Geologie en Mijnbouw 67: 157–164 (1988)

Regional inter-relationships in the Proterozoic geology of Bergslagen and Southeastern Central Sweden

IUGS UNESCO IGCP 247

Ingmar Lundström
Geological Survey of Sweden, Box 670, S-0751 28 Uppsala, Sweden

Received 10 May 1987; accepted in revised form 9 December 1987

Key words: tectonism and metamorphism, Proterozoic supracrustals, stratigraphic correlation, alteration, Bergslagen Sweden, Svecokarelian

Abstract

The regional tectonic and metamorphic features common to western Bergslagen and to the region lying to the east are described. Metamorphic grade varies from low grade greenschist facies in the west to higher grade amphibolite facies in the east, where migmatized gneisses are also developed. Deformation is also stronger in the eastern region, where E–W trending isoclinal folds predominate, while N–S trending, more open structures are found to the west. Stratigraphic and lateral inter-relationships of the two regions indicate a volcanic proximal area in western Bergslagen, which fed tephra into a depositional basin to the east.

Introduction

This contribution briefly describes the inter-relationships between synvolcanic and syndepositional processes in the context of the regional geology of the Svecokarelian of southern central Sweden. The article does not intend to describe the regional geology of the region, but rather concentrates on some selected features, which have been under more or less continuous discussion among geologists working on the Bergslagen geology during the 1980's (e.g. Frietsch 1982, Oen *et al.* 1982, Baker 1985, Lagerblad & Gorbatschev 1985, Hellingwerf 1986, Lundström 1987, Oen 1987). It is based both on the recent, rather numerous publications concerning the geology of the region and on the author's own experience from mapping for the Geological Survey in the Hällefors-Lindesberg and Nyköping areas. For recent compilations of the regional geology, the reader is referred to Lundqvist (1979) or Lundström & Papunen (1986). The main features of the regional geology are summarized in Figs 1 and 2.

This paper compares two, more or less contrasting regions of the Svecokarelian of southern central Sweden. These will here simply be called the 'western' and 'eastern' regions, respectively (Fig. 2). The obvious type area of the western region is the classic Filipstad-Lindesberg area (Fig. 3), whilst a good type area for the eastern region is the Uppsala-Nyköping area.

Tectonic and metamorphic relationships

A very obvious difference between the western and eastern regions is the generally higher regional metamorphic grade and stronger tectonic deformation to the east. Tectonic and metamorphic processes were most intense in the Stockholm-Nyköping area, where thoroughly migmatized gneisses of high amphibolite, low pressure type facies occur in

