Polarforschung 68: 275 - 281, 1998 (erschienen 2000)

Tectonic Basement of the Eurasian Arctic Shelf: Age and Some Aspects of Evolution.

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THEME 14: Circum-Arctic Margins: The Search for Fits and Matches

Summary: The tectonic basement of the Eurasian Arctic shelf is a combination of tectonic blocks. The basement comprises crystalline metamorphic and igneous assemblages along with intensely deformed and metamorphosed stratified assemblages. In contrast to an oceanic basement which is primarily igneous a continental basement has been originated as a result of the assembly of previously geodynamically variable terranes into a relatively stable regional tectonic domain (superblock or superterrane). A series of superblocks varying in the consolidation age has been mapped: Pre-Riphean, Grenvillian, Riphean, Caledonian, Ellesmerian, Hercynian, and Late Mesozoic. Earlier consolidated rigid blocks have been captured within the superblocks. There are extensive areas of deeply submerged basement (more than 10 km) and the composition is believed to be of oceanic type.

The basement superblocks have undergone constructive and destructive alterations through the post consolidation history. Large scale constructive processes took place in the west in the Ordovician–Devonian and in the Carboniferous to Early Jurassic, and the late Mesozoic in the east. Major destructive events took place in the Devonian to early Carboniferous, in the late Permian to Triassic, in the late Jurassic to early Cretaceous, and from the late Cretaceous to Recent.

The main aim of this paper is to provide constraints and to indicate a starting point for building models of geodynamic evolution of the Arctic.

INTRODUCTION

Once formed, a tectonic basement goes through a complex evolutionary history. An assessment of the age of primary continental basement underlying the Eurasian Shelf, and the time and sense of its subsequent transformations, is a useful method for understanding the tectonic history of the region. To achieve this goal a Basement Zonation Map has been constructed under a current project in VNIIOkeangeologia.

A preliminary version of the Basement Zonation Map of the Russian Arctic Shelf and Adjacent Arctic Ocean Basin was completed in the fall of 1997. The map and constituent slices are presented here in simplified form and they incorporate all geological and geophysical information available by the fall 1996.

The intermediate stage in map compilation comprised preparation and interpretation of potential fields maps and their derivatives, interpretation of seismic surveys and building structural contour maps, analyses of the existing onshore and offshore maps, and of the results of direct geological observations. The project has been supported by regional scale unpublished maps which summarize all available data: Sedimentary Cover Thickness Map of the Arctic, scale 1 : 6 000 000, compiled by VERBA (1996), Free–air Gravity Anomaly Map of the Arctic, scale 1 : 6 000 000, compiled and edited by VERBA & GUBERNOV (1996), Magnetic Anomaly Map of the Arctic, scale 1 : 6 000 000, compiled and edited by VERBA, KARASIK & SHIMARAEV (1996), and Cenozoic Geodynamic Map of the West Arctic Continental Margin, scale 1 : 2 500 000, compiled MUSATOV (1997). The tectonic history of the area was summarized in a set of tectono-stratigraphic charts for key regions showing succession of lithostratigraphic sequences, igneous rock assemblages, tectonic events and environments and geodynamic settings. Data and interpretations contained in basic monographs and papers, or shown on recently published maps have been incorporated (BOGDANOV & KHAIN 1996, DIBNER 1998, GRANTZ et al. 1998, KORAGO et al. 1992, KOS'KO et al. 1997, MAKA'REVA 1997, ROEST et al. 1996, STOLBOV 1997, SURKOV 1995, TEBEN'KOV et al. 1996, VERNIKOVSKY 1996).

The geology of islands and adjacent mainland is known in sufficient detail to serve as a basis for regional tectonic interpretations. The majority of the offshore has aeromagnetic surveys with coverage at 10 km spacing, and gravity surveys with a spacing of 10x10 km or in more detail. North Laptev, north East–Siberian and north Chukchi Seas have poorer potential field surveys coverage. Here aeromagnetic lines spacing can be as wide as 40 km and gravity observations can be as diffuse as 30x30 km. A dense net of reflection seismic lines exists in the Barents Sea. Seismic coverage in the Kara, Laptev, west East–Siberian and south Chukchi Seas is adequate to a small scale regional structural analysis, but the western East–Siberian lines, shot by BGR, have not been interpreted yet. There are only single reflection seismic lines in the central and eastern East–Siberian Sea and in the north Chukchi Sea (GRAMBERG et al. this volume).

REGIONAL GEOLOGY

The area studied embraces the islands and offshore of the Barents, Kara, Laptev, East–Siberian and Chukchi Seas and a

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Manuscript received 02 February, accepted 15 December 1999

strip of the Eurasian mainland, with an arbitrarily boundary on the south. The present day tectonic assemblage of the area is a combination of morphologically pronounced structural highs usually marked by islands and of synclinal basins and troughs.

The adjacent oceanic basins are the Norwegian basin on the west and Eurasian and Amerasian basins on the north. The relationships between the shelf and oceanic structures are variable. There is a wrench zone on the west where Knipovich Ridge reaches the continental rise in the vicinity of Spitsbergen archipelago. A portion of the shelf-ocean boundary from Spitsbergen to Severnaya Zemlya is typical of a passive margin. Within Laptev Sea oceanic structures of the Eurasian Basin including the Gakkel midoceanic ridge abut the shelf orthogonally. Farther east a portion of the Amerasian Basin adjacent to the Eurasian margin encompasses a series of minor basins and borderlands whose bathymetry and geophysical and geological characters show variation from typical oceanic lithosphere (Egiazarov 1977, Gramberg & Pogrebitsky 1984, Gramberg et al. 1988].

