Reconstructing Paleozoic and Mesozoic tectonics of Novaya Zemlya, Arctic

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1. Background

The Novaya Zemlya archipelago is a predominantly NW-verging, early Mesozoic fold-thrust belt that exposes Precambrian to early Triassic successions. It lies on the eastern Barents Sea Shelf and formed near the junction of the palaeocontinents of Baltica and Siberia (Fig. 1). Little is known about its deeper structure and the basement history of the adjacent Barents and Kara shelves. The principal phase of compression in Novaya Zemlya is considered to be early Mesozoic in age. However, the exact timing of this deformation, the associated cooling and exhumation, and its link to Mesozoic deformation events in neighboring regions, such as Taimyr and Pai-Khoi, remain unknown. We present the first study of Neoproterozoic to Permian sedimentary rocks from southern and northern Novaya Zemlya that combines provenance and thermochronological analyses – that is, detrital zircon U-Pb geochronology and apatite and zircon fission track (FT) thermochronology – to integrate cooling and exhumation events with the tectonic evolution of Novaya Zemlya.

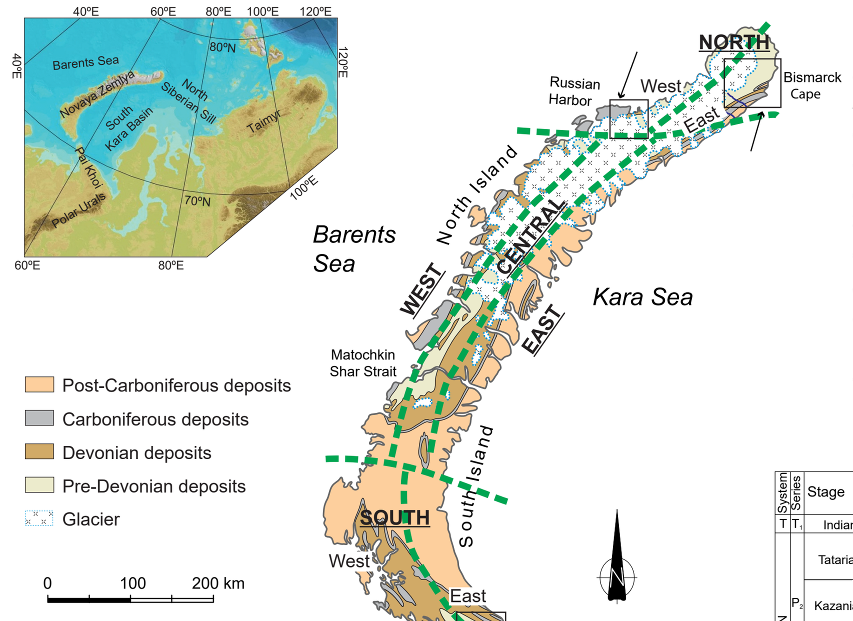


Fig. 1. Geological map of Novaya Zemlya (modified from Lorenz et al. 2013). Squares indicate sample locations. The smaller map shows the regional setting of the Novaya Zemlya fold–thrust belt on the bathymetric map of Jakobsson et al. (2012). Based on sedimentary lithology, northern, western, central, eastern and southern regions are recognized.

2. Sampling & Methods

This study focuses on the northern and southern regions (Figs 1 & 2), each of which can be divided into a western (Barents Sea coast) and eastern (Kara Sea coast) portion. We collected 16 sedimentary rock samples for this study. Ten samples are from the north island of Novaya Zemlya near Russian Harbor and Bismarck Cape and six samples are from the southeastern extremity of Novaya Zemlya (Fig. 1). The samples include siltstones, sandstones and conglomerates with stratigraphic ages ranging from late Silurian to early Permian (Fig. 2).

