Recent understanding of the Svalbard basement in the light of new radiometric age determinations

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Several tectonothermal events in the pre-Carboniferous basement of Svalbard during Caledonian and Proterozoic times have been dated recently by radiometric age determinations. Three or four stages have been recognized in the Caledonian period; a post-orogenic graben formation during the Devonian, a late Caledonian event in the Middle Silurian, an early Caledonian event in the Middle Ordovician and possibly an earliest event in the Middle to Late Cambrian. A latest Proterozoic group of ages, 600–660 Ma, from igneous rocks are not clearly correlatable to a recognized tectonic event, though it is coeval with the Baikalian event at the southeastern coast of the Barents Sea. The Grenvillian event, 950-1270 Ma, has been well established by both radiometric ages and unconformities in Nordaustlandet and southwestern Spitsbergen. Sveco-Karelian ages, 1670–1750 Ma, also have been obtained from Ny Friesland, northeastern Spitsbergen and there is geological support for this event, although it has not been studied in detail yet. Two even older ages (zircon U–Pb upper intercept ages), 2.1 and 3.2 Ga, may suggest the presence of still older crust in Svalbard and adjacent areas.

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This article summarizes recent knowledge of the basement rocks of Svalbard, which have experienced at least three major orogenic movements before the deposition of post-Caledonian Devonian sediments. The complexity of the structures in the basement should be taken into account when considering the younger tectonics.

The metamorphic rocks of the Svalbard archipelago has been considered to be of Precambrian, even Archean age, by the geologists who visited these islands before the 1920s. Holtedahl (1926) was the first geologist to introduce the idea of Caledonian metamorphism to Svalbard. Since then the majority of these rocks have been considered to the products of the Caledonian orogeny, although there are some who insisted upon a Precambrian origin for some of these rocks. Many articles have been published on the lithostratigraphy and sequences of structural events for these rocks, but a time-scale has not been established for them.

K–Ar and classical Rb–Sr datings were made until the middle of the 1980s (e.g. Hamilton et al. 1962; Hamilton & Sandford 1964; Krasil'ščikov et al. 1964; Gayer et al. 1966; Ravič 1979; Hauser 1982) and most of the ages obtained confirmed the presence of the Caledonian thermal events, while some ranged down to the latest Precambrian. Some Rb–Sr whole-rock isochron ages from granitic and silicic extrusive rocks (Edwards & Taylor 1976; Goročov et al. 1977) seemed to indicate Late Proterozoic thermal events.

As part of a radiometric dating project started in 1985, foreign specialists who have elaborate chemical laboratories were invited to study selected localities of metamorphic rocks in Svalbard. The results have been published in various journals (Peucat et al. 1989; Dallmeyer et al. 1990a, b) and summarized into a tectonothermal history by Ohta et al. (1989). Several additional unpublished results are now available and all those radiometric ages obtained by the end of 1990 are compiled in Figs. 1, 2. Some information from the studies of microfossils also are incorporated in the compilation. Regional extents of the rocks of various ages are shown in Fig. 1, based on lithological considerations but with some speculation. The ages spread more and more in the time range of Late Proterozoic to Middle Palaeozoic, when the number of determinations increases. The ages obtained are taken into consideration only when they have confirmable geological events based on lithostratigraphical and structrual observations. However, there will, of course, be the case that an unexpected radiometric age could inspire further detailed field works to find geological evidence so far unknown.

The radiometric ages obtained are grouped into several periods of geological events which have been observed in field work (Fig. 2). The post-Caledonian, Devonian graben formation is overlapped by the range of granite–gneiss cooling ages. Formation of these granitic rocks at depth can be retraced back to about 440 Ma, the Early Silurian late Caledonian event. A flyschoid succession separates the late and early Caledonian events, the latter is characterized by a blueschist–eclogite complex of a subduction product (Hirajima et al. 1988). The flyschoids occur in Motalafjella and south of Hornsund, in the middle and southern parts of western Spitsbergen, respectively, and include pebbles of the early Caledonian metamorphic rocks at the former locality, and are folded by the late Caledonian event at both localities.

