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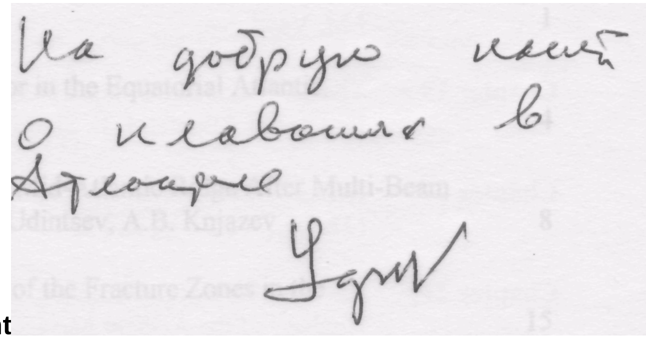

Equatorial Segment of the Mid-Atlantic Ridge

Initial Results of the Geological and Geophysical Investigations under the EQUARIDGE Program, Cruises of r/v 'Akademik Nikolaj Strakhov' in 1987, 1990, 1991

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Chapter 4.

The Structure of Sedimentary Cover from Single-Channel Seismic Profiling Data.

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The goal of single channel seismic profiling (SCSP) during the 7, 11 and 12 cruises of R/V "Akademik Nikolaj Strakhov" was to carry out a detailed survey, discovering and mapping of sedimentary production. This survey (about 50,000 miles) resulted in the determination of numerous sedimentary bodies with various structures and thickness, big enough for thickness and acoustic basement map creation. Multibeam sounding bottom relief data and SCSP data on sediments and acoustic basement were processed together, which allowed for the recovery of lost sounding information in case of bad weather.

Besides the authors, SCSP . actively involved in the survey were: Whitington R. (United Kingdom, 7 cr.), Poberzhin V.M.(11, 12 cr), Erofeev S.A. (7, 11 cr.), Efimov P.N.(12 cr), Abuev A.G. (7 cr.), Gladkikh P.A., Morozov Yu.I. (7, 11, 12 cr). Outboard equipment and survey control were provided by Efimov V.N. Inboard electronic equipment for analog wavefield data acquisition was developed by Efremov V.N., digital acquisition and software was made by Sokolov S.Yu. in collaboration with Vanyan L.L. and Beresnev I.A.; SCSP and sounding data comparative processing software was developed by loffe A.I.; Koltsova A.V. compiled sediments thickness and acoustic basement relief maps and morphostructural scheme of the basement on the basis of bathymetry compuiled by hand by Agapova G.V. (7 cr.), Golod V.M. (11 cr.), Volokitina L.P. (12 cr.) to a scale of 1:250,000 and compiled by computer to a in scale of 1:250,000 and 1:1,000,000 by Udintsev V.G.

SCSP Survey Method and Technique.

SCSP has become a standard method for the investigation of large regions of the ocean bottom and was described by many authors (Ewing, Tirey, 1961, Hersey, 1963, Leenhardt, 1969). Here we present only a brief description of the technique used and survey specifications which are necessary for comparison of our data with other research.

Seismic signal radiation was provided by an array, consisting of two separate airguns (Beresnev etal, 1988, Efimov, 1988), which were operated from both sides of the ship with synchronic shooting. These airguns are arranged as a deeply modified PAR BOLT prototype. High pressure air supply was also provided separately at an average value of 80 bars in 0.5 1 chambers. Operation depth was about 4-5 m at a distance of 1-2 m from the stern and 17-18 m between airguns. This performance of radiation system represents simple linear array.

The reception of seismic signals was provided by single channel seismic streamer, and its basic construction does not differ from that described by Saidov A.Yu. (Saidov, 1975). The streamer consists of main section 30 m long with 50 equally spaced receivers, head section 10 m long, whichis a shock absorber, and the final stabilizing section, which was also 10 m long. The depth of operation was about 4-6 m, with the distance between the center of the main section and the source of seismic energy equal to 350 m. The acquisition of seismic data was made in the frequency band from 70 to 500 Hz. The survey had been undertaken at the speed of 9-12 knots. Firing moments were controlled by the timer, tuned to equal intervals of time. In most parts of the region they were equal to 8 s. In some cases with large values of the bottom depth and sediment thickness, it was increased to 12s. Navigation fixing and correlation of SCSP and multibeam sounding data, containing geographical coordinates from Global Positional System receiver, was made by Greenwich Mean Time.