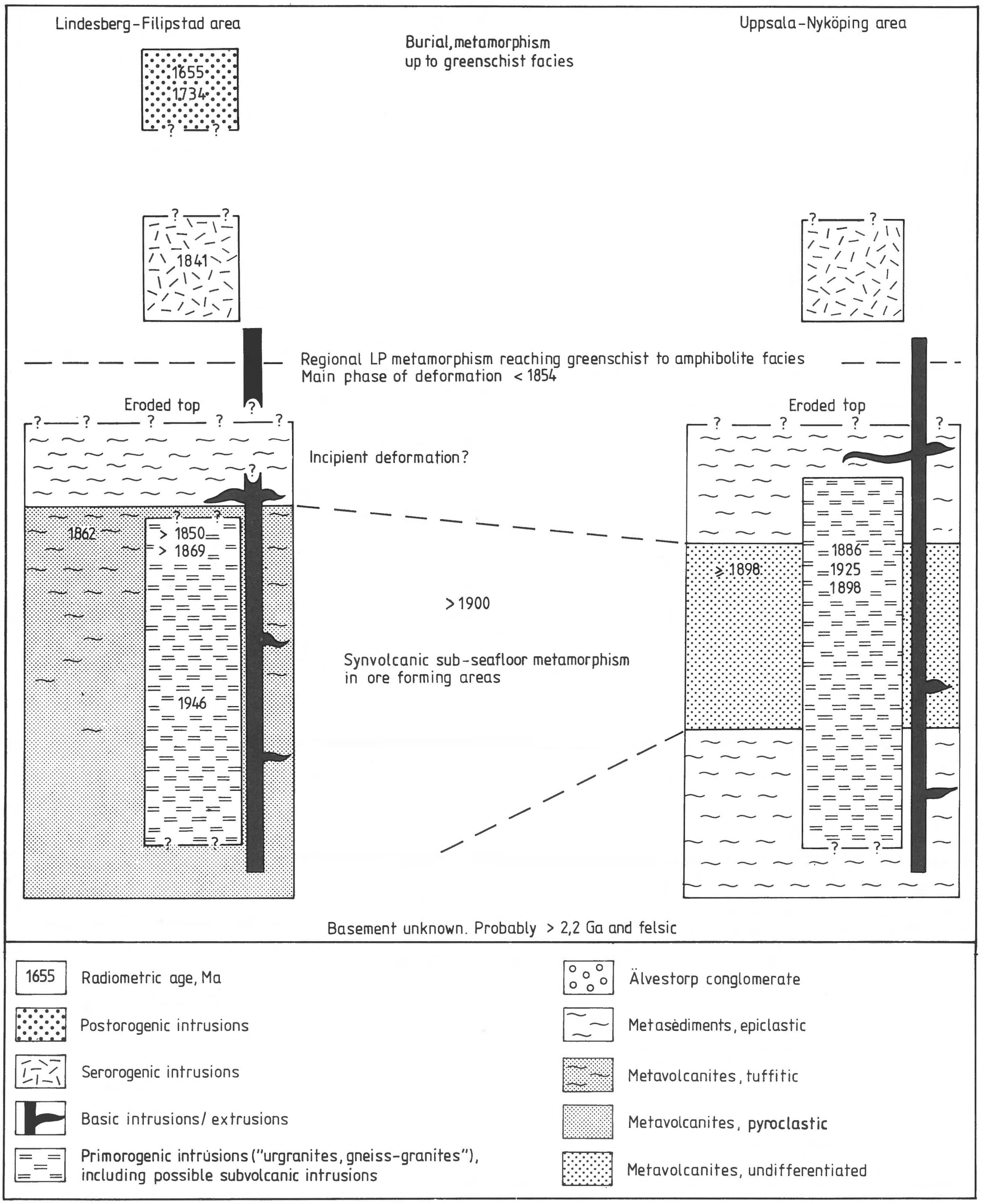

Fig. 1. Main stratigraphic features of the Bergslagen region. Anorogenic dolerites excluded. Cf. text. References for radiometric ages in Ma: 1655 (Welin 1980), 1734 (Åberg & Fredriksson 1984), 1841 (Oen & Wiklander 1982), 1850, 1946 (Åberg *et al.* 1983), 1854 (Welin & Stålhös 1986), 1862 (Welin, Wiklander & Kähr 1980), 1869 (Åberg & Strömberg 1984), 1900 (Åberg *et al.* 1984), 1898, 1886 (Welin, Kähr & Lundegårdh 1980), 1925, 2200 (Welin, 1980, after Åberg, 1978).

