Chapter 5

Studies on Seismicity in the Polar Region

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Additional information is available at the end of the chapter

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Abstract

During the International Polar Year (IPY 2007–2008), several seismological research studies have been conducted as a part of geophysical observations in bipolar regions. In this chapter, recent studies involving seismicity in bipolar regions are introduced on the basis of compiled data from the International Seismological Centre (ISC). The relationship between the present seismicity and the heterogeneous structure of the crust and upper mantle is discussed, together with a review of geoscientific achievements in terms of the tectonic history of the Earth.

Keywords: seismicity, polar region, IPY, International Seismological Centre, GIA, tectonics

1. Introduction

After a half-century of the International Geophysical Year (IGY 1957–1958), the International Polar Year (IPY 2007–2008) was conducted in tight collaboration with related scientists around the world in bipolar regions. During the IPY, various kinds of interdisciplinary and international projects had been carried out so as to figure out the future images for human beings by monitoring the Earth's environmental changes from a viewpoint of the "polar window" at high latitudes. In both the Arctic and Antarctic, particularly Greenland and Lapland, improved seismic observation networks have been established in order to monitor both the global and regional seismicities in addition to conducting studies on the Earth's interiors.

The polar region, particularly the Arctic (here defined as the area within the "Arctic circle" and surrounding low-latitude terrains), which is centered in the Arctic Ocean, has been strongly affected by global warming, which is currently progressing. Particularly, shrinking in time and space, the sea ice and the ice sheet (i.e., the cryosphere) have been drastically altered. However, their influence on the underlying solid Earth and the dynamics involving cryosphere evolution (particularly for the generation of "seismicity") have not been understood well enough to explain the relationship. To continuously monitor the dynamics of polar ice sheet/caps and sea ice from the point view of "seismology," a long-term monitoring of changes in ice mass and their transport the polar region is expected to be conducted, in order to understand the present plate motions from the tectonic history of the Earth.

In this chapter, recent studies involving seismicity in bipolar regions during the IPY are introduced on the basis of the compiled data from the International Seismological Centre (ISC). A relationship between the present seismicity and the heterogeneous structure of the crust and upper mantle is especially focused on, as well as the importance of geoscientific investigations in relation to tectonic history of the Earth.

2. Antarctic region

Seismicity around the Antarctic region is mainly concentrated at the plate boundaries between the Antarctic Plate, with the Antarctic continent situated in the center, and its surrounding plates (Australian, South American, African, and Indian subcontinents). Most plate boundaries are under the influence of extensional tectonic regimes: oceanic spreading ridges and transform faults. Inside the Antarctic Plate, both in the Southern Ocean and in the Antarctic continent, there are relatively small number of seismic events compared with other tectonic provinces (geological terrains) of the globe. Particularly for East Antarctica, where majority of the continental blocks are composed of several Precambrian age terrains, quite a few number of tectonic- and volcanic-origin seismic events have been identified [1–4]. In contrast, West Antarctica including the Antarctic Peninsula has been composed of relatively younger geological terrains formed after the Paleozoic age. Local earthquakes within the crust and volcanic activities have been identified from the West Antarctic Rift System (WARS; see Figure 1 of Chapter 1) to the Marie Byrd Land (MBL) and the Antarctic Peninsula. Moreover, in the Scotia Plate, which is located to the northeast of the Antarctic Peninsula, high seismic activities have been recorded particularly near the South Sandwich Islands, where the subduction of tectonic regime has been developed at the eastern margin of the Scotia Plate as one of the remaining portions of the Southern Atlantic Ocean, spreading effects between the South American and African continents ([4], **Figure 1**).

