Project: Metamorphic rocks of the Stanovoy belt: petrogenesis and geodynamics of their formation

1. Brief summary of the project.

The project is intended to solving a basic problem of new global tectonics concerning the nature of relationships between metamorphic and tectonic processes through the example of examining the formation of the Stanovoy belt metamorphic complexes from the standpoint of its petrogenesis and geodynamics. The geodynamic model is based on the studies of thermodynamic conditions of metamorphic rocks formation and their fluid regime, analysis of the pre-metamorphic geodynamic settings of originally-magmatic rocks converted later to metabasalts and metaandesites as well as on the determination of isotope ages of protoliths and metamorphism of igneous rocks. A new approach to the problem of formation and breakup of an ancient supercontinent Rhodinia is being developed.

2. Formulation of the problem.

Since the late 1980s of the last century a number of investigators have been attempting to reconstruct the positional relationship between the Precambrian shields of North America and the Siberian Platform (Sears and Prices, 1978; Hoffman, 1991; Condie and Rosen, 1994; Frost et.al, 1998). All these models hypothesize that the Siberian Platform and North America represented in certain period of geologic time a single supercontinent – Paleo-Pangea or Rhodinia. History of Rhodinia development and its breakup were discussed in a number of works as well as at the two International Symposia held in Strasbourg (EUG 10, Strasbourg, 1999) and Osaka (Gondvana Research, Vol. 4, No.4, 2001). As a result of discussions, most authorities agree that rifting of Rhodinia commenced at the time interval 600–800 Ma. It is worthy of note that a concept of the Stanovoy belt, the vast megastructure bordering the southern portion of the Aldan shield, is practically lacking in the models concerning the subject of the formation and breakup of the supercontinent Rhodinia. While, the geological position of this belt, which started to form as far back as in the Archean (Larin, Kotov, Kovach et.al., 2002) or beginning in Early Proterozoic time (Nutman, 1992) and whose latitudinal structures transect the predominantly north-south-striking geologic units of the Aldan Shield, clearly indicates that the breakup of Rhodinia (on the assumption of validity of these authors' geotectonic models) has taken place or started to occur even before the Stanovoy belt formation. Assuming that the formation of the Stanovoy belt belongs to the pre-Rhodinia stage of the Siberia Craton evolution, the relative positions of the Precambrian shields of North America and the Siberian Platform should be reconstructed with regard to the position of the Stanovoy belt. In other words, if that's the case, the analogues of the metamorphic rocks of the Stanovoy belt should be found within the North American continent. An additional motive for subject-setting of this grant lies in the existence of the reliable data pointing to the fact that the metamorphic rocks of the Aldan shield have suffered global recrystallization in Proterozoic time (1.9 Ga) (Frost et.al, 1998). There are good grounds to believe that the metamorphism of the Stanovoy belt is related to Proterozoic recrystallization of the Aldan Shield and it is desirable to clarify the nature of the above interrelation. The present problem forces us to recognize that the study of metamorphic rocks of the Stanovoy belt ranks among the most important and topical tasks. The resolution of this issue will give an insight into historical development of the mechanisms of new global tectonics and an opportunity to get a new angle on the formation and disintegration history of Rhodinia.

3. Regional geology

Precambrian rocks of East Siberia are exposed throughout the vast region extending from Lake Baikal to the Sea of Okhotsk. To a first approximation, they may be divided into two provinces – the Aldan shield in the northern part of the area and the Stanovoy belt in the south. The Aldan shield includes four major blocks or terranes (from the west to the east): the Olekma, Aldan, Uchur, and Batomga blocks (Rosen et al., 1994) (Fig. 1). The Olekma terrane is a granite-greenstone terrane that is composed of rocks dated at 3.0 to 2.5 Ga (Rosen et al., 1994). The Aldan and Uchur terranes are considered as the zones of primarily granulite facies metamorphism. Situated between the Aldan and Uchur terranes, the Idzhek zone is mainly composed of charnokites. The Batomga terrane bearing a general resemblance to the Olekma one is poorly studied. The geologic units of the Aldan shield have predominantly north-south-striking. On the basis of different data, the granulite metarocks of the Aldan shield were always assigned to the Archean. At present time, however, it can be said with assurance that there occurred a wide spread recrystallization of the Aldan shield rocks in Proterozoic time (2.2–1.9 Ga), (Frost et al., 1998). The conception of Proterozoic recrystallization of the Aldan shield was proposed by Nutman (Nutman et al., 1992) and some Russian geologists as well

