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Research paper

Seismicity, structure and tectonics in the Arctic region

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A B S T R A C T

The "Arctic" region, where the North Pole occupies the center of the Arctic Ocean, has been affecting the environmental variation of the Earth from geological time to the present. However, the seismic activities in the area are not adequately monitored. Therefore, by conducting long term monitoring of seismic phenomenon as sustainable parameters, our understanding of both the tectonic evolution of the Earth and the dynamic interaction between the cryosphere and geosphere in surface layers of the Earth will increase. In this paper, the association of the seismicity and structure of the Arctic region, particularly focused on Eurasian continent and surrounding oceans, and its relationship with regional evolution during the Earth's history is studied. The target areas cover representative tectonic provinces in the Eurasian Arctic, such as the wide area of Siberia, Baikal Rift Zone, Far East Russia, Arctic Ocean together with Greenland and Northern Canada. Based on discussion including characteristics of seismicity, heterogeneous structure of the crust and upper mantle, tectonic history and recent dynamic features of the Earth's surface in the Arctic are summarized.

1. Introduction

The "Arctic" region, where the Arctic Ocean surrounds the North Pole, has been affected by environmental variation of the Earth in both short and long terms of time scale. As an example of the short term variation, the global warming currently in progress is the most significant phenomena to influence a rapid change in the cryosphere (sea ice, ice sheet, ice shelves, ice caps, glaciers) in the Arctic (IPCC, 2007). In contrast, a long term environmental variation during the Earth's history has been affecting the deformation of solid Earth underneath the cryosphere. The different variations of the surface environments in space and time can be measured and investigated using seismological and geological approaches. However, the seismological phenomenon attributed by seismicity, structure of the Earth and its dynamics in the Arctic have not fully revealed during last few decades. Therefore, when monitoring these parameters for long terms with a sustainable procedure, an understanding of both the tectonic evolution of the Earth and the dynamic interaction among the cryosphere–geosphere system is expected to be revealed.

Regarding seismicity and structure in the Arctic, the largest continent of the Earth; the "Eurasia" is the most significant factor involving global tectonics during Earth's history in terms of amalgamation and disposal of super-continents (Fig. 1). The continent is characterized by a complex composition with various crustal provinces in ages from the Archean to Phanerozoic (Maruyama et al., 2007; Pisarevsky et al., 2008). These tectonic terrains have grown their areas with mutual interaction, evolving from several nucleuses of the Precambrian cratons, followed by adjacent mobile belts, recent subductions, the rift systems and other tectonic active areas. An increase of knowledge on seismicity and tectonics in the Arctic region could give rise to a better understanding of the evolutional process of the Earth, viewed from high northern latitude. Identification of the growth process, formation mechanism of the super-continents and super-plumes have significance in the effort to learn more about the structure and dynamics of deep interior, as well as the interaction between the mantle-core system and the surface layers of the Earth.

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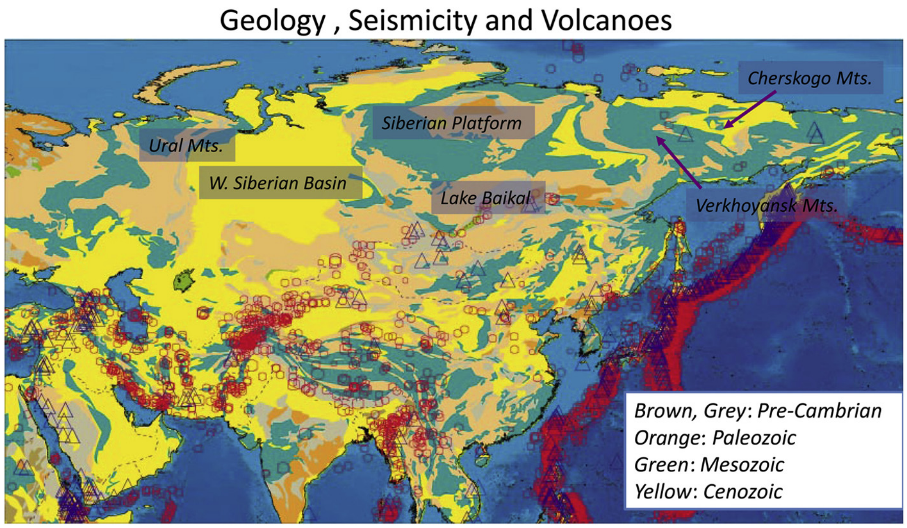

Figure 1. Distribution of tectonic provinces, seismicity and volcanoes in Eurasian continent and surrounding regions (after database of Cornell University; the world geology map, seismicity is after the International Seismological Centre (ISC), 2011). Tectonic provinces are classified as follows: Pre-Cambrian (brown; Archaean, gray; Proterozoic), Paleozoic (orange), Mesozoic (green), Cenozoic (yellow).