Seismicity of East Antarctica and adjacent Southern Ocean (the Indian Ocean sector including the Eastern Dronning Maud Land and Enderby Land, which contains the Japanese Syowa Station) was activated by the occurrence of the largest earthquakes in the last half-century within the Antarctic Plate (Balleny Island region, M 8.0, March, 25, 1998) and the Sumatra-Andaman earthquakes (M 9.0, December, 26, 2004). Characteristic time-space distributions of seismicity were identified corresponding to the variations in the tectonic stress field within the plates around the earthquake focal area of these large events, spreading ridges and transform faults of the Southern Ocean, together with the Wilkes Land in East Antarctica [1, 4]. The Balleny Island earthquake is considered to be an inner plate deformation at the triple-point among the

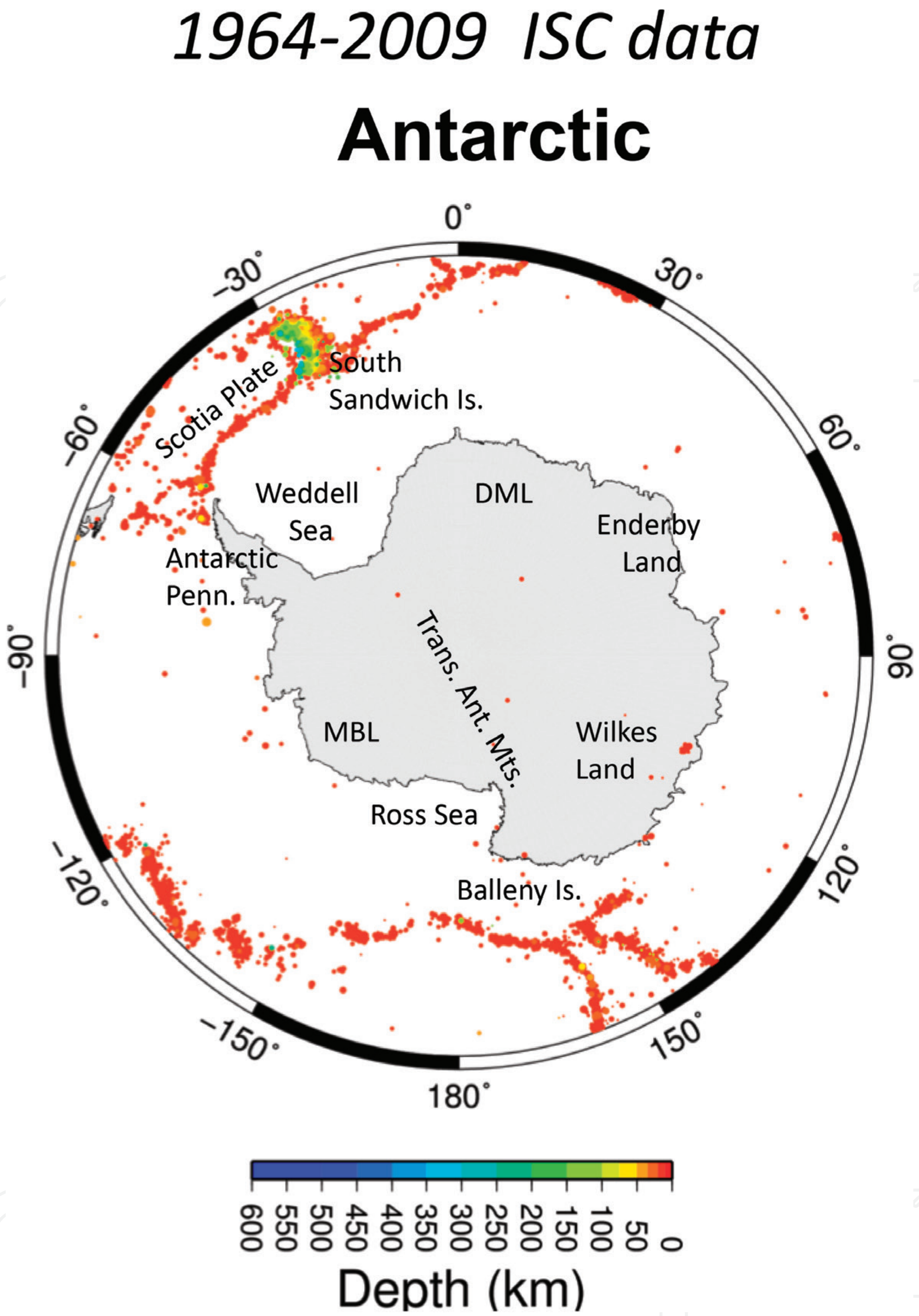

Figure 1. Seismicity of the Antarctic from compiled data from ISC (1964–2009; modified after [4]). Copyright Clearance Center (CCC, http://www.copyright.com/). License Number: 4276351216219, License date: January 26, 2018.