An age group 500–550 Ma has no correlatable distinctive event, except for two possible block tectonic stages

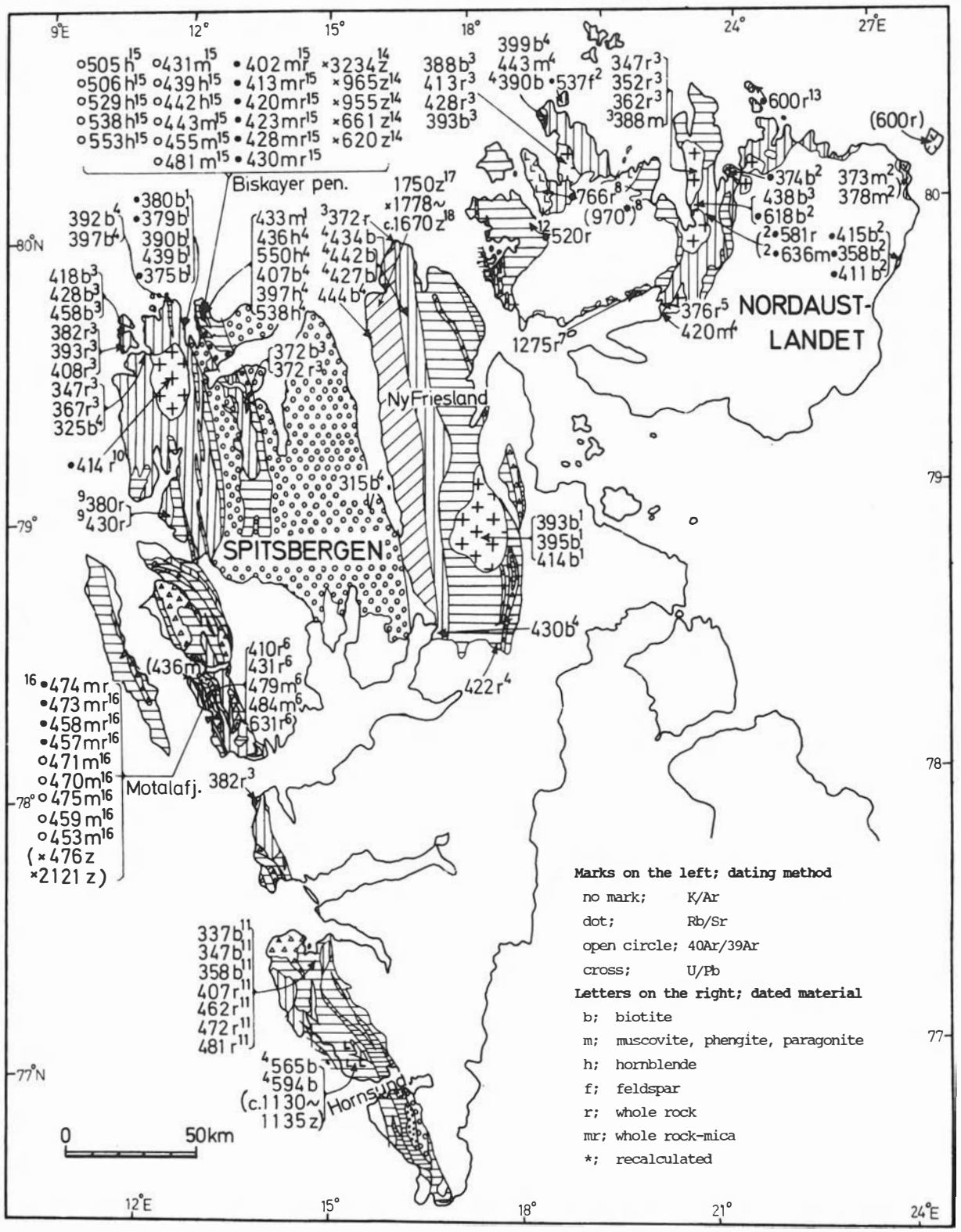

Fig. 1. Radiometric ages (Ma) obtained in the Svalbard basement, including four unpublished preliminary data (in brackets), determined by Peucat, Dallmeyer and Teben'kov. The legend for the distribution of rocks of various ages is shown in the fourth column of Fig. 2. Numbers at the upper left or right corners of the ages refer to references: 1, Hamilton et al. 1962; 2, Hamilton & Sandford 1964; 3, Krasil'ščikov et al. 1964; 4, Gayer et al. 1966; 5, Krasil'ščikov 1970; 6, Horsfield 1972; 7, Edwards & Taylor 1976; 8, Goročov et al. 1977; 9, Ravič 1979; 10, Hjelle 1979; 11, Hauser 1982; 12, Ohta 1982; 13, Lauritzen & Ohta 1984; 14, Peucat et al. 1989; 15, Dallmeyer et al. 1990a; 16, Dallmeyer et al. 1990b; 17, Gee 1991; 18, Gee et al. 1991. The K–Ar data from 1, 3, 4, 5 and 6 are recalculated using the new decay constant after Steiger & Jäger (1977).

