Geological Survey of Finland

Bulletin 351

Geochemical characteristics of mesothermal gold deposits in the Fennoscandian Shield, and a comparison with selected Canadian and Australian deposits

by Pekka A. Nurmi, Pekka Lestinen and Heikki Niskavaara

Geologian tutkimuskeskus
Espoo 1991

Geological Survey of Finland, Bulletin 351

GEOCHEMICAL CHARACTERISTICS OF MESOTHERMAL GOLD DEPOSITS IN THE FENNOSCANDIAN SHIELD, AND A COMPARISON WITH SELECTED CANADIAN AND AUSTRALIAN DEPOSITS

by

PEKKA A. NURMI, PEKKA LESTINEN and HEIKKI NISKAVAARA

with 59 figures, 21 tables and 5 appendices

GEOLOGIAN TUTKIMUSKESKUS
ESPOO 1991

Vammala 1991 Vammalan Kirjapaino Oy

Nurmi, P.A., Lestinen, P. and Niskavaara, H. 1991. Geochemical characteristics of mesothermal gold deposits in the Fennoscandian Shield, and a comparison with selected Canadian and Australian deposits. *Geological Survey of Finland, Bulletin* 351. 101 pages, 59 figures, 21 tables and 5 appendices.

Abundances of ca. 70 elements are given for 137 bulk samples from 55 mesothermal gold deposits/ore bodies and their altered wall rocks located throughout the Late Archean and Early Proterozoic terrains of the Fennoscandian Shield (44 deposits), the Superior Province in Canada (9 deposits), and the Norseman — Wiluna belt in Western Australia (2 deposits). The most typical drill core material from each of the Finnish deposits was used to make representative bulk samples both from the gold ore and from the adjacent altered wall rocks. Chip-channel samples across typical lodes were taken from the remaining 13 mines. All samples were prepared using the same procedures, and were analyzed as a single set using ICP, ICP-MS, DCP, XRF, NAA, FAAS and GFAAS in addition to various other methods.

The results demonstrate that mesothermal gold mineralization in: 1) Late Archean greenstone belts; 2) the intracratonic Early Proterozoic Lapland greenstone belt; and 3) the juvenile Early Proterozoic Svecofennian complex, exhibits characteristic geochemical patterns, which reflect contrasting sources and deposition processes. Gold is the only element showing a systematic $>10^3$—10^4 times enrichment compared to average basalt. A number of Au-affiliated elements may occasionally show extreme enrichments but are generally only moderately concentrated, irrespective of host-rock lithology. The Archean deposits are characterized by the element association (median enrichment relative to basalt given in parentheses) Au (4100), Te (150), As (50), S (42), Ag (30), Bi (20), W (20), and B (11); deposits in the Lapland greenstone belt by Au (3900), S (110), Te (100), Bi (72), W (23), Se (21), and As (21); and deposits in the Svecofennian domain by Au (4100), As (1200), Bi (550), Te (340), Se (75), Ag (37), S (36), W (33) and Sb (20). Boron, Mo, Cu, U, Hg and Pb may locally be highly enriched, but are on average between 0.2—5 times the values for basalt. The mesothermal gold mineralization differs from epithermal types in having distinctly higher Au/Ag ratios, as well as lacking or showing only sporadic enrichment of Hg, Tl, Sb, Ba and F.

Wall-rock alteration has a complex history recording the effects, to varying degrees, of mineralizing, synvolcanic and metamorphic fluids. Hydration and potassic alteration, as well as carbonation in the greenstone-hosted deposits, are characteristic of mesothermal mineralization, as demonstrated by relative additions of H_2O, CO_2, K and Rb. Alteration is most pervasive in the Lapland province due to extensive synvolcanic processes and low metamorphic grade, and only weakly developed in the Svecofennian province as a consequence of smaller scale hydrothermal systems and post-mineralization metamorphism.