SCSP Data processing and Map Description.

SCSP data processing for map construction was carried out through the digitizing of seismic sections from line scan recorder performance. The bed of sediments was outlined by the tops of the diffracted waves hyperbolas, because in most cases the acoustic basement could be considered a scattering surface. Seismic waves propagation velocity in sediments was assumed to be equal to 2 km/s. It was shown (Neprochnov, 1976) that the use of this value could lead in thickness determination to a relative mistake of no more than 15% in thickness range from 500 to 2500 m, which is quite normal for mapping. According to the general model (Semenov, 1990) in abyssal basins of the Atlantic ocean with pelagic character of deposits, sedimentary layer with 450 m thickness has a linear increase of velocity from 1.45 to 1.78 km/s. Having this value of velocity, the thickness could appear to be enlarged by 20-30%. It seems to us that having no velocity determination on each local structure and no chance of experimentally providing the model, mentioned above, the usage of 2 km/s value in the discovered region is admissible. Estimated at this value of velocity, the thickness of sediments in meters is numerically equal to the two-way travel time of seismic waves in milli-seconds. Moreover, the reestimation would be significantly easier with the addition of more precise information about velocities. Acoustic basement determination control was provided by adding of central beam relief data to the seismic section interpretation.The sediment thickness and acoustic basement relief maps are done with the other sounding beam information in the space between the seismic lines.

SCSP Results.

The region discovered (total square 240,000 sq. km) is located between the St. Paul fracture zone (f.z.) in the south and the Sierra-Leone f.z. in the north, and includes the equatorial segment of the Mid Atlantic ridge (MAR), Strakhov (4° N) and St.Peter (2°40' N) f.z. and the blocks between them (Plate 2, 23) . Our study resulted in the series of profiles (Plate 24-33), sediment thickness map (Plate 8)) and map of acoustic basement relief (Plate 9) on a scale of 1:1,000,000 with the isoline section corresponding to 100 and 200 m. The morphostructural scheme of the acoustic basement was created on this basis (Plate 10). Following the results of our survey certain corrections were inserted into the map "Thickness of sedimentary cover" (Tucholke, Uchupi, 1989-1990) included in the "International Geological-geophysical Atlas of the Atlantic Ocean".

The quality analysis of SCSP sections wavefield has shown that sedimentary cover in the region studied could be classified in three seismic complexes: upper, middle and lower. The upper complex. is represented by well stratified sediments, with horizontal layering or inclination which corresponds to regional inclination of the basement surface. It is characterized by good phase correlation of observed internal reflections. According to SCSP data, this complex is universal for the equatorial segment of the Atlantic and usually has good representation on seismic records. The thickness of this complex in the basins reaches 300 m. The middle complex is also stratified, but as opposed to the upper complex, does not have long phase correlation. Numerous discontinuities, dislocations and wedging out of layers were observed in this complex. The middle complex has no legible roof. The thickens in the basins reaches 300 m. The lower complex is poorly stratified and fills numerous basins in acoustic basement relief. Dislocations could also be observed in this complex.

Sedimentary cover in rift zone.

The rift zone of the ES MAR is divided by the Strakhov and St. Peter faults into three segments: northern, central and southern. Sedimentary cover is very irregularly developed within their limits. It is represented by upper and middle seismic complexes and often complicated by basement intrusions up to the bottom surface. In the northern segment of MAR the sediments are virtually absent. The rift valley of the central segment sometimes contains only a few isolated sedimentary bodies, which have a thickness of up to 100m, and on the ridges of up to 250 m. The sediments are also absent in the rift valley of the southern segment. However, the quantity of sedimentary bodies on the rift adjusting ridges is gradually growing towards the equator.

The sediment bodies are mostly situated in numerous small submeridional depressions or in the transverse fault with a small shift zone, where they are sitting on its sublatitudinal depression's southern slope. The sediments are found also to the east of the rift valley's Northern segment, where they occupy the lower parts of wide depressions, oriented northwest-southeast.