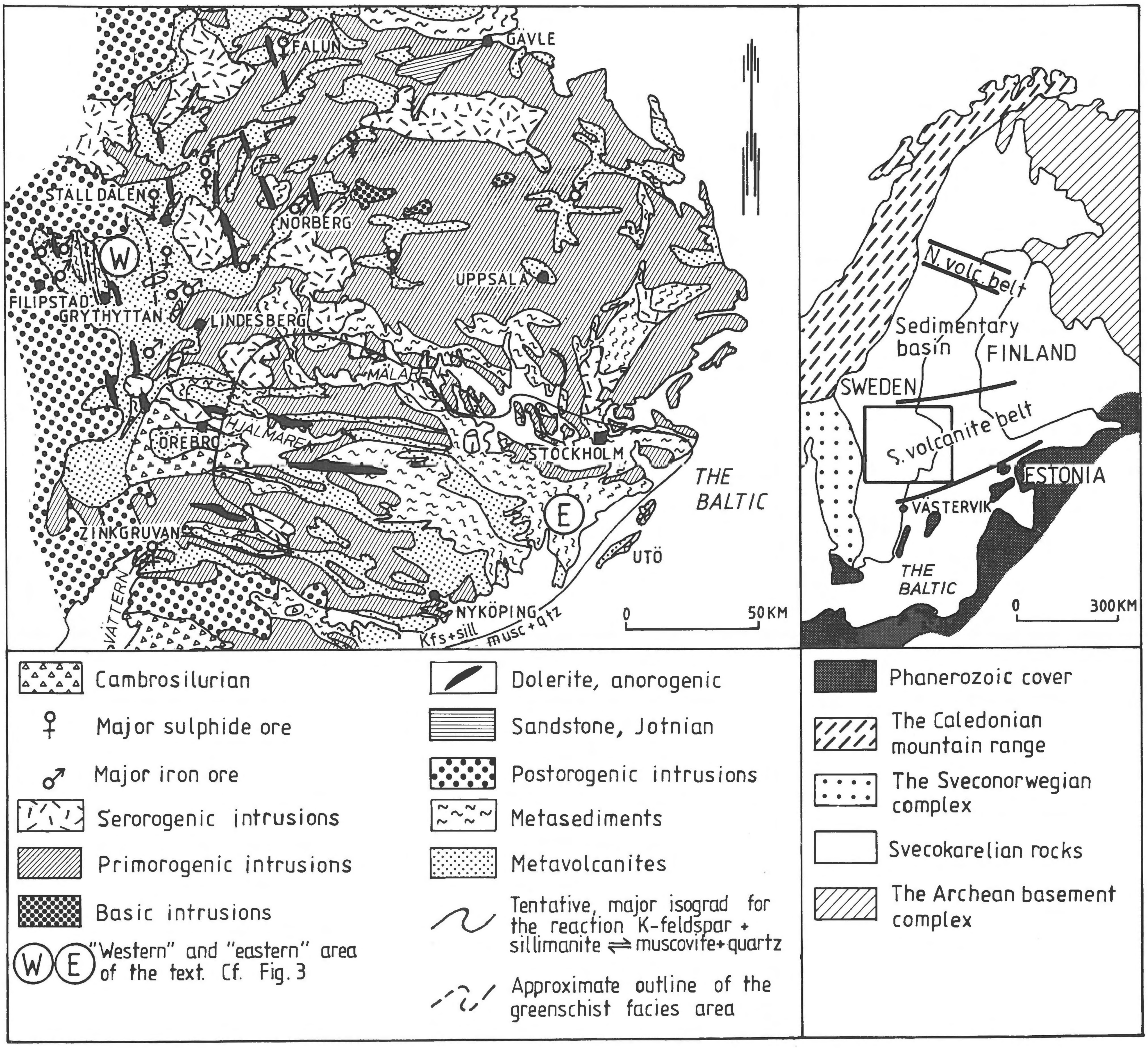

Fig. 2. Geological sketch map of south-eastern middle Sweden. Eastern part of muscovite isograd drawn according to Stålhös (1975, p. 67).

an isoclinally folded pattern. The approximate outlines of the high amphibolite facies area are shown by the muscovite isograd, tentatively drawn in Fig. 2. Also compare Table 9 of Lundström (1974) with Table 19 of Lundström (1983). Within the central parts of this area, east-west, isoclinal fold structures seem to predominate, while north-south trending, isoclinal as well as more open fold structures appear to characterize the peripheral parts, adjoining to or within the lower grade areas. These north-south trending structures are persistently overturned towards the west, reflecting an east-west compression (F1). Once these folds were created, a north-south commpression (F2) imposed a regional, east-dipping lineation on their limbs and probably created the east-west structures of the Stockholm-Nyköping area as well (Stålhös 1984). The maximum age of these deformations is 1854 Ma, since this is the age of a pegmatite of supposed primorogenic age, affected by both F1 and F2 (Welin & Stålhös 1986). As the regional metamorphic textures tend to overprint and heal deformational textures, and because metamorphic isograds frequently crosscut fold structures, the regional metamorphism necessarily outlasted deformation.