A justification of the development of seismic networks in the Arctic with respect to both the unique aspects of seismology in a polar region and general issues that would be common to global Earth sciences; for example: lithospheric dynamics in an ice-covered environment; how lithospheric processes drive and may be driven by global environmental change (sea level, climate); the scale and nature of rifting as a process that has shaped a continent and dominated its evolution; the role of Antarctica as the keystone in the supercontinent formation and break-up throughout Earth's history; how the tectonic and thermal structure of the Antarctic lithosphere affect current ice sheet dynamics; age, growth, and evolution of the continent and processes that have shaped the lithosphere; the effect of improved seismic coverage on global models of the lithosphere, mantle, and core.

The International Polar Year (2007–2008) was a great opportunity to fulfill the Arctic seismic deployment in an attempt to achieve these targets (Rapley et al., 2004). During the IPY, many internationally collaborating geo-scientific projects were conducted in the polar regions, such as the Polar Earth Observing Network (POLENET) and the Antarctica's Gamburtsev Province (AGAP) (Wilson and Bell, 2011). These inter-disciplinary projects aimed to monitor the present status of environmental variations of the Earth, as viewed from polar regions, and simulating future activities of human beings. In the Arctic and Antarctic, development of seismic networks was achieved to study the interior of the Earth, dynamics and seismicity in polar regions.

In this paper, the seismicity and structure of the Arctic region, in particular focused on the largest continent of the Earth; the Eurasia and surrounding oceans, are demonstrated associated with the relationship to their regional evolution during Earth's history. The target areas cover several tectonic provinces of the Eurasian Arctic, such as the broad areas of Siberia, Baikal Rift Zone, Far East Russia, Arctic Ocean as well as Greenland and northern Canada. Seismic evidence is summarized with regard to the characteristics of seismicity, heterogeneous structure of the crust and upper mantle, tectonic history and recent dynamic features of the Earth's surface in the Arctic. The paper aims to demonstrate and reevaluate the relationship between the causes and effects in terms of seismicity and geodynamic processes in the Arctic, as well as how these investigations may fruitfully are influencing on the present surface ongoing dynamics of the Earth among global environmental variability.

2. Eurasian Arctic

The present structure and past evolution of the lithosphere in the Eurasian Arctic, where the majority of areas belong to Russian Federation, provide unique information on the process of amalgamation and separation of the past super-continents (Maruyama et al., 2007). The current status on lithospheric environment, moreover, gives rise to a unique aspect on the formation process of super-continent in future. The largest continental block on the present Earth, Eurasia, has been formed by assembly of several sub-continental blocks including Asia, India and Europe. The continent is also considered to be the nucleus of a future super-continent, which is expected to be formed about 250 myr after the present (Rosen, 2003; Maruyama et al., 2007; Pisarevsky et al., 2008). In this Chapter, several topics on lithospheric structure and evolution are demonstrated on the basis of recent studies of northern Eurasia, in particular focused on Siberia in the Russian Arctic.

Characteristic features of the Eurasian continent are attributed by the existence of various tectonic provinces over time from the Archean to Phanerozoic (Fig. 1). These tectonic terrains have been evolved from the nucleus of Precambrian cratons (Pisarevsky et al., 2008), followed by interaction with adjacent Proterozoic mobile belts (orogens), Mesozoic and Cenozoic terrains, the recent subduction, rifts and lithospheric deformed areas (Nokleberg et al., 2001). A remarkable growth processes in some terrains was revealed. For example, crustal structure of the Ural Mountains represents the frozen architecture of the paleo conversion tectonics inside the present lithosphere (Suvorov et al., 1997, 2002; Brown et al., 2006; Rybalka et al., 2007). Nikishin et al. (2010) discussed about the tectonic evolution of the Siberian Platform during the Vendian and Phanerozoic, to the present time evolution of the Siberian paleo-continent with the Siberian Craton making up its nucleus. They showed that the paleo-continent underwent significant intra-plate compression deformations with vertical movements and formation of inversion structural features within broad areas.

Seismicity of northern Eurasia and the surrounding area is found to be concentrated along the subduction zones in Western Pacific Ocean, with connection towards the inland high mountains such as the Himalaya (Figs. 1 and 2). The other tectonic regions hold relatively low seismicity, in distribution across large areas of the inland