In the areas of maximum sedimentation their thickness reaches 500-600 m. Three seismic-units are distinguished analogous to the above described units II, III and IV for the Sao-Paulo FZ polygon. This is evidence of the common development of the MAR equatorial segment from at least 3o30'N to the Equator during the formation of units II-IV. In our opinion, the similarity of the seismic sections of sediments in the Sao-Paulo FZ and riftogenic ridge sublatitudinal depressions is evidence of the absence of significant differences in the sedimentation patterns of these structurally very different forms.

The features of the deposits yielded evidence of the presence of sediment bodies on the rift valley bottom (Plate 8), which is very important for an understanding of rift valley tectonics. The sediment thickness exceeds 150 m. The whole sediment section represents seismic-unit IV and, judging by seismic record character and the absence of deformations, it is possible to speak of quiet sedimentation conditions. It is interesting that sediment bodies are related to the uplifted parts of the rift valley bottom with depths of 3200-3700m. Some bodies are situated in the near-slope part of the rift valley bottom.

The sediment distribution pattern described allows us to suppose that the rift valley had been generated before the seismic-unit IV formation. After that, in the rift valley's most active parts a sediment reworking occurred as a result of a tectonic collapse, with deepened bottom parts formed or sediments buried by fresh rift basalt flows.

At 2°35'N along the step on the small transverse fault depression's southern slope are located a series of elongated isolated sediment bodies united by the same direction of big axes. The differences observed in their structure and deposition are the following: to the west of 3 liu25'W seismic-units III and IV are distinguished, while to the east - only unit IV; the sediments to the east of 31in25'W are characterized by deformation and top surface tilting, while to the west - deformations exist only in unit III and unit IV is distinctly horizontally layered. These differences may be explained by different sediment position relative to the rift valley northern segment; that is the sediment deformation zone which is situated along the nodal basin side at 31°25'W.

Most sediment bodies are related to submeridionally oriented depressions of riftogenic ridge. The sediments in them are of two types, each related to depressions having a specific position to MAR. Sediment bodies related to interblock depressions are bigger in surface, have a more complex inner structure (units II, III and IV are observed) and have greater thickness (up to 400-500 m).

In-block sediments are not so thick (up to 200 m) and represent only the upper seismic-unit, but bear traces of contemporary deformations indicating the relatively small-amplitude in-block tectonics which dominate here.

The sediments in the set of depressions oriented northwest-southeast are sharply different. These depressions are situated to the east of the rift valley north segment, and they are much wider and longer than submeridional depressions. They have anomalously thick sediments - up to 750 m, and are found only 40 miles from the rift valley. The sediment section has 3 seismic-units - II, III and IV. It is curious that traces of consedimental slope uplifts during units II and III formation are marked on seismic records. Thus we assume the northwest-southeast depressions to be rather old structures (older than the age of unit II), which had undergone activation during the formation of units II and III. This activation is expressed as a generation of positive "protruding" structures of the same orientation as the main direction of depressions.

Regional section analysis shows that sediment thickness to the west of MAR is greater than to the east and that both maximal and mean values at equal distance from the MAR axis differ about 1,5 times. The thickness increases both due to the thickening of corresponding seismic-units and due to the emergence of the most ancient seismic-unit I. Furthermore, the tectonic processes clearly express themselves more actively on the eastern flank of the ridge. This activity is seen in the edge dislocation zone, where sediment top surface distortions, numerous "protruding" structures, inner sediment deformations, acoustic basement deformations interpreted as horsts and faults..

Sedimentary cover of the Strakhov fault.

