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Notes

Chapter 16

Geological structure and petroleum potential of the eastern flank of the Northern Barents Basin

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Abstract: New seismic research was carried out by JSC Marine Arctic Geological Expedition in 2006–2008, providing the first integrated geophysical grid (20 × 30 km). The main purpose was to study the geological structure of the sedimentary cover of the north Barents shelf and investigate the structural–tectonic plan at different stratigraphic levels. The geological results yielded new information on the tectonic structure, depositional environments, palaeobasin geometry, bathymetry and regional history of geological development. The geological interpretation of the Lower Palaeozoic part of the section provided the most interesting results.

The offshore area of the Northern Barents Syneclise remains the least-studied part of the Barents Sea shelf (Fig. 16.1). At the same time, as geological and geophysical studies of recent years indicate, it is one of several areas on the Russian shelf where discoveries of large hydrocarbon fields, including oil fields, are possible. The oil and gas potential of this offshore area is associated with Triassic and Palaeozoic strata.

The petroleum potential of Triassic reservoirs is determined by the presence of anticline structures (more than 20), the largest (about 1000 km^2) of which are the Orlovskaya, Gidrografov and Salmskaya structures, located within the limits of the Albanovsko–Gorbovsky step. Their petroleum potential is confirmed indirectly by natural bitumen shows in the Franz Josef Land archipelago; these occurrences are reliable indications of the sedimentary stratum's productivity according to many researchers (Grigorenko *et al.* 2002).

The petroleum potential of the Palaeozoic strata is determined by their belonging to a Late Devonian–Early Permian continental margin and by the existence of the large anticline structure Varnekskaya at Zhelaniya Cape High; its size is comparable with the size of Admiralteisky Megaswell uplifts.

The Novaya Zemlya and Franz Josef Land archipelagos are located close to each other. Their climatic conditions are harsh and this will constrain the development of large fields, but this is not an extraordinary obstacle. As an example, it is appropriate to indicate the history of exploration and development of petroleum basins of the northern Canada and Alaska (Northern Alaska, Mackenzie Delta–Beaufort Sea, Sverdrup Basins), which started in the 1960s. Today the explored recoverable hydrocarbon reserves of the offshore fields in the Northern Alaska Basin amount to 1.5 billlion tons of oil and 750 bcm of gas; in the Mackenzie Delta–Beaufort Sea Basin, 500 million tons of oil and 100 bcm of gas; and in the Sverdrup Basin, 250 million tons of oil and 1.13 tcm of gas (Klubov & Vinokurov 1998).

This paper is based upon the results of integrated geological–geophysical studies, performed by OAO MAGE according to the state contract with the Department of Subsoil Usage on the continental shelf and in the World Ocean (MORGEO) on the eastern flank of the Northern Barents Basin in 2005–2007.

Geological structure

The geological section of the Northern Barents Basin's eastern flank is divided into two structural–tectonic stages (STS): lower and upper. They are separated by a surface of discontinuity represented by a distinct regional unconformity $III_2(PZ_1\text{-}D_3)$, which within the limits of the Barents Sea is associated with regional pre-Frasnian erosion and obviously is linked with Hercynian phase of tectonogenesis (Fig. 16.2).

The *lower structural–tectonic stage* includes the heterogeneous *basement*, which underlies the sedimentary cover, and a *Lower–Middle Palaeozoic lithological–stratigraphical complex* (LSC). The following tectonic elements can be outlined on the surface of the reflector $III_2(PZ_1\text{-}D_3)$ surface: *Pre-Novaya Zemlya structural area*, *Northern Barents Syneclise* and *Franz Josef Land High* (Fig. 16.3).

The Pre-Novaya Zemlya structural area includes, from south to north, the following structural elements: Admiralteisky Megaswell, Sedov Trough, Zhelaniya Cape High, Carlsen Trough and Pospelova High. The northern pericline of the Admiralteisky Megaswell, the Zhelaniya Cape High and the Pospelova High, associated with the basement highs, are separated by the Sedov and Carlsen troughs, which represent north–south elongated graben-like structures, limited by deep faults.

The Northern Barents Syneclise represents a large linear negative structure, elongated in sub-latitudinal direction, delineated by contour line 13 500 m of the lower STS top. The internal structure of the syneclise is terminated in the west by the Northern depression and in the east by the western Fobos Trough.

The basement (reflector VI) of the Pre-Novaya Zemlya structural area has a block structure, formed by high-amplitude deep faults; some of them penetrate the sedimentary cover of the upper STS. Seismic character distinguishes two types of blocks. The first type is characterized by a lack of reflections (Admiralteisky Megaswell); the second has an internal layered pattern (Zhelaniya Cape High). These features of the seismic styles suggest different times and degrees of the basement blocks' consolidation.

The basement surface cannot be traced in the seismic sections within the Northern Barents Syneclise, so it is not possible to

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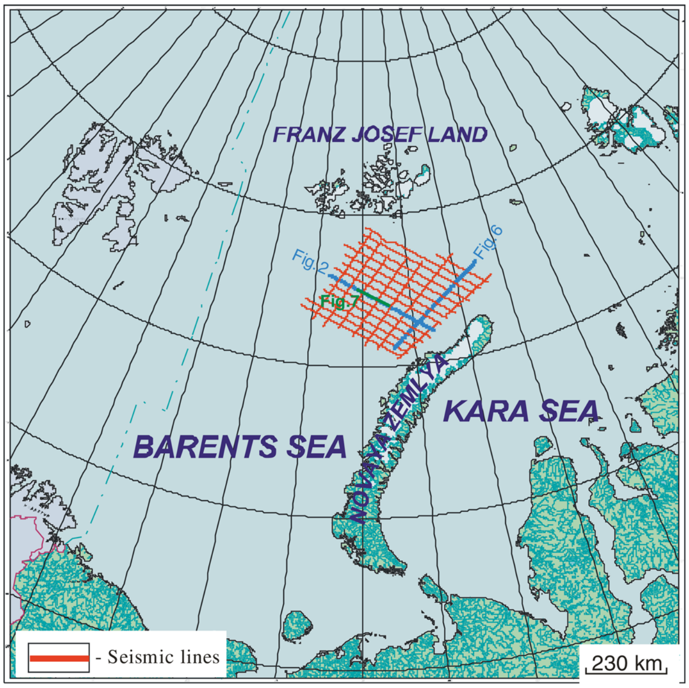

Fig. 16.1. Study area and seismic grid.

infer its depth and seismic type. The Lower–Middle Palaeozoic complex formations are represented by strata of Ordovician–Early Devonian age and fill depressions of the basement in the Pre-Novaya Zemlya structural area. Reflector IV(S?) is traced within the complex. It is associated with a Silurian erosion surface and truncation. In the Northern Barents Syneclise the Silurian–Early Devonian strata cover the deepest complexes. The Lower–Middle Palaeozoic complex is limited by sharp angular erosion truncation (horizon $III_2(PZ_{1+2}$-$D_3))$, indicating a long period of tectonic stabilization of the region.