The east-west-trending Stanovoy metamorphic belt borders on the Aldan shield along its southern side. Between the Stanovoy belt and Aldan shield, there is a zone of the high-pressure (8-9 kbars) and high-temperature (750-9000Ñ) granulite terranes, namely, the Kurulta, Zverev, Sutam, and Dzhugdzhur ones (fig.1). Most of the rocks of the Stanovoy belt have experienced metamorphism in the amphibolite facies (550-6500Ñ, 6-12 kbars). There is reason to believe (Kozyreva, Avchenko, Mishkin, 1985) that the rocks of the eastern part of the Stanovoy belt were meramorphosed at higher fluid and lithostatic pressure (8-12 kbars). The geological structure of the Stanovoy belt is peculiar by a presence of differing in size granulite terranes within the belt. The contacts of the granulite terranes with the surrounding amphibolite facies rocks are of tectonic nature (fig.1). These granulite terranes are similar to the aforementioned high-pressure and high-temperature terranes of South Aldan Shield in terms of its metamorphism conditions and available isotopic data.

On examining the tonalite gneisses and cross-cutting amphibolites in the the Stanovoy belt area, A.P. Nutman (Nutman et.al., 1992) has distinguished two varied in age groups of zircons. The first, older zircon group, collected from the tonalite gneisses was dated at 2750 Ma. This age is interpreted by A.P. Nutman (Nutman et al., 1992) as corresponding to a widely occurring magmatic stage, and so, in our opinion, it may be the age of the protolith of the Stanovoy gneisses. The second younger group of zircons is 1916-1962 Ma in age, and it occurs only in green hornblende-plagioclase-quartz assemblage, i.e. in a paragenesis that is typical of metamorphic rocks of the Stanovoy belt. So we believe that the age of 1916-1962 Ma may indicate timing of amphibolite facies metamorphism of the Stanovoy belt rocks .

4.The proposed geodynamic model.

Analysis of all available data allows us to recognize the following, to a certain extent proved, statements:

1. metamorphism of amphibolite facies rocks of the Stanovoy belt is similar in age to the Proterozoic recrystallization of the Aldan shield .
2. the contacts between the granulite terranes found inside the Stanovoy metamorphic belt and the enclosing amphibolite facies rocks are tectonic in nature;
3. metamorphism of the amphibolite facies rocks of the Stanovoy belt, at least in its eastern

portion, could be of higher lithostatic pressure than metamorphism of the high-pressure granulites of the South Aldan shield;
4. Toward the top of the vertical section, the granulite rocks of the South Aldan shield and those located inside the Stanovoy belt do not grade into the amphibolite facies rocks. This conclusion follows from the field study (Kozyreva, Avchenko, Mishkin, 1985).

So, on the basis of these four stated conclusions we can suggest the following geodynamic model of the Stanovoy belt and the Aldan shield interrelation:

Proterozoic recrystallization of the Aldan shield is related to the metamorphism of the Stanovoy belt and caused by the subduction of the Stanovoy lithosphere under the Aldan shield.

