Economic Geology
Vol. 98, 2003, pp. 1271–1290

Metallogeny of Gold in the Precambrian of Northern Europe

KRISTER SUNDBLAD†
Department of Geology, FIN-20014 Turku University, Finland

Abstract

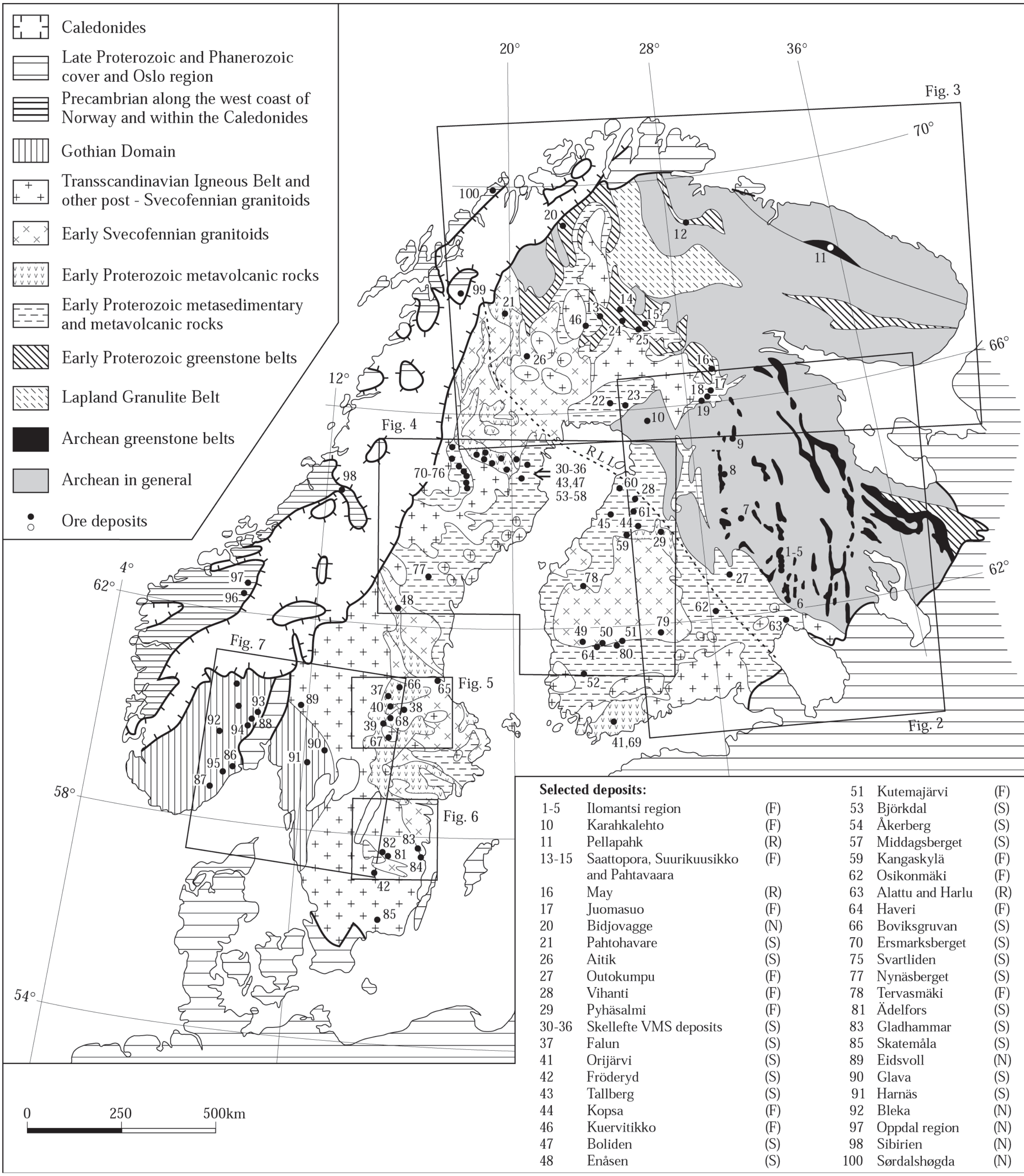
Fennoscandian gold deposits have been successfully explored in a wide range of Precambrian geological environments in Sweden and Finland during the last two decades. Under-explored areas still exist at other sites in the Fennoscandian Shield, particularly in Russia and Norway, and there is a high potential for future new discoveries of economic gold in northern Europe. Careful geological documentation of a number of previously productive gold deposits, such as Haveri and Saattopora (Finland), Boliden, Ädelfors, and Enåsen (Sweden), and Eidsvoll and Bidjovagge (Norway), is now available in the literature. Kutemajärvi, Pahtavaaraa, and Suurikuusikko (Finland), and Björkdal, Åkerberg, Harnäs, and Pahtohavare (Sweden) represent a new generation of gold mines, and recent research on these enables an improved base for formulating regional and local metallogenetic models. Younging trends from northeast to southwest characterize both the crust- and ore-forming regional patterns in the Fennoscandian Shield. Orogenic (or mesothermal) gold deposits are found in a wide range of host rocks and are closely linked to either the Paleoproterozoic Svecokarelian or the Neoproterozoic Sveconorwegian orogeny. Unlike these shear zone-related deposits, significant amounts of gold were concentrated in volcanogenic massive sulfide (VMS) deposits by magmatic-hydrothermal processes in conjunction with formation of Paleoproterozoic Svecofennian juvenile crust. Hundreds of gold deposits of a variety of ages and genetic styles are, therefore, now known in the Precambrian of northern Europe, of which some are economic, others subeconomic, and still others only of scientific interest. One hundred representative deposits in Sweden, Norway, Finland, and Russia are discussed in this review. Literature references are provided for each of them, and detailed maps show the location of each deposit or prospect. Listed data on tonnage and grades for the most recent exploration targets, as well as the economically and historically most significant deposits, show that they were formed during the entire Precambrian. Yield of gold in the Fennoscandian Shield is, so far, confined to Proterozoic deposits, but the potential to find economically viable gold deposits in the Russian parts of the Archean greenstone belts should not be underestimated.

Introduction

THE PRECAMBRIAN of northern Europe is dominated by the Fennoscandian (Baltic) Shield, which is the largest exposed segment (some 1,417,400 km^2) of Precambrian crust in Europe (Fig. 1). It occurs in an almost ideal shield shape, being bordered in all directions by flat-lying platform sediments. The Precambrian along the west coast of Norway, and in tectonic windows within the Caledonides, is, strictly speaking, not part of the Fennoscandian Shield, but makes up another 86,300 km^2 of Precambrian crust immediately to the northwest of the shield. The total area of the Precambrian in northern Europe is, thus, 1,503,700 km^2, of which 25.0 percent is located in Sweden, 24.9 percent in northwestern Russia, 23.1 percent in Finland, and 12.7 percent in Norway. Another 14.3 percent of the shield is covered by seawater (i.e., the Baltic Sea, Bothnian Sea, and Gulf of Finland), but most parts are relatively well exposed and easily accessible for geological investigations. All parts of the Precambrian of northern Europe are also relatively unweathered, due to recent glaciation. The name "Fennoscandian" is the most logical and preferred name for the shield, and was coined in 1907 by Wilhelm Ramsay and Jakob Johannes Sederholm. Sederholm (1932) was also the first to put forward a coherent Fennoscandian perspective on the Precambrian in Finland, Sweden, Norway, and westernmost Russia, and defined the basics of orogenic cycles in the entire shield. The term "Baltic Shield" is sometimes used as a synonym for the Fennoscandian Shield but is considered less appropriate, since the shield is not exposed anywhere in the Baltic republics or in the Baltic Sea.

The Fennoscandian Shield can be divided into three crustal domains (Gaál and Gorbatschev, 1987; Alm et al., 2002): (1) the Archean, (2) the Svecofennian (including the Transscandinavian igneous belt), and (3) the Gothian domains. The Archean domain comprises the oldest pieces of continental crust in northern Europe and consists of the Karelian province, the Belomorian province, and the Kola Pensinsula, which became amalgamated and cratonized in the Late Archean. Several failed efforts to rift the Archean craton in the Paleoproterozoic resulted in emplacement of mafic volcanic rocks and associated sediments, which now are preserved as Paleoproterozoic greenstone belts in the failed rift arms within the Archean craton. The Svecofennian domain consists of juvenile crust produced by the successful rifting of the Archean craton along an axis that runs from northern Sweden through central Finland to lake Ladoga (the Raahe-Ladoga line). The Svecofennian environments include remnants of ca. 1.9 Ga magmatic and sedimentary components of ophiolites, island arcs, and active continental margins, which all were amalgamated and accreted to the Archean (Lopian) craton during the Svecokarelian orogeny (Nironen, 1997). The Transscandinavian igneous belt is a 1.65 to 1.85 Ga batholith of complex origin that extends from the southeastern part of Sweden to the Caldedonides. It postdates the Svecokarelian orogeny and intruded along the southwestern margin of the metamorphosed Svecofennian crust. The Gothian domain consists of orthogneisses and local metasedimentary strata in southwestern Scandinavia. The principal crustal

† E-mail, Krister.Sundblad@utu.fi



Selected deposits:

1-5	Ilomantsi region	(F)	51	Kutemajärvi	(F)
10	Karahkalehto	(F)	53	Björkdal	(S)
11	Pellapahk	(R)	54	Åkerberg	(S)
13-15	Saattopora, Suurikuusikko and Pahtavaara	(F)	57	Middagsberget	(S)
16	May	(R)	59	Kangaskylä	(F)
17	Juomasuo	(F)	62	Osikonmäki	(F)
20	Bidjovagge	(N)	63	Alattu and Harlu	(R)
21	Pahtohavare	(S)	64	Haveri	(F)
26	Aitik	(S)	66	Boviksgruvan	(S)
27	Outokumpu	(F)	70	Ersmarksberget	(S)
28	Vihanti	(F)	75	Svartliden	(S)
29	Pyhäsalmi	(F)	77	Nynäsberget	(S)
30-36	Skellefte VMS deposits	(S)	78	Tervasmäki	(F)
37	Falun	(S)	81	Ädelfors	(S)
41	Orijärvi	(S)	83	Gladhammar	(S)
42	Fröderyd	(S)	85	Skatemåla	(S)
43	Tallberg	(S)	89	Eidsvoll	(N)
44	Kopsa	(F)	90	Glava	(S)
46	Kuervitikko	(F)	91	Harnäs	(S)
47	Boliden	(S)	92	Bleka	(N)
48	Enåsen	(S)	97	Oppdal region	(N)
			98	Sibirien	(N)
			100	Sørdalshøgda	(N)

Fig. 1. The Fennoscandian Shield (and adjacent Precambrian terranes on the west coast of Norway and within the Caledonides), with location of 100 representative gold-bearing ore deposits and prospecting targets. Gold deposits are marked with numbers according to Table 1. F = Finland, N = Norway, R = Russia, RLL = Raahe-Ladoga line, S = Sweden.

units, including posttectonic granites, have ages between 1.65 and 0.9 Ga and the main metamorphic event took place during the 1.05 to 0.9 Ga, Sveconorwegian orogeny. The Precambrian units on the west coast of Norway, and in the tectonic windows in the Caledonides, can be subdivided into autochthonous and allochthonous units. The autochthonous units were parts of the Fennoscandian Shield in Late Proterozoic time, whereas the allochthonous units represent suspect terranes (emplaced in their present position during the Caledonian orogeny) with uncertain shield provenance.

Each of the three main domains of the Fennoscandian Shield, as well as the Precambrian units within the Caledonides, is host to gold mineralization. Economic gold deposits, with mines operating during the last decade, are found in a number of geological environments ranging from early Paleoproterozoic to Neoproterozoic ages, but each environment is confined to relatively restricted time spans and geographical extents. They are interpreted to have formed by a wide range of processes, including magmatic-hydrothermal, metamorphic-hydrothermal, and surficial processes. In this text, the term "gold deposit" is applied to any natural occurrence of gold, from an uneconomic prospecting target to an economically viable deposit, either for gold as a primary product or as a byproduct to other metal commodities. One hundred representative deposits are discussed in this paper, with appropriate key references (Table 1).

The first metallogenic overview of the Fennoscandian Shield was made by Gaál and Sundblad (1990), who noted that a larger number of gold mines were active in Fennoscandia during the 1980s than ever before, including Enåsen, Björkdal, and Åkerberg (Sweden), Saattopora (Finland), and Bidjovagge (Norway). During the 1990s, six new gold mines went into production or were proven to be economic at that time: Pahtohavare (Kiruna greenstone belt, northern Sweden), Pahtavaara and Suurikuusikko (Lapland greenstone belt, northern Finland), Harnäs (Mjøsa-Vänern district, southwest Sweden), Kutemajärvi (Tampere schist belt, southern Finland), and Pampalo (Hattu schist belt, Ilomantsi area, eastern Finland). This increased prospecting and production activity has also led to a significant increase in our knowledge of the gold-forming processes in the Fennoscandian Shield. Results from a number of detailed investigations during the last 10 yr have been published on various types of deposits, and a number of key references are now available for most of the gold-bearing areas in Fennoscandia (see reference list). Although only 13 yr have passed since the review of Gaál and Sundblad (1990) was published, an updated review of Fennoscandian gold metallogeny is already warranted. The purpose of this contribution is to provide an overview of the geographical, geological, and metallogenetic features of known gold mineralization in the shield, including economic and subeconomic deposits and occurrences of primarily academic interest. A more extensive database on individual deposits in Finland has been compiled by Eilu (1999).

Gold in Archean Greenstone Belts

The Archean domain of the Fennoscandian Shield is located in the northeastern part of the shield, where the oldest parts are composed of 3.1 to 2.9 Ga tonalites, trondhjemites, and granodiorites. Other significant crustal components of the Archean domain include granitoids and orthogneisses, as well as locally abundant greenstone belts with metamorphosed komatiites, tholeiitic basalts, calc-alkaline volcanic rocks, and sedimentary rocks. The Archean domain can be subdivided into three crustal provinces: the Karelian, the Belomorian, and the Kola Peninsula provinces. The southernmost of these, the Karelian province, is a classical granite-greenstone terrane, with a number of ore-bearing, north-south–trending, low- to medium-grade greenstone belts (Fig. 2). The Belomorian province is a high-grade gneiss terrane (without greenstone belts) to the northeast of the Karelian province (Fig. 3). The Kola Peninsula province is another

FIG. 2. Gold-bearing ore deposits and prospecting targets in the eastern part of the Fennoscandian Shield, particularly featuring deposits hosted by Archean greenstone belts in the Karelian province. Gold deposits are marked with numbers according to Table 1. The Raahe-Ladoga line (RLL) marks the concealed southwestern margin of the Archean craton. V = Varkaus.

