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Recent geodynamic regime of the Eurasia – North American interplate boundary: Evidences from seismology of Arctic

A.N. Vinogradov[1,2], S.V. Baranov[1]

[1] *Geophysical Survey of RAS, Apatity*

[2] *Apatity Branch of MSTU, Geology and Minerals Department*

Abstract. The paper considers seismological evidences on a geodynamic regime in the Arctic segment of the interplate boundary between Eurasian and North American lithosphere plates. A scope of earthquakes occurred in the Mon, Knipovich and Gakkel mid-ocean ridge belts (MORB) has been made, and distribution of double-couple (DC) and non-double-couple (NDC) sources has been evaluated. As revealed, the DC events, caused by shearing tectonic movements, prevail among earthquakes in all MORBs. In the Arctic MORBs with ultra low speed of spreading the NDC earthquakes, caused by normal rifting or volcanic eruptions, are responsible for 9 % seismic energy release only, whereas in the Mon Ridge (North Atlantic spreading belt with the average speed of extension about 3 cm per annum) their contribution is 5 times higher. Thus, the seismological data give evidences that the Arctic segment of the interplate boundary between Eurasian and North American lithosphere plates belongs recently to the transform geodynamic type, and only in the North Atlantics (within the Mon Ridge) a divergent type is still alive.

Аннотация. Выполнен анализ тензоров сейсмических моментов землетрясений, зарегистрированных в XX веке в Арктическом сегменте пограничной области, разделяющей Евразийскую (ЕА) и Северо-Американскую (СА) литосферные плиты. Показано, что сейсмически активные зоны сосредоточены в срединно-океанических хребтах (СОХ) Мона, Книповича и Гаккеля. Источники сейсмической эмиссии представлены двумя типами: *DC* (сдвиговых тектонических движения) и *NDC* с доминированием растяжения (раздвиги, области сферического расширения над вулканическими очагами). В Арктических хребтах Гаккеля и Книповича, характеризующихся средней скоростью спрединга 0,5-2 см в год, на долю землетрясений типа *NDC* приходится всего 9 % энергетической разрядки, тогда как в СОХ Северной Атлантики, имеющих скорость расширения около 3 см в год, их вклад в пять раз выше. Это различие может свидетельствовать о том, что Арктический сегмент области сочленения ЕА и СА плит в настоящее время находится в режиме трансформной границы, обеспечивающей вращение ЕА плиты против часовой стрелки, а дивергентный режим межплитного раздела сохраняется лишь в хребте Мона.

Key words: seismicity of the Arctic, geodynamic regime of interplate boundary, Eurasian and North American lithosphere plates
Ключевые слова: сейсмичность Арктики, геодинамический режим межплитной границы, Евразийская и Северо-Американская литосферные плиты

1. Introduction

The area of the Spitsbergen Archipelago is a place where the passive continental edge of the Eurasian lithospheric plate is jointed to the area of modern oceanic forming in the North Atlantic and West Arctic. In the oceanic part of the region seismic activity is concentrated in mid-ocean ridge belts (MORBs) of Mon, Knipovich, Gakkel, and into the Spitsbergen Fracture Zone (SFZ) as well. The faults of SFZ have north-western orientation and cross both a continental slope and MORB in the local spreading centre Molloy. Within a continental segment of the Eurasian lithosphere plate an active seismicity is observed in the Western margin of the Barents Sea shelf, including the Spitsbergen Archipelago and neighboring areas of sea bottom. According to the modern seismo-tectonic model (*Yudakhin et al.*, 2003) seismic events are caused by wave deformation processes, generating in the MORBs, and so tension (compressive) strains have to dominate shear dislocations.

Traditionally it is supposed that the earthquake is linked with shear displacements caused by the tangential stress accumulated as a result of tectonic deformations. Such displacements appear if an absolute value of a shear stress exceeds a friction force in the plane of fault. The equivalent system of forces for displacement along the fault is a pair of force couples without net torque (a "double couple" or DC model) (*Julian et al.*, 1998).

Increasing density and sensitivity of seismological networks together with new methods of estimating an earthquake source allowed to reveal a presence of "non double couple" (NDC) component in some earthquake sources corresponding to explosive or implosive events. Such component appears in areas with volcanic or geothermal activity (*Julian et al.*, 1998) in association with shear displacements and crack opening caused by tension in the source neighborhood. If a seismic source has a NDC component, its fault plane solution cannot be described by a pair of force couples. Moment tensor of such earthquakes has to contain compensated linear vector dipole (CLVD) component as well (*Lay, Wallace*, 1995).

