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New Insights in Composition and Structure of the Sedimentary Cover on the Lomonosov Ridge

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THEME 4: The Lomonosov Ridge: History, Boundaries, Function

Summary: The paper presents new data on the Russian transarctic profile TA-92 running across the Lomonosov Ridge. Velocity parameters and thickness variations of seismic units recorded in the section are considered. A trough with sediments of up to 5.5 km thick has been found. These data and those collected during previous years on the Lomonosov Ridge and the Amundsen Basin are summarized in Table 1. It gives detailed information on the amount, thicknesses and velocity parameters of seismic units on the section, used in this study. Sections from TA-92 (KIM et al. 1998), LOREX and ARCTIC-91 expeditions are compared for the first time, with regard to their position in the structural-tectonic map of the region. The peculiar blocky pattern of the ridge along strike influences the thickness distribution and completeness of the seismic sections. Sediment thicknesses in the whole region increase from the circumpolar part of the ridge towards the Siberian Shelf. A conjugate linear system of narrow grabens inferred from gravimetry data, is corroborated by seismic evidence. The seismic units of the grabens have layer parameers like those on the ridge and show considerable thicknesses. A new dating scheme of the seismic units is proposed. It is based on geological evidence from areas surrounding the Arctic Basin.

INTRODUCTION

The Lomonosov Ridge is among the major structures of the Arctic Basin. Evidence on its internal structure was first collected during drifts of the Russian polar stations NP-21, 22, 23, 24, 28 (KISELEV 1986, POLKIN 1986, GRAMBERG et al. 1991). Fundamentally new data for the ridge structure were acquired during the last decade by LOREX (SWEENEY et al. 1982) and RV „Polarstern" expeditions close to the North Pole (JOKAT et al. 1995) and by the Russian transarctic profile TA-92 (KIM et al. 1998).