TABLE 1. 100 Representative Gold-Bearing Deposits in the Fennoscandian Shield
(and adjacent Precambrian terranes along the west coast of Norway and within the Caledonides)

No. Deposit name	Country	Key references
Gold in Archean greenstone belts		
1. Kuittila	(F)	Nurmi and Sorjonen-Ward (1993); Stein et al. (1998a)
2. Korvilansuo	(F)	Nurmi and Sorjonen-Ward (1993)
3. Rämepuro	(F)	Nurmi and Sorjonen-Ward (1993)
4. Pampalo	(F)	Nurmi and Sorjonen-Ward (1993)
5. Hosko (Valkeasuo)	(F)	Nurmi and Sorjonen-Ward (1993)
6. Jalonvaara	(R)	Hausen (1935); Ivashchenko and Lavrov (1994)
7. Sepponen	(F)	Luukonen (1993)
8. Palovaara	(F)	Eilu et al. (2003)
9. Moukkori	(F)	Luukonen (1993); Eilu et al. (2003)
10. Karahkalehto	(F)	Juopperi and Karvinen (1999)
11. Pellapakh	(R)	Gavrilenko and Dain (1999)
Gold in Paleoproterozoic greenstone belts		
Orogenic deposits		
12. Gjeddevannet	(N)	Ihlen (1999)
13. Saattopora	(F)	Korvuo (1997); Grönholm (1999)
14. Suurikuusikko	(F)	Härkönen et al. (1999)
15. Pahtavaara	(F)	Korkiakoski (1992)
16. May	(R)	Turchenko et al. (1991); Gavrilenko et al. (1999a)
17. Juomasuo	(F)	Pankka and Vanhanen (1992)
18. Konttiaho	(F)	Pankka and Vanhanen (1992)
19. Kouvervaara	(F)	Pankka and Vanhanen (1992)
20. Bidjovagge	(N)	Bjørlykke et al. (1990); Ettner et al. (1994)
21. Pahtohavare	(S)	Martinsson (1997)
22. Kivimaa	(F)	Rouhunkoski and Isokangas (1974)
23. Vähäjoki	(F)	Eilu et al. (2003)
Paleoplacers		
24. Outapää	(F)	Härkönen (1986)
25. Kaarestunturi	(F)	Härkönen (1984)
Gold in the Svecofennian domain and Transscandinavian igneous belt		
Gellivare region		
26. Aitik	(S)	Zweifel (1976); Wanhainen et al. (1999)
VMS-hosted gold		
27. Outokumpu	(F)	Kontinen (1987); Gaál and Parkkinen (1993)
28. Vihanti	(F)	Rouhunkoski (1968); Weihed and Mäki (1997)
29. Pyhäsalmi	(F)	Helovuori (1979); Weihed and Mäki (1997)
30. Renström	(S)	Allen et al. (1996a)
31. Udden	(S)	Allen et al. (1996a)
32. Holmtjärn	(S)	Allen et al. (1996a)
33. Maurliden	(S)	Allen et al. (1996a)
34. Näsliden	(S)	Allen et al. (1996a)
35. Storliden	(S)	Chevalier (1999)
36. Kristineberg	(S)	Allen et al. (1996a)
37. Falun	(S)	Allen et al. (1996b)
38. Garpenberg	(S)	Allen et al. (1996b)
39. Saxberget	(S)	Allen et al. (1996b)
40. Ö. Silvberg	(S)	Allen et al. (1996b)
41. Orijärvi	(S)	Latvalahti (1979)
42. Fröderyd	(S)	Sundblad et al. (1997a)
Intrusion-related gold		
43. Tallberg	(S)	Weihed (1992); Weihed and Fallick (1994)
44. Kopsa	(F)	Gaál and Isohanni (1979)
45. Jouhineva	(F)	Eilu (1999)
53. Björkdal	(S)	Broman et al. (1994)
Skarn-hosted gold		
46. Kuervitikko	(F)	Hiltunen (1982); Eilu et al. (2003)
Metamorphosed epithermal gold		
47. Boliden	(S)	Bergman Weihed et al. (1996)
48. Enåsen	(S)	Hallberg (1994); Hallberg and Fallick (1994)
49. Isovesi	(F)	Luukonen (1994)
50. Järvenpää (Ylöjärvi)	(F)	Luukonen (1994)
51. Kutemajärvi	(F)	Luukonen (1994); Poutiainen and Grönholm (1996)
52. Jokisivu	(F)	Luukonen (1994)
Svecokarelian orogenic gold		
53. Björkdal	(S)	Weihed et al. (2003)
54. Åkerberg	(S)	Matsson (1991); Weihed and Mäki (1997)
55. Grundfors	(S)	Bergman (1992); Billström and Weihed (1996)
56. Fäbodliden[1]	(S)	Sundblad et al. (1993)
57. Middagsberget	(S)	Sundblad et al. (1993); Öhlander and Markkula (1994)
58. Vargbäcken	(S)	Blomqvist and Leijd (1999)
59. Kangaskylä	(F)	Mäkelä et al. (1988); Sundblad et al. (1993)
60. Laivakangas	(F)	Mäkelä and Sandberg (1985)
61. Pöhlölä	(F)	Mäkelä et al. (1988)
62. Osikonmäki	(F)	Kontoniemi and Nurmi (1998)
63. Alattu and Harlu	(R)	Vassily Ivashchenko (pers. commun., 2001)
64. Haveri	(F)	Mäkelä (1980); Karvinen (1997)
65. Hamrånge	(S)	
37. Falun (Östra Hårdmalmerna)	(S)	Åberg and Fallick (1993)
66. Boviksgruvan	(S)	Bergman and Sundblad (1991)
67. Källfallet	(S)	Bergman and Sundblad (1991)
68. Malsjöberg	(S)	Bergman and Sundblad (1991)
69. Pyhälammi	(F)	Isomäki (1989)
Gold in the Bothnian basin metasediments		
70. Ersmarksberget	(S)	
71. Barsele	(S)	
72. Stortjärnhobben	(S)	Torbjörn Grahn (pers. commun., 2001)
73. Sjöliden	(S)	
74. Mejvankilen	(S)	
75. Svartliden	(S)	Hart et al. (1999)
76. Fäbodliden[1]	(S)	Torbjörn Grahn (pers. commun., 2001)
77. Nynäsberget	(S)	Johansson et al. (1999)
78. Tervasmäki	(F)	Lestinen et al. (1991)
79. Tammijärvi	(F)	Luukonen (1994)
80. Ahvenlammi	(F)	Luukonen (1994)
Orogenic gold within Transscandinavian igneous belt		
81. Ädelfors	(S)	Sundblad et al. (1999)
82. Fifflekull	(S)	
83. Gladhammar	(S)	
84. Solstad	(S)	Söderhielm and Sundblad (1996)
85. Skatemåla	(S)	Sundblad et al. (1997b)
Gold within (and along the eastern margin of) the Gothian domain; strata-bound gold		
86. Rørholt	(N)	J.S. Sandstad and P.M. Ihlen (pers. commun., 2001)
87. Skyttemyr	(N)	J.S. Sandstad and P.M. Ihlen (pers. commun., 2001)
88. Haugset	(N)	J.S. Sandstad and P.M. Ihlen (pers. commun., 2001)
Sveconorwegian orogenic gold		
89. Eidsvoll	(N)	Ihlen (1995)
90. Glava	(S)	Oen and Kieft (1984)
91. Harnäs	(S)	Alm et al. (2003)
92. Bleka	(N)	Bugge (1935); Petersen and Jensen (1995)
93. Skuterud	(N)	J.S. Sandstad and P.M. Ihlen (pers. commun., 2001)
94. Liverud	(N)	J.S. Sandstad and P.M. Ihlen (pers. commun., 2001)
95. Vekselmyr	(N)	J.S. Sandstad and P.M. Ihlen (pers. commun., 2001)
Gold in Precambrian crust along the west coast of Norway and within the Caledonides		
96. Snøhetta	(N)	Sigmund Rise (pers. commun., 2001)
97. Oppdal region	(N)	Sigmund Rise (pers. commun., 2001)
98. Sibirien	(N)	Grenne (1990)
99. Gautelisfjell	(N)	Skyseth and Reitan (1995)
100. Sørdalshøgda	(N)	Sandstad and Nilsson (1997)

[1] Note that deposit no. 56, Fäbodliden, in the Skellefte district should not be confused with deposit no. 76, Fäbodliden, in the Bothnian basin

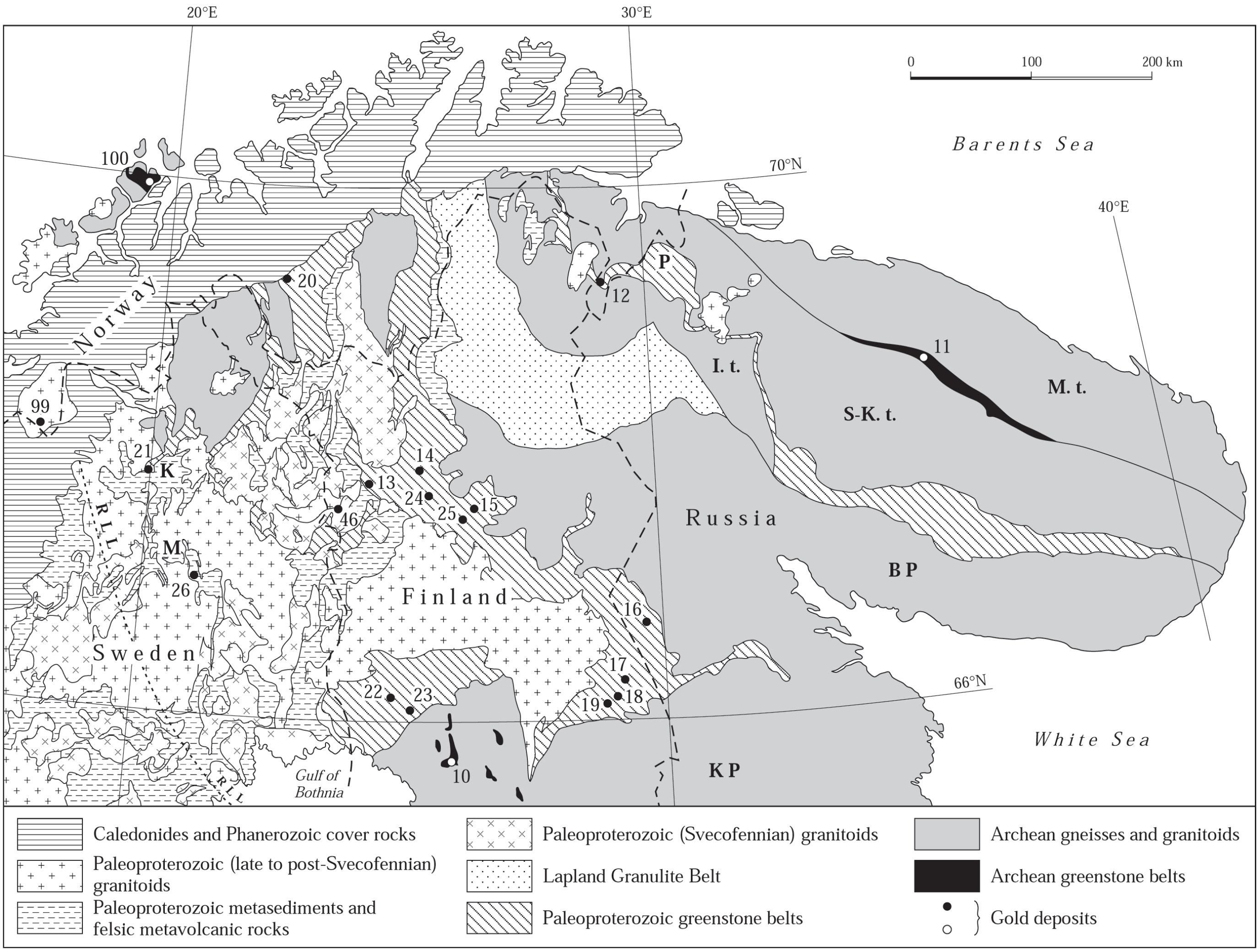


FIG. 3. Gold-bearing ore deposits and prospecting targets in the northern part of the Fennoscandian Shield. I.t. = Inari terrane, M.t. = Murmansk terrane, S-K.t. = Sørvaranger-Kola terrane; together, they constitute the Kola Peninsula province. BP = Belomorian province. Gold deposits are marked with numbers according to Table 1. Other major ores: K = Kiruna apatite-magnetite iron deposit, M = Malmberget apatite-magnetite iron deposit, P = Pechenga (Petsamo) nickel deposits. RLL = Raahe-Ladoga line.

high-grade gneiss complex, separated from the Belomorian province by the Paleoproterozoic Lapland granulite belt (Fig. 3). The Kola Peninsula province can be subdivided into three orthogneiss complexes: the Murmansk, Sørvaranger-Kola, and Inari terranes, separated from each other by both Archean and Paleoproterozoic greenstone belts. The Archean domain was metamorphosed and cratonized during the Lopian orogeny at 2.9 to 2.6 Ga. The ore potential of the Archean domain has, for a long time, been focused on the Karelian province in eastern Finland and westernmost Russia, where a number of greenstone-hosted banded iron formation (bif) ores (e.g., Kostamuksha, Russia) and tonalite-hosted molybdenum ores (e.g., Lobash and Mätäsvaara) are located (Turchenko, 1992). Recent discoveries of greenstone-hosted gold deposits in easternmost Finland (Nurmi and Sorjonen-Ward, 1993) suggest that the greenstones in the entire region of the Karelian province have a high potential for further exploration. The Russian parts of the Karelian province are particularly underexplored in this respect.

The Karelian province

The most significant gold prospects of the Karelian province have been found in the metasediment-dominated Hattu schist belt (Nurmi and Sorjonen-Ward, 1993), including Kuittila, Korvilansuo, Rämepuro, Pampalo, and Hosko (nos. 1–5; Fig. 2). The Pampalo deposit (no. 4) has currently the highest economic potential in the area. Ore reserve calculations at Pampalo indicate several hundreds of thousands of tons of ore, with a grade of 8 ppm Au (Table 2). The gold mineralization in the Hattu schist belt is characterized by relatively high contents of Te, Bi, and B, and low contents of As, Ag, W, and S (Nurmi et al., 1993). The gold deposits are typically mesothermal and follow closely ductile shear zones, which deform all rocks in the area. The ages of the main host

TABLE 2. Grade and Tonnage of Selected Gold (-bearing) Deposits in the Fennoscandian Shield

No.	Deposit	Active	Size (Mt)	Au (ppm)	Ag (ppm)	Cu (%)	Grade Zn (%)	Pb (%)	Co (%)	S (%)	Gold (kg)	References
Gold in Archean greenstone belts												
3.	Rämepuro	–	0.25	5	–	–	–	–	–	–	1,250	Nurmi and Sorjonen-Ward (1993)
4.	Pampalo	–	0.5–0.9	5–8	–	–	–	–	–	–	4,000–7,000	Sorjonen-Ward and Nurmi (1997)
Gold in Paleoproterozoic greenstone belts												
13.	Saattopora	1989–1995	2.2	3.4	–	0.31	–	–	–	–	7,480	Grönholm (1999)
14.	Suurikuusikko	–	2.7	6.6	–	–	–	–	–	–	17,820	Härkönen et al. (1999)
15.	Pahtavaara	1996–	1.3	3.4	–	–	–	–	–	–	4,420	Korkiakoski and Kilpelä (1997)
17.	Juomasuo	–	1.0	5-6	–	–	–	–	0.2	–	5,500	Sorjonen-Ward and Nurmi (1997)
20.	Bidjovagge	1985–1991	1.7	4.1	–	1.19	–	–	–	–	6,970	Ekberg and Sotka (1991)
21.	Pahtohavare	1989–1997	1.68	0.88	–	1.89	–	–	–	–	1,478	Martinsson (1997)
Gold in the Svecofennian domain and TIB												
VMS-hosted gold												
27.	Outokumpu	1913–1988	28.5	0.8	8.9	3.8	1.07	–	0.24	25.3	22,800	Gaál and Parkkinen (1993)
28.	Vihanti	1954–1992	28.1	0.5	25	0.48	5.12	0.36	–	–	13,769	Weihed and Mäki (1997)
29.	Pyhäsalmi	1962–	30.3	0.4	14	0.79	2.47	0.06	–	35	12,120	Weihed and Mäki (1997)
30.	Renström	1952–	9.0	2.8	155	0.8	6.5	1.5	–	15	25,200	Allen et al. (1996a)
31.	Udden	1971–1990	6.7	0.7	36	0.4	4.3	0.3	–	24	4,690	Allen et al. (1996a)
32.	Holmtjärn	1924–1925 1986–1992	0.5	7.4	92	0.4	4.0	0.4	–	22	3,700	Svensson and Willdén (1986)
33.	Maurliden	–	6.9	0.9	4.9	0.2	3.4	0.4	–	39	6,210	Allen et al. (1996a)
34.	Näsliden	1970–1989	4.6	1.3	35	1.1	3.02			29	5,980	Allen et al. (1996a)
35.	Storliden	–	1.8	0.3	29	4.0	10.0	0.7	–	–	540	Chevalier (1999)
36.	Kristineberg	1940–	20.1	1.0	35	1.0	3.7	0.5	–	25	20,100	Allen et al. (1996a)
37.	Falun	13th c.–1992	28.1	2–4	13–24	2–4	4	1.5	–	–		Allen et al. (1996b)
38.	Garpenberg	14th c.–	21.5	0.65	98	0.3	5.3	3.3	–	–	13,975	Allen et al. (1996b)
39.	Saxberget	1880–1988	6.8	0.4	42	0.9	7.1	2.2	–	–	2,720	Allen et al. (1996b)
40.	Ö. Silvberg	14th c.–1922	0.2	4.5–7	45–70	<0.9	5.6–22.5	1.2–2.9	–	–	1,000?	Allen et al. (1996b)
42.	Fröderyd	1769–1919 (periodically)		0.07	41	0.76	8.1	2.7	94	–		Sundblad et al. (1997a)
Intrusion-related gold												
44.	Kopsa	–	25.0	0.57	4	–	–	–	–	–	14,250	Gaál and Isohanni (1979)
Metamorphosed epithermal gold												
47.	Boliden	1924–1967	8.3	15.5	50	1.4	0.9	0.3	–	25	128,650	Allen et al. (1996a)
48.	Enåsen	1984–1991	1.7	3	–	0.2	–	–	–	–	5,100	Hallberg (1994)
51.	Kutemajärvi	1994–	1.2	9	2.9	0.008	0.02	0.01	–	1.4	10,800	A. Kinnunen, pers. commun. (1999)
Svecokarelian orogenic gold												
53.	Björkdal	1989–1999; 2001–	20.0	2.5	–	–	–	–	–	–	50,000	Weihed et al. (2003)
54.	Åkerberg	1989–2001	1.0	3	–	–	–	–	–	–	3,000	Matsson (1991)
64.	Haveri	1942–1960	1.5	2.8		0.37	–		–		4,200	Sorjonen-Ward and Nurmi (1997)
Gold in the Bothnian basin metasediments												
75.	Svartliden	–	2.5	5.4	–	–	–	–	–	–	13,500	Hart et al. (1999)
Orogenic gold within TIB												
81.	Ädelfors	1741–1916 (periodically)		11.2	7	0.005	0.003	0.002	0.005		145	Tegengren (1924)
Sveconorwegian gold within (and along the eastern margin of) the Gothian domain												
89.	Eidsvoll (Brustad)	1758–1907 (periodically)	0.050	2–15							≈ 300	Ihlen (1995)
91.	Harnäs	1993–1995	0.060	2	–	–	–	–	–	–	120	Alm et al. (2003)
92.	Bleka	1870–1900		25	45	1.5	–	–	–	–	≈ 200	Petersen and Jensen (1995)