The present paper is devoted to revealing earthquakes with the essential (NDC) component within the sector of the circumpolar area: from -7° till 120°E and from 72° till 90° N (Fig. 1). The research was based on the data taken from CMT catalog containing seismic moments and seismic moment tensors.

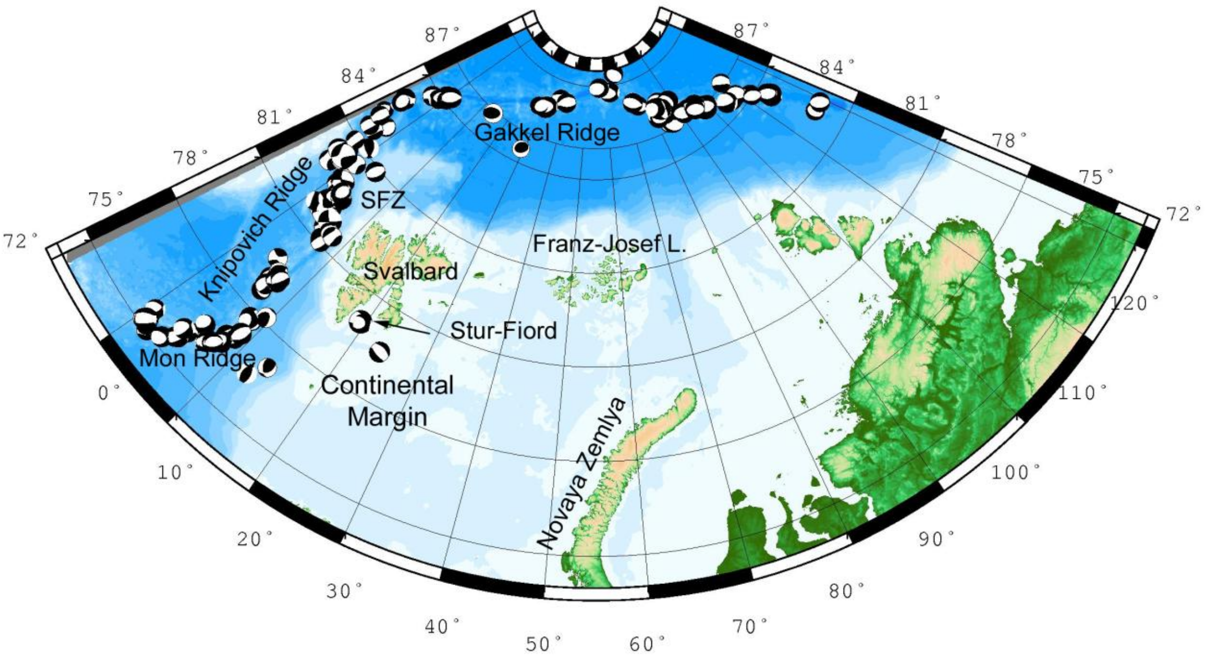

Fig. 1. Seismic zones and fault plain solutions of strong earthquakes occurred in the North Atlantics and Arctic for the period 1977-2011 (based on the CMT Catalog data)

2. Research methodology

To describe an earthquake source we have used a seismic moment tensor, M, which is connected with displacement field by the following relation (*Aki, Richards*, 1980):

$$u_n = M_{pq} * G_{np,q}\,, \qquad (1)$$

where u_n (n = 1, 2, 3) is the component of displacement; $G_{np,q}$ is the derivative of Green function, which gives displacement component number p caused by single forces along the q direction; * denotes a convolution. The seismic moment tensor is symmetrical and has 6 independent components characterizing deformation field at the source. *S. Yunga* (1979) assumed that a type of deformation type (shear, tension or compression) might be recognized by means of computation the Lode-Nadai index:

$$LN = 3V_2 / (V_1 - V_3), \qquad (2)$$

where $V_1 \geq V_2 \geq V_3$ are eigenvalues of the tensor M. The LN index allows estimate a type of deformation:

if $-0.3 < LN < 0.3$ the shear deformation dominates,

if $LN > 0.3$ (or < -0.3) the compressive (tension) strain dominates.