Seismic information on the structure of the lower part of the Lower–Middle Palaeozoic lithologic–stratigraphic complex and basement within the Northern Barents Syneclise is limited by the seismic record length of 8 seconds. This information and uncertain tracking of seismic reflectors is not enough for a confident geological interpretation.

Upper structural–tectonic strata overlie the Lower–Middle Palaeozoic formations with a sharp angular unconformity. The Upper STS structure is formed by five lithological–stratigraphical complexes, which characterize the Late Palaeozoic–Mesozoic history of the Northern Barents Syneclise's development: *Upper Devonian–Lower Permian*, *Middle Permian*, *Upper Permian*, *Triassic*, *Jurassic* and *Cretaceous* (Fig. 16.2).

Upper Devonian–Lower Permian LSC ($III_2(PZ_{1+2}$-$D_3)$–$Ia(C_3, P_1)$) sediments in the Pre-Novaya Zemlya structural area accumulated under conditions of progradational expansion of a shelf and formed as two large alluvial fans within the Sedov and

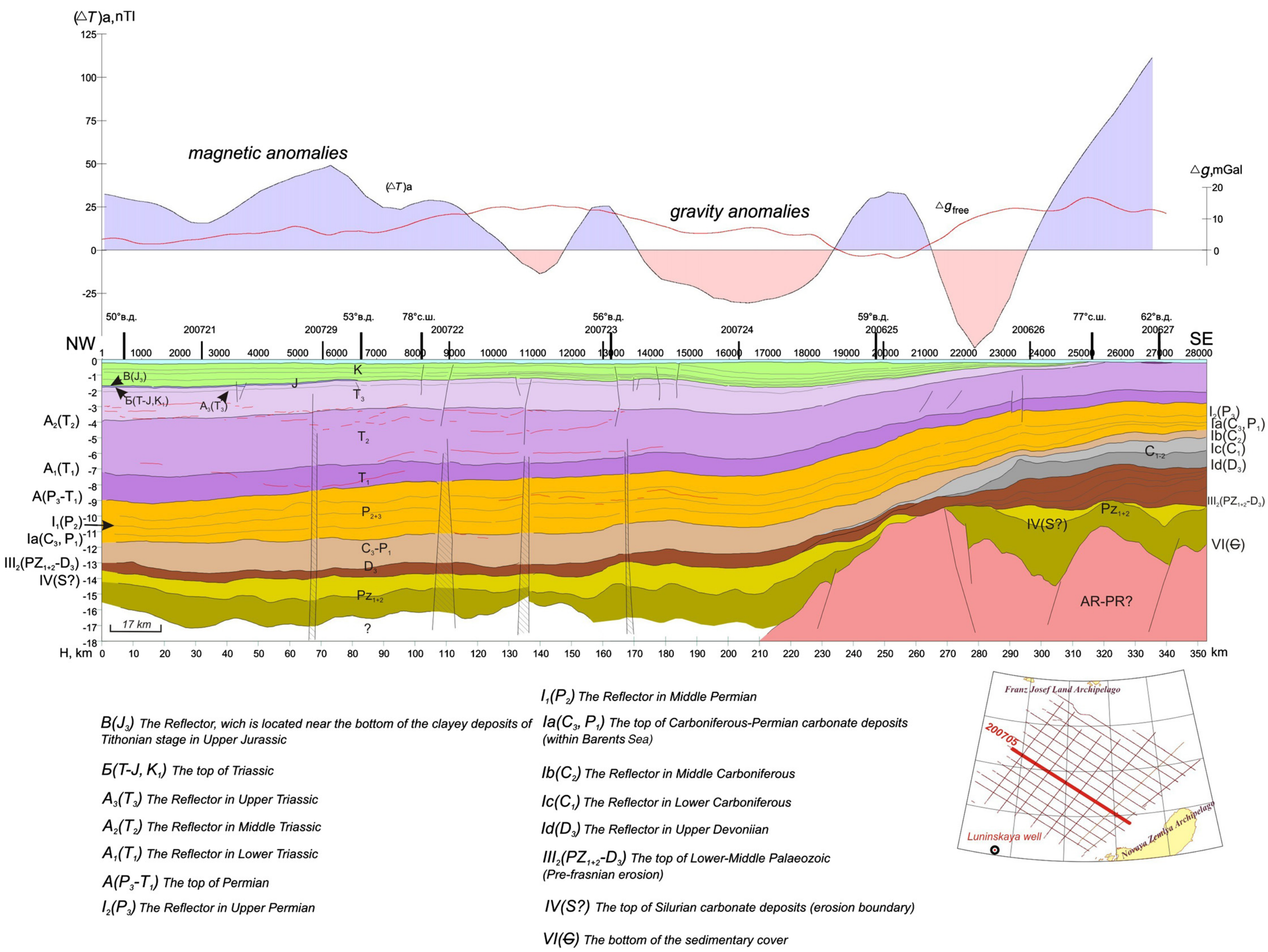

Fig. 16.2. Geological section. Profile 200705.

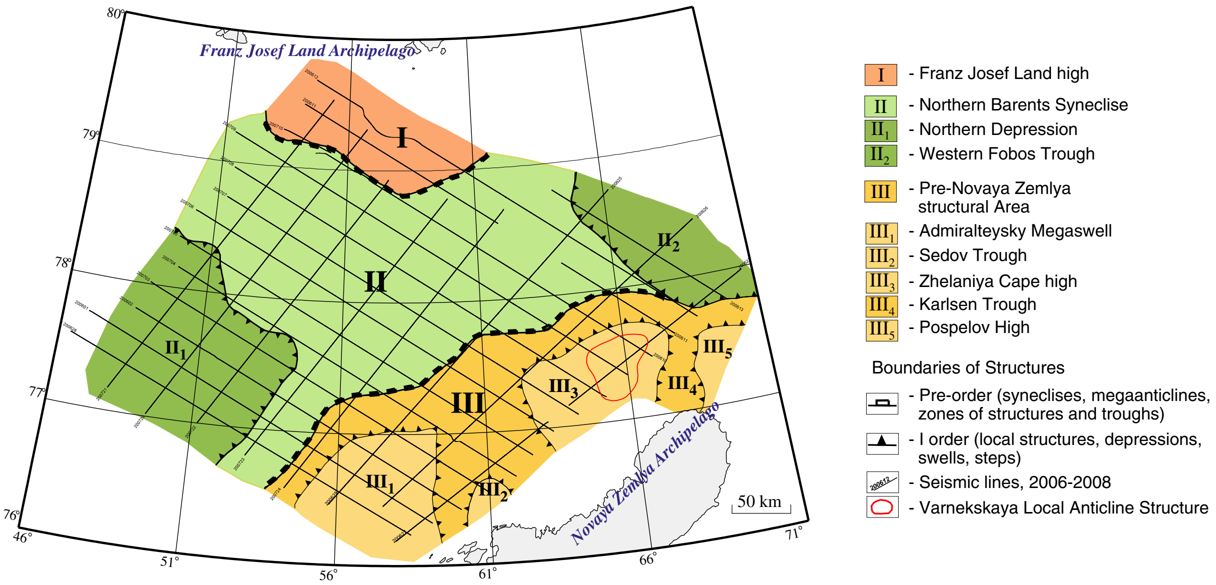

Fig. 16.3. Tectonic zones at the top of reflector $III_2(PZ_1\text{-}D_3)$, which is connected with Pre-Frasnian erosion.