TIB = Transscandinavian igneous belt

rocks have been determined at ca. 2750 to 2760 Ma (Vaasjoki et al., 1993). The timing of the gold deposition associated with shearing has been constrained by the Re-Os method to 2607 ± 47 Ma (Stein et al., 1998a). The sulfide-bearing Hattu schist belt can be further traced southward into the Jänisjärvi area north of Ladoga, where the Jalonvaara deposit (no. 6) is located. At this site, an early (possibly syngenetic) generation of pyrite and chalcopyrite mineralization occurs in the supracrustal units, together with a later generation of Mo, W, Pb, Zn, and Au related to Archean granitoids (Hausen, 1935; Ivashchenko and Lavrov, 1994).

Several mesothermal gold deposits are also known in the volcanic-dominated sequences of the Kuhmo-Suomussalmi greenstone belt farther to the northwest in eastern Finland (nos. 7–9), of which Sepponen and Moukkori are hosted by tholeiitic metabasalts, whereas Palovaara is BIF hosted. Gold deposition in the Kuhmo-Suomussalmi greenstone belt is considered to have been coeval with the main mineralizing event in the Ilomantsi region (Eilu et al., 2003). Recent discoveries of gold mineralization in the Oijärvi greenstone belt have demonstrated that this part of the Karelian province also has potential for additional gold discoveries (Juopperi and Karvinen, 1999). The most promising target so far, Karahkalehto (no. 10), is characterized as mesothermal mineralization, located in a km-wide, hydrothermally altered shear zone, which cuts through a sequence of tholeiites, basalts, basaltic komatiites, and komatiites (Eilu et al., 2003).

The Kola Peninsula province

The Kola Peninsula province in the northeastern part of the Shield is another region with significant potential for future gold discoveries. At present, exploration in these parts of Russia is hampered by difficult climatic conditions and, in most areas, lack of roads. The most promising target so far is the Mo-Cu-Au deposit at Pellapahk (no. 11), which is hosted by a granite-porphyry rock, considered to be one of the earliest intrusions in the 2.83 Ga Kolmozero-Voronya belt (Gavrilenko and Dain, 1999). In this region, the Kolmozero-Voronya greenstone belt structurally separates the Murmansk and Sørvaranger-Kola gneiss terranes from each other (Fig. 3).

Gold in Paleoproterozoic Greenstone Belts

Following the cratonization of Archean crust in conjunction with the Lopian orogeny, this new continent (in this paper, referred to as the "Lopian continent") was subject to several failed rifting events already by the earliest Paleoproterozoic. These rifts resulted in mafic magmatism and the development of several sedimentary basins, which are preserved as greenstone belts in the northernmost part of the Fennoscandian Shield (the northern parts of Norway, Sweden, and Finland, as well as the northwesternmost part of Russia). These Paleoproterozoic greenstone belts comprise the Lapponian Supergroup, which contains komatiitic and tholeiitic metavolcanic rocks, as well as metamorphosed arkoses, sandstones, and pelites. The greenstone belts occur in north-south– and northwest-southeast–trending structures (Fig. 3). One of the most important Paleoproterozoic greenstone belts is the Pechenga-Varzuga greenstone belt, which extends over 700 km from the Caledonian front along the Kola Peninsula toward the White Sea. It separates the Sørvaranger-Kola gneiss terrane from the Inari terrane and the Belomorian province, and is metallogenetically well known as the host to the major Ni-Cu-PGE deposits at Pechenga (Petsamo). Local names for other important Paleoproterozoic greenstone belts include Karasjok, Kautokeino, Lapland, Kiruna, and Kuusamo, as well as the metasediment-dominated Peräpohja schist belt. These are described below. The Paleoproterozoic greenstone-hosted Cu-Au ± Co deposits in northern Fennoscandia are generally characterized by an association with shear zones and hydrothermally albitized rocks. The largest concentration of economic gold deposits occurs in the Lapland greenstone belt in the Kittilä region (Finland), but all other greenstone belts also host economic to subeconomic gold targets. Although the 2.4 to 2.1 Ga greenstones are the most common host rock, the gold-controlling structures are invariably related to the 1.9 to 1.8 Ga Svecokarelian orogeny (e.g., Bjørlykke et al., 1990; Eilu et al., 2003).

Lapland and Kuusamo greenstone belts

The Lapland greenstone belts are host to a number of epigenetic Au-Cu deposits, including Saattopora (no. 13; Korvuo, 1997; Grönholm, 1999), Suurikuusikko (no. 14; Härkönen et al., 1999), and Pahtavaara (no. 15; Korkiakoski, 1992). These deposits are hosted by albitized greenstones and are structurally controlled by branches to the Sirkka line (Eilu et al., 2003). Paleoplacer gold, hosted by mono- and polymict conglomerates in the Kumpu formation of the Lapponian greenstones, also occurs in the Kittilä region: Kaarestunturi and Outapää (nos. 24 and 25; Eilu et al., 2003). The Kuusamo greenstone belt is a southern, and more metasedimentary, prolongation of the Lapland greenstone. Several, at present subeconomic, targets have been identified in this belt, including May in Russia (no. 16; Turchenko et al., 1991; Gavrilenko et al., 1999a), as well as Juomasuo, Konttiaho, and Kouvervaara in Finland (nos. 17–19; Pankka and Vanhanen, 1992; Vanhanen, 2001). The sulfide deposits are hosted by metasedimentary units in the stratigraphically lowest part of the greenstone sequence, and have formed from deformation-induced hydrothermal solutions causing Fe-Mg-silicate and K-silicate alteration, as well as carbonatization and silicification. Three groups of deposits exist: U deposits (e.g., Kouvervaara), Co-Au-U–bearing sulfide deposits (e.g., Juomasuo and Konttiaho), and Fe-sulfide deposits. The timing of the mesothermal gold mineralization in the Kittilä and Kuusamo regions is related to the main compressional stage of the Svecokarelian orogeny at 1.90 to 1.88 Ga, roughly at peak conditions of metamorphism and deformation (Eilu et al., 2003).

Pechenga-Varzuga greenstone belt

The recently discovered Au-As–anomalous zones at Gjeddevannet in the Pasvik area, Norway (no. 12; Ihlen, 1999), indicates that the major Pechenga-Varzuga greenstone belt on the Russian side of the border also has potential for gold (Gavrilenko et al., 1999b). The prospects are located stratigraphically above the productive Ni layer in the Pechenga (Petsamo) sequence.

Kautokeino greenstone belt

The Bidjovagge deposit (no. 20) was mined from 1970 to 1975 as a Cu-Au deposit, and from 1985 to 1992 as a Au-Cu deposit. The ore consists of chalcopyrite, pyrite, and pyrrhotite, native gold, and several tellurides, hosted by an albitized, graphitic felsic volcanic unit. The ore occurs within a shear zone along the border between greenschist and amphibolite facies metamorphic rocks in the Kautokeino greenstone belt (Bjørlykke et al., 1987; Bjørlykke et al., 1990; Ekberg and Sotka, 1991; Cumming et al., 1993; Ettner et al., 1993, 1994; Cook, 1999).

Kiruna greenstone belt

The potential for gold exploration in the Kiruna greenstones was realized when the stratiform Cu deposit of Viscaria was discovered in the 1970s (Godin, 1986), which soon led to the identification of epigenetic Cu-Au deposits. The most important of these was Pahtohavare (no. 21), which was mined from 1989 to 1996. The host rock to the ore is an albitized felsic volcanic unit. Ore deposition was associated with brittle to ductile deformation (Martinsson, 1997).

Peräpohja schist belt

Mineralization in the sediment-dominated Peräpohja schist belt is similar to that in the volcanic-dominated greenstone belts. The most important deposit is Kivimaa (no. 22), which was mined for copper and gold in 1969 (Rouhunkoski and Isokangas, 1974). The Vähäjoki Cu-Fe-Au deposit (no. 23) is characterized as an epigenetic ironstone-hosted deposit (Eilu et al., 2003).

Gold in the Svecofennian Domain and Transscandinavian Igneous Belt

After many failed rifting events in the earliest Paleoproterozoic, successful rifting of the Archean craton eventually took place at ca. 2.0 Ga, and an ocean opened to the southwest of the margin of the Lopian continent, now delineated by the Raahe-Ladoga line in Figures 1 to 4. Magmatic activity and sedimentation became focused in a number of geological

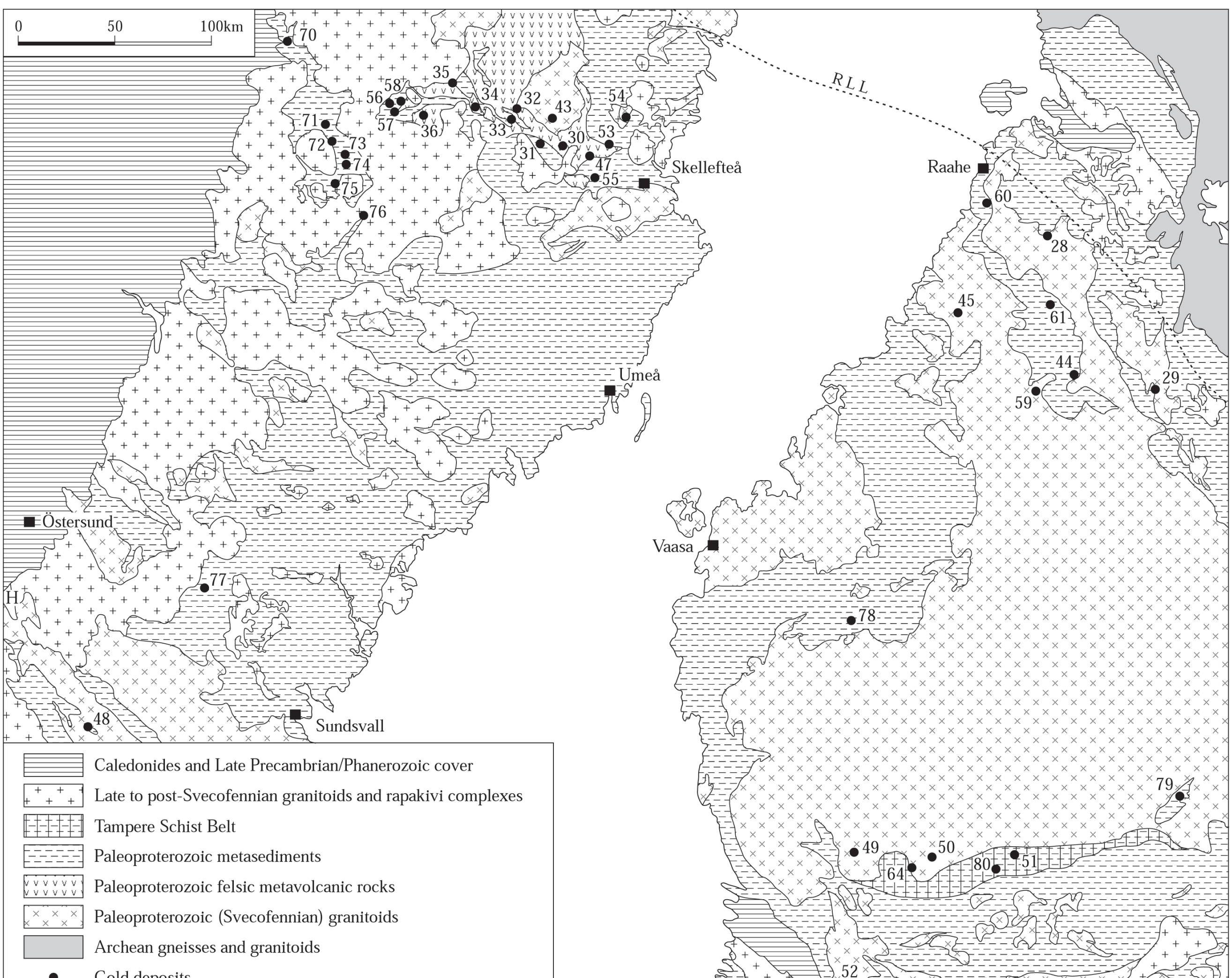


FIG. 4. Gold-bearing ore deposits and prospecting targets in the central part of the Fennoscandian Shield. The dense concentration of deposits and prospecting targets west of Skellefteå (deposits nos. 30–36, 43, 47, and 53–58) constitutes the Skellefte district. H = Hackås, RLL = Raahe-Ladoga line.

environments along, and particularly outboard of, the Lopian continent in the period between 1.96 and 1.89 Ga. The resulting juvenile crust is referred to as Svecofennian. The six most significant elements of the Svecofennian are as follows.

1. Oceanic crust formed during incipient ocean opening. The oceanic crust is preserved in the Jormua ophiolite in eastern Finland (Kontinen, 1987), and can be further traced into ore-bearing amphibolites in the Outokumpu district (Fig. 2), which are hosts to several major VMS deposits.

2. Continental margin volcanism within, and immediately to the southwest of, the Lopian craton. The products of these magmatic arcs are represented by felsic metavolcanic rocks and Svecofennian granitoids in the Kiruna-Malmberget region in northern Sweden (Fig. 3). This geological paleoenvironment has a modern analog in present-day Chile, which also allows for a metallogenetic comparison between the world-class Kiruna and Malmberget apatite iron ores and the magnetite flows at El Laco, Chile (Nyström and Henriquez, 1994). Other significant ores tied to this continental margin environment are the Aitik Cu-Au deposit (northern Sweden) and the VMS deposits at Vihanti and Pyhäsalmi in the Main sulfide belt in Finland (Fig. 2).

3. Deep- to shallow-marine volcanism and sedimentation in an island-arc environment, at sufficient distance from any continent to prevent crustal contamination into the arc-derived sediments. This paleoenvironment is now preserved in the Skellefte district and the Tampere schist belt (Fig. 4). An analog with present-day Japan and a comparison between the abundant VMS deposits in the Skellefte district and the kuroko deposits have been suggested in the past (Rickard and Zweifel, 1975). However, the Tonga-Kermadec arc in the present-day Western Pacific may be an even more appropriate analog for the Skellefte district (Allen et al., 1996a).

4. Turbiditic sedimentation with a major input of continentally derived sedimentary detritus. This paleoenvironment is preserved today to the south of the Skellefte and Tampere magmatic arcs (Bothnian basin metasediments) shown in Figure 4.

5. Felsic-intermediate continental margin coeval with turbiditic or fluvial sedimentation with significant amounts of continentally derived Archean detritus. This paleoenvironment is represented by Svecofennian granitoids, felsic metavolcanic rocks, and metasedimentary rocks in the Bergslagen district (Fig. 5), which is one of the richest, and historically most significant, metallogenetic provinces of Fennoscandia.