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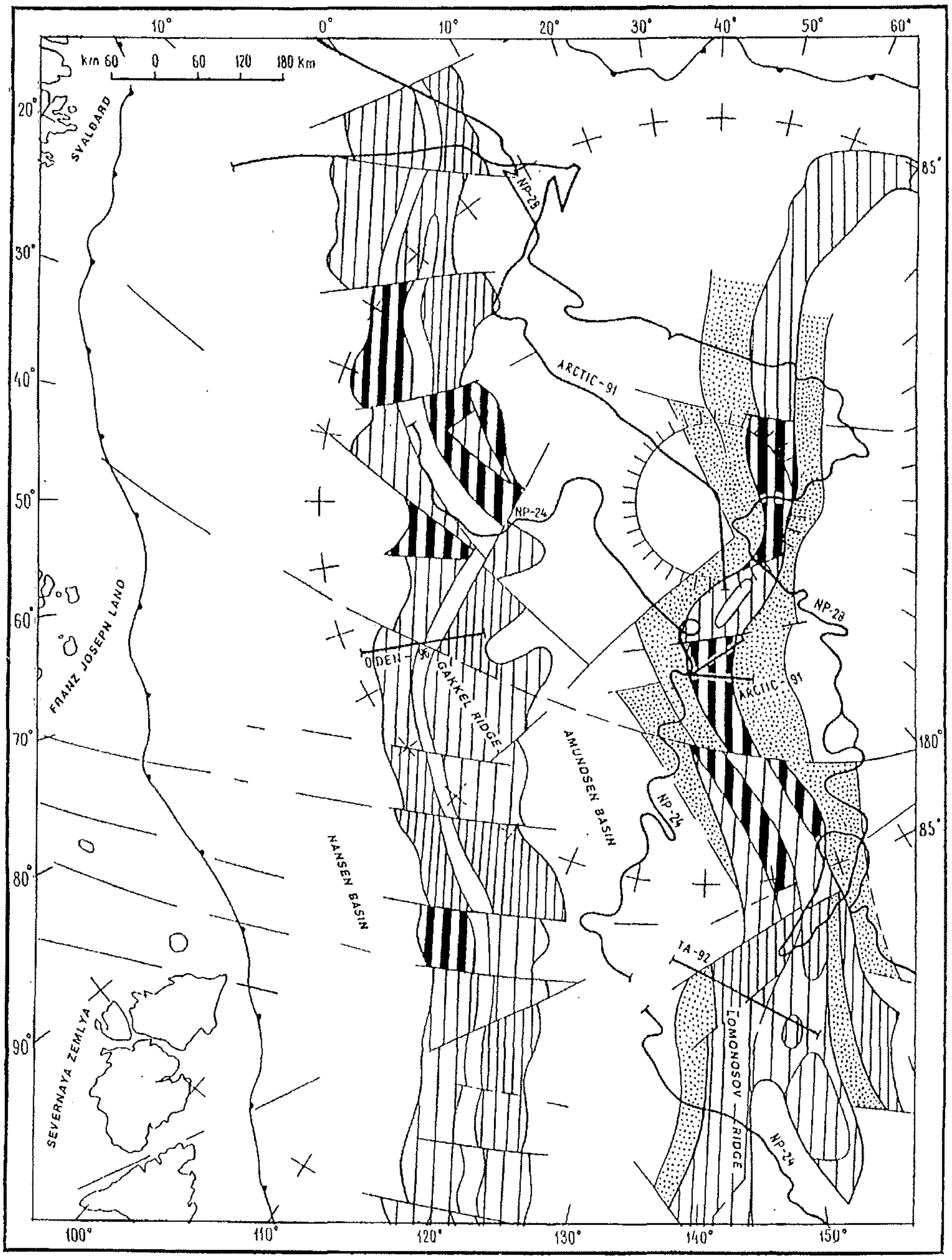
As stratigraphic models were proposed indepently by various authors, we try to integrate all available data in one model. For this purpose, previous data were reanalyzed and reinterpreted in some cases. This is especially true for seismic profile TA-92 (84° 03' N, 134° 31' E – 82° 51' N, 153° 52' E) conducted in 1992 by the Polar Marine Expedition for Geological Exploration (KIM et al 1998). The profile intersects the Lomonosov Ridge almost perpendicular to strike; its reinterpretation is included in the following discussion. The western end of the profile is in the Amundsen Basin, the eastern one is in the marginal part of the Podvodnikov (Makarov) Basin. The ridge is asymmetric along the profile (the Eurasian wall is steeper than the more gentle Amerasian one) and it is broken by faults responsible for its blocky pattern (Fig. 1).

RESULTS

The Lomonosov Ridge

The seismic section on profile TA-92 was obtained from deep seismic and MRW (multi channel seismic reflection) soundings. Seven seismic units were defined in the segment over the ridge (table 1). The sedimentary unit lying directly on the basement and forming the lower part of the sedimentary cover, is not characterized by layer velocities. The unit occurs between horizons with boundary velocities of 6.0 km/s and 4.5 km/s and changes upward to a seismic unit with a layer velocity of 4.1 km/s. A reflector was recorded in the time section inside the unit, which can be traced well in the eastern wall and the central part of the ridge. This reflector divides the unit into two independent components described below (Fig. 1, Tab. 1).

The seismic units LR1 and LR2 are the oldest parts of the ridge's sedimentary cover. Inferred layer velocities are 5.0-5.2 km/s and 4.6-4.7 km/s for LR1 and LR2, respectively. These units were also observed on the NP-28 drift line (Fig. 1) which intersected the Lomonosov Ridge three times and in the data of ARCTIC-91 (JOKAT et al. 1995). A unit with seismic velocity of 5.0 km/s was recorded by NP-28 in the ridge section along the drift line. Two seismic units with layer velocities of 5.0-5.2 km/s and 4.6-4.7 km/s underlying a seismic unit with 4.0-4.3 km/s were recorded by ARCTIC-91. The total thickness of LR1 and LR2 increases along the profile towards the center of the ridge. It is 0.7 km and 0.6 km at the western and eastern



– location of MCS-CDP lines
– rift valley
– faults
– tracks of NP—24, 28 stations drift
– grabens
– shelf break.
– intensity of relative uplift of blocks within the Lomonosov and Gakkel Ridges: 1– weak, 2 – weak to moderate, 3 – moderate to intense, 4 – intense

Fig. 1: Morphostructural pattern of the central Arctic Basin.