An important question is how far west into the low-grade, and in part only weakly deformed western region (Fig. 3) these regional tectonic and metamorphic features can still be recognized. Also, how far can we discriminate between regional metamorphic assemblages and textures and synvolcanic or syndepositional alteration features, and how can we distinguish structures resulting from regional compressional tectonics and those which might be expected to result from the extensional, rift-related tectonics proposed by Oen *et al.* (1982) and Oen (1987)? A problem is that the structural features expected to be generated by extensional tectonics, which now should be reflected in the regional structural geology of Bergslagen, have never been manifestly stated. Presumably, the sole fold structures that could be generated by extensional tectonics would be local, syndepositional, isoclinal folds, characterized by their lack of regional consistency. Therefore, regional compressive tectonics should have predominated in areas where regionally consistent, isoclinal, overturned folds prevail. This argument seems particularly valid in areas between the presumed rifts or synclines, because such folds must be more likely to occur within an overturned anticline than within a horst, in which gravity-generated, more or less syndepositional folding can be excluded. In the Lindesberg area, compressional tectonics are thus certainly still recognizable in both the Ställdalen and Guldsmedshyttan synclines as well as in the adjacent Vasselhyttan anticline, because these are all isoclinal and overturned to the west (Lundström 1983, 1985, Figs 5 and 27), in conformity with large areas to the east. The nearby Gränsjön syncline is a rather open, but still partly overturned synformal structure, open to the south, which likewise seems more compatible with folding than with rifting. East-dipping, planar and linear penetrative structures which are predominant in the east seem to prevail for some further ten kilometres to the west, but their relation to fold geometries is unknown so far. However, in the heavily foliated area to the north of lake Grecken (Fig. 3) a small granite body is penetratively lineated by east-dipping lineations, which seems easiest to reconcile with the regional east-dipping lineation pattern of the eastern region.

Helmers (1984) demonstrated that the synvolcanic alteration patterns become increasingly overprinted by regional metamorphic recrystallization in an eastward direction, in the Grängen area. This area largely coincides with the westernmost limit of regional amphibolite facies metamorphism (cf. Fig. 3). In this area, regional metamorphic alteration thus actually increases stratigraphically upwards, towards the Ställdalen syncline. Therefore, regional metamorphism was necessarily late- to post-deformational here too. The mineral ages from this area, determined by Moorman *et al.* (1982) to 1.83 Ga, are therefore certainly metamorphic ages. Similar, regional metamorphic overprinting of earlier textures can occasionally be recognized also elsewhere on the low-metamorphic side of the muscovite isograd (e.g. the Uppsala area, Stålhös 1972).

Despite the different regional tectonic and metamorphic development of the eastern and western regions, patterns typical of the former region can thus easily be recognized deep within the latter. Therefore, it is reasonable to assume that the two regions had largely the same tectonic and metamorphic history with no major discordancy separating them. Consequently, attempts at stratigraphic correlations are both justified and desirable.

Stratigraphic and lateral relationships

The major stratigraphic and lateral difference between the east and the west is that metasediments are much more common in the east, where they also clearly underly the meta-volcanites (Fig. 1). This is best documented on Utö island in the Stockholm archipelago (Gavelin *et al.* 1976, Stålhös 1982), but is also observed as far west as in the Norberg (Ambros 1983), Zinkgruvan (Wikström, pers. comm. 1985) and Falun (Kresten 1986) areas. This probably reflects an eastward deepening and widening of the depositional basins, which was also suggested by Gorbatschev (1969) from *inter alia* the