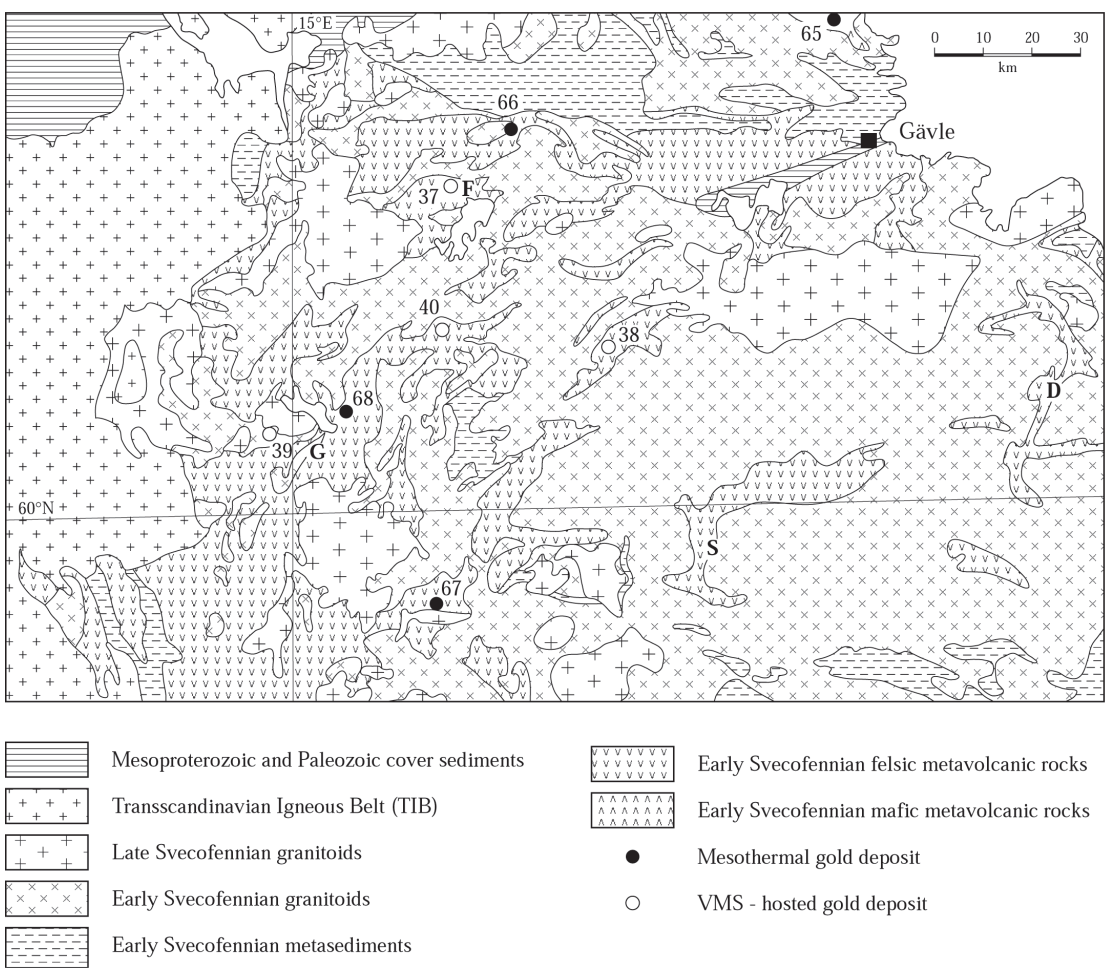


FIG. 5. Gold-bearing ore deposits and prospecting targets in the Bergslagen district. Gold deposits are marked with numbers according to Table 1. Major ores (all abandoned mines): D = Dannemora (Fe), F = Falun (Cu-Zn-Pb-Ag-Au), G = Grängesberg (Fe), S = Sala (Ag).

It includes such world-class deposits as Grängesberg and Dannemora (Fe), Sala (Ag), Falun and Garpenberg (Cu-Zn-Pb), and Zinkgruvan (Zn-Pb). The continent along which the Bergslagen paleoenvironment developed was probably not the Lopian continent, but another ancient continent, which later was separated from the Bergslagen successions (Kumpulainen et al., 1996).

6. Formation of primitive oceanic crust, possibly representing a rift separating the continental margin paleoenvironment of Bergslagen and the unknown ancient continent. A small fragment of this paleoenvironment is now preserved at Fröderyd (no. 42) in southern Sweden (Fig. 6), where a number of small VMS deposits have been described (Sundblad et al., 1997a).

Shortly after these paleoenvironments were active, the individual fragments of Svecofennian juvenile crust were accreted to the Lopian continent. This event is referred to as the Svecokarelian orogeny and led to metamorphism, deformation, and obduction of ophiolite. The Lopian continent, together with the cratonized Svecofennian crust, which is referred to in this contribution as the "Lopian-Svecokarelian continent," was subsequently intruded by several generations of late- to postorogenic granitoid intrusions. The Transscandinavian igneous belt is the largest of the postorogenic granitoid complexes; it intruded over a prolonged period (1.85–1.67 Ga) into the Svecofennian crust as a coastal batholith (comparable to the present situation in Peru). Gold is associated with a number of geological processes active during formation of the Svecofennian crust and the Transscandinavian igneous belt.

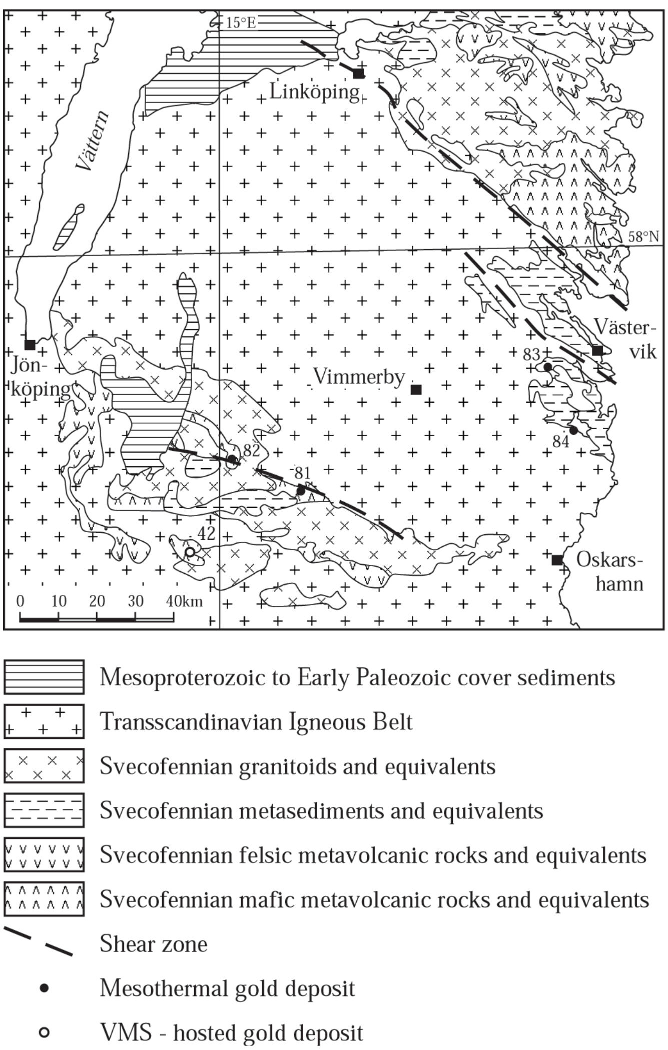


FIG. 6. Gold-bearing ore deposits and prospecting targets in the south-eastern part of Sweden. Gold deposits are marked with numbers according to Table 1.

Gellivare region (Aitik and others)

The Aitik Cu-Au deposit (no. 26) in northern Sweden is one of the largest concentrations of copper and gold in the Fennoscandian Shield. A combined estimate of ore production and reserves amounts to 700 Mt, with an annual production of 18 Mt at 0.4 percent Cu and 0.2 ppm Au (Wanhainen et al., 1999). Disseminated chalcopyrite, pyrite, pyrrhotite, and native gold are hosted by microcline gneisses, biotite schists, and muscovite schists, surrounded by hornblende gneisses and quartz-biotite gneisses, as well as gabbro and quartz monzodiorite (Zweifel, 1976; Monroe, 1988). These highly metamorphosed rocks have been interpreted as ca. 1.9 Ga felsic volcanic rocks (Monroe, 1988). Genetic models suggested for the ore include sedimentary processes (Zweifel, 1976; Wanhainen et al., 1999) and porphyry-type hydrothermal processes (Monroe, 1988; Wanhainen et al., 1999). The main metal concentrating process was clearly premetamorphic, although later orogenic events may have caused significant remobilization of the ores. The porphyry model fits with continental-margin volcanic activity along the ancient southwestern boundary of the Lopian craton, and is analogous to the situation in present-day Chile.

VMS-hosted gold

All of the Svecofennian paleoenvironments described above are hosts to massive sulfide deposits. Although copper and zinc have been the main products from these deposits, lead, silver, and gold have often been important byproducts. Because the size of several of these deposits was significant (Table 2), even moderate gold contents have resulted in large amounts of gold recovered from each of these deposits, and the gold produced as a byproduct from these massive sulfide ores exceeds, by far, the gold production from many gold-only producers. The geological characteristics, genetic models, and metal contents of these deposits are slightly different from district to district.

Outokumpu region: The Outokumpu district was discovered in 1910 and was mined until 1988. About a dozen VMS deposits were mined, producing a total of 50 Mt of sulfide ore (Gaál and Parkkinen, 1993). The Outokumpu deposit (no. 27) was, by far, the largest and produced 28.5 Mt of ore during its lifetime, with an average grade of 0.8 ppm Au. The geological association with the Jormua ophiolite (Fig. 2) suggests a genetic model comparable to models for the Cyprus-type deposits (Gaál and Parkkinen, 1993).

Main sulfide belt: The massive sulfide deposits at Vihanti (no. 28) and Pyhäsalmi (no. 29) were major ore producers in Finland during the past century (each producing ca. 30 Mt, with grades of about 0.5 ppm Au), of which Pyhäsalmi is still active. They are hosted by felsic metavolcanic rocks and form part of a metallogenetic belt called the Main sulfide belt (Kahma, 1973), which often has been correlated with the Skellefte district. The association with continental-margin metavolcanic rocks, which can be followed all the way along the Raahe-Ladoga line from Tjåmotis (100 km southwest of Malmberget) in northern Sweden to Varkaus in southeastern Finland (Fig. 2), indicates, however, that the volcanic association in the Main sulfide belt should not be confused with the island arc succession in the Skellefte district.

Skellefte district: Many tens of massive sulfide deposits occur in the Skellefte district (Fig. 4). Current ideas suggest that a variety of different ore-forming systems may have operated in the district, including VMS, epithermal, and mesothermal systems. Weihed and Mäki (1997) suggested that most of the massive sulfide ores are comparable to kuroko-type VMS deposits (e.g., nos. 30–36: Renström, Udden, Holmtjärn, Maurliden, Näsliden, Storliden, and Kristineberg), whereas some (e.g., the exceptionally gold rich Boliden deposit, no. 47) have been reinterpreted to be epithermal (Bergman Weihed et al., 1996; see below). The gold contents in Skellefte massive sulfide ores are often unusually high (e.g., at Holmtjärn (8 ppm) and Näsliden (4.6 ppm)). It is still uncertain whether this is a result of simple volcanic-hydrothermal processes or if some gold could have been added epigenetically to the massive sulfide ore (cf. Weihed et al., 2002).

Bothnian basin: Only a few small massive sulfide deposits are known in the Bothnian basin (e.g., Rockliden). Little is known about the occurrence of gold in these deposits.

Bergslagen and southwestern Finland: The massive sulfide deposits in the Bergslagen district (Fig. 5) have been subject to mining during most of the past millennium. The longest mining records were kept in Falun (no. 37), where copper was produced from the 800s to 1992. Mining in the still-active Garpenberg deposit (no. 38) started significantly later (14th century), but represents a remarkably long mining history. Other massive sulfide ores with significant gold contents are Saxberget (no. 39) and Östra Silvberg (no. 40), both now abandoned. Sulfide ores in comparable geological environments are also known in southwesternmost Finland (e.g., Orijärvi; no. 41). Although some of these sulfide ores are relatively gold rich, gold production has never played a major role in the mining of the massive sulfide ores in Bergslagen. The minor gold contents present in the massive sulfide ores were, for many hundreds of years, both unknown and of too low level to be extracted profitably. In 1790, however, it became possible to recover gold from the massive pyrite-sphalerite-galena-chalcopyrite ore in Falun as a byproduct of the copper production. The total gold production from Falun was less than 1 kg/yr from 1790 to 1860, but after 1863, gold-rich parts of the mine (the so-called "Östra Hårdmalmerna") were discovered and the gold production rose (up to 107 kg/yr) until the 1920s (Tegengren, 1924). This increased gold production was a result of the discovery of a gold-rich zone with geological characteristics completely different from the typical copper resource in Falun (see below).

Fröderyd: The massive sulfide deposits Fredriksberg and Krongruvan in the tholeiitic Fröderyd group (Fig. 6) have never produced any significant amounts of ore, and the gold contents are very low (<0.2 ppm). The gold in these volcanogenic ores was probably emplaced simultaneously with other metals (Sundblad et al., 1997a).

Intrusion-related gold

Magmatic-hydrothermal gold deposits in intrusive rocks have been documented at Tallberg (no. 43) in the Skellefte district (Weihed, 1992), and Kopsa (no. 44) and Jouhineva (no. 45) in the Raahe-Haapajärvi region (Gaál and Isohanni, 1979). These deposits comprise stockwork Cu-As-Au mineralization in ca. 1.88 Ga tonalitic intrusions, which are considered to be comagmatic with the island arc volcanic rocks in the Skellefte district (Fig. 4). Although the tonnage may be significant in some deposits, the combined copper and gold contents are too low (Table 2) for economically viable exploitation.

The Björkdal deposit (no. 53) is located in the eastern part of the Skellefte district and is considered by some authors to be part of the intrusion-related group of gold deposits. It was discovered in 1985 as a result of a successful till geochemistry program, which paved the way for further gold prospecting in the Skellefte district. The Björkdal ore was mined from 1988 to 1999, and the deposit was reopened in 2001. It was the largest gold-only producer in Europe during the 1990s. The Björkdal ore consists of a swarm of cm- to m-wide quartz veins in a Svecofennian tonalite (Weihed et al., 2003). The veins are predominantly northeast trending and parallel to local reverse shear zones (Weihed et al., 2003). The mineral paragenesis is characterized by abundant tellurides and scheelite, and the notable absence of arsenopyrite (Wikström and Sundblad, 1999). The isotopic signature of ore lead in Björkdal is considerably more complex than in other gold systems in the Skellefte district, suggesting several generations of fluids (Billström et al., 1997). The origin of the Björkdal ore is controversial. Based on fluid inclusion and stable-isotope studies, Broman et al. (1994) suggested that the main ore-forming stage was premetamorphic and took place from dominantly magmatic fluids mixed with a fluid of seawater origin. Weihed et al. (2003) suggest an alternative interpretation, based on structural analysis, and suggest an origin closely related to late-orogenic (1.8 Ga) east-west–trending, crustal shortening and magmatism.

Skarn- and epigenetic ironstone-hosted gold

Gold-bearing deposits of contact-metasomatic origin with intrusion-generated fluid migration into carbonate rocks are rare in the Fennoscandian Shield. The Kuervitikko deposit (no. 46) is most probably of such origin, related to synorogenic Svecofennian intrusions (Hiltunen, 1982; Eilu et al., 2003).

Metamorphosed epithermal gold

Epithermal gold mineralization, associated with metamorphosed acid-sulfate–type alteration (high-sulfidation systems), has been recognized in the metamorphosed Svecofennian successions. The most important examples are the major gold producer at Boliden (no. 47) in the Skellefte district (Bergman Weihed et al., 1996) and the Enåsen deposit (no. 48) in central Sweden (Hallberg, 1994). In addition, several gold-bearing Cu ± As ± Sb deposits in the Tampere schist belt, southern Finland, also belong to this group: Isovesi (no. 49), Järvenpää (no. 50), Kutemajärvi (no. 51), and Jokisivu (no. 52; Eilu, 2003).