The Strakhov f.z. shifts the rift valley almost up to 110km. It was studied on the interval of 680km. The depth of the fault trough reaches 5100 m in nodal basins, and the tops of the rises, and surrounding trough have a depth of about 1600 m. Thus, the relief depth difference in the "active" zone of the fault is nearly 2000-3000m, and in the "passive" - 1000-1500 m. Sedimentary bodies of an "active" fault zone are distributed over the slopes and basins, and have an average thickness of about 100-150 m. Sediments are absent in nodal basins. "Passive" zones of the Strakhov f.z. are separated from the "active" zone at 31°30' W and 33°33' W by complex built fault crossing escarpments, which are located at depths of about 3800 m. One can observe a few sedimentary bodies at the trough bottom between escarpments, with a maximum thickness of 250 m, including the upper and lower seismic complex. Horizontal layering of the sediments attests to calm conditions of deposition. The bottom of the trough to the East and West of the escarpments is flat. There is, however, a V-form depression of acoustic basement, which is filled by deposits of all three seismic complexes with a total thickness from 300 to 800m. These sediments on the map have bead-like west-east performance with the length of each chain about 20-30 km. They are divided by narrow (2-8km) isthmuses. The sediments on rift adjusting rises are located mosaically and have a thickness of no more than 100-200 m sediments. The absolute depth of the fault trough decreases from 1800 m to 1000 m in the basins. The southern and northern slopes are not symmetrical.

Sedimentary cover of the St.Peter f.z..

According to a recent detailed survey (21st cruise of r/v "Akademik Boris Petrov") the St.Peter f.z. does not intersect the rift valley . The seismic profiling of its west branch was rather detailed, but the east branch was not sufficiently studied.

The relief depth difference at the western branch of the fault is about 2500-3000 m. . In the trough bottom of the west branch we observe three steps running in sequence from west to east. Each of them is from 80 to 10 km long, and their depths are equal to 4000, 3800 3600 m. These steps are bordered by escarpments with a depth difference of 200-400 m. One could thus outline a steplike rise of ocea nic crust on the approach to the rift zone.

The fault trough of the acoustic basement is V-shaped and filled with sediments of all three seismic complexes. The maximum thickness of sedimentary cover (up to 1000m) is observed on the central step. Average thickness here is 600-800 m. Acoustic basement surface along the fault trough direction is very complicated. Sedimentary cover is sometimes penetrated by basement intrusions. In such places the lower seismic complex is absent. It is also necessary to note that the St. Peter f.z. trough contains the biggest values of each seismic complex thickness. For instance, the thickness of the middle complex is 200-300 m greater than the same complex thickness in the Strakhov f.z.. A few mosaically located sedimentary bodies are observed on fault adjusting rises, which are represented by the upper seismic complex, with a thickness of about 100-200 m. On these rises the acoustic basement surface produces stronger reflections than other regions. The rises are crossed by depressions filled with sedimentary cover with up to 600 m thick, in which it is possible to determine all three seismic complexes.

Sedimentary cover of the Sao-Pauio fracture zone.

The Saint Paul (Sao Paulo) fracture zone (FZ) bathymetry is relatively well studied, but polygon surveys with single-channel seismics (CSP) in this region are not mentioned in existing publications. On an overview map of sediment thickness of the Atlantic (Geological-Geophysical Atlas) the Sao-Paulo FZ depression is marked as filled with sediments whose thickness regularly increases at a distance from the Mid-Atlantic ridge (MAR) axis. On the 7-th cruise of R/V "Akademik Nikolaj Strakhov" the Sao-Paulo FZ central part was surveyed with 24 meridian lines (Plate 8).

Five sublatitudinal depressions can be seen within the polygon . The maximum sediment thickness reaching 900 m is observed on the northeast of the polygon. Based on the wavefield characteristics the sediment section in the areas of maximum accumulation may be divided into four seismostratigraphic units. The lower seismic-unit I lies on the rough acoustic basement, the sediments are strongly deformed, and the wavefield is fiill of diffracted waves. The relatively acoustically transparent seismic-unit II with slightly inclined inner reflectors lies above. The seismic-unit III with strongly deformed inner reflectors is higher. The section is topped by the well-stratified seismic-unit IV, characterized by horizontal layering.