Methods include:

1. Detrital Zircon U-Pb Dating
2. Apatite Fission Track Dating
3. Zircon fission Track Dating

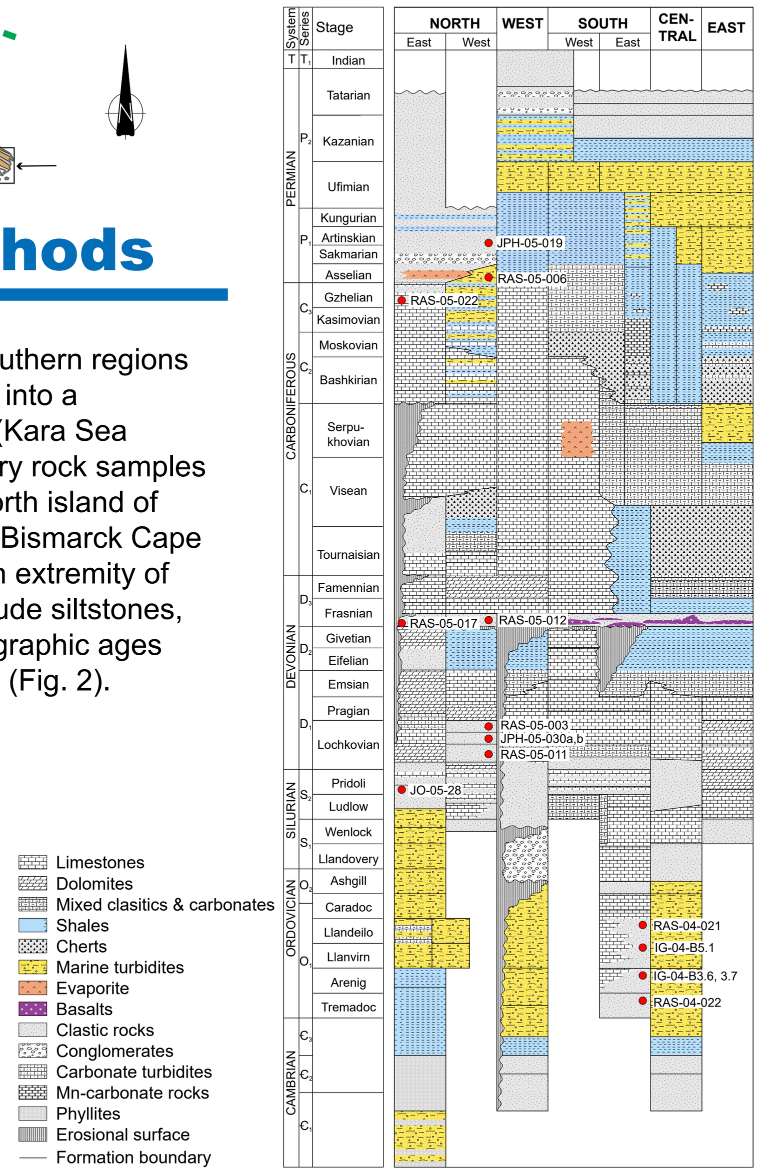
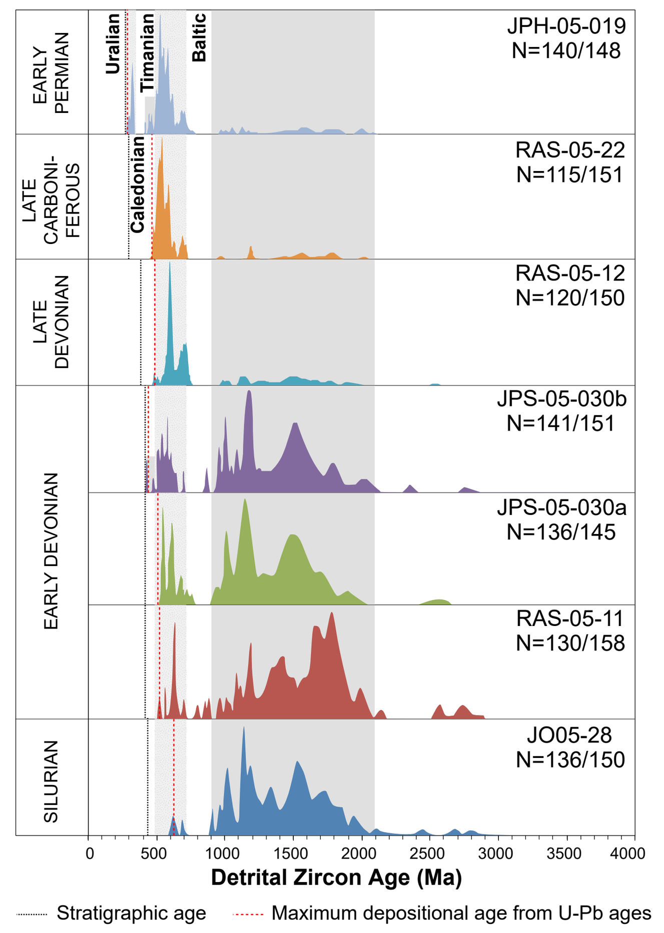


Fig. 2. Generalized stratigraphy and sedimentary facies for the Cambrian and Palaeozoic successions of Novaya Zemlya (modified after Sobolev et al. 2004).