Western Fobos troughs. The complex is limited by the regional unconformity of pre-Frasnian erosion $III_2(PZ_{1+2}\text{-}D_3)$ at the base and by the heterochronous surface $Ia(C_3, P_1)$ at the top. The Upper Devonian–Lower Permian complex's thickness in the alluvial fan of the Western Fobos Trough reaches 8 km and in the Sedov Trough 4.5 km (Fig. 16.4a). Four sedimentary cycles are present in these thick sedimentary prisms and characterize the buildup of the ancient continental margin in the Late Devonian–Early Permian epoch: *Upper Devonian* (*III_2–Id*), *Lower Carboniferous* (*Id–Ic*), *Middle Carboniferous* (*Ic–Ib*) and *Upper Carboniferous–Early Permian* (*Ib–Ia*(C_3, *P_1*)).

During Late Devonian time progradation expanded from the NNE, where intensely eroding onshore areas existed (Fig. 16.5). Reduction of the Upper Devonian thickness in the area of the Zhelaniya Cape High indicates that, by that time, this uplift already existed as a positive structural element. The alluvial fan of the Sedov Trough could have been formed both by sediment transport from the Western Fobos Trough and from its own source, located in the area of today's Northern Island of the Novaya Zemlya archipelago. This picture indicates the existence of a united ancient continental margin. One can note that, in Late Devonian time, the Admiralteisky Swell apparently did not exist as a dominant positive structural form.

Intense sedimentation under conditions of downward tectonic movement in the Sedov Western Fobos troughs continued also during Early Carboniferous time (Fig. 16.5). At that time the sediment accumulation rate supported the progradation regime. The Zhelaniya Cape High remained relatively stable in Early Carboniferous time.

Within the limits of today's Admiralteisky Megaswell northern pericline, carbonate sediments accumulated on a carbonate platform (Reading 1990). This circumstance indicates the region's

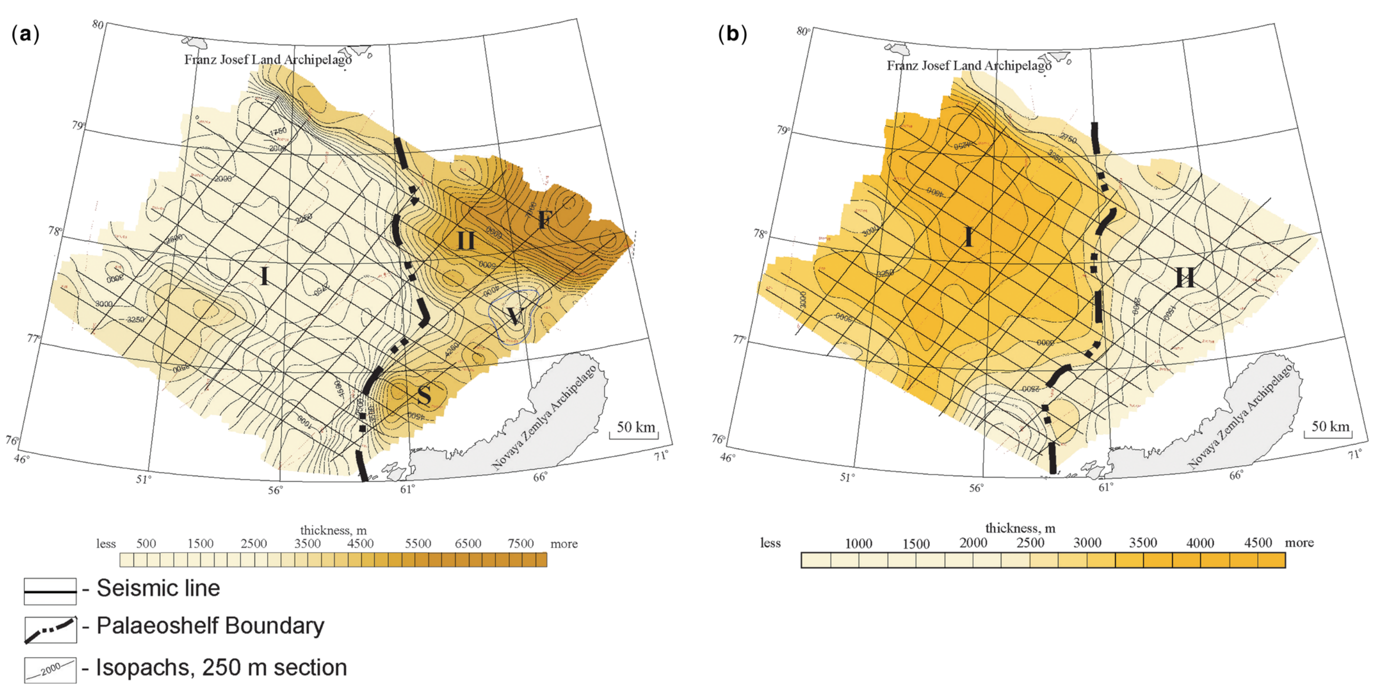

Fig. 16.4. Isopach maps of: (**a**) Upper Devonian–Lower Permian deposits ($III_2(PZ_{1+2}\text{-}D_3)\text{-}Ia(C_3, P_1)$), and (**b**) Middle–Upper Permian deposits ($Ia(C_3, P_1)\text{–}A(P_3\text{–}T_1)$). S, Sedov Trough fan; F, Western Fobos Trough fan; V, Varnekskaya structure; I, Bathyal Deposit Area; II, Shelf Deposit Area.