The different angles of intermediate layers' inclination can be observed. This may indicate sharp differential vertical tectonic movements occurring on the sides of the depressions in which these sediment bodies lie (Plate 26). The possibility of the existence of regional sediment gap cannot be excluded, but this may be proved only through special seismic studies and deep-sea drilling. Five separate sublatitudinal depressions can be seen, with" acoustic basement highs of a complicated shape. All the depressions are parallel to each other. It is interesting that mean depth values of all of the depression bottoms are nearly equal - 4500-4600 m, excluding nodal basins with values of 5100-5300 m. The depth of the depression on the northeast of the polygon is also similar - 5200 m. All depressions are bead-like in shape, their wide deepened parts are separated by narrow saddles, and all of them are lying on approximately the same level - 4000-4200 m.

Morphometric analysis of the acoustic basement topography map showed that the lengths of the long axes of the deepened hollows of the depressions are within the two intervals with modal values 15 and 25 miles. In the limits of a depression the deepened hollows of both types may be found. The depressions' axis lines are wavy in shape, and the distance between the axis lines varies from 12 to 19 miles, with the most frequent value 16 miles.

Thus the two types of relief rhythmics expressed in the acoustic basement topography form fragmentation of two levels which are distinctly visible on the acoustic basement topography map.

To simplify the description we gave numbers running from south to north to all the depressions comprising Sao-Paulo FZ on the polygon . Two rift valley segments are traced on the polygon: the northern - between depressions 3 and 2, and the southern - between depressions 1 and 2. A small amount of sediments is observed in both segments. In the northern the sediments up to 100 m thick are on the near-foot step of the rift valley western slope. In addition, two spots of sediments of the same thickness are observed on the rift valley slopes facing nodal basins of depressions 2 and 3 respectively. Strongly deformed sediments up to 200 m thick exist on the uplifted part of the rift valley bottom.

The sediments in the "active" part of the depression 2 are represented by 4 bodies isolated by the depression slopes uplifts. The maximum sediment thickness is 400 m. The angles of inner reflectors in some cases reach 5-8°- Based on the sediment structure and distribution features in the "active" part of the Sao-Paulo FZ depression 2 it may be asserted that a common sediment cover existed on the site of both the "active" zone and of 2 segments of the rift valley. Then it was reworked during rift valley formation. Tectonic and volcanic processes causing the sediment transformation also began in the "offset" part of the depression. We can suggest this as due to certain features of the CSP method even a relatively small sediment reworking by volcanic, magmatic or metasomatic processes will produce a wavefield on the record similar to acoustic basement, but not to sediments.

The Sao-Paulo FZ northern depression bottom in its western "passive" part is covered with sediments up to 800 m thick. The area of maximum sedimentation presents the seismic-units II, III and IV, and the top surface of all of them is practically horizontal. The units III and IV are everywhere characterized by the sticking of inner reflectors to the depression sides. At 26° 17'W one can see a strong sediment deformation - on the record a prograding dome-like structure is visible which caused obvious post-sedimentary distortions of inner reflectors. This structure may have been caused by the rifting process. From the acoustic basement topography map it is seen to lie on the fault cutting the ridge which separates depressions 1 and 2, and this fault is one of the set of en echelon faults, the main one of which forms the rift valley northern segment's west side.

In the depression 2, the western "passive" part the sediments occupy 3 deepened hollows. In the section seismic-units III and IV are marked with different inner reflectors inclination. The significant feature of unit III is a connection to the sides and an enveloping of the hollow bottom which may indicate the consedimentary relative uplift of the corresponding sides.

The reflectors of the unit IV in the eastern hollow are inclined to the south, in the central hollow - towards the north, and in the western area lie horizontally. Thus different directions of neotectonic movements of ridges bordering the depressions can be concluded. Evidence pointing to the existence of tectonic movement inversion was noted . On line 22 a distinct northern dip of unit III reflectors and their connection to the depression's southern side is seen, and on the other hand, the southern dip of unit IV reflectors may be observed.