Pacific Plate, Indian-Australian Plate, and Tasmania microplate [5, 6], the unique point among the stress field inside the Antarctic Plate because of the fracture zones across the sea mountain just above the hypocenter [7], as well as the effects of crustal deformation after deglaciation [8, 9]. Regarding the aftershock activities of the Balleny Island earthquake, statistical analysis was carried out to obtain time-space variations for long-period fluctuations [10]. Before and after the Balleny event, static seismic activity except aftershocks has been drastically changed, and raapid increase in the tectonic stress field within the Antarctic Plate was statistically identified (**Figure 2**). It is assumed that the large earthquake events were generated in tectonically nonactive and nonvolcanic regions around Antarctica, by combined effects of inner-plate deformation of the oceanic lithosphere according to the stress concentration caused by the plate movement, in addition to the stress drop related to deglaciation.

The Sumatra-Andaman earthquakes (M 9.0, December, 26, 2004), the largest seismic events around the region of the Indian-Australian Plate, and their relationship with the seismic activities at the Indian sector of the Antarctic Plate have been investigated [11]. Before one decade of the Sumatra-Andaman earthquakes, there were quite a few events more than M. 7.0 at the oceanic ridges between the African Plate and the Indian-Australian Plate except for the Balleny Island event in March 1998. In contrast, there had been no earthquakes more than M. 7.0 at the oceanic ridges and transform faults of the Indian sector of the Antarctic Plate in the same decade. Moreover, the number of events more than M 6.0 were limited within 30 during the same decade. In addition to these events, after the Sumatra-Andaman earthquakes, characteristic seismic activities were identified around the eastern ridges of the Australia Antarctic