The plate plunged mainly from the south to the north, so the northern parts of the plate became most submerged. In these mostly submerged zones of the plate, reaching the mantle level, the upper part of the Stanovoy lithosphere melted producing magmatic melts, which ascended and intruded the ancient crust of the Archean Aldan shield and initiated its granulite metamorphism and remelting. Melts were crystallized under the conditions of the dehydrated crust of the Aldan shield of Archean age resulting in emplacement of Proterozoic charnokite intrusions within the Aldan shield. At the same time, metamorphism of the amphibolite facies rocks of the Stanovoy lithosphere upper crust took place in its less subsided parts, or, geographically, to the south of the modern boundary of subduction (fig. 2). This amphibolite facies metamorphism occurred under the earlier formed Archean granulite crust lithostatic load that resulted in higher values of lithostatic pressure in the rocks of the eastern part of the Stanovoy belt. Recrystallization of overlying granulites in these zones could be realized only on a limited scale, depending on fluids arriving from the Stanovoy belt rocks underlying the granulites. The repeated recrystallization of the South Aldan shield granulites, which occurred at the Proterozic stage (1.9 Ga), is well-recorded (Shemyakin et. al., 1998). In view of stated above, the granulite terranes inside the Stanovoy belt are not its basement, but, quite the contrary, they represent the Archean roof xenoliths occurred above the sinking Stanovoy plate during its metamorphism. Our geodynamic model clearly demonstrates that if the deepest amphibolite facies rocks of the Stanovoy belt are exposed on the surface, the granulite terranes, contacting with them, may be found only in the innermost parts of the Aldan shield, and, thus, they should belong to rocks with the highest P and T parameters, that is the case. It is not improbable that the presence of tonalite gneisses in the Stanovoy complex (Larin, Kotov, Kovach et al., 2002) is suggestive of a collision between the Stanovoy lithosphere and the Aldan shield, in the course of which a part of the Stanovoy continental lithosphere has been subducted under the Aldan shield. So, subduction of the Stanovoy lithosphere under the Aldan shield is likely similar to subduction of the Indian continental lithosphere under the Tibet (Chemenda et al., 2000; O'Brien et al., 2001), distinguishing from the latter by older (Proterozic) age. Besides, our geodynamic model concerning the collision between the Stanovoy lithosphere and the Aldan shield suggests that if the Siberian platform and North America formed parts of a single Archean continent (Frost et al., 1998), its breakup must have been occurred in the time before 1.9 Ga.

5. Research plan.

So far, the suggested geodynamic model is only a suitable hypothesis generalizing the known facts. For this hypothesis to be the proved theory a large number of various geochemical, isotopic, and petrological studies are obviously needed.

The following specific tasks of this project are:
1. to study the formation thermodynamic conditions and fluid regime of amphibolite facies rocks of the Stanovoy belt;
2. to reveal the pre-metamorphic stage geodynamic environments existed in the Stanovoy belt area during formation of originally-magmatic rocks converted to metabasalts and metaandesites;

3. to solve a problem of isotope ages of protoliths and metamorphism of the Stanovoy belt igneous rocks;
4. to construct a geodynamic model for the origin of the Stanovoy belt.

6. Description of methods to be applied for the tasks solution

1. Based on semi-quantitative estimates, the previous works (Kozyreva, Avchenko, Mishkin, 1985; Avchenko, 1990) have shown that metamorphism of the eastern part of the Stanovoy belt at least had not been less in depth level than the metamorphism of the highest-pressure and highest-temperature granulites of South Aldan shield. Both these complexes differ from one another mainly by the thermal and fluid conditions. This conclusion is of particular importance as it allows us to understand that it was impossible for granulite sequences of South Aldan shield to be a basement of the Stanovoy belt. Hence, the Stanovoy belt formation occurred under other geotectonic environments. At the same time, the extent to which this corollary is proved remains insufficient. Therefore, on estimating metamorphism conditions, we plan to put in the forefront several up-to-date computer programs and new factual data on mineral assemblages. In an early stage of our study, minerals composition from the most informative parageneses will be studied by electron microprobe analysis. In the next stage, the minerals compositions will be calculated by using the special computer programs. Basic among them are TERMOCALC (Holland, Powell,1998, 2000), PTMAFIC (Soto & Soto, 1995), and SELECTOR (Karpov et al., 1998) programs. The important distinction of TERMOCALC program is the possibility of estimations of metamorphism pressure based on examining the mineral assemblages containing garnet, amphibole, epidote, and muscovite. In this case, uncertainties arising at use of not quite correct models of solid solutions of minerals are taken into account. Further advantage of this program is that estimations of P-T conditions for rocks metamorphosed in greatly different environments is carried out on the basis of an uniform consistent general system of thermodynamic equations. To estimate the composition of metamorphogenic fluids, we intend investigating of gas and liquid inclusions in minerals of the Stanovoy belt metamorphites. Such studies are of major importance, as they became more informative with the advent of new database on thermodynamics and experiments as well as of advanced efficient apparatus.
2. Reconstruction of the pre-metamorphic geodynamic settings existed during magmatic mafic rocks formation (it is concerning the second task solution) will be carried out on the basis of geochemical data analysis. To ensure proper study, the samples collected from the metabasites of the Stanovoy belt will be analyzed for informative microelements - Ti, Zr, Y, Sr, Nb, V, Cr as well as for rare earth elements (REE). All metabasite samples will be analyzed for the major elements as well. The data obtained in conjunction with analysis of all known discriminant diagram will enable us to solve the second task. At present, such geochemical data on the Stanovoy belt metabasites are almost lacking.
The third task is the most important and, at the same time, the most challenging and difficult part of the project. To solve the task, we designed several approaches to its solution:
à). the Sm-Nd model ages determination;
á). the U-Pb datings of zircons;
â). the U-Pb datings of sphenes;
À). In laboratory of Isotope Geology run by A.B. Kotov (Institute of Geology and Geochronology of Precambrian, St.-Petersburg), much work is now underway to estimate age of protolithes of felsic rocks of the western and central parts of the Stanovoy belt. The problem of the age of protoliths from the eastern part of the Stanovoy belt still remains to be solved. Our data on protoliths ages will be based on the examination of whole-rock samples by the Sm-Nd method. On examining mafic rocks, this method may yield age overestimate. Therefore, the estimates of the Sm-Nd model ages for felsic rocks need to be performed simultaneously. The real protolith