The elements most applicable to exploration for mesothermal gold deposits are, in relative order of importance: Au, Te, Bi, As, Ag, W and Se, while S, Sb, B, Mo, Cu, U, Hg, Pb, Sn and Co may locally be useful. In general, only Te, Bi and Ag correlate well with Au, suggesting roughly simultaneous deposition, and thus these are of most use in tracing ore lodes. Although other elements only locally correlate with Au, their deposition is often related to the same mineralization

systems, and therefore may indicate ore-potential zones on a broader scale. Elements related to wall-rock alteration, such as K, Rb, Na, Ca, Sr, Si, CO_2 and H_2O, delineate in general the pathways of hydrothermal fluids.

Key words: geochemistry, gold ores, chemical composition, trace elements, tellurium, bismuth, selenium, enrichment, epigene processes, Precambrian, Finland, Sweden, Norway, Canada, Australia

Pekka A. Nurmi:
Geological Survey of Finland, SF-02150 Espoo, Finland

Pekka Lestinen:
Geological Survey of Finland, P.O. Box 1237, SF-70701 Kuopio, Finland

Heikki Niskavaara:
Geological Survey of Finland, P.O.Box 77, SF-96101 Rovaniemi, Finland

ISBN 951-690-403-3
ISSN 0367-522X

CONTENTS

INTRODUCTION

Gold mineralization has been intensively investigated during the last few years and major advances have been made in the understanding of the geological control and genesis of gold deposits (see, e.g., Berger and Bethke, 1985; Macdonald, 1986; Groves et al. 1987; Ho and Groves, 1987; Colvine et al. 1988; Ho and Groves, 1988; Kerrich and Fyfe, 1988; Bursnall 1989; Kerrich, 1989; Keays et al., 1989; Hedenquist et al., 1990). Such studies have mostly been directed towards the geological setting, wall-rock alteration, light stable isotopes and fluid inclusions associated with gold mineralization, whereas geochemical studies concerning systematic analysis of a wide range of elements are few (e.g., Radtke et al., 1972; Boyle, 1979; Kerrich, 1983). Quantitative data for many rare elements, such as Te, Bi and Se, which are known, on mineralogical evidence, to be commonly associated with gold deposits are particularly scarce.

Until the end of the 1970's only a few gold deposits were known in the Fennoscandian Shield and there were no clear ideas about the regional gold potential. Significant investment in gold exploration during the 1980's has rapidly changed the situation and a number of deposits and potential provinces have been found throughout the shield. Geochemical methods, mainly utilizing glacial drift as the sample media have been very important in delineating new gold bearing areas particularly in Finland, where about 100,000 samples have been analysed for this purpose during 1984—1988 (Nurmi, 1991). A number of elements, including Cu, As, Te, Ni, Co, W, Mo, Ag, Bi, Sb and B, have proven to be useful pathfinders for gold deposits. Since the set of elements seemed to vary between targets and no systematic data existed on the trace element composition of gold mineralization, a comprehensive project to study the geochemistry of gold mineralization was initiated in 1988, concentrating principally upon Finnish deposits.

This project is concerned with epigenetic mineralization, in which gold is the only or most important ore metal, and thus all deposits included are generally of the shear zone or vein type, and exhibit intense wall-rock alteration. To obtain a representative set of samples from different provinces, almost all gold occurrences known in Finland at the beginning of 1989 (altogether 42), and two mines from other parts of the Fennoscandian Shield were sampled. In addition to this, mines from well-known gold provinces in the Superior Province in Canada and the Norseman — Wiluna belt in Western Australia were included as a reference, together with a set of samples from commonly occurring host rock types.