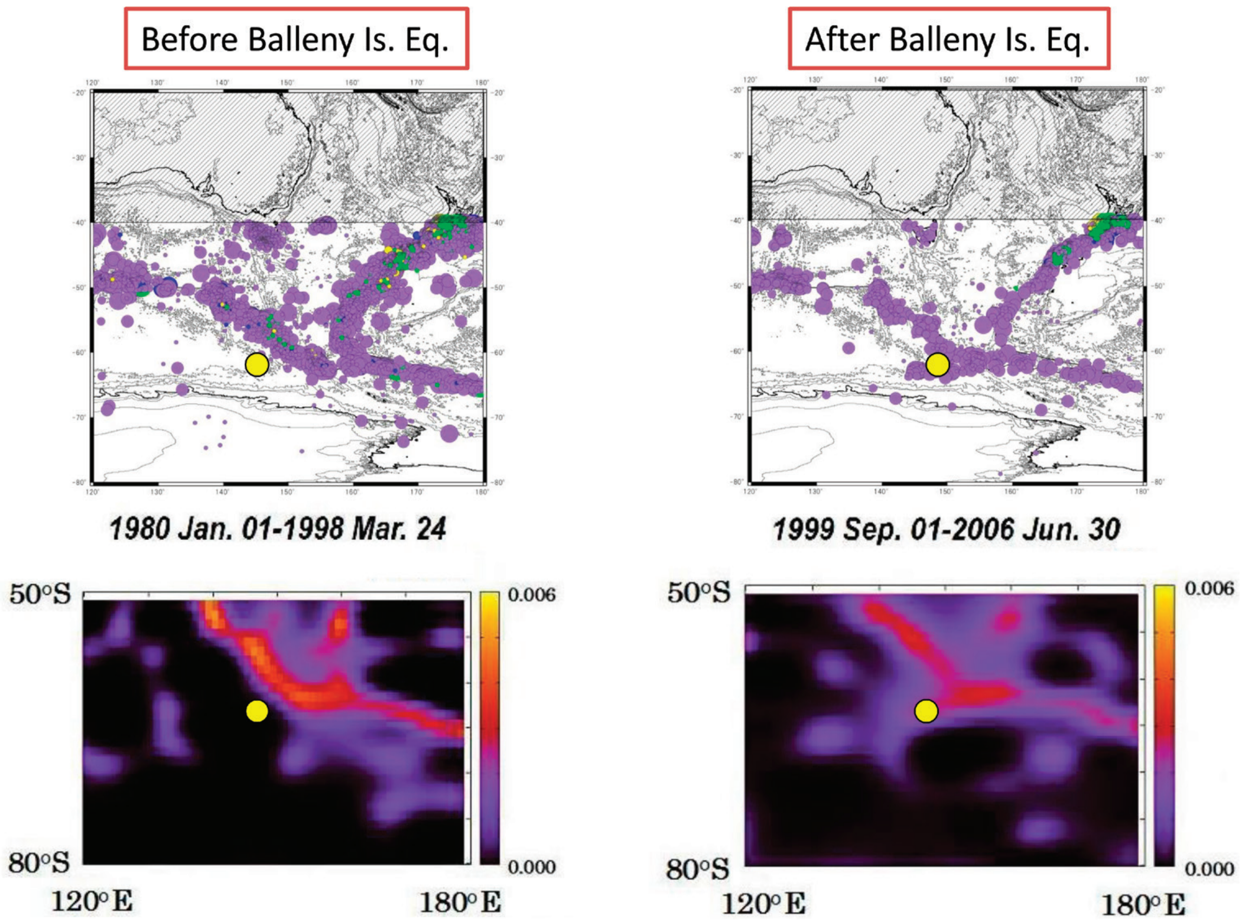

Figure 2. Time-space variations before and after the Balleny Island earthquake marked by yellow circle (March 25, 1998) [10] (upper, hypocentral distribution; lower, stationary activities determined by statistic method). Copyright Clearance Center (CCC, http://www.copyright.com/). License Number: 4276361324576, License date: January 26, 2018.

Discordance (AAD) [11]. From these evidences of events occurring at the ocean bottom like in the Southern Ocean, it is possible to say that the existence of microearthquakes cannot be recorded by the existing observation networks. In summary, in the inner part of the Antarctic Plate, particularly in the oceanic region surrounding the Antarctic continent, seismicity has generally been low and tectonically stable except for the focal regions of two large earthquakes in the last two decades as mentioned earlier [11].

Among the earthquakes around the Antarctic Plate, in addition to the middle-to large events as mentioned earlier which are recordable by the present global networks, there are characteristic "local events" in particular located around the margin of the Antarctic continent. The activities of these local events are quite low on average; however, the earthquakes are considered to be of tectonic origins within the crustal depths mostly associated with glacial isostatic adjustment (GIA), related to the transform faults at the ocean bottom and coastal margins of the continent. For example, the number of local events that occurred near the Syowa Station, East Antarctica, was only one in a year during the last decade [12, 13]. Hypocenter of these local events concentrated on the boundary between the continent and the ocean, that is, the coastal line at the margin of the continental ice sheet, ice shelf, and glaciers. There is a possibility for these events to be reported as tectonic events (inner crustal events) rather than ice quakes. (Details of the "ice quakes" (cryoseismic events) are given in Chapter 7.) In other areas of the Antarctic, several hypocenters of the local events were reported by individual regional networks; many of them were determined near the coastal areas, particularly at the edges of large glaciers [14–16]. Many of these events could be explained by cryosphere dynamics as mentioned in detail in Chapter 7.

With these evidences regarding seismicity in the Antarctic, methods for detecting seismic events in the polar region have been developed in the last two decades, particularly the onshore area for the improvement of both seismographs and observation networks. However, a long-term monitoring of seismicity including the oceanic area of the Southern Ocean, as a significant portion of the global network, is also expected to be conducted. These developments in the polar region could efficiently contribute to the prediction of global seismic activities, together with providing early warning such as tsunami waves affecting the polar region.