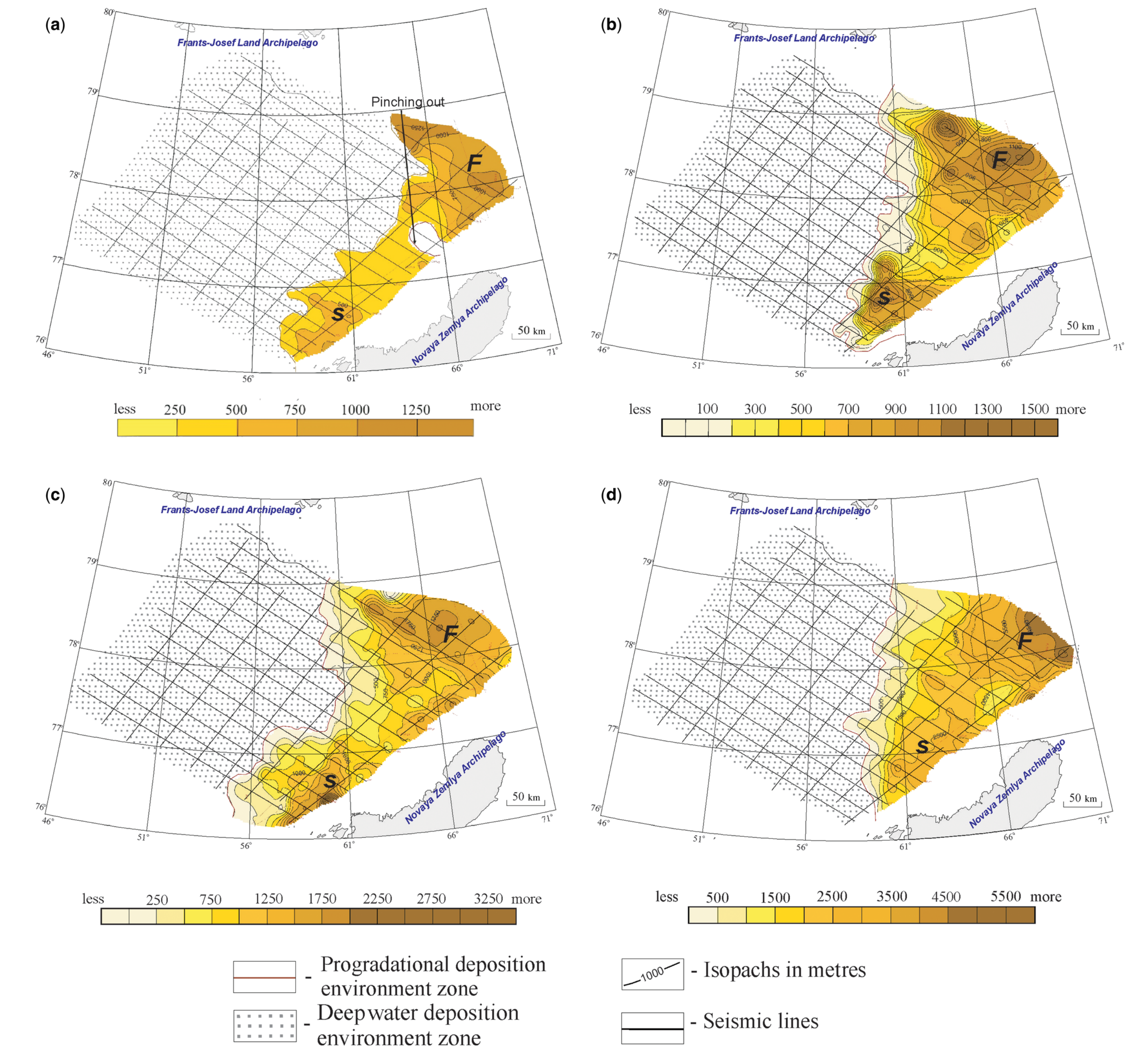

Fig. 16.5. Evolution of the continental palaeomargin during Middle–Upper Palaeozoic. Isopach maps in metres of (**a**) Upper Carboniferous–Lower Permian deposits, (**b**) Middle Carboniferous deposits, (**c**) Lower Carboniferous deposits and (**d**) Upper Devonian deposits. S, Sedov; F, Western Fobos troughs.

tectonic restructuring process: the uplifted Admiralteisky Megaswell compared with the sinking Sedov Trough block (Fig. 16.6).

During Middle Carboniferous time the sedimentation rates were much higher than the subsidence of the Sedov and Western Fobos troughs. As a result of the high sedimentation rates the troughs were overcompensated by sediments (Fig. 16.5).

During the Late Carboniferous–Early Permian (Ib–Ia) epoch progradation within the today's Pre-Novaya Zemlya area was significantly reduced. The regime of transit sedimentary area was established and sedimentary material started to accumulate predominantly in the depression of the Northern Barents Syneclise. The same palaeogeographical environments were also preserved during the Middle Permian epoch (Ia–I_2; Fig. 16.5).

The thickness of Upper Permian sediments (I_2–A) within the limits of the Northern Barents Syneclise varies quite smoothly. This indicates a balanced regime of sedimentation in relatively deepwater conditions, with stable subsidence of the Northern depression relative to the Pre-Novaya Zemlya structural area, which remained a transit zone for sedimentary material (Fig. 16.4b).

Triassic sediments overlie the Palaeozoic formations and indications of unconformable contact are found only in the Pre-Novaya Zemlya structural area. The Triassic lithological–stratigraphical complex has a base limited by unconformity A(P_2-T_1) and a top at the regional erosion surface Б(T-J, K_1), linked with the Cimmerian phase of tectonogenesis. Within the Pre-Novaya Zemlya structural area, the limit of the Triassic complex is eroded and outcrops under the seabed towards Novaya Zemlya. The Triassic strata vary in thickness from 7500 m in the Northern depression to 2000 m in the Pre-Novaya Zemlya structural area.

The complex's top occurs at depths from 2800 m in the Northern Barents Syneclise to 500 m in the Franz Josef Land High and wedges out under the seabed in the Pre-Novaya Zemlya structural area. Three tentatively stratified sub-complexes are marked in the Triassic lithological–stratigraphical complex: Lower Triassic