Bulk sampling from ore and adjacent wall rocks was deemed preferential to other techniques in order to avoid, as far as possible, sampling bias caused by the heterogeneous distribution of rare elements in gold ores, and to minimize the number of samples. Drill-core material was available from the Finnish deposits, and the most representative intersection was selected from each target together with local geologists and/or on the basis of exploration reports. Furthermore, data concerning the geology and exploration history of each occurrence was gathered, and has been published elsewhere (Nurmi, 1991). Since drill core was not available from the other mines, chip-channel samples were taken

from typical lodes either by mine geologists or the authors.

All samples were to be analysed for a wide set of elements with special attention given to Au-affiliated rare elements, with techniques allowing detection limits below the background levels. Analytical methods, employing graphite furnace atomic absorption spectrometry, which were developed at the Geological Survey of Finland for analysing low abundances of Au, Te, Se, Ag, Pd and Pt (Kontas et al., 1986, 1990; Niskavaara and Kontas, 1990), offered a good starting point for the study, and were supplemented with other advanced methods. Some elements were determined with different methods, a number of samples were analysed twice and a suite of reference samples representing typical host rocks was also included in the study in order to establish the reproducibility of results and detect any systematic errors in the analytical procedures. Furthermore, contamination due to milling was tested by analysing preparation blanks.

The main purpose of the study was to obtain a comprehensive understanding of the association of a wide range of elements present in mesothermal gold mineralization in different geological settings. This is particularly important in planning geochemical exploration and offers valuable data for classifying and studying the genesis of gold mineralization. The present paper is intended to present complete geochemical results, along with a detailed description of sampling and analytical procedures. Genetic aspects of the data will be discussed elsewhere later.

GEOLOGICAL SETTING OF GOLD DEPOSITS IN THE FENNOSCANDIAN SHIELD

The Fennoscandian Shield comprises vast areas of Late Archean and Early Proterozoic terrains, but although geologically analogous to other shield areas, it has never been significant gold producer in world terms. Gold has principally been extracted as a by product of the exploitation of massive sulfide deposits and only a few mines have been operated purely for gold (see, Gaál and Sundblad, 1990; Puustinen, 1991). However, intensive exploration in the 1980's has led to the discovery of a number of economically interesting gold deposits and zones of good potential, in addition to the opening of a number of gold mines: Enåsen (in 1984) and Björkdal (1988) in Sweden; as well as Bidjovagge (1985) in Norway; and Saattopora (1988) in Finland. Gold mineralization in the Fennoscandian Shield is not restricted to the Archean greenstone belts but numerous deposits, including all the above mentioned operating mines occur within Early Proterozoic complexes.

Gold mineralization can be divided into three main groups in relation to tectono-stratigraphic units (Nurmi, 1991), namely deposits associated with: 1) Late Archean greenstone belts in eastern Finland; 2) the intracontinental Early Proterozoic Lapland greenstone belt in the northern part of the shield; and 3) Early Proterozoic, juvenile Svecofennian complex in southwestern Finland and southern Sweden (Fig. 1).

Gold mineralization in the Archean greenstone belts

Archean gold occurrences are known in the Ilomantsi and Kuhmo greenstone belts (Fig. 1; Table 1), formed between 2.9—2.7 Ga. Supracrustal rocks comprise narrow, bifurcating zones attaining 50 to 100 km in length but only a few kilometres in width within an extensive gneiss —