The Boliden deposit is one of the most famous of all gold mines in Fennoscandia, partly due to its large gold production and partly because its discovery was closely related to unraveling a new ore district, which still is the most productive in the whole shield. A sulfide-rich ore boulder was discovered near the Bjurliden farm in the summer of 1921, which immediately led to systematic exploration by means of geophysics and drilling. The first diamond-drill penetration of the ore was on December 10, 1924, and mining on a small scale started in 1925 (Grip and Wirstam, 1970). Since the Bjurliden farm had been misspelled on the topographic map, the original claim was registered in the name Boliden, which still is the name of the mining company. The Boliden deposit was the largest gold producer in Europe during its lifetime (1925–1967) and produced more than 125 t of gold, together with large amounts of arsenic and base metals (Table 2). The deposit is hosted by the same volcanic succession as the many massive sulfide deposits in the Skellefte district, and the genetic views on the Boliden ores have closely followed the trends established for the rest of the Skellefte district (cf. Gavelin, 1939; Rickard and Zweifel, 1975). It was not until the recent study by Bergman Weihed et al. (1996) that the Boliden deposit was redefined as belonging to a separate genetic group in the Skellefte district, which is compared to high-sulfidation epithermal systems.

The Enåsen Cu-Au mine in central Sweden was, when it opened in 1984, the first new gold mine in Sweden for 60 yr. The Enåsen ore consists of disseminated gold, chalcopyrite, pyrrhotite, and pyrite in a high-grade topaz-bearing, quartz-sillimanite gneiss, surrounded by biotite gneisses (interpreted as metamorphosed andesite) and veined paragneisses and amphibolites. This ore-bearing succession is geographically isolated from the main Svecofennian metallogenetic districts, but lead isotope systematics on galena indicate that the ore formed contemporaneously with other Svecofennian volcanogenic systems (Hallberg, 1989). Like Boliden, Enåsen has been interpreted as an analog of epithermal gold deposits associated with metamorphosed acid-sulfate–type alteration in a high-sulfidation environment (Hallberg, 1994; Hallberg and Fallick, 1994). Similar features, although at lower metamorphic grade, have also been documented in the Kutemajärvi deposit in southern Finland (Poutiainen and Grönholm, 1996).

Svecokarelian orogenic gold

The Svecofennian terranes were subject to deformation and metamorphism in conjunction with accretion onto the Lopian continent during the Svecokarelian orogeny. These processes generated metamorphic fluids, which are considered to have been responsible for the formation of orogenic (or mesothermal) gold deposits, particularly along second- or third-order shear zones. Most of the favorable structures are 50 to 200 km southwest of the Raahe-Ladoga line in the Skellefte district, as well as in the Raahe-Haapajärvi and Savo regions. Other similar structures are found in the Tampere schist belt, Bergslagen, and southwest Finland.

The Skellefte district: Several types of lode gold deposits have been distinguished in the Skellefte district (Weihed et al., 1992). In this summary, a distinction will be made between gold deposits formed during the accretionary stage (early orogenic) and gold formed as a result of late-orogenic magmatism.

Early-orogenic gold deposits are widespread in the Skellefte region, but economically viable deposits have not been found. Examples include the Fäbodliden, Middagsberget, and Vargbäcken deposits (nos. 56–58; Sundblad et al., 1993; Öhlander and Markkula, 1994; Blomqvist and Leijd, 1999). These veins are generally hosted by metasedimentary rocks or dioritic intrusions in a metasedimentary environment. The quartz veins commonly carry pyrrhotite and/or pyrite, as well as arsenopyrite, chalcopyrite, sphalerite, and galena. Lead isotope data indicate that the ore-forming event could not have taken place more than 10 to 20 m.y. after the volcanic activity and associated formation of VMS deposits in the district (Sundblad et al., 1993). The Grundfors (no. 55) veins have a more simple ore mineral assemblage, with only arsenopyrite and gold (Bergman, 1992), and are considered to have formed during peak metamorphic conditions at ca. 1.84 to 1.82 Ga (Billström and Weihed, 1996).

According to Weihed et al. (2003), the Björkdal deposit (no. 53) is closely related to late-orogenic (1.8 Ga), east-west–trending crustal shortening and magmatism, in contrast to what has been proposed by Broman et al. (1994). The Åkerberg deposit (no. 54) is another significant deposit of uncertain origin. It is located in the eastern part of the Skellefte district and was discovered in 1987. It was in production from 1989 to 2001, with an annual production of 200,000 t/yr and with total reserves of 1 Mt at 3 ppm Au (Matsson, 1991). The ore is hosted by a set of cm-wide quartz veins with very low sulfide content. The quartz veins occur in a 10- to 30-m-wide and 350-m-long, northeast-southwest–trending shear zone in the marginal parts of a layered gabbro of probable Svecofennian age. The timing of the ore-forming process at Åkerberg is uncertain, but a minimum age is provided by 1.80 Ga pegmatites cutting the ore zone.

The Raahe-Haapajärvi, Savo, and Ladoga regions: The orogenic gold deposits in the Raahe-Haapajärvi and Savo regions in central Finland have many characteristics in common with the early orogenic lode deposits in the Skellefte region. The veins in the Raahe-Haapajärvi region (e.g., no. 59, Kangaskylä; no. 60, Laivakangas; and no. 61, Pöhlöl; Fig. 4) are hosted in Svecofennian tonalites or metasedimentary rocks. Osikonmäki (no. 62, Fig. 2) occurs along a shear zone in a tonalite. All veins are structurally controlled and occur in secondary to tertiary shear zones related to the zone of weakness along the concealed southwestern boundary of the Archean craton (the Raahe-Ladoga line). The major ore minerals in the veins are arsenopyrite, pyrrhotite, and pyrite, with minor amounts of sphalerite, chalcopyrite, and galena. These deposits were formed at or shortly after the peak of metamorphism (Eilu et al., 2003), which is consistent with the timing of the As-Au–bearing lode deposits in the Skellefte district (cf. Sundblad et al., 1993). Comparable gold deposits have recently also been discovered at Alattu and Harlu (no. 63), north of lake Ladoga, where the most promising targets are represented by shear zone-hosted veins with quartz, arsenopyrite, gudmundite, native Bi, native Sb, and electrum, cutting 1.85 Ga gabbros and tonalites (V. Ivashchenko, Petrozavodsk, pers. commun., 2001).

The Tampere schist region: The Tampere schist belt, along the southern margin of the Central Finnish batholith in southern Finland (Fig. 4), can be correlated with the Skellefte district and is host to several types of gold deposits. The Haveri deposit (no. 64), hosted by metabasalts, was the first to be proven economic and was mined during the 1940s and 1950s. It has been interpreted as a volcanogenic Cyprus-type deposit (Mäkelä, 1980) or as base metal mineralization overprinted by mesothermal gold mineralization (Eilu et al., 2003).

Bergslagen and southwest Finland: The so-called “Östra Hårdmalmerna,” located to the east of the massive sulfide ore at Falun, consists of a quartz-rich and sulfide-poor ore type, where Bi-Pb-Se-S compounds (Atterberg, 1874) and native gold (Nordenström, 1882) were identified. Later mineralogical work in this gold-rich zone has revealed complex intergrowths of several Se-bearing compounds, among them laitakarite, weibullite, and bismuthinite (Karup-Møller, 1970). Based on a fluid inclusion study, it has been suggested that the Se-Au–rich ore at Falun was formed from a complex hydrothermal system that postdated the massive sulfide ore deposition and subsequent deformation (Åberg and Fallick, 1993). Lead isotope data (K. Sundblad, unpub. results) indicate a relatively short time span between formation of massive sulfide ore and the Se-Au ore. The prevailing theory of gold genesis at Falun is that an orogenic (Svecokarelian) Au-Se mineralization overprints an older (Svecofennian) VMS system.

Several mines in Bergslagen (e.g., no. 66, Boviksgruvan; no. 67, Källfallet; no. 68, Malsjöberg) exhibit similar gold overprints. The Boviksgruvan deposit, 18 km northeast of Falun, is best documented in this respect. It was primarily mined for iron and zinc from a Svecofennian volcanogenic magnetite-sphalerite-galena-chalcopyrite-pyrite ore. This ore was locally overprinted by an epigenetic Pb-Bi-Au association, which was emplaced shortly after the volcanogenic sulfides (Bergman and Sundblad, 1991). The massive sulfide deposits in the Orijärvi region (no. 41) in southwestern Finland have, for a long time, been compared with Bergslagen in general and the Falu region in particular (cf. Eskola, 1914; Latvalahti, 1979). The presence of Se-bearing minerals immediately adjacent to the massive sulfide ore at Orijärvi (Vorma, 1960; Ciobanu et al., 2002) may indicate that a Au-Se zone also exists here. One possibility is that the Au-Se–rich zones are genetically related to the massive sulfides. High gold contents (up to 7 ppm Au) in quartz-rich zones are reported from the Pyhälammi prospect (no. 69), 8 km northeast of the Orijärvi massive sulfide deposits (Isomäki, 1989). Further investigations of the enrichment of gold in the Bergslagen-southwest Finland region are needed to shed light on the spatial and possible genetic relationship to the massive sulfide ores.

Gold in the Bothnian basin metasediments

The Precambrian geology south of the Skellefte district is dominated by vast areas of medium- to high-grade metasedimentary rocks known as the Bothnian basin. This metasedimentary complex extends into south-central Finland and can be followed along the southern border of the Tampere schist belt (Fig. 4). The Bothnian basin is a Paleoproterozoic sedimentary sequence, dominated by turbiditic metagreywackes, interlayered with narrow zones of exhalative magnetite-quartzites, graphitic schists, and subordinate Mg-rich metabasalts (Lundqvist, 1987). The ore-bearing, Mg-rich meta-basalts in the Hackås area (Fig. 4) have primitive geochemical and isotopic characteristics and are interpreted as tholeiitic early Svecofennian, submarine volcanic rocks (Sundblad, 1994), which extruded simultaneously with the clastic sedimentation in the long and complex evolution of the Bothnian basin (Lundqvist et al., 1998). At least four generations of calc-alkaline granitoids intruded the Bothnian basin from 2030 to =1870 Ma (Lundqvist et al., 1998), prior to metamorphism (Claesson and Lundqvist, 1995). The high-grade metamorphism has locally transformed the metasediments to migmatites and 1.82 Ga anatectic two-mica granites. This region has, for a long time, had low priority for prospecting, but recent discoveries of gold mineralization, particularly in the Lycksele region (immediately to the southwest of the Skellefte district), have changed the metallogenetic concepts for the basin. Although several economic and subeconomic targets have been found during the last few years in this region (e.g., no. 70, Ersmarksberget; no. 71, Barsele; no. 72, Stortjärnhobben; no. 73, Sjöliden; no. 74, Mejvankilen; no. 75, Svartliden; no. 76, Fäbodliden; no. 77, Nynäsberget; no. 78, Tervasmäki; no. 79, Tammijärvi; and no. 80, Ahvenlammi), little is known about their setting and genesis. This group of deposits may include epithermal, mesothermal, and other types of mineralization. Several deposits are now in an advanced stage of planning for mining, including Ersmarksberget, Barsele, Stortjärnhobben, Svartliden, and Fäboliden. The many discoveries made during the last decade in this previously unrecognized metallogenetic province suggest that the Bothnian basin region has a continued high potential for further ore discoveries if appropriate exploration tools are used in combination with careful petrogenetic studies.

The Ersmarksberget deposit (no. 70) occurs as an elongate body in Bothnian basin metasediments along the intrusive contact of a tonalitic intrustion (the Juktan dome). The ore body consists of two separate ore types: a brecciated Zn-Pb-Ag ore and an Au-As ore in quartz veins. Preliminary resource calculations indicate 6.9 Mt with 1.78 percent Zn, 0.8 percent Pb, and 9 ppm Ag, and 0.9 Mt with 3.7 ppm Au.

Barsele (no. 71), Stortjärnhobben (no. 72), Svartliden (no. 75), and Fäbodliden (no. 76) are a group of gold deposits in metasedimentary rocks, all of which are planned for mining in the near future. They are all located along a positive magnetic anomaly. The mineralized zone in the Stortjärnhobben deposit runs in a north-south–trending structure near the contact with a two-mica granite. The ore zone consists of a strongly silicified zone in graphite-bearing metagreywackes and siliceous tuffaceous greenstones. The gold, together with pyrite, chalcopyrite, and aresenopyrite, occurs in the silicified metasediments. Drill core intersections of the mineralized zone include several meters with grades between 1.5 and 8.6 ppm Au. The mineralized zone in the Svartliden deposit consists of graphitic metasediments and finely laminated, calc-silicate–altered metasediments (Hart et al., 1999). The mineralized sequence is ca. 14 m thick and contains 8 ppm Au. The

Fäbodliden deposit consists of gold-bearing iron formation in graphitic metagraywackes in a succession composed of arenites, quartzites, and tuffaceous greenstones, close to the intrusive contact with post-Svecofennian granitoids.

The Nynäsberget deposit (no. 77) is another example where gold-bearing quartzites coincide with positive magnetic anomalies. These quartzites display banding of Fe-rich silicates, sulfides, and oxides, and are interpreted to be exhalative in origin, often spatially associated with high-Mg amphibolites. The gold contents of the Nynäsberget quartzites are, locally, 2 to 9 ppm, and are considered to be concentrated by later metamorphic fluids, possibly related to shear zones (Johansson et al., 1999).

The Tervasmäki deposit (no. 78) is one of several Sb-Au-As occurrences that have been investigated in the Seinäjoki region in west-central Finland. They are generally hosted in partly graphite and pyrrhotite bearing mica schists close to the contact with plagioclase porphyries.

The Tammijärvi (no. 79) and Ahvenlammi (no. 80) deposits are hosted in metasedimentary rocks representing a typical turbidite environment in the Tampere schist region. Tammijärvi is a Au-bearing tin-tungsten ore in metagraywacke schists with graphitic schists, together with meta-arkoses and felsic metavolcanics. Ahvenlammi is an Au-bearing tungsten ore in metagraywacke schists (Luukonen, 1994).

Pre-Sveconorwegian orogenic gold within the Transscandinavian igneous belt

Several occurrences of Cu-Au (± Co)-bearing veins and shear zones are found in southeastern Sweden. The veins occur in supracrustal rocks along the sheared margins of major batholiths (Fig. 6). The most significant of these is the Ädelfors deposit (no. 81), which was the first gold mine in Swedish history. A similar gold-rich zone has been discovered at Fifflekull (no. 82). The ore at Ädelfors consists of Au-Cu-Zn–bearing quartz veins with Co-enriched pyrite in mafic metavolcanic rocks, close to the sheared contact of the 1.8 Ga Transscandinavian igneous belt granitoids. Lead isotope data suggest that the metals in the Ädelfors deposit were derived from the tholeiitic mafic volcanic host rocks, probably shortly after the emplacement of the adjacent Småland batholith. The deposit is considered to be analogous to the Mother lode system in California (Sundblad et al., 1999).

The deposits at Gladhammar (no. 83) and Solstad (no. 84) were also exploited several hundreds of years ago for iron, copper, and cobalt, but it was not until the last decade that their gold content was revealed. Gladhammar is hosted in Early Svecofennian supracrustal sequences in the immediate vicinity of the major 1.8 Ga Småland batholith, whereas Solstad is hosted within the margins of the Småland batholith, thus indicating that the mineralization postdates the emplacement of the batholith (Söderhielm and Sundblad, 1996). The ore mineral assemblage at Solstad is dominated by chalcopyrite, which was the basis for mining activity in the 18th and 19th centuries. In addition, pyrite, Ni-bearing linnaeite, galena, Co-bearing pyrite, pyrrhotite, covellite, marcasite, bornite, sphalerite, and native gold have been recognized (Söderhielm and Sundblad, 1996). The presence of similar mineralization at Skatemåla (no. 85; Sundblad et al., 1997b), well inside the Transscandinavian igneous belt batholith in southeasternmost Sweden, demonstrates that Au-bearing, post-Transscandinavian igneous belt shear zones may be of regional importance.

