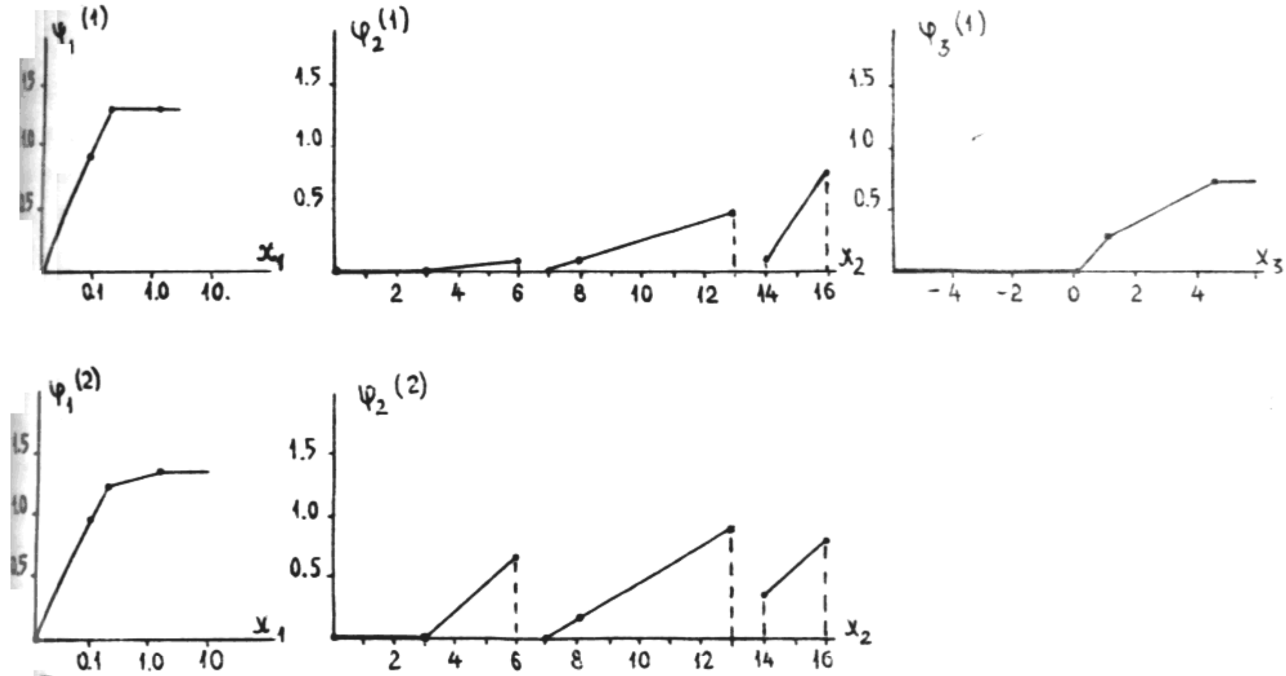

Fig.3. Graphics of the functions $\varphi_i(x_i)$ for the prediction functions $F^{(1)}(x)$ and $F^{(2)}(x)$, where x_1 - seismic activity (by Ju.V.Riznichenko method), x_2 - types of Earth crust, x_3 - the values of local peculiarities Mochorovichich discontinuities relief, which are equal difference between deep of Mochorovichich discontinuities relief and the result of its smoothing by the window with radius 100 km.

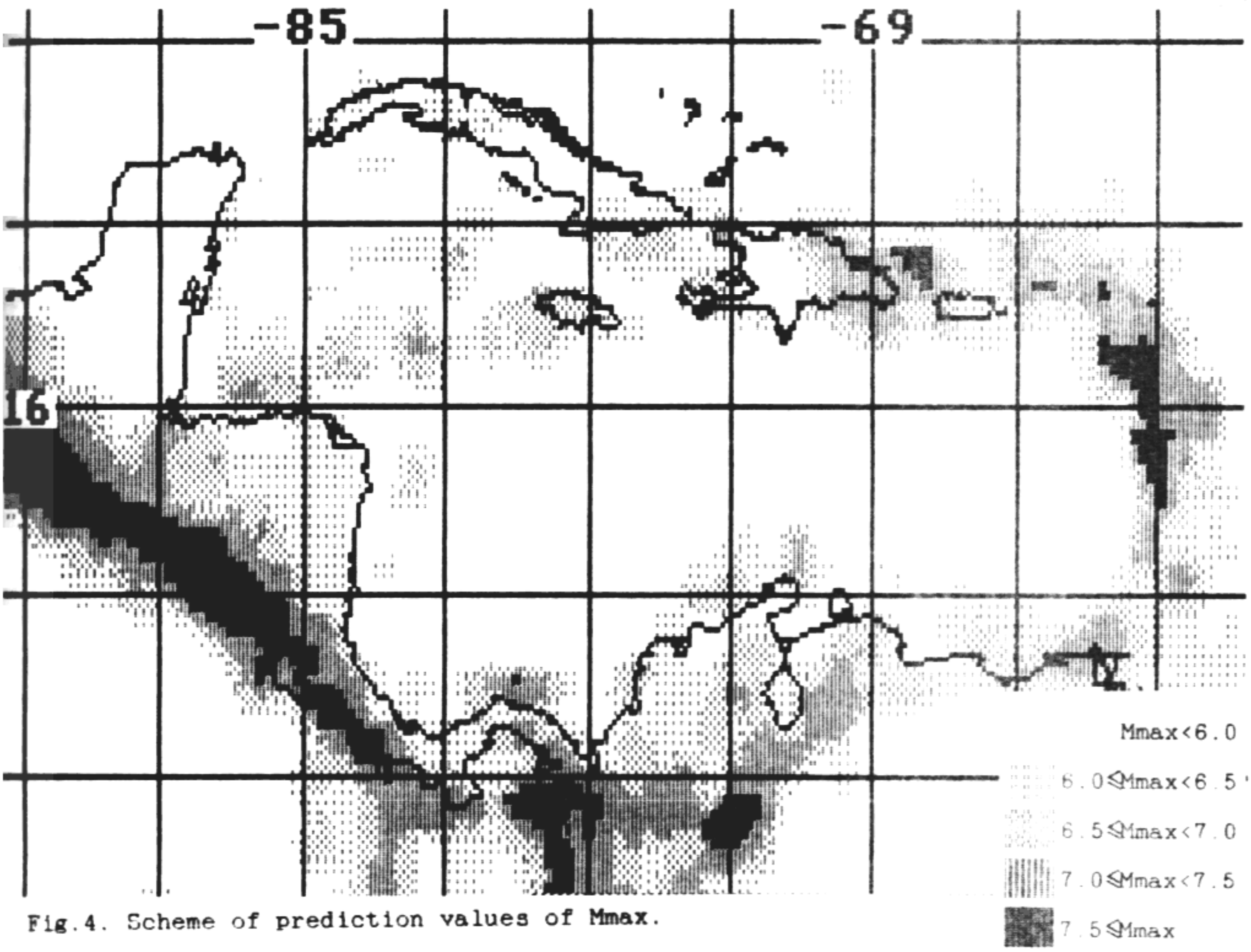

Fig.4. Scheme of prediction values of Mmax.