(Amerasian) flanks, increasing up to 2.5 km towards the center (Kim et al. 1998).

The following seismic unit LR3 is characterized by a layer velocity of 4.1 km/s. A major reflector near its base steps down from west to east as an effect of faulting. The thickness of the unit amounts to 0.5-0.8 km, 1.5-1.6 km and 0.9 km in the western, central and eastern parts of the ridge.

The seismic units LR4 and LR5 were detected by the analysis of a time section of the MRW sounding along TA-92. Their layer velocities are 3.2 km/s and 2.7 km/s, respectively. An additional reflector was recorded inside the common sequence by time section analysis. The reflector is well defined throughout the profile, dividing the sequence into two independent seismic units. Up the section, the bed is overlapped by seismic unit LR6 with a layer velocity of 2.4 km/s. This suggests the presence of an independent unit in the part considered, with a layer velocity of 2.7 km/s, which is not eroded here as on profiles 91090 and 91091 (Jokat et al. 1995) where it crosses one of the most strongly uplifted blocks of the ridge at 87°N. It should be noted that the presence of the seismic unit with layer velocity of 2.7 km/s in the sedimentary cover of the ridge has been observed before (Sweeney et al. 1982). This unit was also recorded in the Podvodnikov (Makarov) Basin adjoining the ridge (Kiselev 1986). The total thickness of LR4 and LR5 within the ridge is 0.4-0.8 km, 1.0 km and 0.5-0.9 km in the western, central and eastern parts.

Seismic unit LR6 with layer velocity of 2.4 km/s can be traced throughout the profile. Its thickness varies slightly between 220 m and 300 m, decreasing down to 160 m at the eastern wall of the ridge. It is 480 m thick within the depression structure complicating the marginal western (more strongly uplifted) block.

Seismic unit LR7 consists of two seismic sequences with very similar (1.9 km/s and 1.7 km/s) layer velocities that allow them to be classified as non-lithified formations. The lower seismic sequence consists of soft sediments, the upper one of soft and indurated sediments. The thickness of both members is fairly persistent (100-150 m, 120-150 m; Kim et al. 1998). The total thickness of LR7 is typically 220-300 m, increasing to 460 m only in a graben at the western wall of the Lomonosov Ridge (Kim et al. 1998). Sediments of this unit are easy to discern by the overlap geometry of their occurrence.

The total thickness of the sedimentary cover along profile TA-92 over the Lomonosov Ridge is 2.5-4 km, 5.5 km and 2.9 km in the western, central and eastern parts. An asymmetric trough is recorded on the profile in the center of the ridge. Its axis is located 45 km east of the more strongly uplifted (Eurasian) part of the ridge (Fig. 1). Seismic units of the lower part of the section with layer velocities of 5.0-5.2 km/s (LR1), 4.6-4.7 km/s (LR2) and 4.0-4.2 km/s (LR3) are responsible for the bulk of the total sedimentary thickness. It is of interest that in the map of isostatic gravity anomalies of the Arctic Basin where the relief is no longer of influence, the ridge shows negative anomaly values from minus 20 up to minus 30-40 mgal, suggesting a great sediments thickness on the central part of the ridge. Correlation of TA-92 data with the results of LOREX (Sweeney et al. 1982) and ARCTIC-91 (Jokat et al. 1995) indicating thicknesses of 5.5; 5 and 2.1 km for the sedimentary cover, provides support for this suggestion.

