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CRUSTAL STRUCTURE OF PALMER DEEP (WEST COAST OF THE ANTARCTIC PENINSULA) BY GEOPHYSICAL DATA

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Abstract. The Ukrainian Antarctic expeditions acquired new geoelectrical data ('short-impulse electromagnetic field formation' – FSPEF, and 'vertical electric-resonance sounding' – VERS) along profiles across Drake Passage and continental shelf of Antarctic Peninsula. The electromagnetic experiments yielded new data set with unique information about the inner structure and new values of the depth of the Moho discontinuity of West Antarctica region.
Deep crustal heterogeneities of the Palmer Deep Basin that were obtained from the VERS- profiles data could be connected with processes of tectonic transformations of the Antarctic Peninsula shelf structures. Possibly, the conformities of continental shelf glacial streams may be explained exactly by a tectonic factor of recent geological past.
New information about sediment distribution and inner crustal structure has an important value for searching and prospecting the hydrocarbon deposits of Palmer Deep region.
Key words: West Antarctica, crustal structure, geophysical data

Структура земной коры впадины Палмер (западное побережье Антарктического полуострова) по геофизическим данным. В.Д. Соловьев, В.Г. Бахмутов, И.Н. Корчагин, С.П. Левашов
Реферат. По данным геофизических исследований, проведенных в УАЭ, изучены особенности глубинного строения структур континентального (тихоокеанского) шельфа Антарктического полуострова. Построенные разрезы характеризуют не только верхнюю часть земной коры, но и её глубинные горизонты. Данные о мощности земной коры показали их значительную дифференцированность по площади. Проведенные в области впадины Палмер исследования впервые показали увеличенную мощность осадочных образований среднего и внутреннего шельфа Антарктического полуострова. Мощные осадочные толщи формировались в пределах отдельных структур, локально осложняющих строение континентального шельфа.
Глубинные неоднородности земной коры и сеть тектонических нарушений в теле фундамента впадины Палмер, выделенные по данным ВЭРЗ, свидетельствуют о длительных процессах тектонических преобразований структур шельфа Антарктического полуострова. Возможно, именно тектоническим фактором объясняются также закономерности формирования ледниковых потоков недавнего геологического прошлого.
Новые данные о распределении мощности осадочного чехла имеют важное значение для определения перспектив этого района на формирование скоплений углеводородов.
Ключевые слова: Западная Антарктика, структура земной коры, геофизические данные

Структура земної кори западини Палмер (західне узбережжя Антарктичного півострова) за даними геофізичних досліджень. В.Д. Соловйов, В.Г. Бахмутов, І.М. Корчагін, С.П. Левашов
Реферат. За даними геофізичних досліджень, проведених в УАЕ, вивчено особливості глибинної будови структур континентального (тихоокеанського) шельфу Антарктичного півострова. Побудовані розрізи характеризують не тільки верхню частину земної кори, але й її глибинні горизонти. Дані про потужність земної кори показали їх значну диференційованість по площі. Глибинні неоднорідності земної кори

западини Палмер, виділені за даними ВЕРЗ, свідчать про тривалі процеси тектонічних перетворень структур середнього і внутрішнього шельфу Антарктичного півострова. Наявність тектонічних зрушень в тілі фундаменту шельфу сприяла новітнім геологічним процесам формування структур западини Палмер і льодовикових потоків континентального шельфу недавнього геологічного минулого.

Нові дані про розподіл потужності осадочного чохла мають важливе значення для визначення перспектив цього району на утворення скупчень вуглеводнів.

Ключові слова: Західна Антарктика, структура земної кори, геофізичні дані

Introduction

Analysis of existent volume of geological and geophysical data about the field's distribution and information of Western Antarctic lithosphere enables only broadly speaking to find out the charts of evolutional development of this region. Therefore new actual material during the Ukrainian Antarctic marine expeditions obtained has an important value for investigation of geophysical crustal heterogeneities and geophysical models of the of West Antarctica bottom structures construction.

Especially it relates to the Pacific Coast of the Antarctic Peninsula, where information data are insufficient for many local structures complicated the shelf inner structure. Investigation of the deep crust horizons behavior of such coastal structures has an important value for the system study of the paleosubduction's zones morphology formed in variable geodinamical conditions.