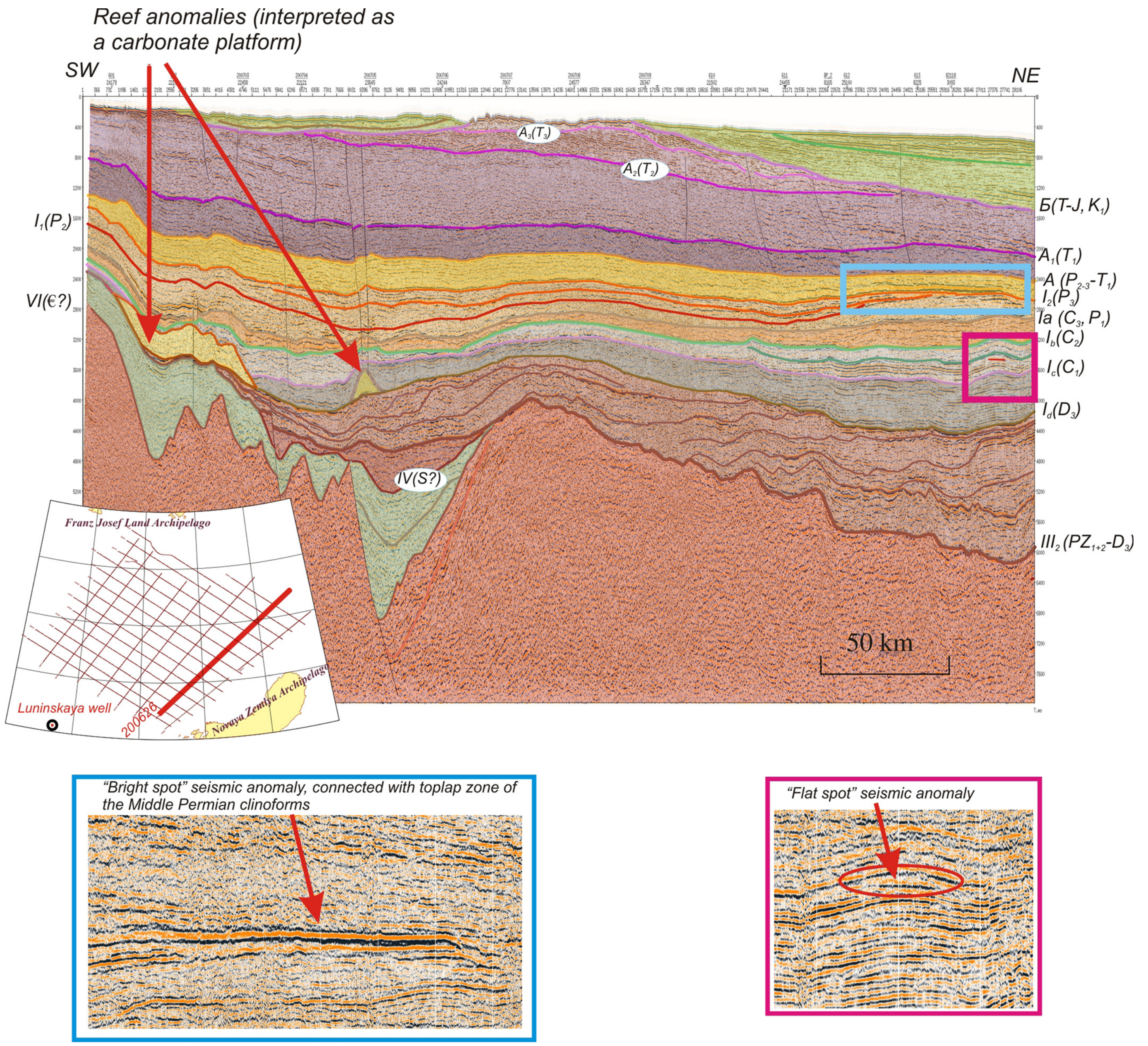

Fig. 16.6. Seismic anomalies within the Palaeozoic petroleum complex. Seismic profile 200626. Seismic horizons are shown in Figure 16.2.

(A–A1), Middle Triassic (A1–A3) and Upper Triassic (A3–Б). In general, during Triassic time, uniform sedimentation conditions were established across the whole studied offshore area. These conditions can be assessed using results of drilling operations on Admiralteisky Swell (Krestovaya and Admiralteiskaya wells).

The continuity of the Triassic interval's seismic reflectors deteriorates within the Northern Barents Syneclise, the Albanovsko–Gorbovsky step and Franz Josef Land. The continuity deterioration is connected with the presence of dynamic, discordant α-reflectors. Their seismic features completely attenuate reflectors of the Triassic LSC and make their tracking very difficult. The propagation area of α-reflectors coincides with very unusual 'column-like' wave anomalies, registered down the section. These anomalies are characterized by a chaotic reflection seismic pattern inside the 'column' and reflector termination at its boundaries (Fig. 16.7). 'Column-like' anomalies correlate from one profile to another, forming extended (up to 100 km) linear zones of northwestern strike. Reflecting horizon α is linked with intrusive bodies (dykes, sills) of dolerite composition, which are widespread at Franz Josef Land and were penetrated by the Ludlovskaya well. 'Column-like' anomalies can be interpreted as magmatic feeder channels.

The structural surface of the Triassic LSC top (Fig. 16.8) shows that the Northern Barents Syneclise, united in the structural layout of the III_2 surface, was divided into two individual tectonic elements: the Eastern Barents Syneclise in the NE, and the Northern Barents Syneclise – which retains its previous name – in the SW. The boundary structure between them is the Albanovsko–Gorbovsky step, which includes the Southern Salmskaya step, the Northern Novaya Zemlya depression and the Albanovskaya and Gorbovskaya saddles.

The Northern Barents Syneclise is complicated by the Northern depression within the limits of contour line 1400 m. The steps of Hercules, Conrad, St Anna depression and the Western Fobos Trough are parts of the Eastern Barents Syneclise.

The Pre-Novaya Zemlya structural area includes the Admiralteisky Megaswell with the Pakhtusovsky High, Sedov Trough and Zhelaniya Cape High and Varnekskaya structure. Franz Josef Land is complicated by the Trubyatchinsky Swell, where the Salmskaya and Gidrografov structures are located.