The geologic regions adjacent to the shelf on its mainland side are the Baltic Shield, Kanin–Timan Belt, Pechora Basin, Pai-Khoi Fold Zone, West Siberian Basin, Taimyr Fold System, Enisey–Khatanga and Lena–Olenek basins and Late Mesozoic fold belt of NE Eurasia comprising Yana–Kolyma, Anui–Lyakhov and Chukchi fold systems and Chukchi Massif. Some of those regional features extend offshore.

ASSUMPTIONS AND DEFINITIONS

Some terms are to be defined here to facilitate discussion: Continental basement is the upper "granite" layer of the solid earth crust. It comprises crystalline metamorphic and igneous assemblages along with intensely compressed, deformed and metamorphosed supracrustal strata. Continental basement formed through the assembly of previously geodynamically variable terranes which combined to build a relatively stable regional tectonic domain (superblock, or superterrane). This basement is called initial continental basement in the following discussion.

"Basalt windows": Inside the shelf there are areas without a granite layer.

Rejuvenation (accretion, construction) of continental basement is thickening of granite layer as a result of lateral compression, resulting in deformation, metamorphism and intrusion of supracrustal strata deposited on pre-existing continental basement.

Destruction of continental basement is thinning resulting from lateral extension, identifiable by extensional faulting and intrusion and eruption of basalt. Destruction of continental basement means growth of total thickness of basaltic layers as a percentage of a total thickness of the crust.

Manifestations of basic magma and normal faulting in the sedimentary cover within basalt windows is interpreted as an evidence for lateral extension of basalt layer but it cannot be used to unequivocally determine whether the underlying crust thickened or thinned during extension.

Thus it is assumed that the oceanic basement is composed of mainly basic igneous. The continental crust is composed of layers of "basalt" and "granite" of both igneous and metamorphic origin.

GENERAL STRUCTURAL PATTERN

A prominent feature of the tectonic basement is its division into blocks (Fig. 1). Basement blocks have been identified on the basis of potential fields maps correlated with seismic surveys data and onshore geology. Basement blocks vary in the values, gradients, patterns and grains of potential fields. Block boundaries depict dramatic changes in those characters observable on the relevant maps. In many cases they coincide with faults, changes in structure, and deformation zones in the sedimentary cover defined by seismic data. Some block boundaries can be projected onshore where they occur as igneous/ or deformation zones. Crustal blocks are believed to be stable structural units bounded by crustul weakness zones along which relative block motions took place.

The general structural pattern is a combination of linear and curved trends. Concentric structure dominates a portion of the Severnaya Zemlya to Nortn Taimyr region. The De Long area represents another example of mostly curvilinear structural pattern, but a portion of the concentric zone is intensely modified by intersecting straight and less curved trends. A linear pattern dominates the East–Siberian to Chukchi Seas area. Straight boundaries and elongated blocks are typical of this portion of the continental margin. The dominance of either type of structural trends is not easily distinguishable in most of the rest of the margin.

Depth to the top of the basement is another important structural indicator. Firstly it provides an estimate of the total vertical motions through the tectonic history of an area. Some blocks and groups of blocks are presently deeper than 10 km. Being beyond the resolution range of most data, the basement here is not identified in respect to age and composition. It is most likely that the granite layer is absent or extremely thin at that depth. In cases when "basalt windows" are captured within continental crust it is equally hypothetical as to whether they are relic oceanic crust or new oceanic crust built as a result of rifting. Identifying and mapping these deep seated blocks are important in the discussion on interaction of continental and oceanic crust on a regional scale. In historical and geodynamic terms it is assumed that continental crust cannot exist below supracrustal cover that is deeper than 10 km.

INITIAL CONTINENTAL BASEMENT

Tectonic zonation of the Eurasian margin in terms of the age of the initial continental basement is shown on Figure 2. The