Crustal heterogeneities and fracture zones can be clearly seen in geoelectrical images. The field procedures of this study combined the methods of "short-impulse electromagnetic field formation" (FSPEF) and "vertical electric-resonance sounding" (VERS). The FSPEF method is based on the use of small ferrite dipole antennas to transmit and receive short-impulse electromagnetic fields. This method uses short but high-power electric pulses. Compared with earlier techniques, this method has the benefits of increased field efficiency and productivity. The VERS method is based on processes which polarize naturally-occurring electric fields at the surface of Earth. The polarized fields are analyzed for their spectral characteristics. The method makes possible the efficient and accurate determination of a stratigraphic model beneath a sounding site. These techniques were applied during the 2004 (9th) and 2006 (11th) Ukrainian Antarctic expeditions. Marine observations were carried out from the vessels Ushuaya (2004) and Humboldt (2006) using compact, computerized equipment. The portable measuring equipment “GEMA” (Geo-Electromagnetic Application) was an important element of this technology. GEMA was connected with a GPS-receiver and a laptop computer using special program interfaces. This equipment allows investigations to be carried out over large areas in short time-frames and at minimal expense (Levashov et al., 2003; Levashov et al., 2006). The aim of this paper is to show practical examples of the application of these geoelectrical techniques in the marine environment.

It's also necessary for the determination of the major stages of evolution and dynamics of development of basic tectonic elements of the West Antarctic passive margin.

The Palmer Deep is one of such characteristic enclosed structures of the Pacific continental shelf of the Antarctic Peninsula not far away from Anvers Island (Fig.1).

It's known that this region of shelf was a real platform for glacial development and advance across the inner continental shelf edge during the most recent glaciation's period.

The Palmer Deep is located at the convergence of three distinct accumulation centers: Anvers Island, Bruce Plateau and the Graham Coast (Rebesco M. et al., 1998). It was a center of the convergence of ice streams crossed the continental shelf at a distance more than 200km from Antarctic Peninsula coast. The Palmer Deep's basins with different bottom relief depth features are the separate parts of a common region which consists of the Palmer Deep basin, the Palmer Deep Outlet Still and the Hugo Island Trough (Fig.1,A). This inner-shelf trough consists (Fig.1, B) of three basins (I-III) oriented in a SW-NE direction with various depth from 1100m (basin I) to 1500m (basin III). The basic morphological features of these basins are determined by postglacial processes of sediment