3. Arctic region

Seismicity and related seismological research studies/observations in the Arctic region before the IPY are discussed in detail by [17]. Recently, compiled data from the International Seismological Centre (ISC) represent the general image of seismicity in the Arctic region [4] (**Figure 3**). Major seismicity in the Arctic region can clearly be traced along the plate boundaries from the Northern Atlantic Ridges, the Barents Sea, the Gakkel Ridge within the Arctic Ocean, the Laptev Sea in the northern part of Siberia, to the Far East region of Russia. On the other hand, seismicity involving subducting plates and deglaciation process associated with GIA can be seen around the Alaska and the Baltic Sea, and others. Seismic activities in the Lapland, northern Europe, relating to GIA, are reported in detail by [18], in which

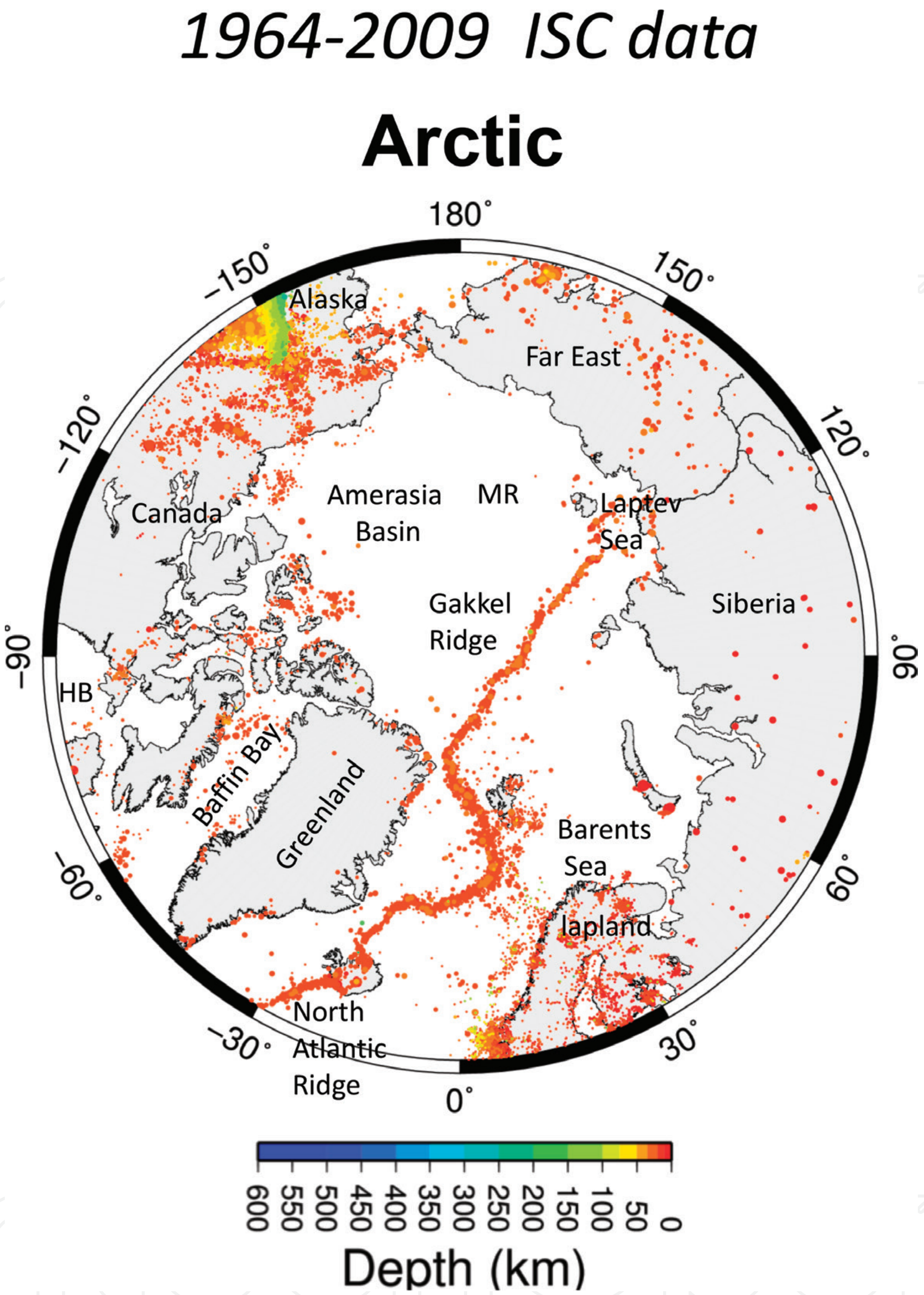

Figure 3. Seismicity of the Arctic from compiled data from ISC (1964–2009; modified after [4]). Copyright Clearance Center (CCC, http://www.copyright.com/). License Number: 4276351216219, License date: January 26, 2018.

the seismic events were recorded by the Lapland Network (LAP-NET) deployed during the IPY. Moreover, local earthquake events have occurred around Greenland, Baffin Island, and Eastern Canada (**Figure 4**). Since these areas are known to be tectonically stable terrains in the geological framework, these events are assumed to mostly be of cryoseismic origins such as the glacial earthquakes, or characteristic events relating to GIA. In