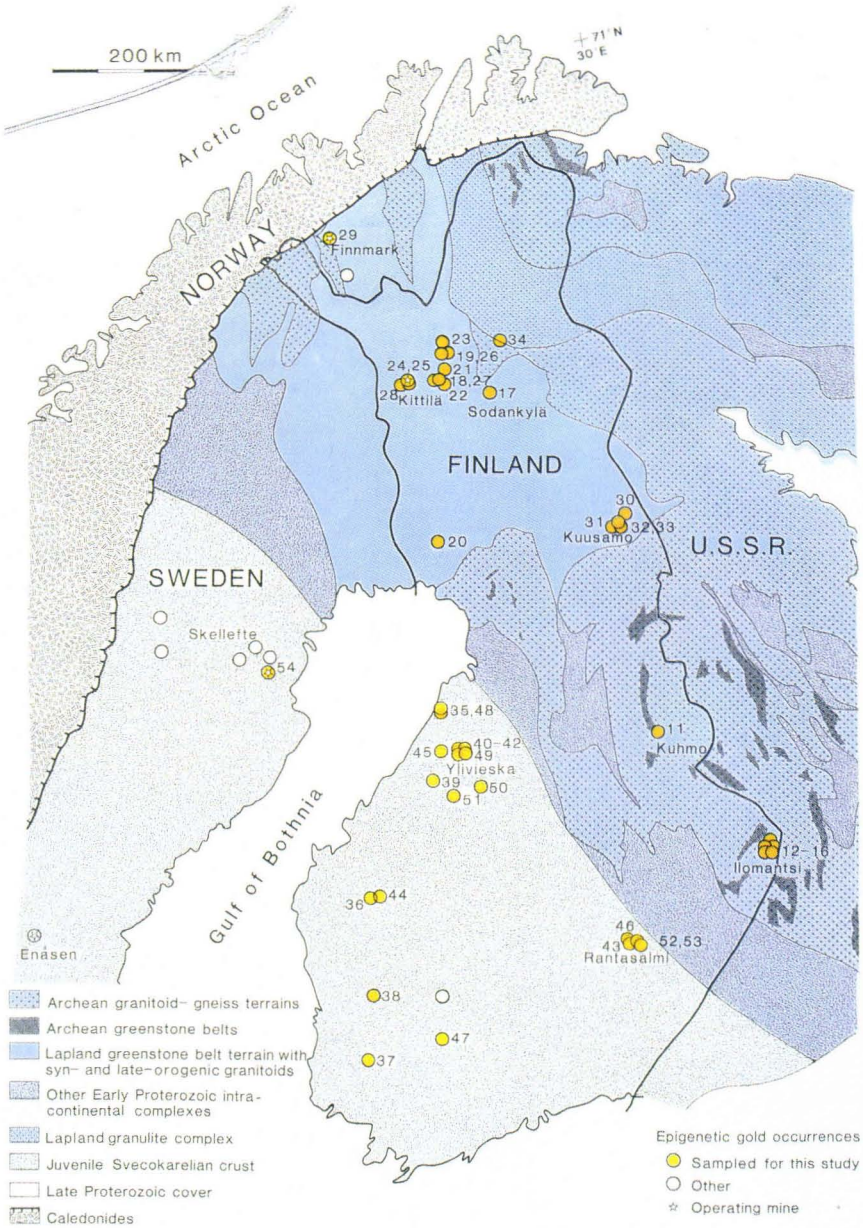


Fig. 1. Major geological provinces and location of mesothermal gold deposits in the Fennoscandian Shield. *Archean greenstone belts* (11—16): 11. Lokkiluoto, 12. Kelokorpi, 13. Muurinsuo, 14. Korvilansuo, 15. Rämepuro and 16. Kuittila; *Lapland greenstone belt* (17—34): 17. Pahtavaara, 18. Lälleävuoma, 19. Sukseton, 20. Kivimaa, 21. Suurikuusikko, 22. Hirvilavanmaa, 23. Rovaselkä, 24. Saattopora N, 25. Saattopora S, 26. Iso-Kuotko, 27. Soretiavuoma, 28. Sirkka W, 29. Bidjovagge, 30. Juomasuo, 31. Säynäjävaara, 32. Sivakkaharju, 33. Konttiaho and 34. Mäkärärova; *Svecofennian complex* (35—54): 35. Laivakangas N, 36. Sudenkylä, 37. Jokisivu, 38. Isovesi, 39. Antinoja, 40. Vesiperä, 41. Ängesneva, 42. Kiimala, 43. Pirilä S, 44. Kalliosalo, 45. Kurula, 46. Pirilä N, 47. Kaapelinkulma, 48. Laivakangas S, 49. Pöhlölä, 50. Kopsa, 51. Kangaskylä, 52. Osikonmäki E, 53. Osikonmäki W and 54. Björkdal.