The previously compiled structural-tectonic map of the western and central parts of the Arctic Basin (Kim et al. 1998) was an important tool for the analysis of the geophysical evidence for the ridge. Locations of the profiles of TA-92 (Kim et al. 1998), ARCTIC-91 (Jokat et al. 1995), LOREX (Sweeney et al. 1982) and others plotted in the map, permitted to analyze the completeness of the sections and the thickness distribution within the ridge taking into account its peculiar blocky pattern. It was established that the lack of seismic units with velocities of 3.2 km/s and 2.7 km/s (Tab. 1) in the sections of profiles 91090 and 91091 (Jokat et al. 1995) can be explained by erosion on tectonically uplifted blocks. This is supported by an erosional unconformity observed at the top of seismic unit LR3. In contrast, thicker and more complete sections are observed over subsided blocks of the ridge (profile TA-92, Tab. 1).

The lack of some seismic units on the uplifted blocks and their presence on subsided ones suggests that uplift of some blocks

structure	Amundsen Basin							
author	Yu.G.Kiselev, 1985 Ya.I.Pol'kin et al, 1986	G.G.Dik et al., 1989	S.B.Sekretov et al., 1992		W.Jokat et.al., 1995			seismic sequence
seismic method	*reflection refraction*	*reflection*	*CDP*		*CDP*			
number profile, sonobuoy, ice station	NP-21, 22, 23, 24	NP-28	line 90700	line 90700	sonobuoys 9109	sonobuoys 9110	line 91098	
V-velocity km/s	1.5 - 1.7(no 0.6-1.0)	1.6-1.7(0.4-06)	1.8(0.4)	1.8-1.9(0.4)	1.9	1.9	AB8 1.9(0.19)	AB6
			2.0(0.8)	1.9(0.4)	1.9	1.9	AB7 1.9(0.15)	
					2.2	2.2	AB6 2.2(0.18)	AB5
		2.0-2.2(0.45)			2.2	2.2	AB5 2.2(0.02-0.05)	
	1.7-2.3(0.5-1.5)	2.4(0.9)	2.3-2.4(1.0)	2.3(1.2)		2.2	AB4 2.2(0.36)	
	2.5 - 3.0	2.7-3.0(0.5-0.8)	2.8-3.0(1.2)	3.0-3.2(1.0)	2.9	2.9	AB3 2.9(0.26)	AB4
			3.5(0.3-1.4)	3.5(0.9)	3.5	3.4	AB2 3.5(0.56)	AB3
		4.2(1.6)						AB2
				4.0-4.5(2.5)	4.6	4.5	AB1 4.5(0.94)	AB1
		Vb =5.5-6.0						

structure	Lomonosov Ridge											
author	J.Sweeney et.al, 1982	Yu.G.Kiselev, 1986	G.G.Dik et al, 1989	Yu.Yu.Zamansky et al., 1993		W.Jokat et.al., 1995				seismic sequence	Age seismic sequence	
seismic method	*refraction, DSS*	*reflection refraction*	*reflection*	*reflection, DSS*		*CDP*						
number profile, sonobuoy, ice station	LOREX, line C-C'	NP-21, 22, 23, 24	NP-28	TA-92		sonobuoys 9104	sonobuoys 9105	sonobuoys 9108	line 91090			
V-velocity km/s		1.5-1.7	1.7	1.7-1.8		1.8	1.8	1.8	LR6 1.8(0.08-0.1)	LR7	N_2-Q	
									LR5 1.8(0.12-0.15)			
				1.9	(0.7)	2.0	2.0	2.0	LR4 2.0(0.12)			
	?	1.7-2.3				2.2	2.2	2.2	LR3 2.2(0.11-0.15)	LR6	N_1	
			2.4	2.4								
	V=2.7(0.07)	2.5-4.5		?						LR5	P_3	paleogen
				3.2(0.4-0.8)						LR4	P_2	
			4.2	4.1(0.5-3.0)		4.0	4.2	4.3	LR2 4.0-4.6 (0.55-0.83)	LR3	P_1	
	Vb=4.7(5)			Vb=4.5			4.7	4.6		LR2	$Mz(K_2)$	
	?	5.0-6.0	5.0-5.3	Vb=5.3-5.5 5.1		5.0		5.2	LR1 4.7-5.2 (0.85-1.65)	LR1	Pz(?)-Mz	
				Vb=5.9-6.0		V_0=5.8						
	Vb=6.6		Vb=6.4	Vb=6.5-7.0				V_0=6.3				
				Vb=7.2-7.6								
	Vb=8.3			Vb=8.0-8.6								