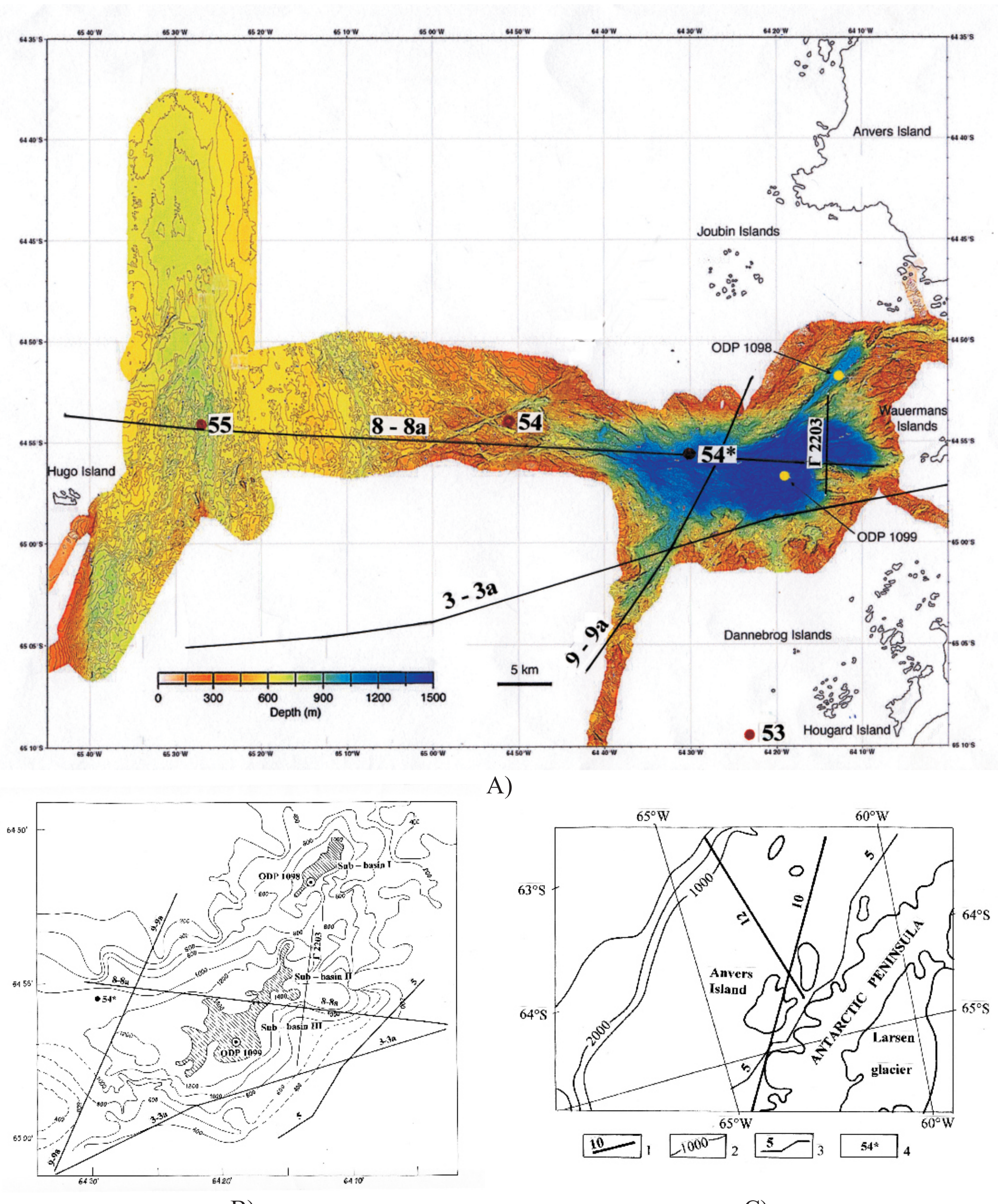

Fig. 1. Detail bathymetric map of the Palmer Deep region (A, B) and the geophysical profiles location at the Antarctic Peninsula continental shelf study area (C). Location of ODP (Leg178) sites 1098 and 1099 is indicated. Bathymetry maps - by (Domack E., et al., 2005, Rebesco M. et al., 1998).

Legend: 1-location of deep seismic sounding (DSS) recorded by (Sroda P. et al., 1997); 2-bottom bathymetry with a contour interval of metres; 3-geophysical (VERS) profiles location; 4-location of VERS points.

accumulation that forming in change conditions of erosion and deposition phases. There are some seafloor features such as relic terraces, sub-glacial lake deltas, numerous channels and levees which were formed as a result of water-courses action and erosion processes at the structural weakness zones within the faulting basement rocks.

The three sub-basins are filled with a layered sedimentary succession which consists of mud turbidities and different glacial marine deposits of siliciclastic character. The total sediment thickness of glacial and interglacial sediments is about 270m (Rebesco M. et al., 1998) of the Holocene down to at least the last Glacial Maximum (11000 years BP).These sediments are divided into four units consistent with division at the site ODP-1098 lithofacies. It's interesting that the upper horizon is characterized by relatively high magnetic susceptibility, reflecting a dominance of multidomain magnetite (Domack E. et al., 2005).

An acoustic basement at this area consists of Mesozoic to Early Cenozoic volcanic and plutonic rocks. The fracture zones that bound the Palmer Deep and influence on the sedimentary succession are in correspondence with the projection of the South Anvers Fracture Zone. This large-scale fracture zone divides the western slope of MOR to a set of separate segments. Also it has a great value for the tectonic segmentation of the Antarctic Peninsula margin. The significant part of the shelf's structure displacement may be connected with the scale geodynamic processes of this fracture zone.