3. Results

3.1 Detrital zircon U-Pb Dating



The detrital zircon age spectra of seven samples contain 2.0-0.9 Ga and 700-490 Ma zircons in varying proportions. From the early Devonian to late Devonian, the 2.0-0.9 Ga ages decrease dramatically, whereas the 700-490 Ma ages become dominant. Zircons of 336-302 Ma ages appear in the early Permian sample. Very few zircons of 470-420 Ma exist in the early Devonian sample JPH-05-030b and the early Permian sample RAS-05-003. Maximum depositional ages are defined by the two or three youngest grains. For the Silurian to Carboniferous samples, the maximum depositional ages range from 626 to 450 Ma, consistently older than the depositional ages. The Permian sample's maximum depositional age of 310 Ma is closer to its known stratigraphic age.

Fig. 3. Normalized probability plot of U–Pb detrital zircon ages of Palaeozoic samples from Novaya Zemlya. The principle main age sources are shown as vertical grey bars.

3.2 Detrital zircon Fisstion Track Dating

The radial plots of single-grain FT ages (Fig. 4) show that the zircon FT central ages range from 324±22 Ma to 548±80 Ma (1σ), older than or equivalent to individual stratigraphic ages considering their uncertainties. The majority of single-grain FT ages of the seven samples are older than the stratigraphic ages, with only a few younger grains considering their uncertainties. This indicates that the fission tracks of zircons in all samples have not been annealed since deposition and, hence, they preserve the cooling ages of their source rock(s). Most analyses show no extra-Posisson variation, apart from samples RAS-05-017 and JPH-05-030b, but their level of over-dispersion is not considered significant because only seven grains in each sample were countable. All of the zircon fission track results are represented by a single unimodal age component.