Vb - boundary velocity (km/s)
(0.6-1.0) - in brackets: thickness of the seismic sequence (km)
- erosion of the deposits

Tab. 1: Correlation of velocity characteristics of the sections of Arctic geodepression regional structures.

took place either during the formation of these units or immediately before.

The structural-tectonic map (Fig. 1) shows that the location of the Lomonosov Ridge along strike is well controlled by narrow elongate grabens bounding it on the east and west which are distinct in the gravimetry map (KIM et al. 1998). These grabens parallel to the ridge have been found on the profiles 91091, 91097 (JOKAT et al. 1995) and on TA-92. Seismic units of the grabens have layer velocities equivalent to those on the ridge.

The following statements can be made from the comparative structural analysis of profiles TA-92, ARCTIC-91 and LOREX, all crossing the ridge:
1) The blocky pattern of the ridge structure is responsible for the thickness pattern of the sediments.
2) The completeness of the stratigraphic sections and the total thickness (2.1 to 5.5 km/s) of the sedimentary cover increase regionally from the circumpolar part of the ridge towards the Siberian Shelf.
3) The linear system of the grabens parallel to the ridge is filled by sediments of considerable thickness suggesting that the latter formed in a single basin. The thickness of sediments in the western (Eurasian) graben in the circumpolar area reaches 3.4 km (JOKAT et al. 1995), while the thickness of sediments in the graben south of 84 °N is 2.5 km (KIM et al. 1998).
4) The basement of the ridge is heterogeneous as shown by sharply varying values of boundary velocities near its top along profile TA-92. The blocky pattern of the ridge is initially caused by different hypsometric positions of basement blocks and by their subsequent uplift along faults. The thickness of the crust within the ridge is inferred to vary between 20 km and 28 km. Velocity parameters of deep-seated crustal layers indicate a continental crust characterized by 6.0-6.5 km/s and 7.2-7.6 km/s velocities (KIM et al. 1998).

The Amundsen Basin

Profile TA-92 describes only a small part of the basin, including the graben developed on the Eurasian flank of the ridge. Seismic unit AB1 represents the oldest sediments of the cover in the major part of the Amundsen Basin. Judging from the analysis of seismic sections obtained during the drifts of NP-24 and NP-28 (see Tab. 1), a seismic unit with a layer velocity of 5.0-5.2 km/s is developed only in the graben adjacent to Lomonosov ridge and cannot be traced beyond magnetic anomaly 24 where it is broken by a normal fault.

The top of the seismic unit AB1 has a boundary velocity of 4.5 km/s, while its bottom is characterized by a boundary with a seismic velocity of 5.3-5.5, km/s, which is also the roof of the underlying seismic basement. In the same graben but in the circumpolar area, RV „Polarstern“ expedition found a layer velocity of 4.5 km/s for seismic unit AB1 (JOKAT et al. 1995). The seismic unit is 600 m (KIM et al. 1998) thick in the graben. The bottom of the unit on the ridge beyond the graben could not be detected by MRW soundings during TA-92, so variations in its thickness cannot be determined (KIM et al. 1998).