Table 1. Location, geology and gold contents of studied gold occurrences and analysed drill cores from the Fennoscandian Shield. See App. 5 for abbreviations.

Target no	Name	Commune/ country	Company[1]	Drill core	Map sheet	Analysed depth intervals (m) Whole length	Ore
11	Lokkiluoto	Kuhmo	KAJ	KR 16/290	4413 02	001.80-020.95	001.80-007.43[2]
12	Kelokorpi	Ilomantsi	GSF	R 329	4244 08	125.45-146.30	134.90-138.70
13	Muurinsuo	Ilomantsi	GSF	R 320	4244 08	014.00-042.20	024.00-032.00
14	Korvilansuo	Ilomantsi	GSF	R 325	4244 08	124.70-146.40	134.70-136.70
15	Rämepuro	Ilomantsi	OKU	IMHÄ 9	4244 09	045.65-060.70	053.05-055.80
16	Kuittila	Ilomantsi	GSF	R 309	4244 08	148.00-170.00	153.00-160.00
17	Pahtavaara	Sodankylä	GSF	R 508	3714 05	104.50-127.90	114.00-119.00
18	Lälleävuoma	Kittilä	OKU	PÄI 1	2743 01	038.50-063.35	048.50-053.70
19	Sukseton	Kittilä	OKU	SUK 5	2744 04	023.93-032.82	026.12-030.78
20	Kivimaa	Tervola	OKU	T 5	2631 10	025.00-045.20	032.00-038.20
21	Suurikuusikko	Kittilä	GSF	R 407	2743 05	036.00-054.00	041.00-049.00
22	Hirvilavanmaa	Kittilä	GSF	R 343	2734 06	045.30-075.30	055.80-064.80
23	Rovaselkä	Kittilä	OKU	ROV 4	2744 05	032.60-050.10	038.80-040.10
24	Saattopora N	Kittilä	OKU	SP 235	2741 04	012.70-033.00	015.70-028.50
25	Saattopora S	Kittilä	OKU	SP 207	2741 04	096.50-121.70	104.40-113.00
26	Iso-Kuotko	Kittilä	GSF	R 309	2744 04	058.00-094.00	066.00-076.00
27	Soretiavuoma	Kittilä	GSF	R 307	2743 01	039.60-058.40	048.40-049.40
28	Sirkka W	Kittilä	OKU	SKK 12	2741 07	018.90-046.00	029.00-033.00
29	Bidjovagge	N Norway	BIDGR	Mine	-	-	-
30	Juomasuo	Kuusamo	GSF	R 320	4613 02	120.00-165.70	130.00-154.20
31	Säynäjävaara	Kuusamo	GSF	R 305	4611 07	081.00-128.10	091.00-116.50
32	Sivakkaharju	Kuusamo	GSF	R 348	4611 10	020.10-054.50	031.10-047.50[3]
33	Konttiaho	Kuusamo	GSF	R 361	4611 10	003.50-035.50	020.50-025.50
34	Mäkärärova	Sodankylä	GSF	R 301	3724 11	137.00-150.00	139.00-143.00
35	Laivakangas N	Raahe	OKU	RHLAI 28	2441 07	026.00-046.50	029.90-036.85[4]
36	Sudenkylä	Ilmajoki	MAKA	R 4	2222 04	009.60-019.55	014.15-015.05
37	Jokisivu	Huittinen	OKU	HUJS 1	2112 01	009.80-032.92	021.54-025.40
38	Isovesi	Suodenniemi	OKU	SDNIS 1	2122 05	017.10-028.70	022.65-024.55
39	Antinoja	Kannus	OKU	KNSAN 15	2342 05	004.00-030.15	011.90-020.10[5]
40	Vesiperä	Haapavesi	GSF	R 307	2433 02	043.40-064.85	053.50-058.50
41	Ängesneva	Haapavesi	GSF	R 369	2433 02	031.35-067.50	042.00-061.45
42	Kiimala	Haapavesi	GSF	R 390	2433 02	032.60-067.80	042.60-059.85
43	Pirilä S	Rantasalmi	GSF	R 322	3233 06	070.00-100.90	079.85-091.50
44	Kalliosalo	Nurmo	GSF	R 318	2222 07	147.40-162.40	156.40-159.40
45	Kurula	Ylivieska	GSF	R 316	2431 08	009.70-021.50	012.75-015.00
46	Pirilä N	Rantasalmi	GSF	R 375	3233 06	045.55-063.55	051.55-053.55
47	Kaapelinkulma	Valkeakoski	GSF	R 305	2132 03	000.70-017.70	003.35-007.30
48	Laivakangas S	Raahe	OKU	RHLAI 56	2432 09	075.45-097.25	088.00-091.45
49	Pöhlölä	Haapavesi	OKU	HPVPÖH 7	2433 02	000.00-007.33	003.20-003.75
50	Kopsa	Haapajärvi	OKU	K 66	2344 07	019.00-050.10	032.50-050.10[6]
51	Kangaskylä	Reisjärvi	OKU	RE 61	2341.12	039.65-055.40	047.70-048.65
52	Osikonmäki E	Rantasalmi	GSF	R 421	3233.09	165.00-226.00	176.00-214.00
53	Osikonmäki W	Rantasalmi	GSF	R 391	3233.09	111.00-134.50	118.00-126.00
54	Björkdal	N Sweden	TEMI	Mine	-	-	-