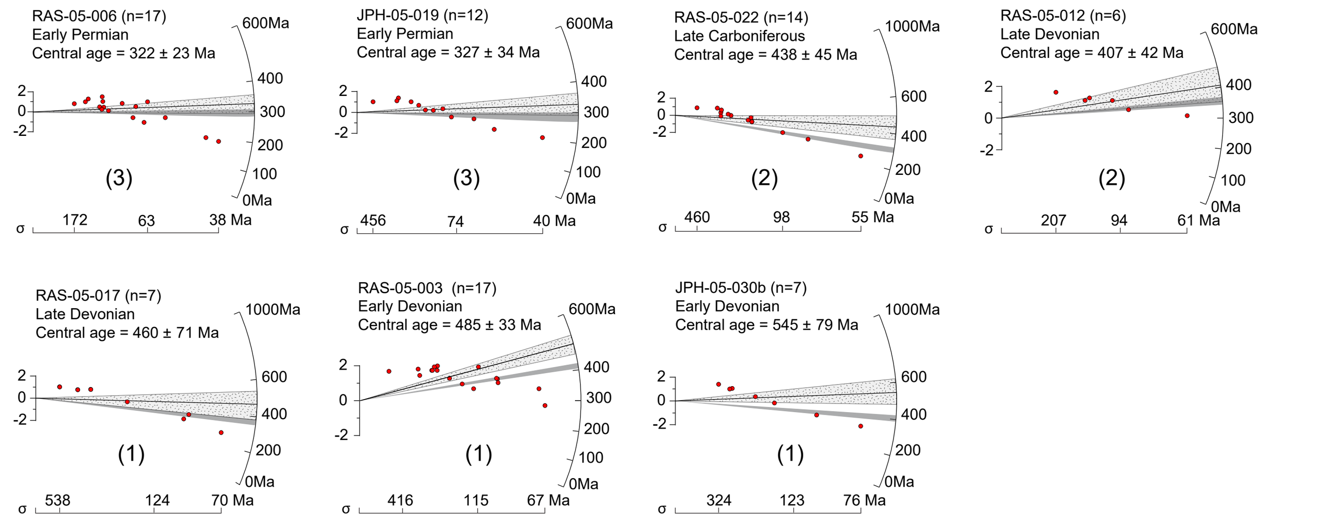


Fig. 4. Radial plots of the zircon fission track sample results from Novaya Zemlya. The shaded fan in each age spectra represents the depositional age of the sample and the solid line with the shaded pattern represents the central age of the sample. Each age has the unit standard error (+2σ) on the y-axis. Precision is indicated on the x-axis and the further the data point plots from the origin, the more precise the measurement. The age is read by extrapolating a line from zero through the plotted point to intercept the logarithmic age scale on the right perimeter.

3.3 Detrital Apatite Fisstion Track Dating

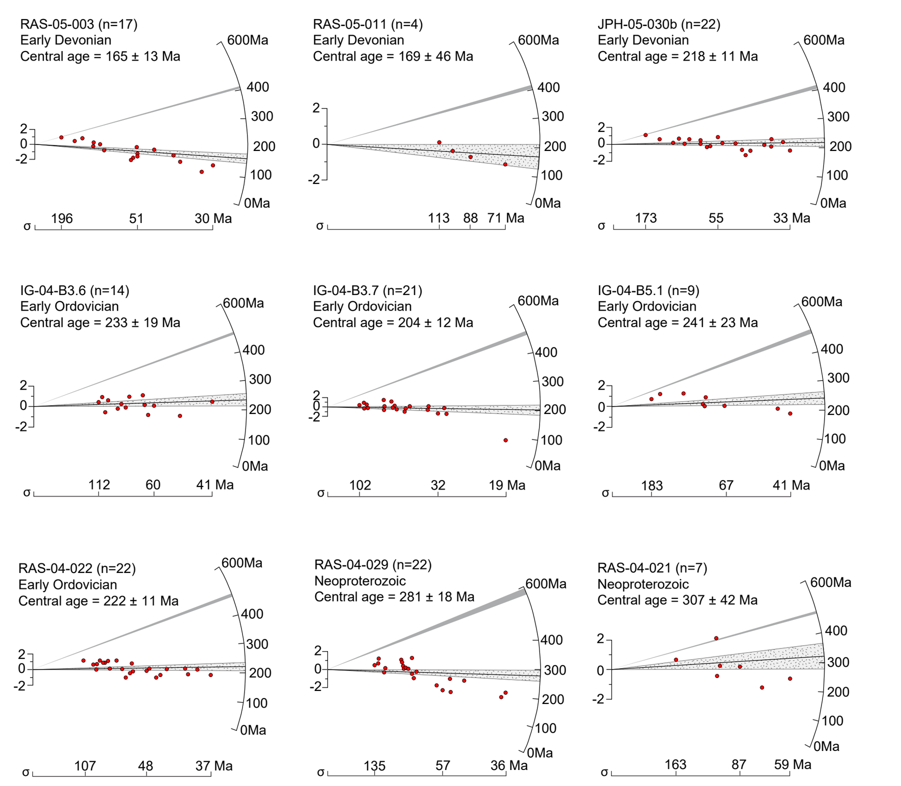


Fig. 4. Radial plots of the zircon fission track sample results from Novaya Zemlya.