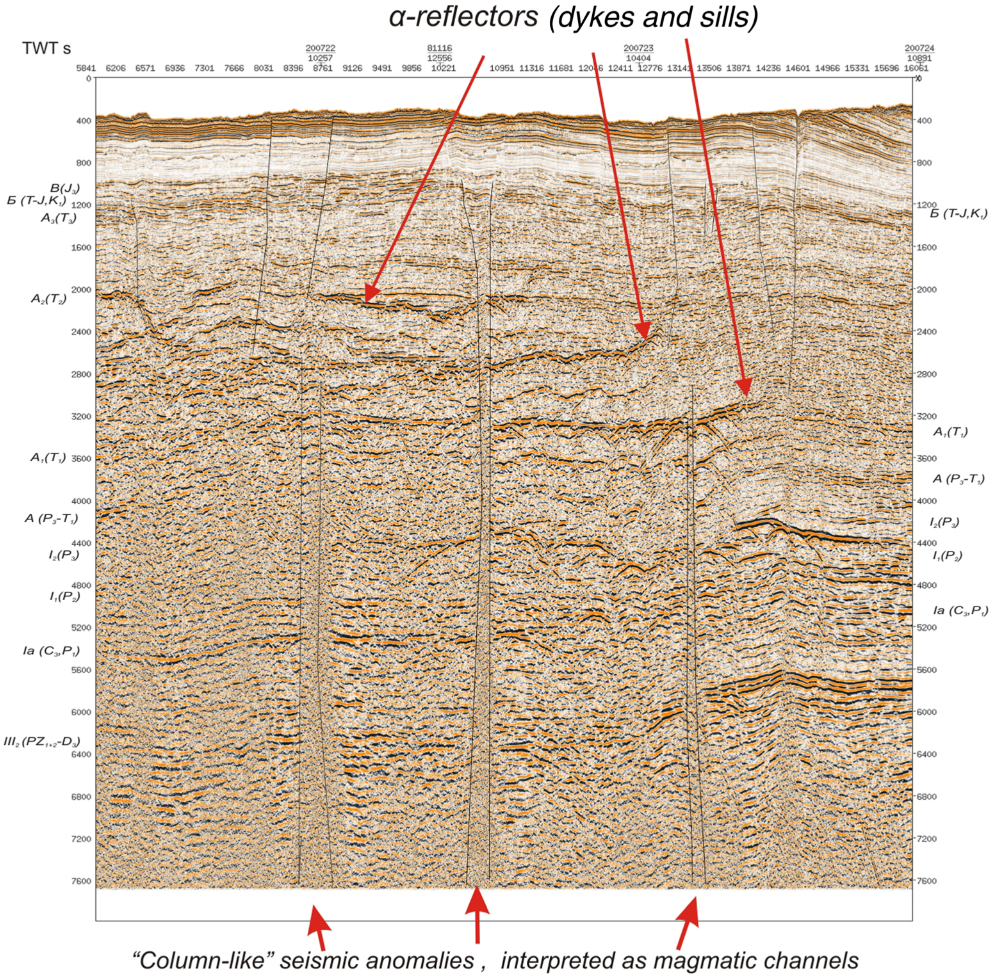

Fig. 16.7. Seismic anomalies within the Triassic LSC. Seismic horizons are shown in Figure 16.2.

The *Jurassic lithological–stratigraphical complex* is limited by seismic reflectors (T-J, K_1) at the base and B(J_3) at the top within the Northern depression (Fig. 16.9). The thickness of the Jurassic sediments varies from 400 m in the Northern depression to zero, where it wedges-out on the western flanks of the Albanovsko–Gorbovsky step and the Admiralteisky Megaswell. The mechanism of the Jurassic complex wedging out is still unclear: either it wedges out at the flanks of relatively uplifted zones represented by the Albanovsko–Gorbovsky step and Admiralteisky Megaswell, or due to denudation in Early Cretaceous time.

It should be noted that the Lower Jurassic sediments of Franz Josef Land apparently cannot be attributed to the Jurassic sedimentary basin of the Northern Barents Syneclise, because the reduction of the thickness of the Jurassic formations at its flanks

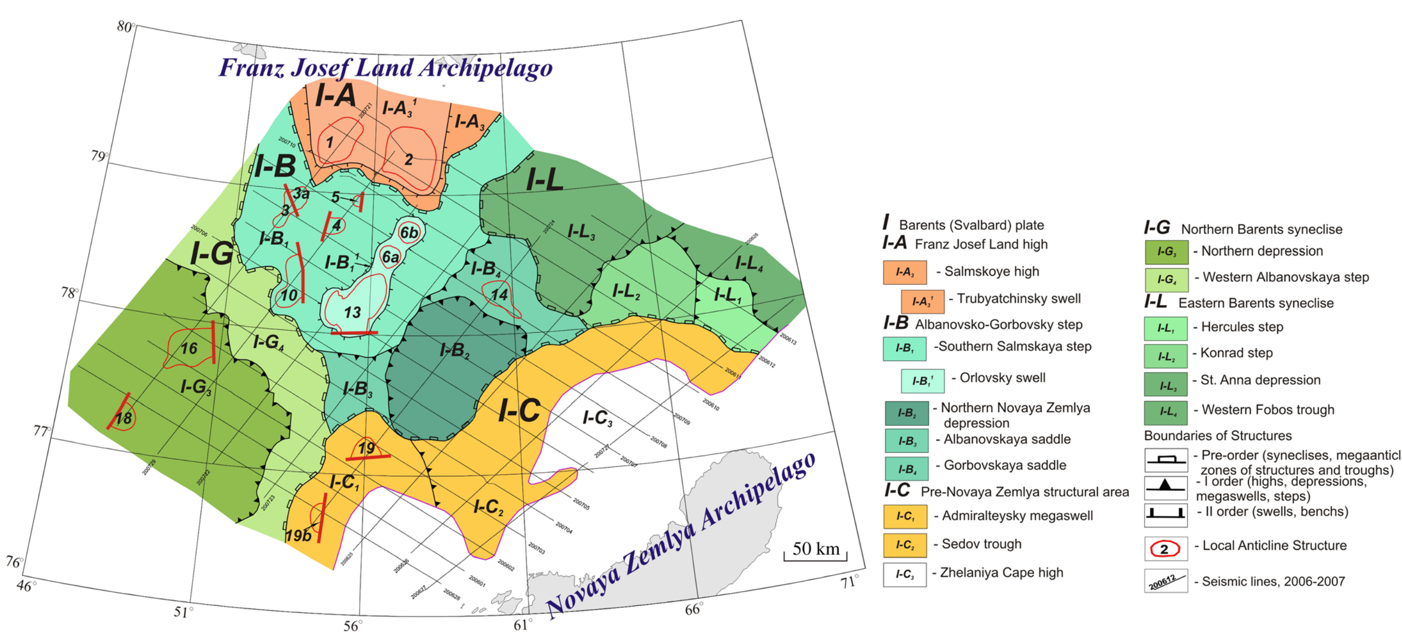

Fig. 16.8. Tectonic zones at the surface of reflector Б(T-J, K_1), which is connected with regional erosion surface (Cimmerian phase of tectonogenesis).