Gold within and along the Eastern Margin of the Gothian Domain

The oldest crust in southwestern Scandinavia is composed of 1.65 Ga Gothian granitoids and mafic metavolcanic rocks (Fig. 7), which formed after the main Transscandinavian igneous belt magmatic activity. The spatial relations between the Lopian-Svecokarelian continent and the juvenile Gothian crust are, however, uncertain, and they may have been located far from each other in pre-Sveconorwegian time. The Gothian crust was intruded by later granitoids until it collided with the Svecokarelian-Lopian continent at ca. 1000 Ma, resulting in Sveconorwegian deformation and metamorphism,

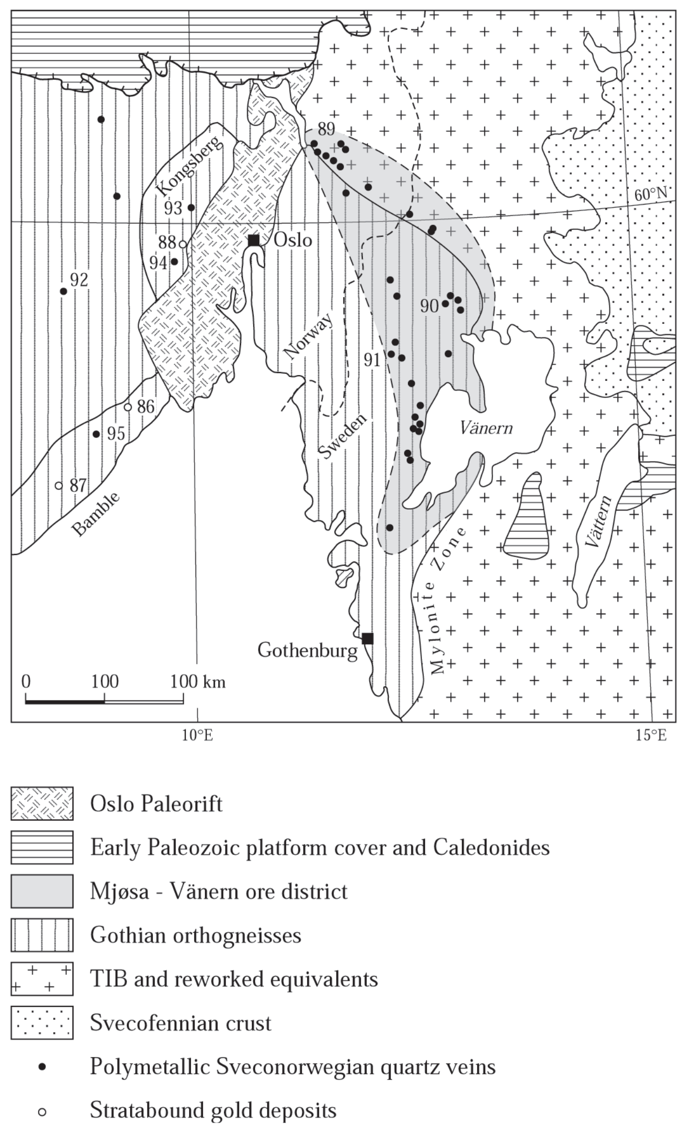


FIG. 7. Gold-bearing ore deposits and prospecting targets in the southwestern part of the Fennoscandian Shield. Gold deposits are marked with numbers according to Table 1. TIB = Transscandinavian igneous belt.

locally at granulite facies conditions. Gold has been recognized both in stratiform Gothian sulfide ores but, more significantly, in relation to Sveconorwegian shear zones within (and along the eastern margin of) the Gothian domain.

Strata-bound gold

Strata-bound sulfide ores, hosted by the oldest supracrustal sequences in the Bamble and Kongsberg sectors (Fig. 7), west of the Permian Oslo Paleorift (Norway), have recently been revealed to be gold bearing (J.S. Sandstad and P. Ihlen, pers. commun., 2001). These stratiform deposits occur in medium- to high-grade Mesoproterozoic volcanosedimentary sequences truncated by gabbroic intrusions and granitoid batholiths. Gold is mainly enriched in syngenetic, strata-bound Cu-Zn sulfide deposits (no. 86, Rørholt; no. 87, Skyttemyr; and no. 88, Haugset), but high gold contents have also been recorded together with Co, Cu, and As in bifs (no. 94, Liverud).

Sveconorwegian orogenic gold

A number of Sveconorwegian polymetallic veins occur along the tectonic border (Mylonite zone) between the Gothian domain and Transscandinavian igneous belt (Fig. 7). These veins constitute the Mjøsa-Vänern ore district (Ihlen, 1986; Alm and Sundblad, 1994; Sundblad et al., 1996; Alm et al., 2003), located approximately along the Sveconorwegian orogenic front. The Mylonite zone is a major Sveconorwegian shear zone, which extends from southeastern Norway to southwestern Sweden and, at least partly, separates Gothian crust from older crust related to the Transscandinavian igneous belt and the Lopian-Svecokarelian continent. The Mjøsa-Vänern ore district includes such economic to subeconomic Au deposits as Eidsvoll (no. 89), Glava (no. 90), and Harnäs (no. 91). Other significant gold-bearing veins, including the Bleka (no. 92), Vekselmyr (no. 95), and Skutterud (no. 93) deposits, occur in the Telemark region to the west of the Oslo Paleorift.

The Mjøsa-Vänern ore district: The Harnäs deposit was recently subject to small-scale mining, producing 60,000 t of ore with an average Au content of 2g/t. The Harnäs veins occur in local shear zones that crosscut the regional (Sveconorwegian) metamorphic fabric in the surrounding 1.6 Ga calc-alkaline orthogneisses (Alm et al., 2002). The ore mineralogy is dominated by pyrite accompanied by some galena and chalcopyrite, and accessory Te- and Bi-bearing phases. Fluid inclusion and stable-isotope data suggest ore formation from metamorphic fluids during the waning stage of the Sveconorwegian orogeny and incipient rapid uplift of the thickened crust (Alm et al., 2003). Sulfides in selected veins in the Harnäs area have yielded a Re-Os age of 973 ± 34 Ma (Stein et al., 1999), in accordance with a Sveconorwegian origin. A similar origin is proposed for the Eidsvoll gold-bearing quartz veins (Ihlen, 1995; Alm et al., 2003), based on general characteristics and fluid inclusions. The Eidsvoll mining area includes the first gold mines in Norwegian history, active from 1758 to 1907 (Ihlen, 1995). Initial production, however, extracted Cu, and chalcopyrite is the dominant sulfide in the quartz veins. Pyrite, galena, and accessory Bi-bearing phases are important ore constituents (Ihlen, 1995). Unlike the Harnäs veins, the Eidsvoll Au veins are related to steep faults close to the Mylonite zone (Ihlen, 1995). The Glava Cu-Au-Ag deposit was mined for copper from 1916 to 1918, and for a few years during WWII, when native gold was discovered as an ore constituent (Scherbina, 1941). The host rock at Glava is a thin (100–200 m) intercalation of foliated quartz diorite in a Sveconorwegian thrust sheet dominated by metasedimentary rocks. The Glava ore consists of a set of cm-wide, open fractures with infillings of bornite, chlorite, and minor quartz, together with minor amounts of other common sulfides, electrum, a large variety of tellurides, and subordinate selenides (Scherbina, 1941; Oen and Kieft, 1984).

Sveconorwegian deposits west of the Oslo Paleorift: The Kongsberg-Bamble province is dissected by a network of regional high- and low-angle shear zones, which host epigenetic Au-As-Cu quartz veins (Vekselmyr) and the Skutterud Cu-Co-As-Au deposit. The gold-bearing quartz-ankerite veins at Bleka are hosted by orthogneisses west of the Kongsberg province. The Bleka veins contain native gold, together with bismuthinite, chalcopyrite, and pyrite (Petersen and Jensen, 1995), and were mined in the late 19th century.

Gold in Precambrian Crust along the West Coast of Norway and within the Caledonides

Gold-bearing deposits in Precambrian crust along the west coast of Norway and within the Caledonides are known at several sites in Norway (Fig. 1). Although all these deposits probably are orogenic in a broad sense, they include both Precambrian and Caledonian (i.e., Early Paleozoic) deposits. Some of the deposits are hosted by Precambrian rocks, which were already part of the Fennnoscandian Shield prior to the Caledonian orogenic event, whereas others are hosted by Precambrian suspect terranes, which became accreted during the Caledonian orogeny and were, thus, part of other shield complexes in Precambrian time.

Gold in reworked Fennoscandian Precambrian crust

Gold in Fennoscandian Precambrian crust, reworked during the Caledonian orogenic event, can be found in two types of geological environments: (1) Gold associated with pyrite, chalcopyrite, and bornite occurs at several sites in metamorphosed Precambrian granitoids close to thrust contacts of overlying nappes. The ore is located in quartz veins that cut the Caledonian metamorphic fabric in the host orthogneiss, thus indicating a late-Caledonian origin. This type of deposit has been recognized in the Dovre region (no. 96, Snøhetta), in the Oppdal region (no. 97, Grårudfjellet and Snøfjelltjern), and in the Grong region (no. 98, Sibirien); in the latter case, along a 200-m-wide and 3-km-long, sporadically mineralized zone (Grenne, 1990). (2) Gold associated with As and Cu (and Te, Bi, Mo, and Ag) has been recognized in Svecofennian(?) metasediments at Gautelisfjell (no. 99) in the Rombak region (Skyseth and Reitan, 1995). This mineralization is related to late-Caledonian extensional tectonics, postdating Caledonian peak metamorphism.

Gold in Precambrian suspect terranes

The tholeiitic-komatiitic greenstone belts at Ringvassøya in northernmost Norway were previously considered to be Proterozoic and, thus, a probable continuation of the Paleoproterozoic greenstone belts within the northern part of the

Fennoscandian Shield. Recent U-Pb data have, however, demonstrated a Late Archean age (2.84 Ga) for the Ringvassøya greenstones (Motuza et al., 2001), with uncertain correlations within the Fennoscandian Shield. Therefore, a genetic relation to other Precambrian shields, prior to Caledonian time, cannot be excluded for Ringvassøya. Exploration has revealed the presence of several gold targets in these rocks, associated with Cu, As, and Sb (among them, no. 100, Sørdalshøgda).

Comparisons with Other Precambrian Shield Areas

Precambrian crust, of comparable age and composition to those of the Fennoscandian Shield, can be traced under the Palaeozoic cover toward the southeast into Estonia, Latvia, Lithuania, and Belorussia (e.g., Sundblad et al., 1998). The concealed Precambrian in these areas and the Fennoscandian Shield together form a crustal segment Fennoscandia (Gorbatschev and Bogdanova, 1993). The second-largest Precambrian shield in Europe, the Ukrainian Shield, is part of another major crustal segment, Sarmatia, which, together with the Fennoscandia segment and the Volgo-Uralia segment, constitutes the East European craton. Fennoscandia and Sarmatia had separate crustal and metallogenetic histories during the Archean to Paleoproterozoic, and accretion of these two segments did not take place until after 1.8 Ga (Elming et al., 2001). When the metallogeny of the Fennoscandian Shield is compared with that of other Precambrian shields, the most important correlations are, therefore, not necessarily made within the East European craton, but should be sought in shield areas outside Europe.

Although a significant part of the Fennoscandian Shield consists of Archean crust with abundant greenstone belts, no single greenstone-hosted gold deposit has yet become a mine in Fennoscandia. This contrasts with Archean greenstone belts in almost every other shield area in the world, where gold production is significant. The implication is that important gold resources may exist in the under-explored parts of the Karelian province in Russia. Paleoproterozoic greenstone belts with abundant gold mineralization comparable to the Fennoscandian Shield include the Man Shield in the West African craton (Milési et al., 1992; Béziat et al., 2000), the Guiana Shield in the Amazonian craton (Marcoux and Milési, 1993; Norcross et al., 2000), and the Trans-Hudson orogen in the Canadian Shield (Poulsen et al., 2000).

Stratiform sulfide and iron-oxide ores have been recognized in ca. 1.9 to 2.0 Ga supracrustal rocks in drill cores under the Phanerozoic cover to the southeast of the Fennoscandian Shield, both in the Johvi zone in northeastern Estonia (Sundblad and Kivisilla, 1991) and in the Okolov series in the central parts of Belorussia (Sundblad et al., 1994). Based on the geological setting, ore petrology, and ore lead isotope systematics, both occurrences show a clear affinity to Svecofennian VMS deposits. The gold deposits in metamorphosed Paleoproterozoic supracrustal rocks in the Ukrainian Shield, e.g., Mayskie (Bobrov et al., 2002), show no association to VMS deposits and originated at 2.06 Ga in conjunction with regional metamorphism (Stein et al., 1998b), when Sarmatia still was far away from Fennoscandia. The Johvi and Okolov succesions can, therefore, be considered as the southeasternmost representatives of the Svecofennian (and Fennoscandian) metallogenetic region. The Svecofennian VMS-bearing terranes in the Fennoscandian Shield have also been correlated with ore-bearing, 1.9 to 2.0 Ga terranes in North America, based on their geological setting and ore lead isotope signatures (Sundblad et al., 1994). The primitive and homogeneous lead isotope signatures of the VMS deposits in the Skellefte, Vihanti-Pyhäsalmi, and Fröderyd regions are comparable to those in the Trans-Hudsonian Flin Flon district in Canada and parts of the Penokean in Wisconsin, whereas the highly evolved ore lead isotope signature of the Bergslagen ores matches that of other parts of the Penokean in Wisconsin. The gold deposits related to iron formations in Early Proterozoic graphite-bearing metagreywackes and tuffaceous rocks in central Sweden (e.g., Svartliden, Fäbodliden, and Nynäsberget) show many similarities with the Early Proterozoic Homestake gold deposit (Caddey et al., 1991) in western South Dakota. These similarities suggest that the complex pattern of gold metallogeny in the Svecofennian terranes is comparable to the Paleoproterozoic parts of the Canadian Shield. The geological setting of the shear zone-hosted Nalunaq gold deposit in the Ketilidian fold belt on southernmost Greenland (Stendahl and Frei, 2000; Kaltoft et al., 2000) is also strikingly similar to that of the shear zone-hosted gold deposits along the margins of individual batholiths within the Transscandinavian igneous belt (e.g., Ädelfors and Solstad).

The Sveconorwegian orogenic overprint on the Gothian crust (and adjacent parts of the Transscandinavian igneous belt) in southwestern Scandinavia was mainly responsible for the gold deposits in the Mjøsa-Vänern ore district. Comparable reworking of older crust is also known in the Grenville province in North America, with associated, structurally controlled Au mineralization (e.g., the Late Grenvillian Cu-Sb-Au-As Lavant-Darling deposits along the Robertson Lake Mylonite zone: Easton and Fyon, 1992; Sangster et al., 1992).

Conclusions

This compilation of gold deposits in the Precambrian of northern Europe includes 100 representative examples, of which 43 (25 exploited) are located in Sweden, 38 (10 exploited) in Finland, 15 (3 exploited) in Norway, and 4 (none exploited) in Russia. Compared to the surficial distribution of Precambrian crust in each country (25.0% in Sweden, 24.9% in Russia, 23.1% in Finland, and 12.7% in Norway), Russia and Norway are clearly underrepresented in terms of the number of gold deposits (particularly those that have proven to be economic). The large number of deposits in Sweden and Finland is partly a reflection of the abundance of Svecofennian VMS deposits included into the compilation, but also a direct reflection of the intense prospecting and research on gold in these two countries. It is assumed that a correspondingly large number of new discoveries would be made in the Norwegian and Russian parts of the Fennoscandian Shield if adequate exploration and research were carried out at the same level as in Sweden and Finland during the past two decades.

Gold ore deposits occur in almost all parts of the Fennoscandian Shield, within a number of geological environments representing crustal evolution from 2.7 to 0.9 Ga. Although several promising prospecting targets occur in the

Archean, the vast majority of all economic gold deposits formed during the Proterozoic. The economic potential of the gold mineralization that formed in conjunction with Early Paleozoic remobilization of Precambrian crust remains to be proven.

The distribution of gold deposits in northern Europe reflects the evolution of the continental crust. By far, the most common mode of occurrence for economic gold in the Fennoscandian Shield is within epigenetic orogenic structures. Gold is, however, also commonly recovered as a byproduct in many Cu-Zn–dominated, syngenetic VMS deposits. In fact, most of the gold produced in the Fennoscandian mines has been obtained as a byproduct from mining of VMS deposits. Archean gold in the Fennoscandian Shield occurs mainly in classical greenstone-hosted, orogenic (mesothermal) deposits, related to second- or third-order shear zones. Gold formed during the Proterozoic also occurs in typical greenstone-hosted orogenic deposits (apparently more abundant than in Archean terranes), as well as in a number of magmatic-hydrothermal and deformation-induced (mesothermal) deposits in a large variety of host rocks and of various ages. Some of the most important gold producers in Europe, historically and today (e.g., Ädelfors, Eidsvoll, Falun, Boliden, Björkdal), were formed during the Proterozoic, a fact that is overlooked in global summaries of gold metallogeny (cf. Groves et al., 1998; Goldfarb et al., 2001). Hopefully, this compilation will help to achieve a more balanced metallogenetic view of gold deposits in northern Europe and elsewhere in the world.