Practically all the depression 3 western "passive" part bottom is occupied by sediments. 10 miles east from rift valley the sediment thickness already reaches 200 m, and at 25°25'W - even goes up to 800 m (only 55 miles from the rift valley!). Seismic-units II, III and IV with very different inner reflectors inclination are marked here. Near 25°45'W a strong tilt of modern sediments surface is marked indicating the contemporary relative uplift of the depression's southern side. Traces of vertical movements in the unit II, which do not influence the upper sediments, are visible on seismic sections. At 26°15'W a sediment body 200 m thick exists on the bottom of depression 3. A seismic section shows this body wavefield to differ greatly from ordinary sediments in depressions and is in fact very similar to the wavefield of the sediment "cap" situated 1000 m higher. It is possible to presume that these sediment bodies have been united in the past, and then either the uplift of the depression northern side or a deepening of the bottom occurred. In both cases, however, the presumed amplitude of the tectonic movements is about 1000 m.

<u>Blocks between the fracture zones.</u>

Taking into consideration the geographical position and morphostructural features of the region studied we have specified 6 blocks (FB) between the fracture zones (Plate 8, 9). 1, 2, 3, 4 FB are represented by north-south directed ridges and depressions. The ridges appear as intrusions of acoustic basement and have the shape of long and narrow crests with a 10-20 km base width and up to 25-30 km long. They have coulisse-like locations and the crest bottom depth ranges from 2000 to 2800 observed in small square depressions. The thickness of sediments on the slopes of these depressions does not exceed 100-150 and is from 30 to 50 km long. They are filled by sediments of all three seismic complexes. The average thickness of sediments in 1 and 2 FB varies from 200 to 400 m, and in 3 and 4 FB from 400 to 600 m. The reflecting horizon of the middle complex often has a concave shape. In the limits of 3 and 4 FB the biggest total value of all types of deposits can be observed . At 33o W it is possible to watch north-south crest 90 km long, that is crossing 3 FB The acoustic basement relief of 5 FB is strongly dismembered . Depressions are filled by sediments of the upper complex with a thickness of about 200-300m . A big west-east depression is located in the south-eastern part of 5 FB. It is filled by sediments of all three complexes with a total thickness about 400-600 m.

The acoustic basement surface of 6 FB is also strongly dismembered. The roof of sediments has an inclination and is complicated by penetrations of the acoustic basement. An arc-form north-south crest 120km long could be observed in the limits of 6 FB, while the direction changes to eastward in the northern part of FB. We also observe separate sedimentary bodies with a thickness of less than 100 m.. This crest is associated with big depressions filled by sediments of all three complexes with thickness about 400-600 m.

SCSP Survey Result Conclusions

1. Separate sedimentary bodies, having a thickness of about 100m, were discovered at the rift valley of MAR between the Strakhov and St. Paul fracture/.ones. The sediments in the rift valley to the north and south of these bodies are absent in seismic resolution (30 m).

2. Passive parts of the fracture zones have a v-shaped section of acoustic basement and are filled with sediments up to 500 m thick.

3. Complex built fault trough crossing escarpments were discovered in the acoustic basement relief at the Strakhov f.z. near the transfer from the active part to the passive branches.

4. A steplike west-east rise was discovered in the acoustic basement relief of St.Peter f.z... The maximum value of sediment thickness was observed on the central step 180 km from the rift zone axis, and it reaches 1000 m.

5. The maximum average values of sediment thickness are about 600-800m. They were discovered in the limits of the passive zones of transform faults, but there is no increase of average thickness from the rift zone axis to periphery.

6. The acoustic basement relief of fracture zones troughs has bead-like shapes with alternating west-east depressions and narrow isthmuses.

7. Rare and thin (100-150 m) sedimentary bodies were discovered in the active zone of the Strakhov fracture zone.

8.The sedimentary cover is usually absent at fracture zones' adjusting rises and appears only in crossing depressions.