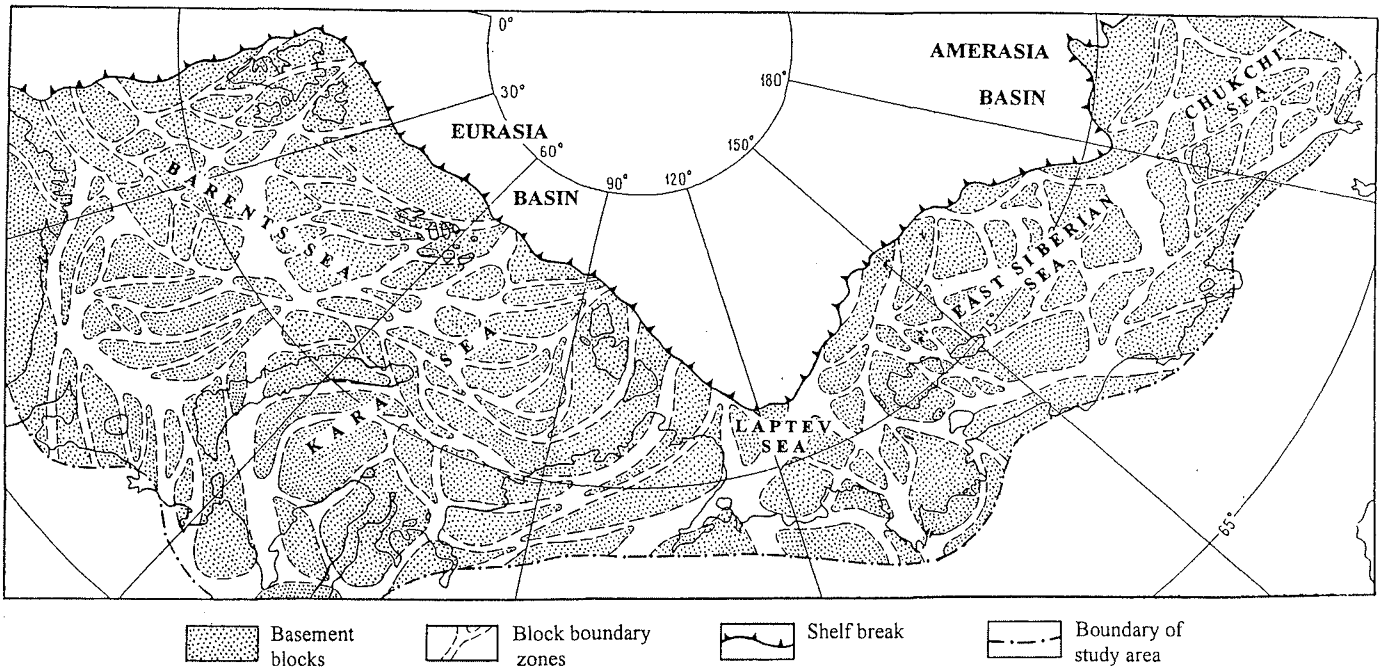

Fig. 1: Basement blocks of the Eurasian Arctic.

scheme shows a series of tectonic domains or superblocks some of which have been reliably dated by projecting onland geology, whereas the age of the others is based on interpretation of other data and is more hypothetical.

There are some new age data for various block domains. A Grenvillian age was attributed to the Spitsbergen superblock on the basis of new radiometric data. Gabbro-diorite-granite bodies and rhyolite are dated as 1200 Ma, as well as deformation and greenschist metamorphism dated at 900 Ma are known in the SW of Svalbard. Synorogenic granite, 1000 Ma in age, and postorogenic granite and acidic volcanics, with 930–960 Ma ages are common on NE Land (TEBEN'KOV et al. 1996, GAVRILENKO et al. 1993). A Baikalian age for the Barents-Kara block domain is based on projection of data from the mainland. It has been supported recently by new radiometric dating and geodynamic inter-

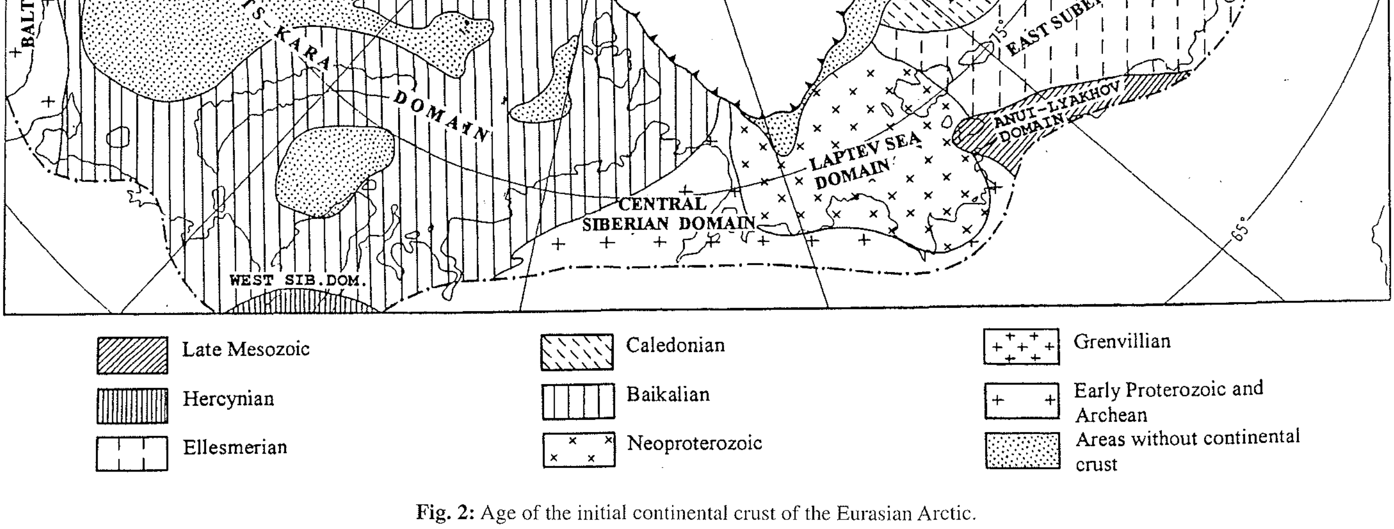

Fig. 2: Age of the initial continental crust of the Eurasian Arctic.