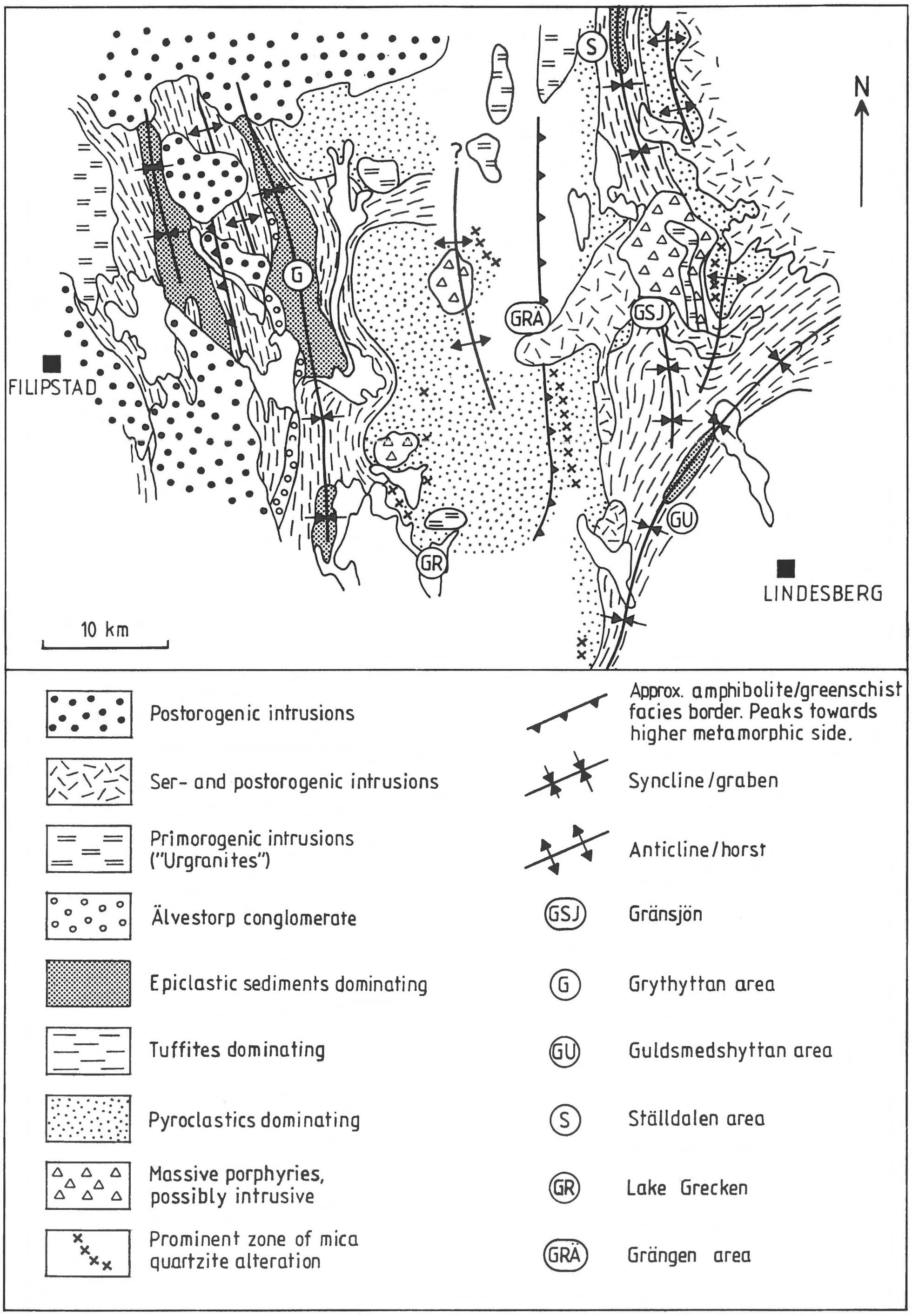

Fig. 3. Geological sketch map of the Lindesberg-Filipstad area.

provenance of conglomerate pebbles north of Örebro. Likewise, both Geijer (1967) and Sundius (1970) pointed out that sedimentation in the west (e.g. Grythyttan), at least commenced in smaller basins than in the east.

The meta-volcanites of the two regions also differ in several respects. More or less alkali intermediate to potassic, rhyolitic tuffites predominate among the acid volcanites in the east (Stålhös 1975, 1979, 1982). These tuffites apparently correspond to the tuffites in the upper parts of the volcanic pile in the western area, whereas the more or less sodic, coarser grained pyroclastic rocks of the lower part of the western sequence are rarer in the east. As the coarser grained pyroclastics in the west presumably reflect a closer proximity to the volcanic source area, a westerly provenance can also be inferred for the finer grained volcanites in the east.