age should lie in the age interval, obtained for both rock groups. According the proposed geodynamic model, the age of the protolithes may range from Archean to Proterozoic, the metabasalts and metaandesites from frontal zones of the Stanovoy plate, which at pre-metamorphic stage were considered as oceanic and island-arc basaltic assemblages, being probably of Proterozoic age. Archean age of protolith is quite probable for the Stanovoy tonalitic gneisses, which were initially (before metamorphism) a constituent part of ancient subcontinental crust of the Stanovoy lithosphere.
B). The U-Pb datings of zircons may indicate, on the one hand, an age of metamagmatic rocks of the Stanovoy belt and, on the other hand, they may reflect timing of metamorphism. As distinct from protolithes age, timing of amphibolite facies metamorphism through the entire Stanovoy plate is presumably of about 1.9 Ga, i.e., it is in accord with timing of recrystallization of the Aldan shield, under which the Stanovoy plate has been subducted.
If zircons are carefully taken from a leucosome of partially melted metapelitic gneisses of the Stanovoy belt (this work is presumed to be carried out in part in the course of our field studies), the U-Pb investigations will allow age estimates for zircons crystallized during metamorphism stage. Moreover, in case of suitable rocks, if zircons are treated by the special procedure, which includes an abrasion of outer edges of zircon crystals or its solution, the age of pre-metamorphic magmatic rocks, based on the U-Pb dating of these zircons, will be obtained.
C). It is well known that many of the mafic and intermediate rocks found in the Stanovoy belt area are characterized by presence of sphene, which is typical mineral of amphibolite facies rocks. Granting that these rocks were initially (before metamorphism) basalts and andesites, it is reasonable to consider sphene as forming at metamorphism stage. Sphenes have sufficient for analysis contents of U and Pb, with ratios 206Pb/204Pb being higher than 100. So, the U-Pb datings of sphenes may yield age estimates for the Stanovoy plate metamorphism.
3. Based on new data concerning geochemistry of metamorphic rocks and conditions of their formation, a geodynamic model of the Stanovoy belt formation is being developed; a draft of the model may be represented as follows.
À). Formation of the Stanovoy plate (including its continental and oceanic crust) as a consequence of the supercontinent Paleo-Pangea or Rhodinia breakup (before 1.9 Ga).
B). Subduction of a part of the Stanovoy plate beneath the Aldan shield and the subsequent collision between the Stanovoy plate and Aldan shield.
C). Amphibolite facies metamorphism of the mostly submerged zones of the Stanovoy plate and the extensive, synchronous with metamorphism recrystallization of the Aldan shield (1.9 Ga)
D). Exhumation of the Stanovoy plate and formation of the Stanovoy metamorphic belt.

7. General schedule of works.

2003 ã.

April - May - study of mineral parageneses composition using an electron microprobe, based on an examination of available and still unexplored samples from the eastern part of the Stanovoy belt.
June – field works organization.
July – August – field works. Included among them is a floating down the Nyukzha River, using an inflatable rubber (see route no. 1 in fig. 2). The Nukzha River traverses the main units of the Stanovoy metamorphic belt from the south to the north. Soon after the beginning of our floating, there will be opportunity to study the Larbinsky granulite terrane
September – December – processing and interpretation of field data; writing out an article.

2004 ã.