pretation of the Taimyr Peninsula (Vernikovsky 1996) and by interpretation of the tectonic history of Novaya Zemlya (Korago et al. 1992). Major consolidation of the domain took place in the late Riphean to pre-Vendian, but this was only the initial stage in its history. Deformation locally extended into early Cambrian. In north Taimyr for example there are subduction–related, high pressure, garnet–amphibolite facies rocks which are dated at 570–606 Ma (Vernikovsky 1996). The De Long domain has been interpreted as Caledonian on the basis of the presence of island arc type igneous bodies most likely close to 450 Ma in age hosted by volcanoclastic proximal turbidites. These rocks are exposed on Henrietta Island. A major portion of the East Siberian and Chukchi Seas domain has been identified as having an Ellesmerian consolidation age. Here a thick Devonian turbidite sequence was intruded by 360 Ma granite, and then buried under Carboniferous unconformity. This is documented on Wrangel Island and on Kiber Point east of Pevek (Cecile et al. 1991, Kos'ko et al. 1993, Lane et al pers. comm. 1998). The Laptev Sea domain is different from the adjacent domains in structural pattern and in potential field character. It is separated from the Central Siberian domain by adjustment zones which were active tectonic boundaries long before the present day structural assembly had been established (Malich et al. 1987). A stable platform regime existed here, as well as in the surrounding area, since the early Paleozoic. So it is possible that, being different from the cratonic basement of the Central Siberian domain, the initial continental crust here is Neoproterozoic in age. In earlier interpretations the Laptev Sea basement was thought to be an assembly of various basements projected in from the surrounding tectonic domains (Gramberg et al. 1984). A recent publication on the Phanerozoic stratigraphy of Northwind Ridge by Grantz et al. (1998) provides age data suggesting that the northernmost extremity of Chukchi Sea Shelf is a Neoproterozoic Domain.

Earlier continental crust has been incorporated into domains during their initial assembly. These are the Karelian block within Spitsbergen domain (Teben'kov et al. 1996), pre-Riphean terranes on the Taimyr Peninsula within Barents-Kara domain (Vernikovsky 1996), and the Chukchi massif within East-Siberian to Chukchi domain (Kos'ko et al. 1990, Krasny et al. 1984].

REJUVENATED CONTINENTAL BASEMENT

Areas where continental crust was rejuvenated, or added to, are shown on Figure 3. This scheme is complementary to the crustal domain diagram (Fig. 2) and illustrates the intermediate and the final stages in the continuing construction of continental crust.

Caledonian tectonism within Spitsbergen Domain, and the north Kara Sea portion of the Barents-Kara Domain is believed to have rejuvenated the existing granite layer and not to have created a new continental basement. This was recently supported by Teben'kov et al. (1996) with respect to Spitsbergen. Extension of the Caledonian rejuvenation to Severnaya Zemlya is based on the presence of a thick Devonian molasse, acidic volcanics and an unconformity in the Ordovician (Kaban'kov pers. com. 1998). Identifying Caledonian basement rejuvenation using these data is consistent with some earlier interpretations under the geosynclinal paradigm. Egiasarov et al. (1977) distinguished a Caledonian fold system developed on a pre-Riphean gneiss, amphibolite and schist on Svalbard. Leonov (1976) considered Devonian orogeny manifested in particular by emplacement of granite and accumulation of molasse type sequences as a specific global scale phenomenon which developed on previously consolidated crust and was not caused by the preceding evolution of early–middle Paleozoic geosynclines. Severnaya Zemlya