Notes: [1] Company acronyms: BIDGR = Bidjovagge Gruber, GSF = Geological Survey of Finland, KAJ = Kajaani Oy, MAKA = Malmikaivos Oy, OKU = Outokumpu Oy, and TEMI = Terra Mining Ab.
[2] Foot-wall alteration zone analysed only.
[3] Low-grade interval 38.10-44.50 excluded.
[4] Post-mineralization granite dike 37.90-41.30 excluded.
[5] Low-grade interval 12.60-14.60 excluded.
[6] Hanging-wall alteration zone analysed only.

granitoid complex. The gold potential of the more extensive greenstone belts occurring to the east in contiguous parts of the U.S.S.R. has not been studied in detail and the existence of gold deposits has not been reported in the literature.

The Kuhmo belt is characterized by bimodal volcanic series from calc-alkaline rhyolite-andesite to tholeiitic and komatiitic mafic to ultramafic volcanic rocks (Luukkonen, 1988; Piirainen, 1988). The eastern part of the Ilomantsi belt,

Table 1, contd.

Grade (ppm Au)	Length (m)	Host rock	Ore type	Mineral resources (Mt)	(ppm Au)	References
4.2	5.63	mtuf	qtz veins	-	-	T. Kopperoinen, pers. commun.
3.0	3.80	ituf	qtz veins & dissemination	-	-	Nurmi and Ward, 1989
2.1	8.00	grw	dissemination	-	-	-"-
4.8	2.00	grw	dissemination	-	-	-"-
19	2.75	grw	qtz-tour veins	0.25	5	Pekkarinen, 1988
2.1	7.00	ton	qtz veins	0.28	2.6	Nurmi and Ward, 1989
7.4	5.00	umr	qtz lenses & veins	0.23	7.3	Korkiakoski et al., 1989
3.8	5.20	umr	crb-qtz veins	-	-	R. Hugg, pers. commun.
2.7	4.66	mvolc	sulfide dissemination	-	-	-"-
4.9	6.00	doler	crb-qtz veins	0.05	5.3	Rouhunkoski and Isokangas, 1974
6.6	8.00	mtuf	crb-qtz breccia	-	-	Härkönen and Keinänen, 1989
10	9.00	umr	crb-qtz breccia	-	-	-"-
2.1	1.30	mtuf	sulfide-qtz breccia	-	-	R. Hugg, pers. commun.
10	12.80	mtuf	crb-qtz veins	1	3.6	Anttonen et al., 1989
3.4	8.60	mtuf	crb-qtz veins	-	-	-"-
2.0	10.00	mtuf	crb-qtz veins	-	-	Härkönen and Keinänen, 1989
3.6	1.00	umr	crb-qtz veins	-	-	Keinänen et al., 1988
5.0	4.00	umr	dissemination	-	-	R. Hugg, pers. commun.
-	-	crbabr	sulfide breccia	>5	0.5-30	Söderholm and Nixon, 1988
4.5	24.20	absechlor	sulfide dissemination	1.2	5	Pankka and Vanhanen, 1989