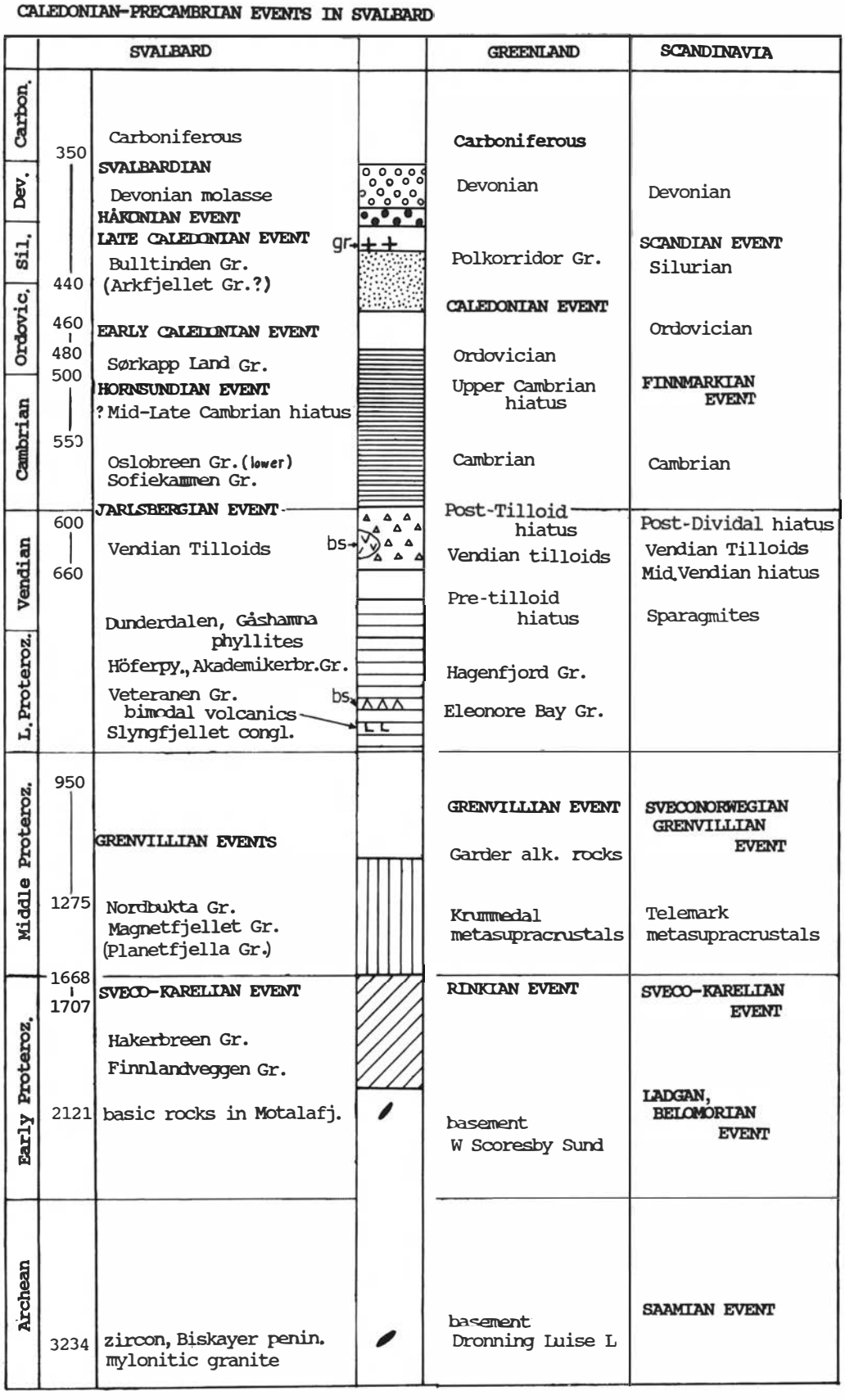

Fig. 2. Summary of tectonothermal events in the Svalbard basement, with simplified comparison with East and North Greenland and the Scandinavian Caledonides.

at the beginning of the Ordovician and the Cambrian, respectively (Birkermajer 1981). These radiometric ages are from the Biskayer peninsula, northwest Spitsbergen; obtained by the $^{40}Ar/^{39}Ar$ method on the high-temperature type ecologite and its related metamorphic rocks, and their geological significance is not clearly understood.

Another age group, c. 600–660 Ma also has not distinct correlatable geological event. These ages have been obtained from both basic and silicic igneous rocks in northern Nordaustlandet and the Biskayer peninsula. Igneous rocks of similar ages have been known from the Baikalian orogenic zone of the Timan–Kanin belt in the southeast of the Barents Sea (Siedlecka 1975). There might have been a large block-tectonic event with igneous activity during this period, but its geological evidence is difficult to detect, i.e., by a conglomerate, since the period is overlapped by that of the Vendian tilloids.