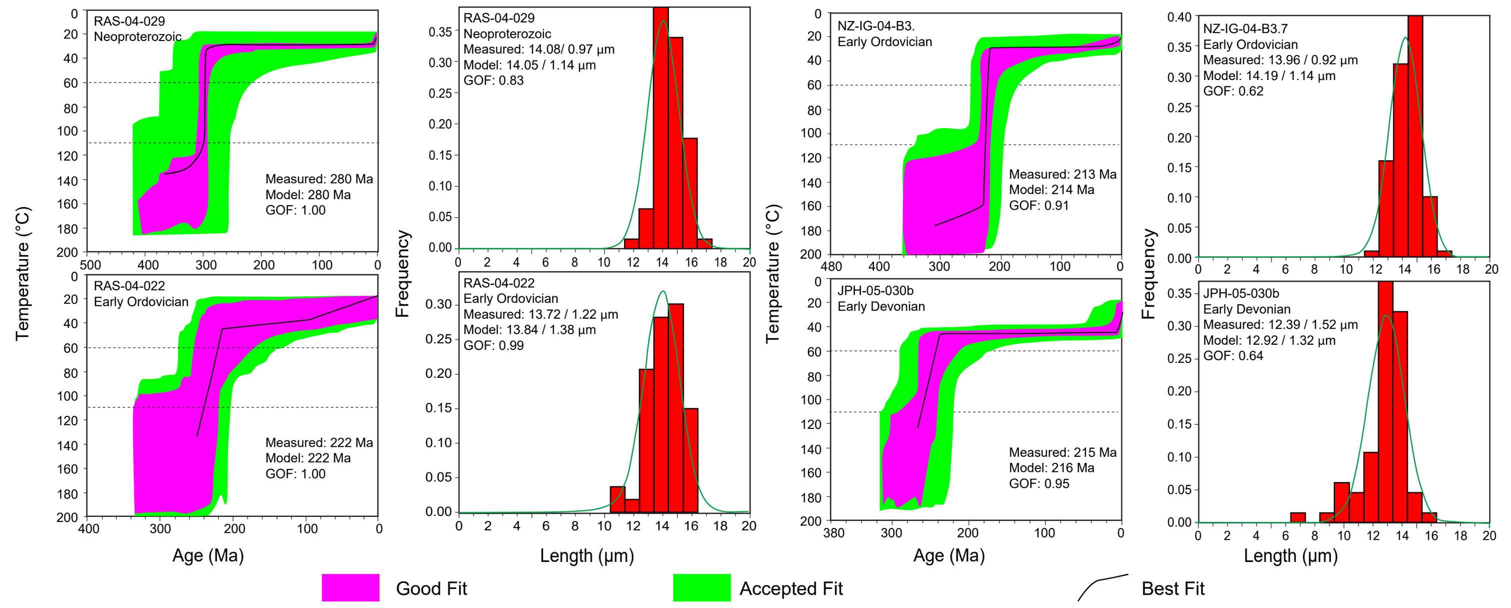


Fig. 6. Results of inverse thermal modelling together with track length distributions. GOF, goodness of fit. The modeling determines probable thermal histories using HeFTy software (Ketcham 2005). It should be noted that only the cooling history inside the partial annealing zone (PAZ) is recorded and modeled with confidence. The 'goodness of fit' (GOF) values give an indication of agreement between observed and predicted data (values close to 1 are the best) and indicate the probability of failing the null hypothesis

The apatite FT central ages of the nine samples range between 163±14 and 308±42 Ma. All samples shows no extra-Poissan variation (Fig. 5). The percentage of age dispersion about the central age also shows that the spread in single-grain ages is not significant (20%). These indicate that the sample age is derived from a single-age population. The mean track lengths for the remaining samples range between 12.39 and 14.09μm, with standard deviations between 0.61 and 1.52 μm, indicating a simple unimodal distribution in all cases.

To define rock-cooling histories, good quality data require more than 50 confined tracks for thermal modeling. Modelling of the Neoproterozoic sample RAS-04-029 (south island) indicates rapid cooling through the PAZ from 110 to 60°C in the late Permian (Fig. 6). The model then requires a long stable period in which the sample remained near the surface, but this is poorly constrained because the thermal modelling cannot resolve variations in temperature below c. 50-60°C. Models for the early Ordovician samples RAS-04-022 and IG-04-B3.7 (south island) and the early Devonian sample JPH-05-030b (north island) all provide best-fit solutions consistent with rapid cooling through the PAZ in the late Triassic (c. 220–210 Ma), as indicated by their central fission track ages.

4. Discussion

The late Paleoproterozoic to early Neoproterozoic ages (c. 1.9-0.9 Ga) are typical of Baltica: ages associated with the Svecofennian orogen (1.92-1.77 Ga), the Trans-Scandinavian Igneous Belt (TIB, 1.85-1.65 Ga) the pre-Sveconorwegian mafic dike swarms and gabbro-dolerite-granite complexes (1.53-1.13 Ga), and the Sveconorwegian orogen (1.14-0.9 Ga). The late Neoproterozoic to early Palaeozoic ages (700-480 Ma) correspond well with the timing of Timanian orogeny. The age group of 336-302 Ma in the late Permian sample can be linked to the Uralides. The few 470 - 420 Ma zircons present may be linked to the 470-400 Ma igneous rocks associated with Caledonian orogen in the Barents Shelf.