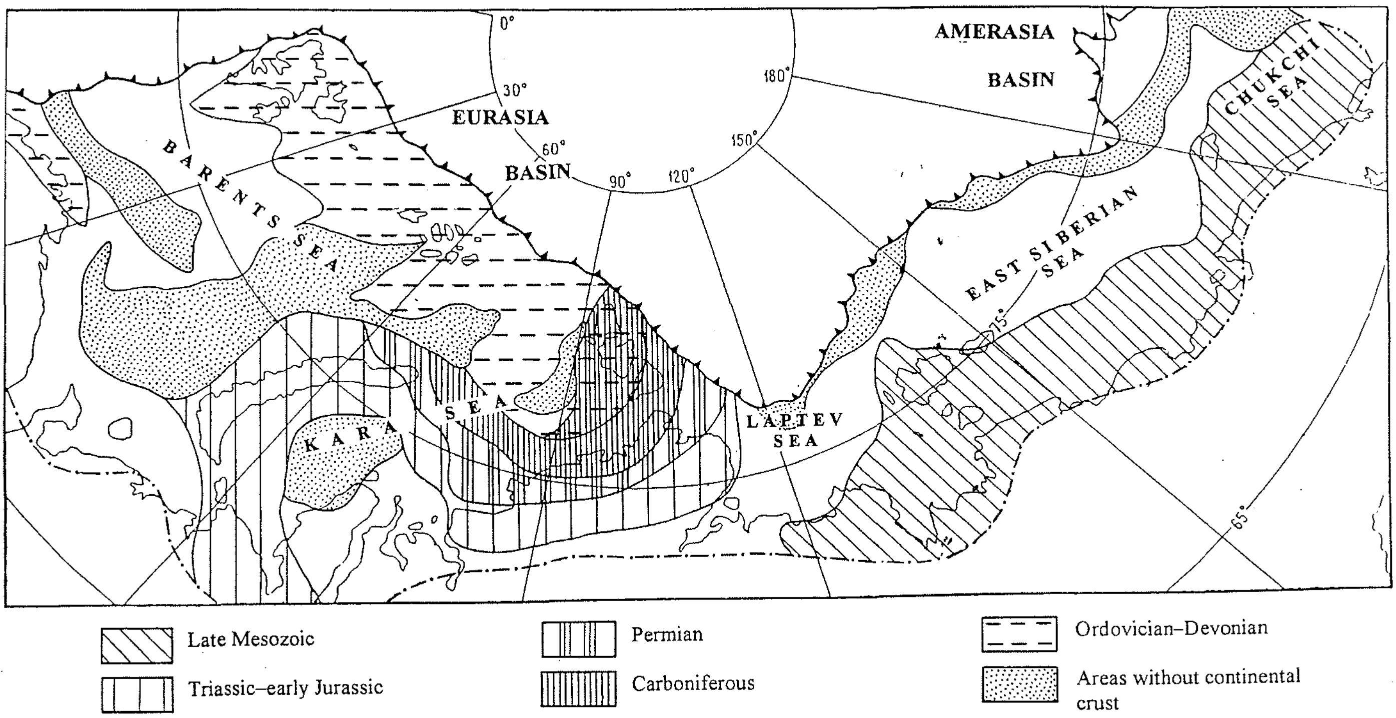

Fig. 3: Age of rejuvination of the continental crust of the Eurasian Arctic.

has been described by Leonov (1976) as an example of an epicratonic orogeny in the Devonian. There are intrusive bodies of alkaline basic rocks on the archipelago with latest Ordovician to earliest Devonian ages. From this we conclude that there was a complicated interaction of destructive and constructive processes with accretion of continental crust dominating during the late Caledonian tectonic epoch.

Migration of orogenesis with granitic magmatism southward from Severnaya Zemlya to south Taimyr indicates rejuvenation of continental basement from the Carboniferous to the Triassic as proposed by Pogrebitsky (1971). The rejuvenation started from a center in the north of the Kara Sea and expanded southwestward, southward, and southeastward. This interpretation has gained support from subsequent data. Undisturbed Permian alluvial plain sediments have been found on Severnaya Zemlya compared to folded and faulted Permian deposits wide spread on the Taimyr Peninsula. Reliable late Paleozoic radiometric ages of orogenic granites on Severnaya Zemlya are older than radiometric age of calcalkaline granite bodies on Taimyr Peninsula which are 275–306 Ma (Vernikovsky 1996). This general constructive trend in the evolution of the area was interrupted by a destructive event at the beginning of the Triassic.

A major portion of Late Mesozoic tectonism in the Russian North–East was essentially a rejuvenation of Paleozoic or earlier continental basement. This rejuvenating tectonism was generally recognized by most of Russian geoscientists by the beginning of the sixties (Puscharovsky 1960). New late Mesozoic continental crust was built within limited zones such as South Anui - Lyakhov suture developed from closure of the ancestral Anui Ocean.

DESTROYED CONTINENTAL CRUST

A series of schematic maps on Figure 4 shows distribution of the destructive zones both in time and area. Vendian to Triassic events belong to pre Arctic Ocean history, while Jurassic and later events have bearing on, and can be correlated to, the evolution of the Arctic Ocean.

Local extensional events in the northern Taimyr close in time to the Vendian–Cambrian boundary (Vernikovsky 1996) and extension has been inferred during the Ordovician in the Severnaya Zemlya area based on chemistry of the igneous rocks. Extension tectonics, which can be projected to offshore areas, dominated most regions of northern Russia in the Devonian to early Carboniferous (Gramberg 1988, Korago et al. 1992, Kos'ko et al. 1997). A similar scale of continental basement