Investigation results

The 2004 (9^{th}) and 2006 (11^{th}) Ukrainian Antarctic expeditions acquired new geoelectrical data along profiles across Drake Passage and along Bransfield Strait, Antarctic Peninsula, with the aim of studying the crustal structure of these features down to depths of >30 km. The sounding on this depth in Antarctic region was the first experience of deep modification of the VERS method using. Modeling experience of deep crustal structure by geophysical data with VERS method shows that there is a possibility to investigate the fluid regime, tectonic disturbances and crush zones in basement and local places of submarine volcanic activity too. The experience of VERS investigations data shows that the normal geoelectrical resistance layer represents unaltered rocks of the upper part of the crystalline basement; the high geoelectrical resistance marks magmatic intrusion and low resistance characterizes the changed rocks with possible hydrothermal activity effect.

This technology also gives a possibility to efficiently divide the cross-section on separate stratigraphic subsections in the sounding site and to determine its depth with high accuracy (Levashov et al., 2003; Levashov et al., 2007). Upper crust cross-sections to a depth of 6000m with VERS using were obtained along 3-3a, 8-8a, 9-9a profiles (Fig.2-4). The basic structural elements of continental shelf (down to depth of >30km) along the profile 5 were determined by deep modification of VERS method during the seasonal works of the 2006(11^{th}) Ukrainian Antarctic expedition (Fig.5).

Geoelectrical models of Palmer Deep crustal structure along three profiles were built on the sounding data in separate points of continental shelf.

The principal shelf's elements of Palmer Deep (sub- basins, the Palmer Deep Outlet Still and the Hugo Island Trough) were crossed by the 8-8a profile (Fig.2). The sedimentation province is distinguished at the upper part of section in transition zone from the axial raising of middle shelf to the structures of the outer continental shelf (fig.2, 0-80km).It's fixed by areas of higher polarization and geoelectrical resistance at 4.0-6.0km depth. An anomalous change of the crust cross-sections is observed at the transition zone between the outer shelf and investigated structures location which complicates the structure of middle and inner shelf near Anvers Island (Fig.2, 130-230km). The deep cross-section of middle and inner shelf here includes higher thickness of the second sediment horizon and crushing zones. There are some dike sets also (fig.2, 170-200km, 215-230km).