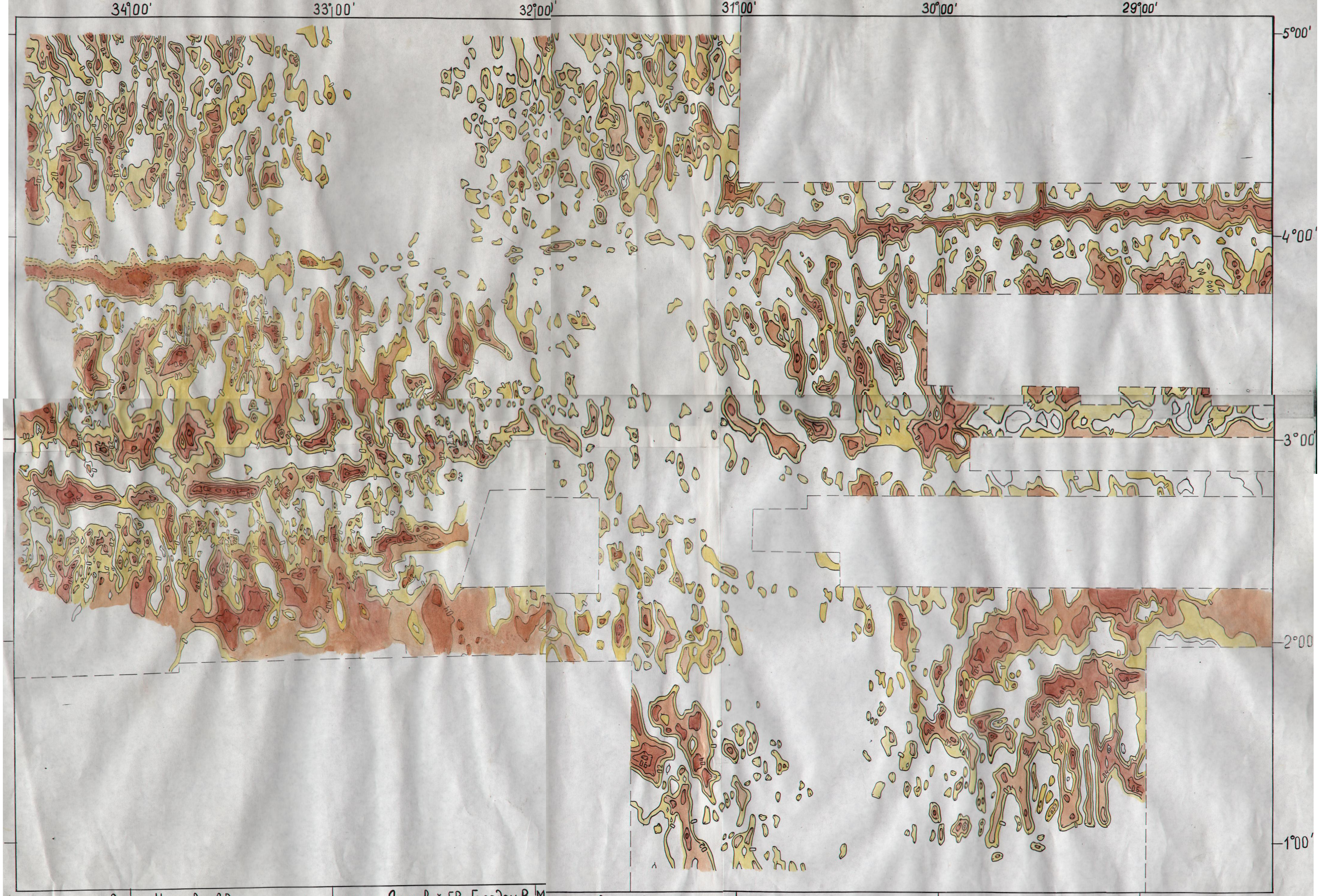
9. The ridge crests in blocks between the fracture zones have coulisse-like location. They alternate with north-south depressions, filled with sediments. The average thickness of sediments is about 300-500 m. The total quantity of sediments increases in the southern direction.

10. Through structural divisions the sedimentary cover, observed in the region studied, could be divided into three seismic complexes: the upper, with horizontal or weak inclined layering of reflecting horizons; middle, with numerous dislocations and penetrations of the acoustic basement and deposited under strong tectonic activity; lower, acoustically apparent, with significant dislocations and probably formed at the early stage of bedrock relief formation.

11. The sediments in Strakhov and St.Peter f.z., and also in big depressions at the blocks between the faults, are represented by three seismic complexes.

12. The basins of the acoustic basement, north-south ridges in the blocks between the faults and fault adjusting rises are represented only by sediments of the upper seismic complex.

КАРТА МОЩНОСТИ ОСАДОЧНОГО ЧЕХЛА



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