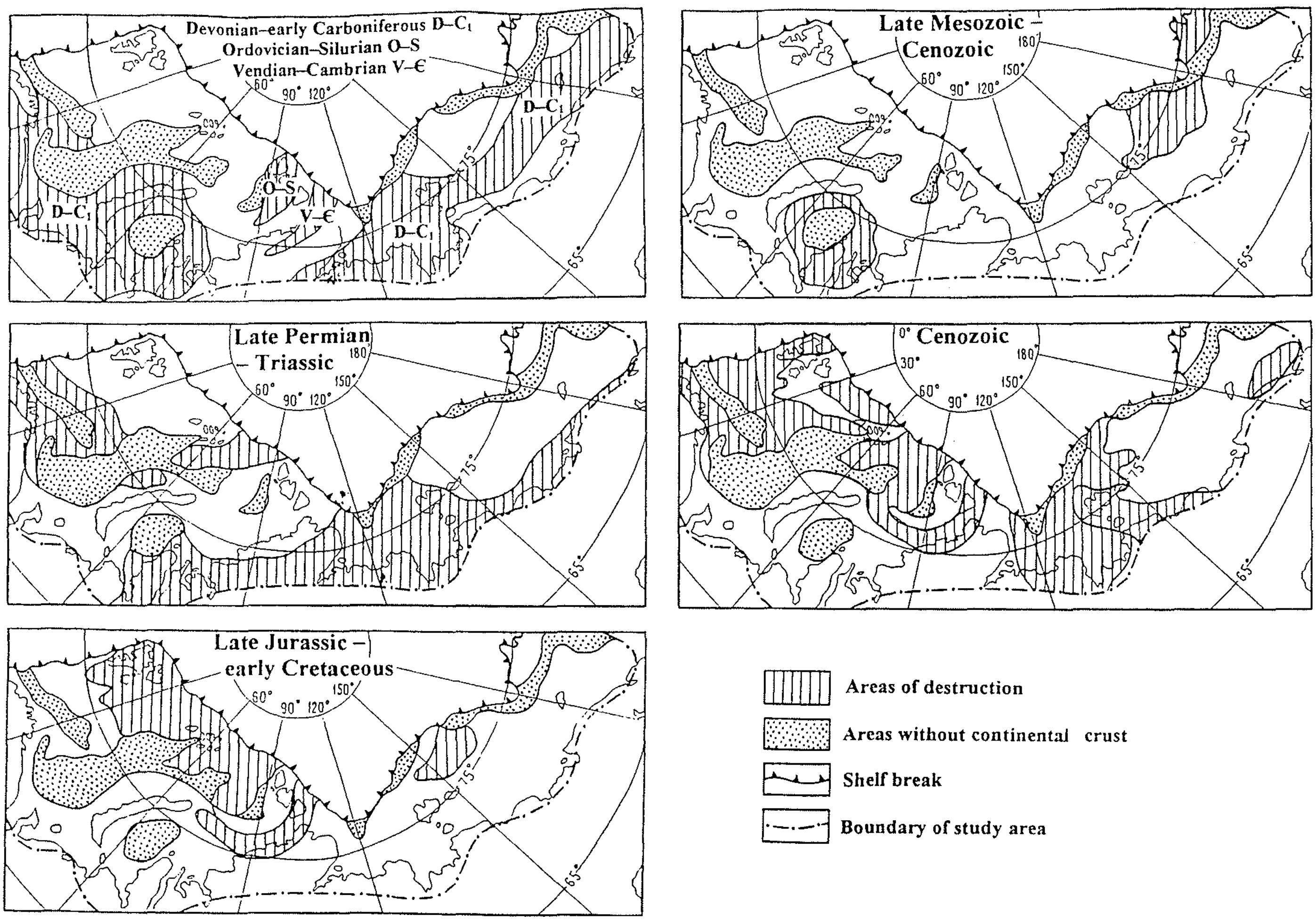

Fig. 4: Age of destruction of the continental crust of the Eurasian Arctic.

destruction by rifting and emplacement of traps took place in the late Permian and the Triassic (Kos'ko et al. 1990, Krasny & Putintsev 1984, Malich et al. 1987, Pogrbitsky 1971, Vernikovsky 1996).

Late Jurassic and early Cretaceous traps have been studied on Franz-Joseph Land (Gramberg 1988, Makar'eva 1997, Stolbov 1997, Dibner 1998). The archipelago is a basalt plateau, split into rectangular blocks by fractures and faults. The traps are volcanic sheets, sills, and swarms of dykes. K-Ar ages of 27 samples give a 92-175 Ma age range. There are some minor local accumulations of early Jurassic (198-203 Ma) traps. Late Jurassic to early Cretaceous traps have been interpreted to extend eastward, southward and westward from Franz-Joseph Land on the basis of magnetic field and seismic lines. Dolerite sills 131-159 Ma in age are found in the late Triassic portion of the sedimentary cover penetrated by a drillhole in the central Barents Sea. Extension of traps was controlled by faults according to Komarnitsky & Shipilov (1991). Extensional type basic igneous activity affected blocks of continental crust and basic windows equally.

Destruction of continental basement dominated the Eurasian shelf from the late Cretaceous to the Recent. It is consistent with its geodynamic nature as a passive margin and is evidenced in particular by its present day relief, the paleogeographic reconstructions (Gramber & Pogrebitsky 1984, Gramberg 1988], by sedimentary basins structure, by development of Tertiary traps and Quarternary alkaline-basic volcanics (Dibner 1998, Gramberg et al. 1984), and by results of the analysis of Cenozoic geodynamics of the west Arctic offshore. Unhatched polygons on Figure 4 show blocks which are behind in the progressive thinning of the continental crust and in the consequent subsidence. Distinction between late Mesozoic to Cenozoic and Cenozoic extension has been made in order to show (i) connection of that tectonism to the development of the oceanic basins during Cenozoic in the west, and late Mesozoic-Cenozoic in the East and (ii) to separate areas of mostly continuous subsidence from those where late Mesozoic–Cenozoic uplift was extensively developed in the west.

DISCUSSION

The division of basement into tectonic blocks is a fundamental structural feature that can be used to interpret the tectonic history of the region. The tectonic evolution of the basement demonstrates assembly and reassembly of elementary blocks into larger blocks under similar tensional/compressional environments that alternated through the geologic history. It is critical to know how deep those blocks and groups of blocks are rooted in the crust and/or in the lithosphere. The wide, areal distribution of a similar environment implies deep roots to crustal blocks. Widespread extensional settings such as those in the Triassic, close to the Devonian/Carboniferous boundary, and others are subplanetary features and so they are likely related to lithospheric plate scale phenomena. It is believed, that deep seismic interpretations and potential field modelling will help to identify the depth of individual blocks and small groups of blocks.