We calculated LN values for all Arctic earthquakes listed into the CMT Catalog (Fig. 1). To measure a partial contribution of the NDC earthquakes to a seismic energy release in a different areas we used a relation of their total seismic moment to the seismic moment of all earthquakes occurred in the aimed area. The seismic moment is defined by $M_0 = \mu Su$, where μ is the shear modulus of rock (Pa), S is the area of the rupture along the fault (m^2), and u is the average displacement on S (m). Physically, seismic moment is a work which was made by an earthquake during displacement of the rock blocks. One can define M_0 of an earthquake from the moment tensor.

3. Results

Distribution of recent strong earthquakes in the Northern Atlantics and Arctic MORBs is shown in Fig. 2. The share of the NDC earthquakes and their contribution to a seismic energy release is indicated in Table. As it is revealed, 25.5 % of the recent earthquakes within NW and Northern segment of the interplate boundary, divided the Eurasian and North American lithosphere plates, have essential value of the NDC component. The total contribution of the NDC earthquakes in a regional seismic moment is 9.4 % only. On the shelf plate margin the significance of the NDC earthquakes is lesser as to MORBs (20 % of total ability and only 1.6 % in energy release). In the Mon Ridge rifting area the NDC earthquakes contribute up to 48.6 % of energy release.

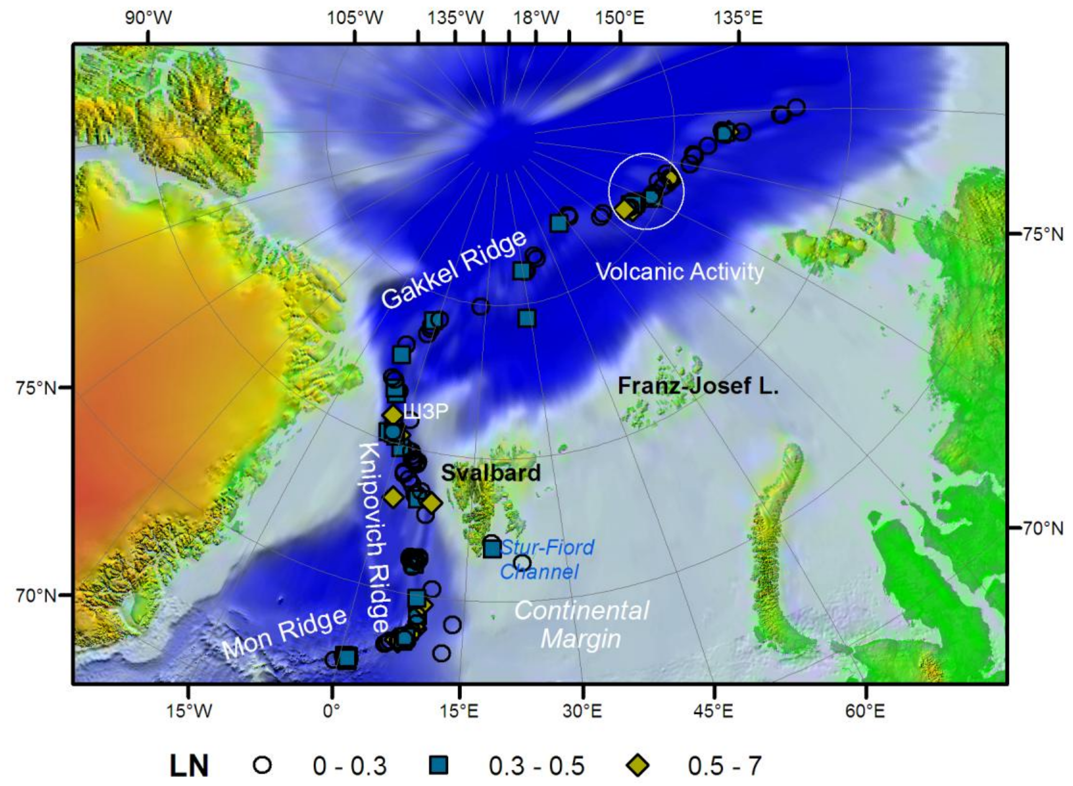

Fig. 2. Spatial distribution of earthquakes occurred in West and Central Arctic for 1977-2011 depending on their absolute values of the Lode-Nadai index (2)