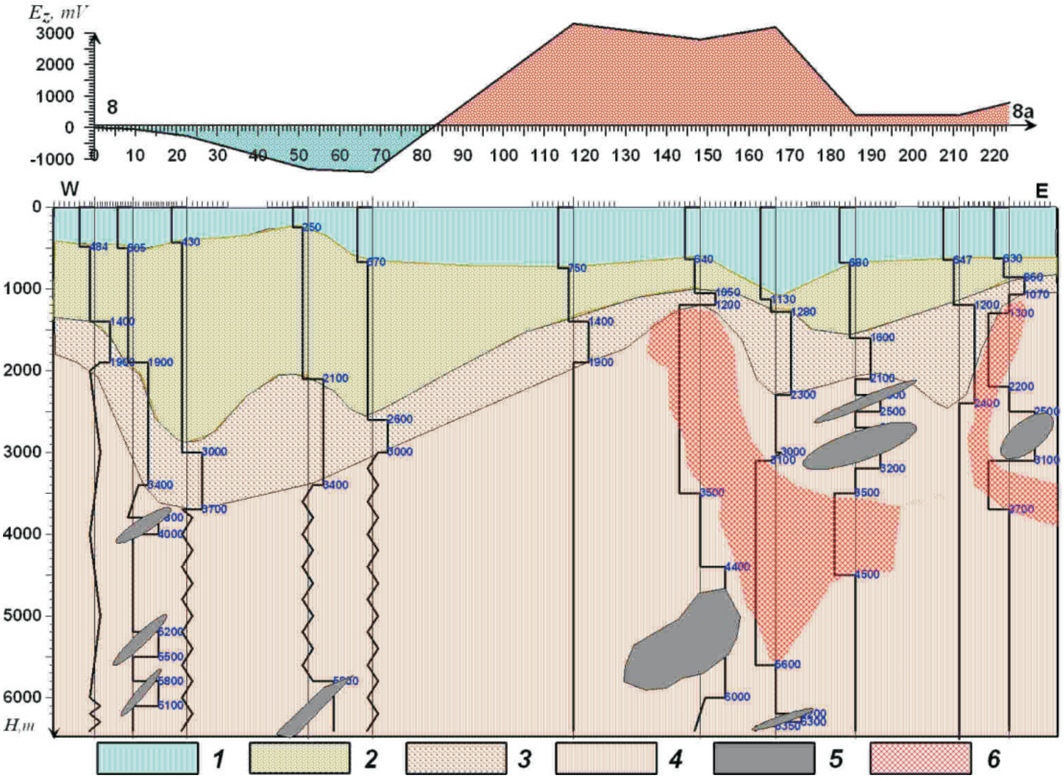

Fig. 2. Interpreted geoelectrical cross-section along the profile 8-8a (the continental shelf of the Antarctic Peninsula, Palmer Deep). Location of profile is shown on Fig.1(A,B). Legend: 1 – water; 2 – sedimentary layer of low geoelectrical resistance (silts, clay and sandy sediment); 3 – layer of high geoelectrical resistance (detrital rocks; muddy sediment; shallow, hydrothermally altered basement rocks); 4 – unaltered basement rocks; 5 – zones of high polarization and resistance in basement rocks, interpreted as volcanic intrusions); 6 – zones of low resistance in basement rocks (interpreted as fracture zones).

The considerable part of the middle shelf cross-section (Fig.2, 70-130km) is a stable area which is not complicated by tectonic fractures. This area coincides with position of the Palmer Deep Outlet Still (Fig.1). The higher thickness of the second sediment horizon and bottom's relief deepening is fixed in the crust cross-section at the Hugo Island Trough (Fig.1, VERS point 55) area. Influencing of crustal tectonic transformations which discovered in the district of Palmer Deep is observed only in the most eastern part of the Palmer Deep Outlet Still (Fig.1, VERS points 54, 54*).

The complicated structure of the continental shelf's middle part by the VERS data for the cross-section along 3-3a profile was obtained (Fig.3). At the upper part of section there are numerous areas of crushing zones and dikes that testifies to different processes of basement's forming in conditions of its large saturation with volcanic rocks of different expansion and deep-seated origin.