contrast, around the area of northern Eurasia, seismicity and tectonics of Russian Far East and Eurasian Arctic, and Siberian regions were summarized in detail by [17]. Relationships among seismicity and volcanic activities, crustal structure, plate movement surrounding Eurasia, and complex tectonic history of the continent were discussed for individual tectonic terrains.

During the IPY, crustal structure and microseismicity of the Gakkel Ridge-Amerasia Basin area were studied by conducting geophysical surveys at the oceanic bottom of the Arctic Ocean [19–22]. A new catalog of seismicity in the midocean ridges in the Arctic Ocean was produced by combining data on teleseismic events compiled from ISC for more than three decades and local seismic events along the ridge detected by using seismometers at the oceanic bottom and over the drifting ice floes [19]. Variations in seismic activities along the ridge were considered to be affected by the ultraslow spreading processes, characterized by having larger earthquake production in magma-rich regions along the rift system. In addition, increases in seismicity of the European Arctic were revealed by making use of a joint processing of the event catalog data from different adjacent seismic networks, such as NORSAR and the International Data Centre (IDC) belonging to CTBTO [20]. The increased areas of seismic activity revealed by the joint processing approach have been found along the Gakkel Ridge to the northern part of the Svalbard Islands, as well as the Franz-Josef Land archipelagos.