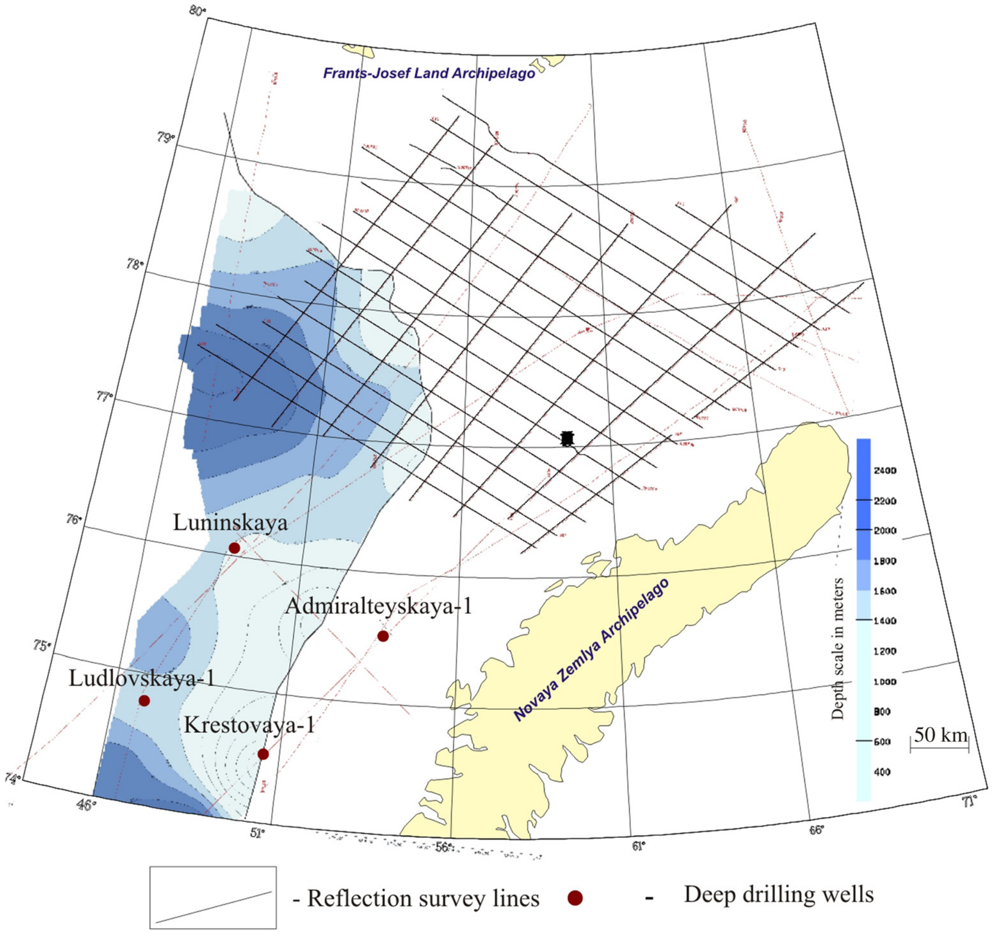

Fig. 16.9. Scheme showing an areal extent of the Jurassic deposits (Б (T-J, K_1)-B(J_3)).

(Admiralteisky Megaswell, Persey High) occurs primarily on account of the lower stratigraphic units.

The few reconnaissance seismic profiles do not enable unambiguous determination of the Jurassic sediments extension boundaries. Because the main hydrocarbon fields of the Barents Sea (Shtokmanovskoe, Ledovoe, Ludlovskoe) are linked with the Jurassic reservoirs, the areal extent of Jurassic sediments is important.

Cretaceous lithological–stratigraphical complex sediments lie unconformably on top of Jurassic formations (Northern depression) and sometimes on Triassic ones (Albanovsko–Gorbovsky step, Pre-Novaya Zemlya structural area). During the Cenozoic cycle of tectonogenesis the Cretaceous sediments were subjected to deep erosion, the depth of which can exceed 1 km. In the Pre-Novaya Zemlya structural area the Cretaceous formations wedge out under the seabed.

The Neocomian part of the Cretaceous lithological–stratigraphical complex has a clinoform structure. The most regular Neocomian clinoforms are traced in the Northern Barents Syneclise, at the Albanovsko–Gorbovsky step and at the Franz Josef Land uplift, but eastern progradation from the Pre-Novaya Zemlya area cannot be excluded.

Petroleum potential

The petroleum potential of the eastern flank of the Northern Barents depression is related to the Palaeozoic and Triassic petroleum complexes (PC) and with the Cretaceous potential petroleum complex (PPC), in sediments of which 20 new local anticline prospects were marked with a total area of 26 890 km^2 (Fig. 16.10). The largest are the Orlovskaya, Gidrografov and Salmskaya structures (Table 16.1). Most of the local anticline objects are linked with the Triassic PC and associated with the Albanovsko–Gorbovsky step and the Franz Josef Land Svodovoye uplift.

Besides the local anticline highs in the area of the Albanovsko–Gorbovsky step, the zones of non-structural traps were marked; these zones are linked with the Neocomian clinoforms of the Cretaceous PPC. The potential of these can be assessed using an analogy with the Neocomian petroleum complex of Western Siberia. Stratigraphic traps are associated with the top of the Triassic erosion surface.

Thus, several factors favourable for petroleum potential development occur together within the Albanovsko–Gorbovsky step limits: anticline and stratigraphic closures in the Triassic PC sediments and Neocomian lithological traps of the Cretaceous PPC. The factor of the sedimentary stratum's maturation shall be mentioned, linked with the relative proximity of a magmatic centre, which is the source of large-scale implantation of intrusive bodies into Lower–Middle Triassic strata during Cretaceous time.

Accessible drilling targets in the Palaeozoic PC are linked spatially with the Pre-Novaya Zemlya structural area. Within the Zhelaniya Cape High limits, the large Varnekskaya anticline structure was marked; this structure can be compared in size with the Admiralteisky Megaswell structures (Table 16.2).

The Upper Devonian–Permian sediments of the northern pre-Novaya Zemlya area in general and of the Varnekskaya structure in particular accumulated under a progradation regime at the continental margin, thus determining their poly-facial composition. This created favourable conditions for petroleum potential, in contrast to the Palaeozoic, especially Permian, formations of the Admiralteisky Megaswell. The potential productivity of the alluvial fan sediments in the Western Fobos Trough and the Sedov Trough are confirmed by the seismic anomalies of 'bright spot' or 'flat spot' types, which are indirect indications of hydrocarbon presence in the sedimentary cover.