Another difference is that intermediate and basic meta-volcanites become more frequent in the east (cf. Geijer 1967). Consequently, the bimodal volcanite chemistry of the western area (Van der Velden *et al.* 1982), thought to indicate magmatism in an extensional regime, becomes less obvious in the east. Thus, the mildly alkaline volcanism in the west, meets a more calc-alkaline one here, which probably emanates from eastern volcanic centres. Recent trace element studies by Lagerblad (1987) in the Filipstad-Garpenberg part of the western area would support this idea.

As sodium and magnesium enrichments are thought to depend *inter alia* on hydrothermal convection due to high volcanic heat flows (Frietsch 1982, Baker 1985, Lagerblad & Gorbatschev 1985) it is not surprising to find such alterations largely confined to the western, presumably more proximal area. Likewise, syn-volcanic stratabound mineralizations, and related crosscutting mineralizing and alteration systems, which demand good access to volcanic heat for their creation, seem to be confined to the western region.

Although a pre-existing basement for the Svecokarelian supracrustals has never been identified, the voluminous acid meta-volcanites indicate a pre-existing, continental, felsic crust (Frietsch 1982, Vivallo & Rickard 1984, Baker 1985). Studies of REE enrichment patterns by Rickard (1981) and of lead isotope relations by Johansson & Rickard (1985) also indicate a pre-existing continental crust in the region. The age of this crust is unknown so far, but Sm–Nd studies by Beunk *et al.* (1985) and Patchett *et al.* (1987) exclude a significant contribution of Archean crust in this part of the Svecokarelian. A basement of Proterozoic age was instead indicated by Åberg (1978) and Åberg & Persson (1984), who found that the provenance area of the detrital zircons in the Västervik and Vetlanda metasediments is 2200–2500 Ma old. Patchett *et al.*'s as well as Huhma's (1986) Sm–Nd data instead record an increasing contribution of Archean crust towards the northeastern part of the Svecokarelian sedimentary basin in central Sweden and Finland. This apparently reflects the increasing provenance from the Archean basement in northern Sweden and Finland.

Conclusion

In summary, western Bergslagen seems to represent a continental margin, proximal to an area of active volcanism on the western fringe of a large depositional basin to the east. This basin apparently covered large areas of central Sweden and Finland, where volcanites were occasionally interbedded with the sediments. In Sweden (e.g. the Uppsala-Nyköping area), the volcanites are dominated by rhyolitic tuffites, which are presumably distal in relation to the acid volcanic centres in western Bergslagen. Towards the east, and particularly in Finland (cf. Ehlers *et al.* 1986) intermediate and basic volcanites become increasingly frequent. These are occasionally beautifully pillowed lavas and are therefore considered rather proximal in relation to an eastern, intermediate to basic volcanic area. The basin was bordered to the north and northeast by an Archean basement.

References

Åberg, G. 1978 Precambrian geochronology of south-eastern Sweden – Geol. För. Förh. 100: 125–154.

Åberg, G. & Fredriksson, G. 1984 Radiometric dating of the postorogenic Järna granite, south central Sweden - Geol. För. Förh. 106: 171–174.

Åberg, G. & Persson, L. 1984 Radiometric dating of precambrian rocks in Småland, southeastern Sweden - Geol. För. Förh. 106: 209–213

Åberg, G. & Strömberg, A.G.B. 1984 Radiometric dating of Svecokarelian metarhyolites and prekinematic granitoids from Bergslagen, south central Sweden - Geol. För. Förh. 106: 209–213.

Åberg, G., Levi, B. & Fredriksson, G. 1984 Zircon ages of metavolcanic and synorogenic rocks from the Svärdsjö and Yxsjöberg areas, south central Sweden - Geol. För. Förh. 105: 199–203.

Åberg, G., Bollmark, B., Björk, L. & Wiklander, U. 1983 Radiometric dating of the Horrsjö granite, south central Sweden - Geol. För. Förh. 105: 78–81.

Ambros, M. 1983 The Precambrian stratigraphy of the Norberg area, central Sweden - Geol. För. Förh. 105: 383–384.