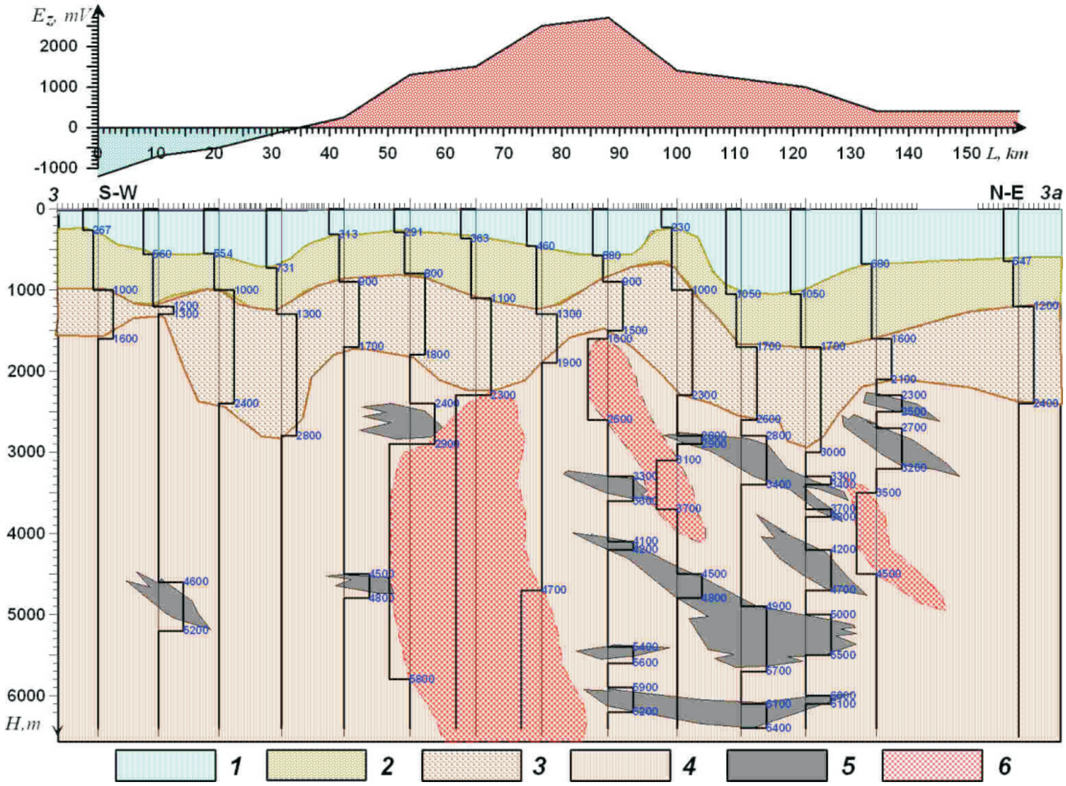

Fig. 3. Interpreted geoelectrical cross-section of the upper part of the crust along the profile 3-3a. Location of profile is shown on Fig.1 (A, B). Legend is shown on Fig. 2.

It should be noted that the area of the Palmer Deep Outlet Still on this section has considerable differences of deep structure from the resulted model of deep structure along profile 8-8a (Fig.2,3). First of all it concerns to depth of 2.0-6.0km, where inhomogeneities in the district of the middle shelf's raising are fixed. The numerous crushing zones and dikes inclusions into the basement body (Fig.4, 85-145km) were found out at the area of profile 3-3a located south of the deepest Palmer Deep sub-basin. Similar features of deep section are obtained for the profile 9-9a (Fig.4) where the deep section of the Palmer Deep structural continuation is enriched with dikes and crushing zones.

The whole series of short-period intensive (up to +300 nT) magnetic anomalies were detected on the magnetic survey profile (Г-2203) crossed the Palmer Deep structures.

The sources of these, most short-period magnetic anomalies, located at the depth of first hundred meters below bottom. The sediment rocks of this horizon are characterized by relatively high and variable magnetic susceptibility. The magnetic anomalies out of the Palmer Deep have another size and intensity; their sources are displaced at depth of 4.0-12.0km. This linear positive anomalies with amplitude up to 250 nT may indicate a variety of possible sources the eastern part of the Pacific Margin Anomaly with intermediate depth bodies (4-12km).Early we suggested that such anomalies are associated with individual shallow plutons and volcanics of the Antarctic Peninsula gabbro-diorite group rocks (Fig.2) as a result of postsubduction volcanism processes.