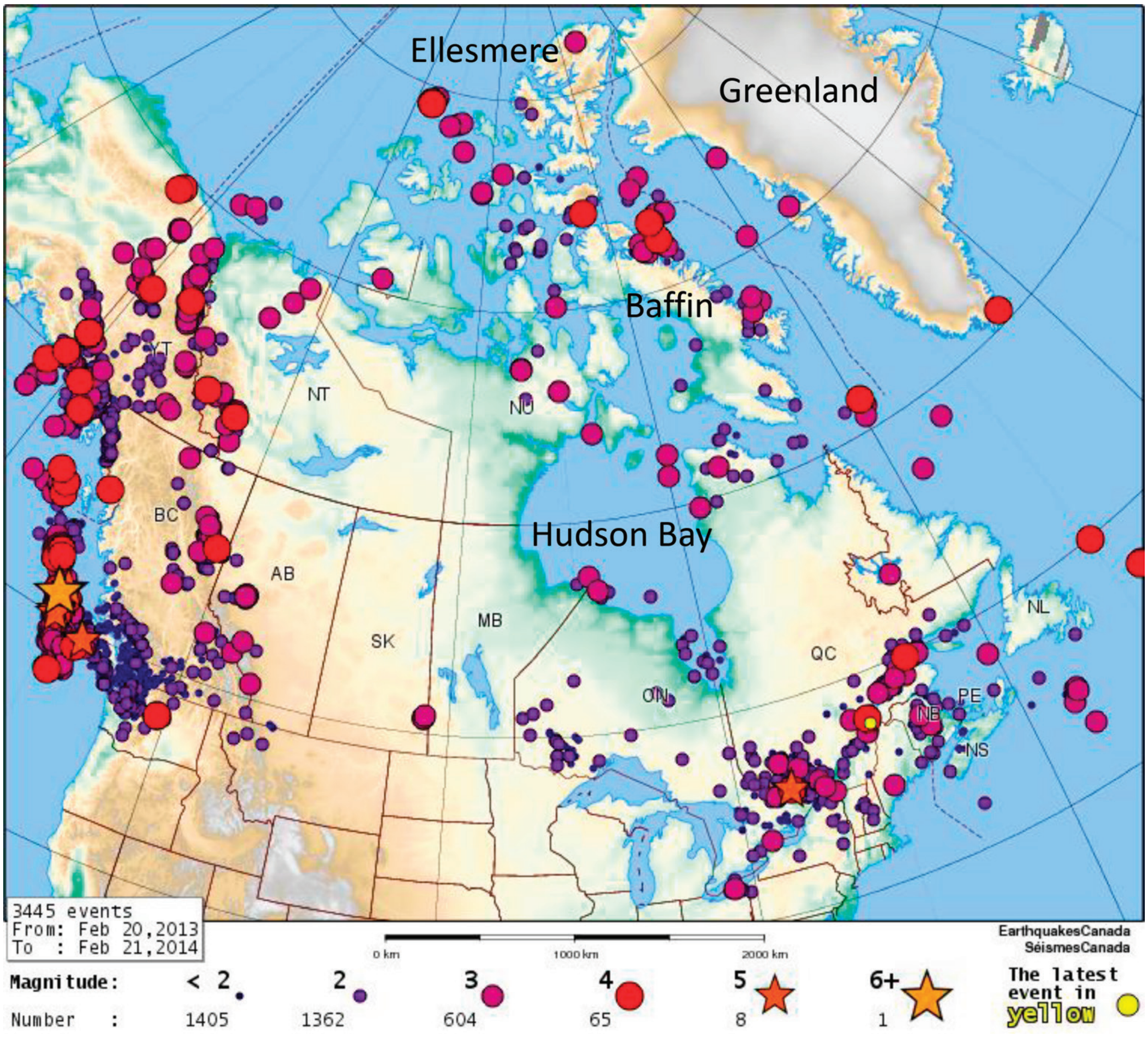

Figure 4. Seismicity around Canada, Alaska, and Greenland (2013–2014). Hypocentral data are from Natural Resources Canada. Copyright https://www.nrcan.gc.ca/home.

Microseismic activities that cannot be detected by deploying global networks have been identified around the remote plate boundaries from the continents such as the oceanic ridges and transform faults by utilizing several kinds of transportable seismographs and hydrophones deployed on sea ices, icebergs, as well as oceanic bottoms (for instance, in the case of the Antarctic Peninsula; see [22]). It is also possible to detect and monitor seismicity by making use of the arrival times and waveforms of the T phases, which propagate within the ocean. In future, microseismic activities and fine crustal structure will be clarified at the sea bottom frontiers in bipolar regions such as the area beneath the Arctic and the Southern Oceans.

4. Summary

In this chapter, seismicity of bipolar regions was reviewed, in relation to surface environment, crustal structure, and tectonics. Majority of the parts of bipolar regions are occupied by relatively stable tectonic provinces, with various evolution histories, subducting slabs, collisions at plate boundaries, deformation inside the continents, upwelling of mantle plumes, extension stress regimes, and so on. Moreover, arapid climate change surrounding the surface layers of the Earth, especially due to the recent global warming, might be affected by the activation of seismicity involving cryosphere dynamics and evolution. On the other hand, geophysical surveys and microseismic monitoring of oceanic bottom have been sufficiently conducted in polar regions so far [23]. Accumulating high-quality seismic data from polar regions through both the global and local networks could firmly contribute to understand the characteristics of seismicity, time-space distribution, and their relationship with structure and dynamics of the crust, and overlying ice sheet, sea ice, and the other cryosphere evolution.

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