Baker, J.H. 1985 The Petrology and geochemistry of 1.8–1.9 granitic magmatism and related sub-seafloor hydrothermal alteration and ore-forming processes, W. Bergslagen, Sweden - Ph.D.thesis University of Amsterdam - GUA Papers of Geology, Ser. 1, 21: 204 pp.

Beunk, F.F., Baker, J.H. & Van Raaphorst J.G. 1985 Sm–Nd isotope study of the 1.85 Ga Hjulsjö volcanoplutonic complex, W. Bergslagen, south central Sweden - Terra Cognita 5: 278.

Ehlers, C., Lindroos, A. & Jaanus-Järkkälä, M. 1986 Stratigraphy and geochemistry in the Proterozoic mafic volcanic rocks of the Nagu-Korpo area, SW Finland - Precamb. Res. 32: 297–315.

Frietsch, R. 1982 Alkali metasomatism in the ore-bearing metavolcanics of Central Sweden - Sver. Geol. Unders. C 791: 54 pp.

Gavelin, S., Lundström, I. & Norström, S. 1976 Svecofennian stratigraphy on Utö, Stockholm Archipelago. Correlations with Finland and Sweden - Sver. Geol. Unders. C 719: 44 pp.

Geijer, P. 1967 The Precambrian quartzite in the Norberg district, central Sweden, and its iron-sand bed - Sver. Geol. Unders. C 619: 36 pp.

Gorbatschev, R. 1969 A study of Svecofennian supracrustal rocks in central Sweden: lithological association, stratigraphy and petrology in the northwestern part of the Mälaren-Hjälmaren basin - Geol. För. Förh. 91: 479–535.

Hellingwerf, R.H. 1986 Contributions to the geology and ore genesis of Western Bergslagen, Sweden - Ph.D. thesis University of Amsterdam - GUA Papers of Geology, Ser. 1, 25: 260 pp.

Helmers, H. 1984. Stages of granite intrusion and regional metamorphism in the Proterozoic rocks of western Bergslagen, C. Sweden, as examplified in the Grängen area - N. Jb Miner. 150: 307–324.

Huhma, H. 1986 Sm-Nd, U-Pb and Pb-Pb isotopic evidence for the origin of the Early Proterozoic Svecokarelian crust in Finland - Geol. Surv. Finl. Bull. 337.

Johansson, Å. & Rickard, D. 1985 Some new lead isotope determinations from the Proterozoic sulphide ores of Central Sweden - Miner. Deposita. 20: 1–7.

Kresten, P. 1986 Geochemmistry and tectonic setting of metavolcanics and granitoids from the Falun area, south central Sweden - Geol. För. Förh. 107: 275–285.

Lagerblad, B. 1987 Tectonic implications of geochemical variations in the Mid-Proterozoic Svecofennian volcanic sequence of Bergslagen, Central Sweden - Proterozoic Geochemistry Abstracts IGCP 217, Lund 1987: 000 pp.

Lagerblad, B. & Gorbatschev, R. 1985 Hydrothermal alteration as a control of regional geochemistry and ore formation in the central Baltic Shield - Geol. Rundsch. 74/1: 54.

Lundqvist, Th. 1979 The Precambrian of Sweden - Sver. Geol. Unders. C 768: 87 pp.

Lundström, I. 1974 Beskrivning till berggrundskartan Nyköping SV (Summary in English) - Sver. Geol. Unders. Af 109: 123 pp.

Lundström, I. 1983 Beskrivning till berggrundskartan Lindesberg SV (Summary in English) - Sver. Geol. Unders. Af 126: 140 pp.

Lundström, I. 1985 Beskrivning till berggrundskartan Lindesberg NV (Summary in English) - Sver. Geol. Unders. Af 140: 131 pp.

Lundström, I. 1987 Lateral variations in supracrustal geology within the Swedish part of the southern Svecokarelian volcanic belt - Precamb. Res. 35: 353–365.

Lundström, I. & Papunen, H. (eds) 1986 Mineral deposits of southwestern Finland and the Bergslagen province, Sweden. 7th IAGOD Symp. and Nordkalott project meeting. Excursion guide No 3 - Sver. Geol. Unders. Ca 61: 5–11.