January – May - study of mineral parageneses composition using an electron microprobe; isotopic-geochronological studies of zircons and sphenes collected during field works of 2003;

Sm-Nd model ages determinations based on the thoroughly selected samples.
June – field works organization.
July – August – field works. Included among them is an inflatable rubber floating down the Gilyui River from the village of Tynda (see route no. 2 in fig. 2). The Gilyui River, which flows from the west to the east, traverses obliquely the Stanovoy metamorphic belt geological units. At the beginning of the route we can continue with our studying the western part of the Larbinsky granulite terrane
September – December – samples processing and interpretation of field data; writing out the article.

2005 ã.

January – July – various analytical investigations of materials obtained in 2003 and 2004. The remaining time– to work at articles.

8. Approximate volume of analytical investigations.

It is necessary to perform not less than 5 - 10 determinations of U-Pb isotope age for zircons and sphenes from metamorphic rocks of various genesis, 15-20 age determinations for protolithes of metamagmatic rocks by the Sm-Nd method, a set of electron microprobe analyses for minerals from the most informative parageneses (100-200 minerals). All samples examined by isotopic and microprobe methods should be analyzed for major elements by wet chemical analysis. About 30-40 samples of metabasalts and metaandesites are to be analyzed for informative trace elements - Ti, Zr, Y, Sr, Nb, V, Cr as well as for rare earth elements (REE).

9. Significance of planned researches

Among western geologists, there is no clear apprehension of the Stanovoy belt structure. Therefore, this megastructure is not even referred to in their global models concerning the Earth's formation and development in the Precambrian. The reason is that the English language articles dealing with the geologic and petrologic peculiarities of metamorphic rocks related to the Stanovoy belt are almost lacking in a western scientific press. The proposed project is aimed at promoting a broad publication of our research results in English in the western geological journals as well as at eliminating gaps in our knowledge. On the other hand, in spite of a great body of geological information on the Stanovoy area, there is ample evidence that Russian geologists have incomplete, foggy, and contradictory notion of the compositional and metamorphic characteristics for rocks composing the Stanovoy belt. The question of possible relation of the Aldan Shield recrystallization to the metamorphism of the Stanovoy belt as well as a proposition of a geodynamic model describing the peculiarities of formation of the Stanovoy metamorphic rocks in Precambrian time were never raised in Russian scientific literature. It is anticipated that our work at this project will give new insight into the mechanism of the most ancient Earth's continents formation in terms of new global tectonics.

9. List of the main published works relevant to the project:

1. I.V. Kozyreva, O.V. Avchenko, M.A. Mishkin. Abyssal metamorphism of Late Archean volcanogenic belts // Moscow. Nauka, 1985. 163 p. (monograph). (in Russian).
2. Î.V. Avchenko. Mineral equilibria in metamorphic rocks and problems of geobarothermometry // Moscow. Nauka, 1990. 181 p. (monograph). (in Russian).
3. B. Ronald Frost, Oleg V. Avchenko, Kevin R. Chamberlain, Carol D.Frost. Evidence for Proterozoic remobilization of the Aldan shield and implications for Proterozoic plate tectonic reconstructions of Siberia and Laurentia // Precambrian Research. 1998. 89. PP. 1-23.

4. Î.V. Avchenko, V.Î. Khudolozhkin, N.P. Konovalova, N.N. Barinov. Reduced, carbon--rich fluids of the Sutam metamorphic complex // Geokhimiya (Geochemistry). 1998. No. 8. PP. 831-841. (in Russian).
5. Î.V. Avchenko, C.D. Frost, B.R. Frost, K.R. Chamberlain. An Archean to Proterozoic age of protolith of granulite gneisses from the Aldan granulite- gneissic area // Doklady RAS. 1999. V. 364, No.5, PP. 655-659. (in Russian).
6. Î.V. Avchenko, Dong-Woo Lee, V.I. Sapin. Mineralogical evidence for reduced fluid – -metamorphic rocks interaction // Geokhimiya (Geochemistry). 2000. No. 6. PP. 592-598. (in Russian).
7. Î.V. Avchenko, I.A. Aleksandrov, V.Î. Khudolozhkin, N.P. Konovalova. Composition and genesis of fluid phase from minerals of the Stanovoy metamorphic complex (the Aldan-Stanovoy shield) // Tikhookeanskaya Geologiya. (Geology of Pacific Ocean). 2000. V. 19, No. 3. PP. 55-64. (in Russian).
8. Î.V. Avchenko. On values of fluid - rock proportions at the regional granulite metamorphism // Doklady RAS. 2001. V. 378, PP. 221-224. (in Russian).