The ZFT unimodal age distribution for each sample indicates a source region with a relatively simple thermal history. There are three sets of ages with three distinct detrital zircon signatures (Fig. 4): (1) Devonian strata with a Baltica Sveconorwegian provenance and Caledonian (Cambro-Ordovician) ZFT ages; (2) late Devonian-late Carboniferous strata with a Timanian provenance and post-Caledonian (Silurian-Devonian) ZFT ages; and (3) Permian strata that have a Uralian provenance and Uralian (Carboniferous) ZFT ages.

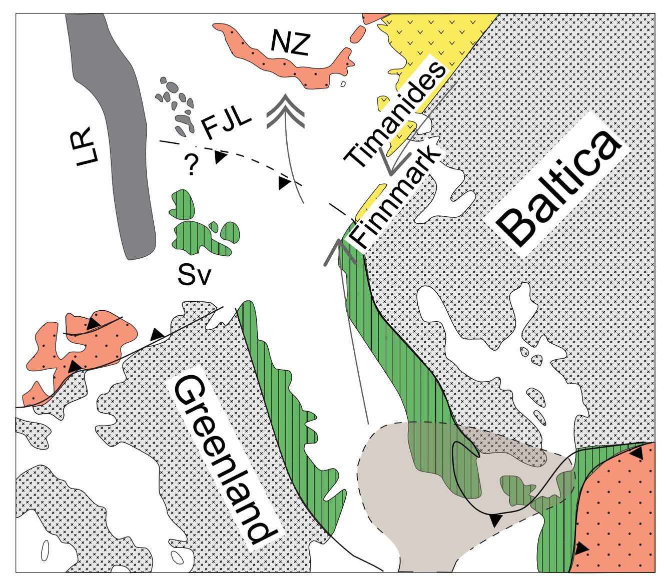


Figure 7 Sketch reconstruction of the Barents Sea Shelf, prior to rifting of the Lomonosov Ridge. Note the sediment path of Sveconorwegian detritus to Novaya Zemlya (modified from Lorenz et al., 2013 and Pease 2011). NZ = Novaya Zemlya; FJL = Franz Josef Land; Sv = Svalbard; LR = Lomonosov Ridge.

Integration of these data indicates that Sveconorwegian sources could be eroded, transported and deposited in the Barents Shelf, and then remobilized to Novaya Zemlya during Caledonian orogenesis (Fig. 7). Late Carboniferous to early Permian cooling ages from the Neoproterozoic to Cambrian samples may suggest greater proximity to the Uralides or a far-field effect of the Uralian orogenesis to southeastern Novaya Zemlya. Further investigations testing these concepts are needed. The late Triassic (c. 220-210 Ma) rapid cooling event revealed by the AFT results is coeval with a Mesozoic deformation phase found in Taimyr and the Polar Urals, implying a regional significance.

5. References

1. Jakobsson, M., Mayer, L., Coakley, B., Dowdeswell, J.A., Forbes, S., Fridman, B., Hodnesdal, H., Noormets, R., Pedersen, R. & Rebesco, M. 2012. The international bathymetric chart of the Arctic Ocean (IBCAO) version 3.0. Geophysical Research Letters, 39.
2. Ketcham, R.A. 2005. Forward and inverse modeling of low-temperature thermochronometry data. Reviews in Mineralogy and Geochemistry, 58, 275-314.
3. Lorenz, H., Gee, D.G., Korago, E., Kovaleva, G., McClelland, W.C., Gilotti, J.A. & Frei, D. 2013. Detrital zircon geochronology of Palaeozoic Novaya Zemlya – a key to understanding the basement of the Barents Shelf. Terra Nova, n/a-n/a, doi: 10.1111/ter.12064.
4. Pease, V. 2011. Eurasian orogens and Arctic tectonics: an overview. Geological Society, London, Memoirs, 35, 311-324.
5. Sobolev, N.N., Bondarev, V.I. & Orgo, V.V. 2004. Palaeozoic stratigraphy. In: Kalenich, A.P., Orgo, V.V., Sobolev, N.N., Bondarev, V.I., Semenov Yu, P. & Musatov, E.E. (eds.) Novaya Zemlya and Vaygach Island: Geological structure and metallogeny. VNIIOkeangeologiya, Saint-Petersburg, 16-27

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