The structural pattern of the basement is a combination of linear and arcuate trends. Arcuate structural pattern in North Kara to Severnaya Zemlya to Taimyr region resulted from rejuvination of continental basement. Concentric patterns in the De Long Islands area has evolved in the course of late Mesozoic(?) - Cenozoic evolution concurrently with basic and alkaline–basic volcanism, indicating destruction of continental crust. A rectangular pattern is characteristic of the Laptev Sea area. It is a network of projections of linear features from the mainland and from the deepwater basin. There is an intersection of a northeast trending and of a NS trending block boundary zones close to the mouth of Khatanga Bay on the west. The NE zone on the mainland is a late Permian-Triassic rift at the base of Enisey-Khatanga basin (Malich et al. 1987). The NS block boundary is known on the Siberian Platform as Udja fault zone. The earliest faulting took place here in the early Proterozoic and extensional episodes are known from close to the middle to late Riphean boundary as well as in the Devonian. So an angular blocky pattern of the Laptev Sea shelf has a long geologic history overprinted by distinct destructive episodes. The offshore limits of the late Mesozoic accretion of continental crust on the east are controlled by essentially linear features. The above examples show that a structural pattern cannot serve as an argument to distinguish construction/destruction of a continental crust.

There is no obvious correlation between the ages of tensional and compressional events and the age of the continental basement. The Devonian-Carboniferous and the Triassic extensions are detectable through the study area. They are planetary scale events well known in the northern Eurasia. Late Jurassic to early Cretaceous extension is attributable to the opening of the Amerasian Basin and it is contemporary to orogeny in the Northeast Eurasia, Alaska and Canada. This contemporaneous development could allow for comprehensive circum-Arctic geodynamic investigation. Late Cretaceous - Cenozoic extensions are correlated with the opening of the Eurasian Basin.

Contemporaneous development of tension / compression is well known on a global scale and on an outcrop scale. There are numerous examples of contemporaneous tensional / compressional development shown on a regional map scale and in results of structural analysis, especially in fault zones. The succession of tensional and compressional settings does not separate contemporaneous tensional / compressional settings within the areas under consideration. An attempt to build a hierarchy of tension/compression complementary pairs, and to map these within the Eurasian continental margin area, was not successful, despite a desire to use this approach as a tool for better understanding of the tectonic evolution.

CONCLUSIONS AND CHALLENGES

The dating of the continental basement discussed here varies dramatically from the earlier published versions. Our version is consistent with recent radiometric dating, revision of earlier known features and with the structural and compositional characters of lower and middle Paleozoic sequences on the islands and nearshore mainland. A proposal to distinguish Caledonian basement from Ellesmerian basement in the East Siberian and Chukchi Seas has been made.

Most of the regional tectonic reconstructions are focused either on the time of origin of continental or oceanic crust, or on subsidence history of sedimentary basins. Highlighting the alternation of rejuvenation and destruction forces in controlling the tectonic evolution of basement is an attempt to contribute to the understanding of the interaction between the tectonic basement and the sedimentary cover.

The interaction between the sedimentary cover and the basement through time directly affects the hydrocarbon potential of the crust. Extensional environments enables the creation of basins with accumulation of organic matter and with potential reservoirs. Compressional settings produce restructuring sedimentary basins and allow for development, migration and redistribution of hydrocarbons. This process results in both the loss of hydrocarbons and their accumulation in traps.

At the start of the compilation we intended to provide constraints and a starting point for building more comprehensive models of the tectonic evolution of the Arctic. It could be helpful to a petroleum explorationist in preliminary assessment of the age of the sedimentary cover.

Our compilation is neutral with respect to both the strict plate tectonic concept on one hand and fixist theories on the other. The constructive ideas and approaches elaborated within both concepts have been considered and implemented. The results of the compilation can contribute to circum-Arctic geodynamic reconstructions both on a modern geographic base map and on plate tectonic maps from the Riphean to Recent. Moreover to build concurrently two sets of circum-Arctic maps - one within recent geography and the other on plate tectonic base maps would be a tool to check the accuracy and/or validity of the plate-tectonic model.

ACKNOWLEDGMENTS

Presentation of the intermediate results of current VNII-Okeangelogia project and attending by Russian authors ICAM III was possible thanks to the support of the organizers and the sponsorship by Deutsche Forschungsgemeinschaft (DFG).

References

Bogdanov, N.A. & Khain, V.E. (eds.) (1996): Tectonic Map of the Barents Sea and the Northern Part of European Russia.Scale 1 : 2 500 000.

Cecile, M.P., Bychkov, YU.M., Gorodinsky, M.Eu., Kos'ko, M.K., Lane, L.S. & Vinograadova, O.N. (1991): Report on the joint visit of Canadian Soviet scientists to the Northeastern Soviet Union.- Episodes 14: 125–130.

Dibner, V.D., (ed.) (1998): Geology of Franz Josef Land.- Norsk Polarinst. Meddelelser 146, 190 pp.