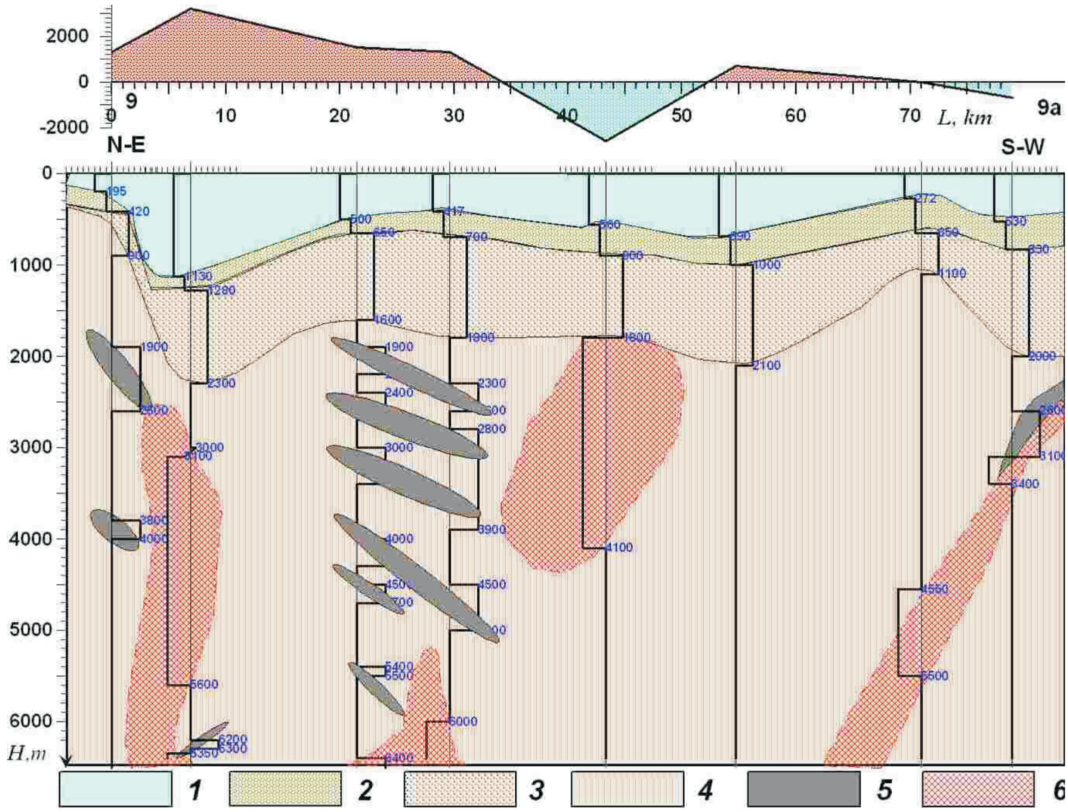

Fig. 4. Interpreted geoelectrical cross-section of the upper part of the crust along the profile 9-9a. Location of profile is shown on Fig.1 (A,B). Legend is shown on Fig. 3.

The obtained results of continental shelf deep structure were confirmed by sounding materials along the profile 5 during works of 2006 (11^{th}) UAE (Fig.5). During these works the deep heterogeneities of the cross-section were obtained not only in upper part of the earth's crust (on depth to 6.0km). but also at 10.0-12.0 and 16.0-18.0km depth.

The major feature of the profile 5 is a complication of deep crust structure due to including of numerous effusive rocks complexes and «crust-mantle» transitional horizon of variable thickness also. The complication of crust is accompanied with an increasing the earth's crust power to 30-31km nearby Anvers Island. The large area of crust tectonic fractures was determined on the profile 5 by the VERS data (Fig.5).

Probably, this fracture zone has a prolonged history of forming as it was showed by the specify cross-section deep features of 8-8a, 3-3a, 9-9a profiles.

It should be noted that by the VERS data there are no crustal complications which would testify the tectonic activity at the cross-section of the profile 10-10a.

Such features are distinctly selected for the VERS-point №53, that can testify the considerable local heterogeneity of deep crustal structure and it's different saturation with magmatic rocks inclusions.

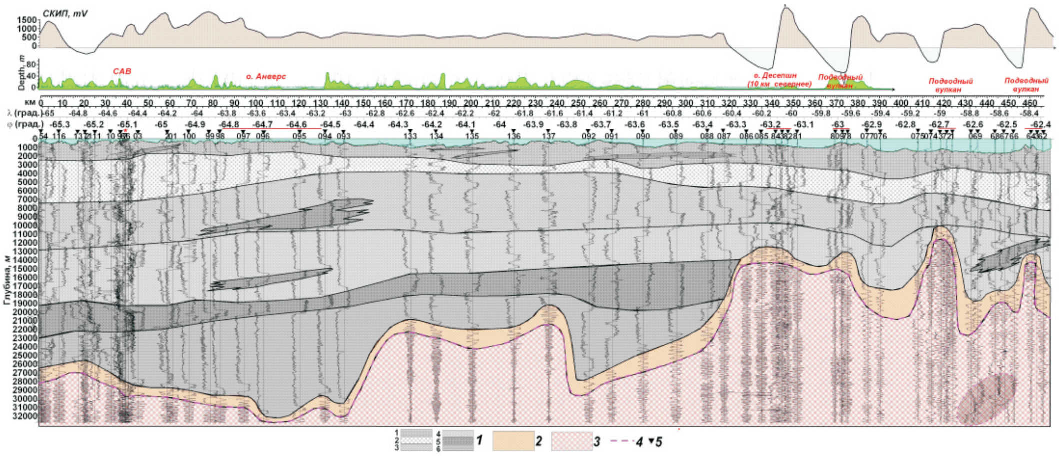

Fig. 5. Interpreted geoelectrical cross-section of the crust and upper mantle along the profile 5. Location of profile is shown on Fig.1(B,C). Legend: 1 – complex of volcanic and crystalline rocks; 2 – rocks of crust–mantle transition layer; 3 – upper mantle; 4 – Moho boundary(?); 5 – VERS points.