Acknowledgments

This paper was presented as a keynote lecture at the Gold 99 meeting in Trondheim, when the author was active at the Norwegian University of Science and Technology (NTNU). The constructive criticism by Elisabet Alm (Stockholm) and Nigel Cook (Trondheim) on earlier versions of this manuscript is most appreciated. Inspiration for the Abstract was received from the AIRIE group, Fort Collins. The professional and artistic skills of A-I. Johannessen (Trondheim) have been most valuable for the illustrations.

REFERENCES

Åberg, A., and Fallick, A.E., 1993, A fluid inclusion and light element stable isotope study of the gold-bearing quartz vein system, Falun, Sweden: Mineralium Deposita, v. 28, p. 324–333.

Allen, R.L., Weihed, P., and Svenson, S-Å., 1996a, Setting of Zn-Cu-Au-Ag massive sulfide deposits in the evolution and facies architecture of a 1.9 Ga marine volcanic arc, Skellefte district, Sweden: ECONOMIC GEOLOGY, v. 91, p. 1022–1053.

Allen, R.L., Lundström, I., Ripa, M., Simeonov, A., and Christofferson, H., 1996b, Facies analysis of a 1.9 Ga, continental margin, back-arc, felsic caldera province with diverse Zn-Pb-Ag-(Cu-Au) sulfide and Fe oxide deposits, Bergslagen region, Sweden: ECONOMIC GEOLOGY, v. 91, 979–1008.

Alm, E., and Sundblad, K., 1994, Sveconorwegian polymetallic quartz veins in Sweden: Neues Jahrbuch Mineralogie Monatshefte., v. 1, p. 1–22.

Alm, E., Sundblad, K., and Schöberg, H., 2002, Geochemistry and age of two orthogneisses in the Proterozoic Mjøsa-Vänern ore district, southwestern Scandinavia: GFF, v. 124, p. 45–61.

Alm, E., Broman, C., Billström, K., Sundblad, K., and Torssander, P., 2003, Fluid characteristics and genesis of the late Proterozoic, orogenic gold quartz veins in the Harnäs area, southwestern Sweden: ECONOMIC GEOLOGY, v. 98, p. 1311–1328.

Atterberg, A., 1874, Om ett selenhaltigt mineral från Falu grufva: Geologiska Föreningens i Stockholm Förhandlingar, v. 2, p. 76–78 (in Swedish).

Bergman, J., 1992, Structural geology of Grundfors, a quartz vein related gold deposit in the Skellefte district, northern Sweden: Geologiska Föreningens i Stockholm Förhandlingar, v. 114, p. 227–234.

Bergman, T., and Sundblad, K., 1991, Boviksgruvan, a Au-Bi–bearing sulphide deposit in the Bergslagen province, south central Sweden: Geologiska Föreningens i Stockholm Förhandlingar, v. 113, p. 327–333.

Bergman Weihed, J., Bergström, U., Billström, K., and Weihed, P., 1996, Geology, tectonic setting, and origin of the Paleoproterozoic Boliden Au-Cu-As deposit, Skellefte district, northern Sweden: ECONOMIC GEOLOGY, v. 91, p. 1073–1097.

Béziat, D., Bourges, F., Debat, P., Lompo, M., Martin, F., and Tollon, F, 2000, A Paleoproterozoic ultramafic-mafic assemblage and associated volcanic rocks of the Boromo greenstone belt: Fractionates originating from island-arc volcanic activity in the West African craton: Precambrian Research, v. 101, p. 25–47.

Billström, K., and Weihed, P., 1996, Age and provenance of host rocks and ores in the Palaeoproterozoic Skellefte district, northern Sweden: ECONOMIC GEOLOGY, v. 91, p. 1054–1072.

Billström, K., Broman, C., and Jonsson, E., 1997, Evidence for a prolonged fluid history at the Björkdal Au deposit, northern Sweden: 4th Biennal SGA meeting, Turku, Finland, August 11–13, 1997, Proceedings: Rotterdam, Balkema, p. 153–156.

Bjørlykke, A., Hagen, R., and Söderholm, K., 1987, Bidjovagge copper-gold deposit in Finnmark, northern Norway: ECONOMIC GEOLOGY, v. 82, p. 2059–2075.

Bjørlykke, A., Cumming, G.L., and Krstic, D., 1990, New isotopic data from davidites and sulfides in the Bidjovagge gold-copper deposit, Finnmark, northern Norway: Mineralogy and Petrology, v. 43, p. 1–21.

Blomqvist, M., and Leijd, M., 1999, Vargbäcken—a quartz vein hosted gold deposit in the westernmost Skellefte district, northern Sweden, *in* Cook, N.J., and Sundblad, K., eds., Gold 99 Trondheim: Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 30–31.

Bobrov, O.B., Gurskiy, D.S., Krasnozhon, M.D., et al., 2002, Main types of rock complexes and mineral deposits in the Ukrainian Shield: 4th GEODE-supported workshop in the Fennoscandian (and Ukrainian) Shields, Kiev, Ukraine, September 18–20, 2002, Geological excursion guidebook, 166 p.

Broman, C., Billström, K., Gustavsson, K., and Fallick, A.E., 1994, Fluid inclusions, stable isotopes, and gold deposition at Björkdal in northern Sweden: Mineralium Deposita, v. 29, p. 139–149.

Bugge, C., 1935, Lead-bismuth ores in Bleka, Svartdal, Norway: ECONOMIC GEOLOGY, v. 30, p. 792–799.

Caddey, S.W., Bachman, R.L., Campbell, T.J., Reid, R.R., and Otto, R.P., 1991, The Homestake gold mine, an Early Proterozoic iron-formation-hosted gold deposit, Lawrence County, South Dakota: U.S. Geological Survey Bulletin 1857-J, 67 p.

Chevalier, A., 1999, Storliden—a newly discovered Cu-Zn deposit in the western Skellefte District [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 58–59.

Ciobanu, C.L., Cook, N.L., and Sundblad, K., 2002, Genetic insights from exotic trace mineral associations at Orijärvi and Ilijärvi, SW Finland [abs.]: 4th GEODE-supported workshop in the Fennoscandian (and Ukrainian) Shields, Metallogeny of Precambrian Shields, Kiev, Ukraine, September 18–20, 2002, Abstract volume, p. 41–45.

Claesson, S., and Lundqvist, T., 1995, Origins and ages of Proterozoic granitoids in the Bothnian Basin, central Sweden: Isotopic and geochemical constraints: Lithos, v. 36, p. 115–140.

Cook, N.J., 1999, Telluride minerals in the Proterozoic Bidjovagge Au-Cu deposit, Finnmark, Norway, and their formation conditions [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 60–62.

Cumming, G.L., Krstic, D., Bjørlykke, A., and Aasen, H., 1993, Further analysis of radiogenic minerals from the Bidjovagge gold-copper deposit, Finnmark, northern Norway: Mineralogy and Petrology, v. 49, p. 63–70.

Easton, R.M., and Fyon, J.A., 1992, Metallogeny of the Grenville province: Ontario Geological Survey, Special Volume 4, p. 1217–1252.

Eilu, P., 1999, FINGOLD—a public database on gold deposits in Finland: Geological Survey of Finland Report of Investigation, v. 146, 224 p.

Eilu, P., Sorjonen-Ward, P., Nurmi, P., and Niiranen, T., 2003, A review of gold mineralization styles in Finland: ECONOMIC GEOLOGY, v. 98, p. 1329–1353.

Ekberg, M., and Sotka, P., 1991, Production mineralogy and selective mining at Bidjovagge mine, northern Norway, *in* Haughton, L.F., and Markgraaff, J., eds., International Conference on Applied Mineralogy, Pretoria: Mineralogical Association of South Africa, v. 1, p. 15.

Elming, S.-Å., Mikhailova, N.P., and Kravchenko, S., 2001, Palaeomagnetism of Proterozoic rocks from the Ukrainian Shield: New tectonic reconstructions of the Ukrainian and Fennoscandian Shields: Tectonophysics v. 339, p. 19–38.

Eskola, P., 1914, On the petrology of the Orijärvi region in south-western Finland: Geological Survey of Finland Bulletin, v. 40, 279 p.

Ettner, D.C., Bjørlykke, A., and Andersen, T., 1993, Fluid evolution and Au-Cu genesis along a shear zone: A regional fluid inclusion study of shear zone hosted alteration and gold and copper mineralization in the Kautokeino greenstone belt, Finnmark, Norway: Journal of Geochemical Exploration, v. 49, p. 233–267.

——1994, A fluid inclusion and stable isotope study of the Proterozoic Bidjovagge Au-Cu deposit, Finnmark, northern Norway: Mineralium Deposita, v. 29, p. 16–29.

Gaál, G., and Gorbatschev, R., 1987, An outline of the Precambrian evolution of the Baltic Shield: Precambrian Research, v. 35, p. 15–52.

Gaál, G., and Isohanni, M., 1979, Characteristics of igneous intrusions and various wall rocks in some Precambrian porphyry copper-molybdenum deposits in Pohjanmaa, Finland: ECONOMIC GEOLOGY, v. 74, p. 1198–1210.

Gaál, G., and Parkkinen, J., 1993, Early Proterozoic ophiolite-hosted copper-zinc-cobalt deposits of the Outokumpu type: Geological Association of Canada, Special Paper 40, p. 335–341.

Gaál, G., and Sundblad, K., 1990, Metallogeny of gold in the Fennoscandian Shield: Mineralium Deposita, v. 25, p. S104–S114.

Gavelin, S., 1939, Geology and ores of the Malånäset district, Västerbotten, Sweden: Sveriges Geologiska Undersökning, v. C 424, p. 221.

Gavrilenko, B.V., and Dain, A.D., 1999, Gold-bearing Mo-Cu Pellapakh deposit in Archaean Kolmozero-Voronya belt, Kola Peninsula (Russia) [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 78–80.

Gavrilenko, B.V., Petrashova, L.S., and Dain, A.D., 1999a, Proterozoic quartz-vein gold deposit Mayskoe in North Karelia (Russia) [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 81–82.

Gavrilenko, B.V., Kazakhov, N.V., Kalinin, A.A., and Rezhenova, 1999b, Native gold in primary and placer deposits of Kola Region (Russia) [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 75–77.

Godin, L., 1986, The Viscaria copper ore, Kiruna, *in* Lindroos, H., and Sundblad, K., eds., Proterozoic mineralizations in northern Sweden: Complementary guide book to IAGOD excursion no 6, Sveriges Geologiska Undersökning, Unpublished report BRAP 86011, p. 9–11.

Goldfarb, R.J., Groves, D.I., and Gardoll, S., 2001, Orogenic gold and geological time: A global synthesis: Ore Geology Reviews, v. 18, p. 1–75.

Gorbatschev, R., and Bogdanova, S., 1993, Frontiers in the Baltic Shield: Precambrian Research, v. 64, p. 3–21.

Grenne, T., 1990, Malmgeologiske undersøkelser Sibirien, Grong, Nord-Trøndelag: Norges Geologiske Undersøkelse, Unpublished report 90.012, 26 p. (in Norwegian).

Grip, E., and Wirstam Å., 1970, The Boliden sulphide deposit: A review of geo-investigations carried out during the lifetime of the Boliden mine, Sweden (1924–1967): Sveriges Geologiska Undersökning, v. C 651, 68 p.

Grönholm, P., 1999, The mesothermal Saattopora copper-gold deposit in the Palaeoproterozoic Central Lapland greenstone belt, northern Finland [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 83.

Groves, D.I., Goldfarb, R.J., Gebre-Mariam, M., Hagemann, S.G., and Robert, F., 1998, Orogenic gold deposits: A proposed classification in the context of their crustal distribution and relationship to other gold deposit types: Ore Geology Reviews, v. 13, p. 7–27.

Hallberg, A., 1989, Metal sources in the Early Proterozoic Svecofennian terrain of central Sweden: Pb isotope evidence: Mineralium Deposita, v. 24, p. 250–257.

——1994, The Enåsen gold deposit, central Sweden: 1. A Palaeoproterozoic high sulphidation epithermal gold mineralization: Mineralium Deposita, v. 29, p. 150–162.

Hallberg, A., and Fallick, A.E., 1994, The Enåsen gold deposit, central Sweden: 2. Light element stable isotope evidence of pre-metamorphic hydrothermal activity: Mineralium Deposita, v. 29, p. 163–169.

Härkönen, I., 1984, The gold-bearing conglomerates of Kaarestunturi, Central Finnish Lapland: Geological Survey of Zimbabwe Special Publication, v. 1, p. 239–247.

——1986, Gold in the Proterozoic conglomerates of Finnish Lapland: Terra Cognita, v. 6, p. 538.

Härkönen, I., Kojonen, K., and Johanson, B., 1999, The Proterozoic Suurikuusikko refractory gold deposit in Kittilä, western Finnish Lapland [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 89–91.

Hart, I., Marsh, S., and Laurent, I., 1999, Svartliden—a new style of mineralisation in the Skellefte district [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 87–88.

Hausen, H., 1935, Das Schwefelkiesvorkommen von Jalonvaara, Südkarelien: Geologiska Föreningens i Stockholm Förhandlingar, v. 57, p. 114–115.

Helovuori, O., 1979, Geology of the Pyhäsalmi ore deposit, Finland: ECONOMIC GEOLOGY, v. 74, p. 1084–1101.

Hiltunen, A., 1982, The Precambrian geology and skarn iron ores of the Rautavaara area, northern Finland: Geological Survey of Finland Bulletin, v. 318, 133 p.

Ihlen, P.M., 1986, Late Proterozoic gold deposits of the Eidsvoll-Odalen district, southeast Norway: Terra Cognita, v. 6, p. 538.

——1995, Geology and gold deposits in the Eidsvoll-Odalen region, Norway: Grønlands Geologiske Undersøgelse, Open File Series, v. 95/10, p. 134–147.

——1999, Gold deposits in Norway—a review [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 96–98.

Isomäki, O-P., 1989, Kultatutkimukset: Suomusjärvi, Pyhälammi 2023 04 D: Outokumpu Oy Exploration, Unpublished report 020/2023 04/OPI/1988, 5 p. (in Finnish).

Ivashchenko, V.I., and Lavrov, O.B., 1994, Magmatogenic ore (Mo, W, Cu, Au) system in the Archean Jalonvaara volcanic-plutonic complex, Karelia: Petrozavodsk, Russian Academy of Science, 128 p.

Johansson, E., Vuorinen, J., and Winnes, K., 1999, Gold potential of the Nynäsberget area, Jämtland, Sweden [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 102–103.

Juopperi, H., and Karvinen, A., 1999, Report on gold exploration during 1996–1999 carried out in Kuivaniemi Community: Geological Survey of Finland, Unpublished report C/M06/3521/99/2/10, 12 p. (in Finnish with English summary)

Kahma, A., 1973, The main metallogenetic features of Finland: Geological Survey of Finland Bulletin, v. 265, 28 p.

Kaltoft, K., Schlatter, D., and Kludt, L., 2000, Geology and genesis of Nalunaq Palaeoproterozoic shear zone-hosted gold deposit, South Greenland: Transactions of the Institution of Mining and Metallurgy, v. 109, p. B23–B33.

Karup-Møller, S., 1970, Weibullite, laitakarite, and bismuthinite from Falun, Sweden: Geologiska Föreningens i Stockholm Förhandlingar, v. 92, p. 181–187.

Karvinen, W.O., 1997, The Haveri copper-gold mine property, southern Finland: Geological Survey of Finland Guide, v. 44, p. 20–22.

Kontinen, A., 1987, An Early Proterozoic ophiolite—the Jormua mafic-ultramafic complex, northeastern Finland: Precambrian Research, v. 35, p. 313–341.

Kontoniemi, O., and Nurmi, P.A., 1998, Geological setting and characteristics of tonalite-hosted Palaeoproterozoic gold deposit at Osikonmäki, Rantasalmi, southeastern Finland: Geological Survey of Finland Special Paper, v. 25, 119 p.