Table. Part (%) of NDC earthquakes and their contribution to total seismic moment in seismic zones at the North West and Arctic margin of the Eurasian plate for period 1977-2011

Seismic Zone	1	2 (%)	3 (10^{16} Nm)	4 (%)
Continental Margin	5	20	189.87	1.62
Gakkel Ridge	69	23.19	1034.27	9.98
Knipovich Ridge + SFZ	58	25.86	3137.87	5.25
Mon Ridge	29	31.03	352.35	48.55
Total Area	161	25.47	4714.37	9.38

Note: 1 – total numbers of recorded earthquakes; 2 – percent of NDC earthquakes ($|LN| > 0.3$); 3 – total seismic moment (10^{16} Nm); 4 – part (%) of the seismic moment corresponds to NDC earthquakes.

4. Discussion

According to the common opinion, in the Knipovich and Gakkel ridges there is ultra slow spreading of oceanic bottom accompanied by volcanism. The spreading velocities on the Knipovich ridge are 0.15-0.5 cm per year (*Crane et al*., 1982); on the Gakkel ridge – 0.9-1.1 cm per year (*Michael et al*., 2003). In 1999 on the Gakkel Ridge a team of US submarine "Hawkbill" reported on a volcanic eruption, which was observed with the side sonars (*Tolstoy et al.*, 2001). The volcanic area location is shown in Fig. 2. It was the first verified volcanic phenomenon in the Arctic MORB. The eruption was contamporanious with "a local earthquake storm"

(252 events with the magnitudes *mb* from 3 to 5.5). The CMT catalog contains seismic moment tensors for 21 of those earthquakes. Their total seismic moment is equal to $299.3\cdot10^{16}$ Nm and 7 of the earthquakes have essential NDC component ($0.3< |LN| < 0.62$). Total seismic moment of NDC earthquakes from the storm is equal to $71.1\cdot10^{16}$ Nm, i.e. these 7 events generated 23.8 % of the storm seismic moment. Thus, this parameter is a reliable marker for distinguishing the volcanic area in other parts of the Gakkel Ridge, where the NDC earthquakes control about 10 % of seismic moment (Table). As for the Gakkel Ridge as a whole, one can see that 76 % of earthquakes were caused by shear dislocations under tangential stresses (Table). DC earthquakes generated more than 90 % of total seismic moment in the ridge. A bit more NDC earthquakes are observed in the Knipovich Ridge and SFZ (Fig. 2, Table).

The major contribution of volcanic processes and rifting to the local seismicity was revealed in the Mon Ridge: the NDC earthquakes generate here > 48 % of total seismic moment. As opposed to this zone the Knipovich Ridge together with crossing it SFZ has the minimal contribution of NDC earthquakes to the total seismic moment (5 % overall).

In contrast to the MORBs, the shelf plate margin has less essential NDC earthquakes. The major parts of earthquakes (4 of 5) and total seismic moment (more than 98 %) of the continental margin are controlled by shear dislocations under tangential stresses (Table). This fact corresponds to traditional view on seismicity.

The above estimation of spatial distribution of NDC earthquakes made for West and Central Arctic part of MOR has led to the following unexpected result. Instead of dominating earthquake sources provoked by the Earth crust spreading or explosion processes in volcanic apparatuses we have seen prevalence of shear strains along the full length of the Mon, Knipovich, and Gakkel ridges bounding northwest part of the Eurasian lithospheric plate.

Thus, in the present time (at least during 100 years of instrumental seismic monitoring in Arctic) major geodynamic process is not a divergent movement of the Eurasian and North American plates but a counter-clockwise rotation of the Eurasian plate. According to this point of view the interplate border, made in the Arctic by the Gakkel and Knipovich ridges, has to be treated as a transform boundary.

5. Conclusion

Tectonic situation and earthquake genesis in the Knipovich and Gakkel Ridges, which form the NW and Northern segment of border between Eurasian and North American lithospheric plates, require more detailed investigation. The revealed pattern of the NDC earthquakes spatial distribution in these areas do not correspond to the geodynamic models which explain that a regional seismicity is controlled by spreading of ocean bottom in the North Atlantic and in Arctic, because the major contribution to the total seismic moment in the Arctic MORBs recently is linked with NDC earthquakes caused by shear dislocations.

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