The Grenvillian event, 1270–950 Ma, is well defined by distinct conglomerates in southwestern Spitsbergen and western Nordaustlandet. This unconformity separates the Hecla Hoek succession into two, the post- and the pre-Grenvillian parts (Ohta 1982; Bjornerud 1990). The c. 20-km-thick Hecla Hoek succession in Ny Friesland (Harland 1985), which was considered to be a single succession metamorphosed by the Caledonian orogeny, should now be separated into two (Ohta 1982, Manby 1990), or even three (Gee 1991; Gee et al. 1991). Several eruptive rocks have been dated as synorogenic igneous activity of the Grenvillian orogeny in southwest Spitsbergen (Teben'kov et al. in prep.) and western Nordaustlandet (Goročov et al. 1977). The Grenvillian rocks in Ny Friesland (Fig. 1) roughly correspond to the Planetfjella Group of Harland (1985) based on lithostratigraphical correlation, but no radiometric age has been obtained yet for this event.

The Sveco-Karelian ages, 1670–1750 Ma, have been obtained recently from the Lower Hecla Hoek rocks, lower than the Planetfjella Group of Harland (1985), in northwestern Ny Friesland (Gee 1991; Gee et al. 1991), and a large part of Hecla Hoek rocks in Ny Friesland is lithologically continuous from the dated rocks. The boundaries between the post-Grenvillian, the Grenvillian and the Sveco-Karelian rocks seem to be a large tectonic breaks, but the actual relationship has not been studied yet.

Two indications of Early Proterozoic and Archean ages are obtained by upper intercept ages of zircon U–Pb dating from Motalafjella (Peucat pers. comm. 1991) and the Biskayer peninsula (Peucat et al. 1989), respectively. Their geological significance is not yet known, but they suggest that there is an older basement in the continental crust of Svalbard and its adjacent areas.

Recent radiometric dating results show that the Svalbard basement has a very complex and old history back to Archean time, as the geologists of the last centrury believed, although the Caledonian events overprinted all older rocks in agreement with Holtedahl (1926). The Grenvillian event is the most distinctive in both radiometric ages and geological observations. All the way from the southern Appalachians to Svalbard, even to the northern Ellesmere Islands, the Caledonian zone is underlain entirely by the Grenvillian rocks (Bartholomew 1984; Peucat et al. 1984; Kullerud et al. 1986; Trettin et al. 1987), and this means that the age of initiation of a mobile belt along this c. 7000 km length is not the Caledonian, but the Grenvillian period of Middle Proterozoic time. The Grenvillian belt of the southeastern Canadian and southwestern Fennoscandian shields are dominated by plutonic rocks emplaced in the older rocks. The calcalkaline to alkali-calcic rocks in the belts are distributed in a NNW–SSE trend from southeastern Sweden to northwestern Norway as the Trans-Scandinavian granite-porphyry belt (Gorbatschev & Gaal 1987), formed during the period 1500–1600 Ma, and some mega-shear zones were developed in the Precambrian rocks of southern Norway in the N–S trend. These tectono-igneous zones infer that the continental mega-shears of roughly N–S tectonic direction were formed after the Early Proterozoic Sveco-Karelian event. Although no definitive evidence of oceanic rocks and deep-sea sediments has been reported from the Grenvillian belt, a hypothesis of Proterozoic rotation of Fennoscandia towards Laurentia, proposed by Stearn & Piper (1984) from palaeomagnetic studies, infers a plate interaction along a continent–ocean boundary during the period of the early Sveconorwegian event (1190–1050 Ma), and the inferred ocean basin was later closed by a continental collision (1050–900 Ma) (Gorbatschev & Gaal 1987; Gower 1990). In Svalbard, the calc-alkaline andesite and rhyolite suite in northwestern Nordaustlandet, possibly 970 Ma old (Goročov et al. 1977), infers an island-arc volcanism (Ohta 1985) which could be related to the closing of an earlier ocean.

The Caledonian is the second event, and roughly followed the axial zone of the Grenvillian belt, which cut the older structures extending from the Fennoscandian across Greenlandian to the Canadian shield (Max 1979; Gee 1989). Thus the first breakdown between the Laurentian and Eurasian plates was in the Middle Proterozoic after the Sveco-Karelian event. If this is the case, the northern Atlantic is a unique region where triple mobile tectonic activities have occurred in roughly similar positions at about 7000 km distance during the last 1500 Ma. Such a region has not been known in any other part of the world. The term 'Iapetus' (Harland & Gayer 1972) or 'Protoatlantic' must now be restricted to the ocean that existed during the Late Proterozoic, while the older ocean in the Middle Proterozoic, if any, could be named 'Protoiapetus'.

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