Korkiakoski, E.A., 1992, Metakomatiite-hosted Pahtavaara gold deposit in Sodankylä, northern Finland, with emphasis on hydrothermal alteration: Geological Survey of Finland Bulletin, v. 360, 96 p.

Korkiakoski, E.A., and Kilpelä, M., 1997, The komatiite-hosted Pahtavaara gold mine near Sodankylä, northern Finland: Geological Survey of Finland Guide, v. 43, p. 27–29.

Korvuo, E., 1997, The Saattopora gold ore and the Pahtavuoma Cu-Zn-U occurrences in the Kittilä region, northern Finland: Geological Survey of Finland Guide, v. 43, p. 21–25.

Kumpulainen, R., Mansfeld, J., Sundblad, K., Neymark, L., and Bergman, T., 1996, Stratigraphy, age, and Sm-Nd isotope systematics of the country rocks to Zn-Pb sulfide deposits, Åmmeberg district, Sweden: ECONOMIC GEOLOGY, v. 91, p. 1009–1021.

Latvalahti, U., 1979, Cu-Zn-Pb ores in the Aijala-Orijärvi area, southwest Finland: ECONOMIC GEOLOGY, v. 74, p. 1035–1059.

Lestinen, P., Kontas, E., Niskavaara, H., and Virtasalo, J., 1991, Till geochemistry of gold, arsenic and antimony in the Seinäjoki district, western Finland: Journal of Geochemical Exploration, v. 39, p. 343–361.

Lundqvist, T., 1987, Early Svecofennian stratigraphy of southern and central Norrland, Sweden, and possible existence of an Archaean basement west of the Svecokarelides: Precambrian Research, v. 35, p. 343–352.

Lundqvist, T., Vaasjoki, M., and Persson, P-O., 1998, U-Pb ages of plutonic and volcanic rocks in the Svecofennian Bothnian basin, central Sweden, and their implications for the Palaeoproterozoic evolution of the basin: GFF, v. 120, p. 357–363.

Luukonen, A., 1994, Main geological features, metallogeny, and hydrothermal alteration phenomena of certain gold and gold-tin-tungsten prospects in southern Finland: Geological Survey of Finland Bulletin, v. 377, 153 p.

Luukonen, E., 1993, Kultamineralisaatio Suomussalmen ja Kuhmon vihreäkivivyöhykkeellä: Vuorimiesyhdistys, Sarja B, v. 54, p. 33–35 (in Finnish).

Mäkelä, K., 1980, Geochemistry and origin of Haveri and Kiipu, Proterozoic strata-bound volcanogenic gold-copper and zinc mineralizations from southwestern Finland: Geological Survey of Finland Bulletin, v. 310, 79 p.

Mäkelä, M., and Sandberg, E., 1985, The gold occurrence at Laivakangas, Raahe: Geologi (Helsinki), v. 37, p. 5–7.

Mäkelä, M., Sandberg, E., and Rantala, O., 1988, Geochemical exploration of gold-bearing veins associated with granitoids in western Finland, *in* MacDonald, D.R., and Mills, K.A., eds., Prospecting in areas of glaciated terrain—1988: Canadian Institute of Mining and Metallurgy, p. 255–270.

Marcoux, E., and Milési, J.P., 1993, Lead isotope signature of Early Proterozoic ore deposits in Western Africa: Comparison with gold deposits in French Guiana: ECONOMIC GEOLOGY, v. 88, p. 1862–1879.

Martinsson, O., 1997, Tectonic setting and metallogeny of the Kiruna greenstones: Unpublished Ph.D. thesis, Lulea, Sweden, Luleå University of Technology, 97 p.

Matsson, B., 1991, Guldfyndigheten Åkerberg: Sveriges Geologiska Undersökning, PM 1991, v. 1, p. 32–34. (in Swedish)

Milési, J-P., Ledru, P., Feybesse, J-L., Dommanget, A., and Marcoux, E., 1992, Early Proterozoic ore deposits and tectonics of the Birimian orogenic belt, West Africa: Precambrian Research, v. 58, p. 305–344.

Monroe, D., 1988, The geology and genesis of the Aitik copper-gold deposit, Arctic Sweden: Unpublished Ph.D. thesis, Cardiff, University of Wales, College of Cardiff, 386 p.

Motuza, G., Motuza, V., Beliatsky, B., and Savva, E., 2001, Volcanic rocks of the Ringvassøya greenstone belt (North Norway): Implication for the stratigraphy and tectonic setting: Journal of Conference Abstracts, v. 6, p. 577–578.

Nironen, M., 1997, The Svecofennian orogen: A tectonic model: Precambrian Research, v. 86, p. 21–44.

Norcross, C., Davis, D.W., Spooner, E.T.C., and Rust, A., 2000, U-Pb and Pb-Pb age constraints on Paleoproterozoic magmatism, deformation, and gold mineralization in the Omai area, Guyana Shield: Precambrian Research, v. 102, p. 69–86.

Nordenström, G., 1882, Fynd av gediget guld i Falu grufva: Geologiska Föreningens i Stockholm Förhandlingar, v. 6, p. 59–69 (in Swedish).

Nurmi, P.A., and Sorjonen-Ward, P., 1993, Geological development, gold mineralization, and exploration methods in the Late Archaean Hattu schist belt, Ilomantsi, eastern Finland: Geological Survey of Finland Special Paper, v. 17, 386 p.

Nurmi, P., Sorjonen-Ward, P., and Damstén, M., 1993, Geological setting, characteristics, and exploration history of mesothermal gold occurrences in the Late Archean Hattu schist belt, Ilomantsi, eastern Finland: Geological Survey of Finland Special Paper, v. 17, p. 193–231.

Nyström, J-O., and Henriquez, F., 1994, Magmatic features of iron ores of the Kiruna type in Chile and Sweden: Ore textures and magnetite geochemistry: ECONOMIC GEOLOGY, v. 89, p. 820–839.

Oen, I.S., and Kieft, C., 1984, Paragenetic relations of Bi-, Ag-, Au-, and other tellurides in bornite veins at Glava, Värmland, Sweden: Neues Jahrbuch Mineralogie, Abhandlungen, v. 149, p. 245–266.

Öhlander, B., and Markkula, H., 1994, Alteration associated with the gold-bearing quartz veins at Middagsberget, northern Sweden: Mineralium Deposita, v. 29, p. 120–127.

Pankka, H.S., and Vanhanen, E.J., 1992, Early Proterozoic Au-Co-U mineralization in the Kuusamo district, northeastern Finland: Precambrian Research., v. 58, p. 387–400.

Petersen, J.S., and Jensen, S.M., 1995, Bleka gold fields in Telemark, south Norway: Grønlands Geologiske Undersøgelse, Open File Series, v. 95/10, p. 62–64.

Poulsen, K.H., Robert, F., and Dube, B., 2000, Geological classification of Canadian gold deposits: Geological Survey of Canada, Bulletin 540, p. 1–106.

Poutiainen, M., and Grönholm, P., 1996, Hydrothermal fluid evolution of the Paleoproterozoic Kutemajärvi gold telluride deposit, southwest Finland: ECONOMIC GEOLOGY, v. 91, p. 1335–1353.

Rickard, D.T., and Zweifel, H., 1975, Genesis of Precambrian sulfide ores, Skellefte district, Sweden: ECONOMIC GEOLOGY, v. 70, p. 255–274.

Rouhunkoski, P., 1968, On the geology and geochemistry of the Vihanti zinc ore deposit, Finland: Geological Survey of Finland Bulletin, v. 236, 121 p.

Rouhunkoski, P., and Isokangas, P., 1974, The copper-gold ven deposit of Kivimaa at Tervola, N-Finland: Bulletin of the Geological Society of Finland, v. 46, p. 29–35.

Sandstad, J.S., and Nilsson, L.P., 1997, Gullundersøkelser på Ringvassøy, sammenstilling av tidligere prospektering og feltbefaring: Norges Geologiske Undersøkelse, Unpublished report 98.072, 35 p. (in Norwegian)

Sangster, A.L., Gauthier, M., and Gower, C.F., 1992, Metallogeny of structural zones, Grenville province, northeastern North America: Precambrian Research, v. 58, p. 401–426.

Scherbina, A.S., 1941, Die goldreiche Kupferglanz-Bornit-Lagerstätte von Glava im Vermland, Schweden, und ihre geologische Stellung: Neues Jahrbuch Mineralogie Abteilung A, Beilage, v. 76, p. 377–458.

Sederholm, J.J., 1932, On the geology of Fennoscandia with special reference to the Pre-Cambrian: Fennia, v. 55, p. 1–30.

Skyseth, T., and Reitan, P., 1995, Geology and genesis of Gautelisfjell gold deposit, Rombak Window, northern Norway: A link between retrograde Caledonian metamorphism and saline fluids: Grønlands Geologiske Undersøgelse, Open File Series, v. 95/10, p. 94–98.

Söderhielm, J., and Sundblad, K., 1996, The Solstad Cu-Co-Au mineralization and its relation to post-Svecofennian regional shear zones in south eastern Sweden: GFF, v. 118, p. A47.

Sorjonen-Ward, P., and Nurmi, P.A., 1997, An overview of the tectonic setting and characteristics of gold mineralization in Finland: 4thBiennial SGA meeting, 4th, Turku, Finland, August 11–13, 1997, Proceedings, p. 309–312.

Stein, H.J., Sundblad, K., Markey, R.J., Morgan, J.W., and Motuza, G., 1998a, Re-Os ages for Archaean molybdenite and pyrite, Kuittila-Kivisuo, Finland, and Proterozoic molybdenite, Kabeliai, Lithuania: Testing the chronometer in a metamorphic and metasomatic setting: Mineralium Deposita, v. 33, p. 329–345.

Stein, H.J., Sundblad, K., Markey, R.J., Sivoronov, A.A., Bobrov, A.B., Malyuk, B.I., and Pavlun, M.M., 1998b, Re-Os ages for molybdenites from Maiske and Sergeevske Au deposits, Ukraine: Geophysical Journal (Kiev), v. 20, p. 114–117.

Stein, H.J., Morgan, J.W., Markey, R.J., and Hannah, J.L., 1999, The status of the Re-Os chronometer for dating sulfides and oxides, *in* Stanley et al., eds., Mineral deposits: Processes to processing: Rotterdam, Balkema, p. 1291–1294.

Stendal, H., and Frei, R., 2000, Gold occurrences and lead isotopes in Ketilidian mobile belt, South Greenland: Transactions of the Institution of Mining and Metallurgy, v. 109, p. B6–B13.

Sundblad, K., 1994, Paleoproterozoic ore-bearing Mg-rich greenstone belts at Hackås, central Sweden: Sveriges Geologiska Undersökning, Unpublished research report, 36 p.

Sundblad, K., and Kivisilla, J., 1991, Evidence for the presence of Svecofennian stratiform oxide and sulphide ores in northeastern Estonia: Geology and mineral resources of Estonia: Tallinn, Eesti Geoloogia Selts, Symposium materials, p. 27–28.

Sundblad, K., Weihed, P., Markkula, H., Billström, K., and Mäkelä, M., 1993, Source of metals and age constraints for epigenetic gold deposits in the Skellefte and Pohjanmaa districts, central part of the Fennoscandian Shield: Mineralium Deposita, v. 28, p. 181–190.

Sundblad, K., Thorpe, R., Vaasjoki, M., and Bibikova, E., 1994, Metallogenic and isotopic systematics of 1.9–2.0 Ga volcanogenic ores in Europe and North America: Terra Nova, v. 6, supplement 2, p. 19.

Sundblad, K., Bjørlykke, A., and Alm, E., 1996, Sources of lead in the Mjøsa-Vänern gold quartz veins, Southwest Scandinavian domain: GFF, v. 118, p. A47–48.

Sundblad, K., Mansfeld, J., and Särkinen, M., 1997a, Palaeoproterozoic rifting and formation of sulphide deposits along the southwestern margin of the Svecofennian domain, southern Sweden: Precambrian Research, v. 82, p. 1–12.

Sundblad, K., Blomquist, M., and Särkinen, M., 1997b, Guld i Blekinge—dröm eller verklighet?: Karlskrona, Blekinges Natur, p. 32–41. (in Swedish)

Sundblad, K., Gyllencreutz, R., and Flodén, T., 1998, The Precambrian crust beneath the Baltic Sea: Geophysical Journal (Kiev), v. 20, p. 121–124.

Sundblad, K., Krstic, D., Bergman, T., and Lindblom, S., 1999, Geology and origin of the Proterozoic gold quartz veins at Ädelfors, southeastern Sweden [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 159–162.

Svensson, S.Å., and Willdén, M., 1986, The Näsliden and Holmtjärn sulphide deposits in the central part of the Skellefte field: Sveriges Geologiska Undersökning, v. Ca 62, p. 33–36.

Tegengren, F.R., 1924, Sveriges ädlare malmer och bergverk: Sveriges Geologiska Undersökning, v. Ca 17, 406 p. (in Swedish).

Turchenko, S.I., 1992, Precambrian metallogeny related to tectonics in the eastern part of the Baltic Shield: Precambrian Research, v. 58, p. 121–141.

Turchenko, S.I., Semenov, V.S., Amelin, Ju.V., Levchenko, O.A., Neymark, L.A., Buiko, A.K., and Koptev-Dvornikov, Je.V., 1991, The Early Proterozoic riftogenic belt of Northern Karelia and associated Cu-Ni, PGE, and Cu-Au mineralizations: Geologiska Föreningens i Stockholm Förhandlingar, v. 113, p. 70–72.

Vaasjoki, M., Sorjonen-Ward, P., and Lavikainen, S., 1993, U-Pb age determinations and sulfide Pb-Pb characteristics from the Late Archean Hattu schist belt, Ilomantsi, eastern Finland: Geological Survey of Finland Special Paper, v. 17, p. 103–131.

Vanhanen, E., 2001, Geology, mineralogy, and geochemistry of the Fe-Co-Au-(U) deposits in the Paleoproterozoic Kuusamo schist belt, northeastern Finland: Geological Survey of Finland Bulletin, v. 399, 229 p.

Vorma, A., 1960, Laitakarite a new Bi-Se-mineral: Geological Survey of Finland Bulletin, v. 188, p. 1–10.

Wanhainen, C., Martinsson, O., and Kontturi, M., 1999, The Aitik Cu-Au deposit, Gellivare region, northern Sweden [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 163–165.

Weihed, P., 1992, Lithogeochemistry, metal, and alteration zoning in the Proterozoic Tallberg porphyry-type deposit, northern Sweden: Journal of Geochemical Exploration, v. 42, p. 301–325.

Weihed, P., and Fallick, A.E., 1994, A stable isotope study of the Paleoproterozoic Tallberg porphyry-type deposit, northern Sweden: Mineralium Deposita, v. 29, p. 128–138.

Weihed, P., and Mäki, T., 1997, Volcanic hosted massive sulphide and gold deposits in the Skellefte district, Sweden and western Finland: Geological Survey of Finland Guide, v. 41, 81 p.

Weihed, P., Bergman, J., and Bergström, U., 1992, Metallogeny and tectonic evolution of the Early Proterozoic Skellefte district, northern Sweden: Precambrian Research, v. 58, p. 143–167.

Weihed, P., Bergman Weihed, J., Sorjonen-Ward, P., and Matsson, B., 2002, Post-deformation, sulphide-quartz vein hosted gold ore in the footwall alteration zone of the Palaeoproterozoic Långdal VHMS deposit, Skellefte district, northern Sweden: GFF, v. 124, p. 201–210.

Weihed, P., Bergman Weihed, J., and Sorjonen-Ward, P., 2003, Structural evolution of the Björkdal gold deposit, Skellefte district, northern Sweden: Early Proterozoic mesothermal gold in the late stage of the Svecokarelian orogen: ECONOMIC GEOLOGY, v. 98, p. 1291–1309.

Wikström, T., and Sundblad, K., 1999, Ore petrology of the Björkdal deposit, Skellefte district, northern Sweden [abs.], *in* Cook, N.J., and Sundblad, K., eds., Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas: Geological Survey of Norway, Gold 99, Trondheim, May 4–6, 1999, Abstract volume, p. 166–168.

Zweifel, H., 1976, Aitik: Geological documentation of a disseminated copper deposit—a preliminary investigation: Sveriges Geologiska Undersökning, v. C720, 80 p.