Deep VERS data conducted in area near Anvers Island and Gerlache Strait (Fig.1, B,C) enable not only to define the structure's features of the west margin deep crustal horizons but also to compare the results with the deep seismic sounding data. The DSS materials show that the considerable differentiation of separate deep horizons position and areas of the prolonged dikes horizons enriching at profile's cross-sections are absent. The values of the depth of the Moho discontinuity obtained by VERS data did not coincide with DSS-results of Polish researchers (Sroda P. et al., 1997) for the profiles 10 and 12 (Fig.1, C). Possibly these VERS-Moho values obtained are coincided with mean position of «lower horizon of the earth's crust», which is selected from the DSS- data.

The VERS researches of Palmer Deep area showed the higher sediment formations power within the middle and internal shelf of the Antarctic Peninsula, which were formed within the limits of separate structures that locally complicated the continental shelf structure.

The prolonged and multistage coastal structures development in the conditions of regional tectonic activation of its separate segments could be favorable to different types of minerals forming in this area.

For example, the anomalous polarized layers in interval to 3500м of "deposit" type are discovered by VERS data near Anvers Island (Fig. 6).

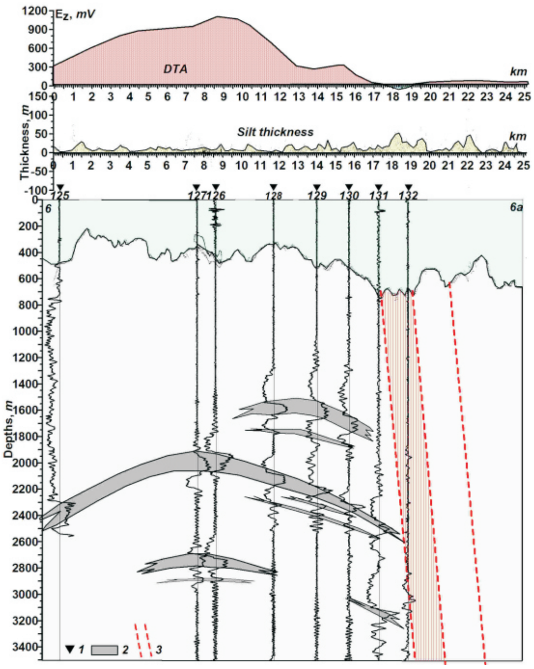

Fig. 6. Interpreted geoelectrical cross-section of the crust of the "hydrocarbon deposit" type in Palmer Deep area. Legend: 1 – VERS-points 125-132; 2 – anomalous polarized layers of "hydrocarbon deposit" type; 3 – tectonic fracture zone.

Unfortunately more detailed researches within this anomalous area were not conducted. The future study of this region may open new perspectives on hydrocarbon deposits areas.

Conclusions

The electromagnetic experiments conducted by the Ukrainian Antarctic expeditions in 2004 and 2006 yielded a new dataset containing information about the internal crustal structure of continental shelf of Antarctic Peninsula. New estimates of the depth of the Moho discontinuity in these areas were obtained.

New obtained data on the geophysical field distribution for the tectonic structures of the West Antarctica lithosphere enabled to separate local crustal inhomogeneities of the continental margin of Antarctic Peninsula. A great effect of the tectonic factors on the formation of the inhomogeneous sediments, some intrusion zones and tectonically active fault zones of continental shelf has been detected.

Deep crustal heterogeneities of the Palmer Deep Basin that were obtained from the VERS data along the series of profiles could be connected with processes of tectonic transformations of the Antarctic Peninsula shelf structures during the processes of postsubduction volcanism.

Possibly, the conformities of continental shelf glacial streams may be explained exactly by a tectonic factor of recent geological past. New information about sediment distribution and inner crustal structure has an important value for the hydrocarbon deposits of Palmer Deep region searching.

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