Moorman, A.C., Andriessen, P.A.M., Boelrijk, N.A.I.M., Hebeda, E.H., Oen, I.S., Priem, H.N.A., Verdurmen, E.A.Th., Verschure, R.H. & Wiklander, U. 1982 K–Ar and Rb–Sr mineral ages of skarns and associated metabasites and leptites in the Hjulsjö area of the Bergslagen ore province, central Sweden - Geol. För. Förh. 104: 1–9.

Oen, I.S. 1987 Rift-related igneous activity and metallogenesis in SW Bergslagen, Sweden - Precamb. Res. 35: 367–382.

Oen, I.S. & Wiklander, U. 1982 Isotopic age determinations in Bergslagen: III. The Hyttsjö suite of gabbro-diorites and tonalite-granites, Filipstad area - Geol. Mijnbouw 61: 309–312.

Oen, I.S., Helmers, H., Verschure, R.H. & Wiklander, U. 1982 Ore deposition in a Proterozoic incipient rift zone environment: A tentative model for the Filipstad-Grythyttan-Hjulsjö region, Bergslagen, Sweden - Geol. Rundsch. 71: 182–194.

Patchett, P.J., Todt, W. & Gorbatschev, R. 1987 Origin of continental crust of 1.9–1.7 Ga age: Nd isotopes in the Svecofennian orogenic terrains of Sweden - Precamb. Res. 35: 145–160.

Rickard, D. 1981 An evaluation of Lanthanide geochemistry in ore petrology - Ann. Rep. Ore Res. Group, Stockholm University: 32–54.

Stålhös, G. 1972 Beskrivning till berggrundskartan Uppsala SV och SO (Summary in English) - Sver. Geol. Unders. Af 105–106: 165 pp.

Stålhös, G. 1975 Beskrivning till berggrundskartan Nyköping NO (Summary in English) – Sver. Geol. Unders. Af 115: 99 pp.

Stålhös, G. 1979 Beskrivning till berggrundskartan Nynäshamn NV/SV (Summary in English) – Sver. Geol. Unders. Af 125: 106 pp.

Stålhös, G. 1982 Beskrivning till berggrundskartan Nynäshamn NO/SO. Utö med omgivande skärgård (Summary in English) – Sver. Geol. Unders. Af 138: 124 pp.

Stålhös, G. 1984 Svecokarelian folding and interfering macrostructures in eastern Central Sweden. In: Kröner, A. & Greiling, R. (eds): Precambrian tectonics illustrated – Schweitzerbart (Stuttgart): 369–379 pp.

Sundius, N. 1970 Topografien och den geologiska utvecklingen inom området Bergslagen-Stockholm södra skärgård under arkäisk och bottnisk tid – Geol. För. Förh. 92: 491–495.

Van der Velden, W., Baker, J.H., de Maesschalk, S. & Van Meerten, Th. 1982 Bimodal early Proterozoic volcanism in the Grythytte field and associated volcanoplutonic complexes, Bergslagen, Central Sweden – Geol. Rundsch. 71: 171–181.

Vivallo, W. & Rickard, D. 1984 Early Proterozoic ensialic spreading-subsidence evidence from the Garpenberg enclave, Central Sweden – Precamb. Res. 26: 203–221.

Welin, E. 1980 Tabulation of recalculated radiometric ages published 1960–1979 for rocks and minerals in Sweden – Geol. För. Förh. 101: 309–320.

Welin, E. & Stålhös, G. 1986 Maximum age of the synmetamorphic Svecokarelian fold phases in south central Sweden – Geol. För. Förh. 108: 31–34.

Welin, E., Kähr, A.-M. & Lundegårdh, P.H. 1980 Rb–Sr isotope systematics at amphibolite facies conditions, Uppsala region, eastern Sweden – Precamb. Res. 13: 87–101.

Welin, E., Wiklander, U. & Kähr, A.-M. 1980 Radiometric dating of a quartzporphyritic potassium rhyolite at Hällefors, south central Sweden – Geol. För. Förh. 102: 269–272.