Seismic unit AB2 shows a layer velocity of 4.1 km/s. Its thickness in the graben is 900 m (TA-92: KIM et al. 1998). The unit decreases in thickness towards the graben margins. The unit increases in thickness again on the shoulder towards the basin being up to 700 m 75 km off the Lomonosov Ridge (Fig. 1).

Seismic unit AB3 is characterized by a layer velocity of 3.2 km/s. Its thickness is 1000 m in the graben and decreases towards its flanks. The thickness of the unit increases again towards the axial part of the basin to be 400 m at the western end of the profile.

Seismic unit AB4 with a layer velocity of 2.7-2.9 km/s is not identified along profile TA-92. In the circumpolar area, however, it is present in sections of the same graben (JOKAT et al. 1995). This fact can be explained only if we assume that the reflector in the upper part of seismic unit AB3 ($V = 3.2$ km/s) was poorly defined and so was not recorded by the analysis of the time section of profile TA-92.

Seismic unit AB5 is characterized by a layer velocity of 2.4 km/s. Its thickness in the graben is 300 m, pinching out towards its flanks. The unit is 320 m thick at the ridge flank facing the Amundsen Basin.

Seismic unit AB6 is represented by two seismic sequences with similar low velocity values of 1.9 and 1.7 km/s and thicknesses of 320 and 260 m.

Along profile TA-92, the combined thickness of the sedimentary cover is 2480 m in the graben and 2000 m on the flank of the Amundsen Basin. However, this profile (KIM et al. 1998) cannot be used to describe the sedimentary cover of the whole basin. Two important features are worth noticing:
- Seismic unit LR1 is absent from most of the basin. Its presence on the ridge and in the conjugated graben suggests their formation in a single basin before the Amundsen Basin was formed.
- Equal (or similar) values of layer velocities of seismic units on the ridge and in the basin suggest that they may be of the same age.

The Age of the Units

Due to the lack of deep drilling data for the Arctic region, interpretation of seismic units can only be based upon a few geological data from the ridge and on the records of the Cenozoic evolution in margin sections surrounding the Arctic Basin. An age estimate for the oldest seismic unit in oceanic basins can be inferred from the time of formation of the oceanic basement within the basins. Under this assumption, it is very important to analyze the evidence from Meso-Cenozoic magmatism along the periphery of the Eurasian Basin and the dating of its peak. Moreover, we consider it possible to correlate velocity-equivalent seismic units within a single basin; particularly if there is a relation to borehole sections in one of the areas.

At the Eurasian flank of the Lomonosov Ridge (88° 52.1' N), siltstones were sampled by corer from a depth of 1520 m. Palynological analysis suggests a Devonian to early Mississippian age (GRANTZ et al. 1998). We consider these sediments to belong to seismic unit LR1 with a layer velocity of 5.0-5.2 km/s lying directly over the basement.

The analysis of effusive and intrusive magmatism in Jurassic-Cenozoic times on the periphery of the Eurasian Basin (Alpha Ridge, Queen Elizabeth Islands, northern Greenland, Svalbard, King Karls Land, Franz Josef Land, De Long Islands) showed its main phase to fall into the early Cretaceous and to reach its peak in the Aptian-Albian (KIM et al. 1998). This suggests that the first and the oldest seismic unit in the Amundsen Basin (AB1) with a layer velocity of 4.5 km/s is of upper Cretaceous age (KIM et al. 1998). This unit can be traced onto the Lomonosov Ridge where it is recorded as LR2 (Vp=4,5 km/s) and it is suggested to be of the same age. During interpretation of the data of the ARCTIC-91 expedition (JOKAT et al. 1995), this seismic unit of the ridge was already previously included in the Cretaceous.