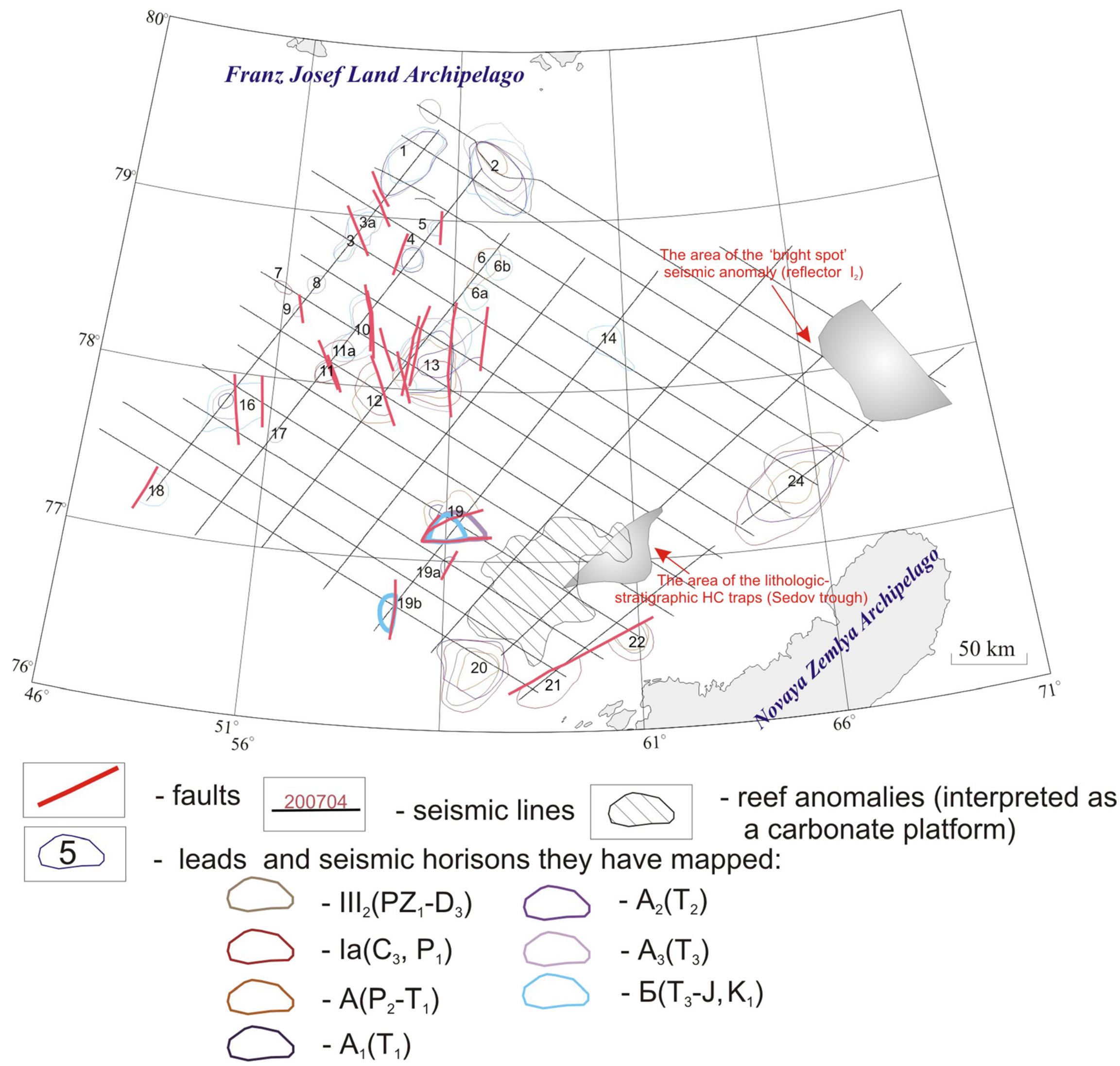

Fig. 16.10. Potential petroleum objects. Leads: 1, Gidrografov; 2, Salmskoe; 3, 3a, 6a, 7–11, 11a, 12, unnamed; 13, Orlovskoe; 14, Gorbovskoe; 16–19, 19b, unnamed; 20, Pakhtusovskoe; 21, unnamed; 22, Pankratjeva; 24, Varnekskoe.

Within the Western Fobos alluvial fan limits, the large (>2000 km^2) area of a 'bright spot' is marked, which can be traced from one profile to another (Fig. 16.6). The seismic anomaly is associated with the unconformity boundary between the Upper Carboniferous–Lower Permian and the Middle–Upper Permian strata $I_2(P_3)$. This boundary characterizes a change in the progradational sedimentation regime within the palaeoshelf, with small variations of sea level and a shift of the accumulation processes into a bathyal area of the palaeobasin.

Anticlines in the alluvial fan strata are accompanied by seismic anomalies of 'flat spot' type, which indicate hydrocarbons (Fig. 16.6). The linear dimensions of the anticlines are less than the profile grid size, so one cannot associate them for sure with the closures, but at the same time the existence of seismic

Table 16.1. *Morphological characteristics of the local uplifts: Salmskoe, Gidrografov and Orlovskoe*

Local uplift name	Reflector; age	Maximum closed contour line (m)	Size (km × km)	Area (km^2)	Amplitude (m)
Gidrografov	Б(T-J, K_1)	650	28 × 43	904	175
Salmskoe		650	42 × 53	1556	75
Orlovskoe		850	(24–38) × 56	1443	225
Gidrografov	A_3 (T_3)	900	26 × 55	1051	250
Salmskoe		900	40 × 53	1640	150
Orlovskoe		1200	44 × 58	1947	250
Gidrografov	A_2 (T_2)	2200	27 × 53	1054	250
Salmskoe		2200	31 × 55	1274	150
Orlovskoe		2600	34 × 41	1049	150
Salmskoe	A_1 (T_1)	4250	19 × 38	601	125
Orlovskoe		5900	14 × 46	721	150

Table 16.2. *Morphological characteristics of the Varnekskoe local high*

Reflector; age	Maximum closed contour line (m)	Size (km × km)	Area (km^2)	Amplitude (m)
A_1 (T_1)	750	39 × 65	1858	125
A (P_3-T_1)	2000	23 × 36	607	125
Ia (C_3, P_1)	3500	41 × 88	2841	625
III_2 (PZ_{1+2}-D_3)	7500	49 × 64	1995	1250

anomalies suggests this. The dimensions of the potential highs are about 100 km^2.

A seismic anomaly of 'reef' type is present in Carboniferous strata at the northern pericline of the Admiralteisky Megaswell. Its area is about 5220 km^2; this anomaly can be interpreted as a carbonate platform (Fig. 16.6). The thickness of the hypothetical carbonate platform is estimated as 1000 m. Finally one can conclude that the studied offshore area, even under such poor exploration maturity (0.05 linear km km^{-2}), demonstrates good petroleum potential.

Conclusions

The sedimentary cover of the Northern Barents Basin's eastern flank is divided into two structural–tectonic stages: Lower and Upper. Most interesting in petroleum potential aspects are the Triassic and Middle–Upper Palaeozoic sediments, where large potential prospects are marked.

Within the limits of today's Pre-Novaya Zemlya structural area in the Middle–Upper Palaeozoic part of the section, thick alluvial fans occur in the Western Fobos Trough and the Sedov Trough; these fans characterize the buildup and development of the ancient continental margin in Late Devonian–Early Permian time. The structure of this part of the geological section is in many aspects unique, both for the Admiralteisky Megaswell and for other parts of the Barents Sea shelf.

The presence of characteristic seismic anomalies is an indirect indication of the prospectivity of the sedimentary cover of the Northern Barents Basin's eastern flank. Advancing understanding of the oil and gas prospects and petroleum accumulation zones will involve carrying out further exploration of the northern part of the Barents Sea shelf.

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