Egiazarov, B.Kh. (ed.) (1977): Tectonics of the Northern Polar Area of the Earth, Explanatory Note to the Tectonic Map of the Northern Polar Area of the Earth, scale 1 : 5 000 000.- Leningrad, 200 pp. (in Russian).

Gavrilenko, B.V., Balashov, Yu.A., Teben'kov, A.M. & Larionov, A.N. (1993): Geokhimia 1: 154–158 (in Russian).

Gramberg, I.S. (ed.) (1988): Barents Shelf Plate.- VNIIOkeangeologia, Transaction 196, "Nedra", St. Petersburg, 263 pp. (in Russian).

Gramberg, I.S. & Pogrebitsky, Yu.E. (eds.) (1984): Seas of the Soviet Arctic, Geology of the USSR and Regularities of the distribution of economic minerals, 9.- Nedra, Leningrad, VNIIOkeangeologia, 280 pp. (in Russian).

Grantz, A., Clark, D.L., Phillips, R.L. & Srivastava, S.P. (1998): Phanerozoic Stratigraphy of Northwind Ridge, magnetic anomalies in the Canada Basin, and the geometry and timing of rifting in the Amerassia Basin, Arctic Ocean..- Geol. Soc. Am. Bull. 110: 801–820.

Komarnitsky, V.M. & Shipilov, E.V. (1991): New geologic data on igneous activity in Barentz Sea.- Doklady Akademii Nauk, 320 (5): 1203–1206 (in Russian).

Korago, Eu.A., Kovaleva, G.N., Ilyin, V.F. & Pavlov, L.G. (1992): Tectonics and Metallogeny of Novaya Zemlya.- Nedra, St.Petersburg, VNIIOkeangeologia, 196 pp. (in Russian).

Kos'ko, M.K., Cecile, M.P., Harrison, J.C., Ganelin, V.G., Khandoshko, N.V. & Lopatin,B.G. (1993): Geology of Wrangel Island, between Chukchi and East Siberian Seas, Northeastern Russia.- Geol. Surv. Canada Bull. 461, 102 pp.

Kos'ko, M.K., Korago, Eu.A., Suprunenko, O.I., Piskarev, A.L. & Verba, V.V. (1997): Tectonic Basement zonation of the Barents and Kara Seas region - Key problems of the geology of the Barents–Kara Self and adjacent Land.- International Workshop, St.Petersburg, February 13–17, 1997, Proceedings of the Workshop. Europroba-VNIIOkeangeologia. St.Petersburg, 25–26.

Kos'ko, M.K., Lopatin, B.G. & Ganelin, V.G. (1990): Major geological features of the Islands of East Siberian and Chukchi seas and the northern coast of Chukotka.- Mar. Geol. 93: 349–367.

Krasny, L.I. & Putintsev, V.K., eds. (1984): Eastern USSR, geology of the USSR and regularities of the distribution of economic minerals, 8.- Nedra, Leningrad, VSEGEI, 560 pp. (in Russian).

Leonov Yu.G. (1976): The tectonic nature of Devonian Orogeny.- Moscow, Nedra, 192 pp, (in Russian).

Makar'eva, E.M. (1997): Description of Franz Josef Land magmatic formations by the Geological Survey Data - Key Problems of the Geology of the Barents-Kara Shelf and Adjacent Land, International Workshop, St.Petersburg, February 13–17, 1997, Proceedings of the Workshop. Europroba-Vniiokeangeologia. St.Petersburg, 31 p.

Malich, N.S., Masaitis, V.L. & Surkov, V.S. (1987): Siberian Platform, geology of the USSR and regularities of the distribution of economic minerals, 4.- Nedra, Leningrad, VSEGEI, 448 pp, (in Russian).

Pogrebitsky, Yu.Eu. (1971): Paleotectonic analysis of Taimyr Fold Belt.- NIIGA Transactions, 166, Nedra, Leningrad, 248 pp, (in Russian).

Puscharovsky, Yu.M. (1960): Verkhoyansk Foredeep and Mesozoides of NE Asia.- Tectonics of the USSR, 5, Acad. Sci., Moscow, 236 pp., (in Russian).

Roest, R., Verhoef, J. & Macnab, R. (1996): Magnetic Anomaly Map of the Arctic North of 64°, Scale 1 : 6 000 000.

Stolbov, N.M. (1997): The discretion of Franz Josef Land basltic magmatism.- Key Problems of the Geology of the Barents–Kara Shelf and Adjacent Land, International Workshop, St.Petersburg, February 13–17, 1997, Proceedings of the Workshop. Europroba–VNIIOkeangeologia. St.Petersburg, 57–58.

Surkov, V.S., ed. (1995): Atlas of Paleotectonic and Paleogeological Landscape Maps of Hydrocarbon Provinces of Siberia, Scales 1 : 5 000 000 and 1 : 10 000 000.

Teben'kov, A.M., Krasil'schikov, A.M. & Balashov, Yu.A. (1996): Major geochronological boundaries and stages of basement development of Svalbard.- Doklady Akademii Nauk, 346, 6, 786–789, (in Russian).

Vernikovsky, V.A. (1996): Geodynamic evolution of Taimyr folded area.- Russian Academy of Sciences, Siberian Branch, United Institute of Geology, Geophysics and Mineralogy, Transactions, Issue 831, Novosibirsk, 202 pp, (in Russian).