Seismic units forming the upper part of the section on the flank of the Amundsen Basin (AB2, 3, 4, 5, 6) and on Lomonosov ridge (LR3, 4, 5, 6, 7) can be traced across strike along profile TA-92 (Fig. 1). They show nearly equal velocities. From the above reasoning they should be the Cenozoic part of the section. This raises the question of whether control exists for the age of these five seismic units? We suggest that this control is provided by the number of Cenozoic transgressive-regressive cycles discernable in the Arctic Basin, on its shelfs and paleoshelfs and corresponding to the number of the respective seismic units. The time interval of these transgressive-regressive cycles (when the seismic units were formed) is inferred from fauna, microfauna and microflora in numerous shelf sections.

Five large transgressive-regressive cycles are known in the shelf sections along the periphery of the Arctic Basin falling into the Paleocene, Eocene, Oligocene, Miocene and Pliocene-Quaternary (KIM & SLOBODIN 1991). The number of these cycles coincides with the number of seismic units included in the Cenozoic. The age of each single seismic unit can therefore be inferred from its position in the section (Tab. 1). A peculiar aspect of dating these seismic units is their correlation with similar units from sections in the Beaufort Sea and on the northern slope of Alaska, calibrated by borehole data of the deep-water part of the Arctic Basin (EITTREIM & GRANTZ 1979).

The proposed dating scheme of seismic units differs from the model proposed before (JOKAT et al. 1995) by its different methodological approach. The ages for the Cenozoic seismic units are considered to be the soundest, since the Arctic Basin was a single structure at that time.

DISCUSSION

The Lomonosov Ridge in the Arctic Basin is presently considered a block of continental crust split off the Barents-Kara Shelf as a result of sea floor spreading and subsided beneath sea level. The Cenozoic sedimentary units of the Eurasian Basin were formed as a result of these processes. The onset of spreading is dated as early Paleocene (60 Ma, VOGT et al. 1979).

If our model is right, the Lomonosov Ridge as positive linear morphostructure in the Arctic Basin has appeared relatively recently. Tectonic movements responsible for the blocky pattern of the ridge can be assigned to three stages. The first stage is associated with faulting in the early Paleocene as shown by the lack of seismic unit LR3 (Tab. 1) in the circumpolar part of the ridge (SWEENEY et al. 1982). The second, more prolonged, stage is associated with renewed tectonic movements in the Eocene and Oligocene resulting in differential uplift of blocks as evidenced by the lack of seismic units LR4 and LR5 (Tab. 1) in the same circumpolar area. The third stage of tectonic activity falls in the periods of late mid-Miocene to early Late Miocene and Pliocene to Qua -rternary. This is documented by the lack of seismic unit LR6 (Tab. 1) not only in the circumpolar part of the ridge, but also south of 84 °N and by increasing thicknesses of seismic unit LR7 towards crestal blocks of the ridge along profile TA-92.

According to the evidence collected by the ARCTIC-91 expedition and the polar drift station NP-28 over Lomonosov Ridge and Amundsen Basin, the oldest seismic units of the basin dip with increasing thickness towards the Gakkel Ridge (JOKAT et al. 1995). These facts indicate that as early as during the formation of seismic unit AB1 in the Late Cretaceous, the future ridge represented a linear uplift in the present circumpolar area.

Closing the analysis of the seismic evidence considered, it should be noted that questions of the dating of seismic units, genetic nature and evolution history of the ridge remain open until results of deep-water drilling on the ridge are obtained.

CONCLUSION

The co-operative analysis of seismic evidence collected on the Lomonosov Ridge, including the reinterpretation of seismic profile TA-92 has produced new results on the seismic stratigraphy. These can be correlated with the tectonics responsible for the peculiar blocky pattern of the ridge, the thickness distribution and the completeness of the stratigraphic section. The proposed age assignment for the seismic units, based on direct and indirect geological evidence from the periphery of the Arctic Basin, is independent from the identification of magnetic anomalies in the Eurasian Basin. The correlation table of velocity parameters for the Lomonosov Ridge and the Amundsen Basin represents a special data bank combining for the first time published and unpublished evidence for these prominent regional structures of the Arctic Basin.

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