3.9	25.50	btchloabr	sulfide breccia	0.4	1	-"-
8.0	10.00	abcrbser	sulfide veins & dissemination	0.1	8	-"-
29	3.00	abcrbr	sulfide dissemination	-	-	-"-
1.8	4.00	fgn	hematite-qtz veins	0.08	2.1	I. Härkönen, pers. commun.
5.7	6.95	mvolc	qtz veins	0.7	4	Mäkelä et al., 1988
12	0.90	mvolc	qtz veins	-	-	P. Huopaniemi, pers. commun.
28	3.86	mvolc	qtz veins	-	-	A. Kinnunen, pers. commun.
1.4	1.90	ivolc	dissemination	-	-	-"-
2.8	6.20	ivolc	dissemination	-	-	T. Huhtala, pers. commun.
9.5	5.00	ivolc	qtz veins & dissemination	-	-	Mäkelä et al., 1988
2.1	19.45	ivolc	dissemination	-	-	E. Sipilä, pers. commun.
2.1	17.25	ivolc	sulfide breccia	-	-	-"-
14	11.65	ivolc	qtz lenses	0.15	8	Makkonen and Ekdahl, 1987
9.7	3.00	ivolc	qtz veins	-	-	P. Oivanen, pers. commun.
1.8	2.25	ivolc	dissemination	-	-	E. Sipilä, pers. commun.
2.2	2.00	fvolc	qtz lenses & dissemination	0.03	2.7	Makkonen and Ekdahl, 1987
3.3	3.95	qtzdr	qtz veins	0.07	8	P. Rosenberg, pers. commun.
6.0	3.45	ton	qtz veins	0.06	8	Mäkelä et al., 1988
13	0.55	ton	qtz veins	-	-	Mäkelä et al., 1988
2.7	17.60	ton	qtz veins & dissemination	1.1	1.9	Gaál and Isohanni, 1979
9.0	0.95	ton	qtz veins	-	-	T. Huhtala, pers. commun.
6.9	38.00	ton	dissemination	4.5	2.0	Kontoniemi and Ekdahl, 1990
4.7	8.00	ton	dissemination	-	-	-"-
-	-	ton	qtz veins	10	2.8	S. Sundberg, pers. commun.

hosting the gold occurrences, is composed predominantly of calc-alkaline dacitic — andesitic volcanic rocks along with their sedimentary derivatives (Nurmi and Ward, 1989). Early tonalitic intrusions at about 2.75 Ga are common. Both belts exhibit complex deformation and metamorphism, which attained amphibolite facies conditions. Gold mineralization occurred relatively late in crustal evolution under retrogressive metamorphic conditions.

Gold deposits show no preferential association with any host-rock lithology, but are controlled by extensive shear and alteration zones typical of mesothermal gold mineralization in other shield areas. In the Ilomantsi belt, however, contact zones between schists and tonalitic intrusions or porphyry dikes seem to have been preferential sites for gold deposition (Nurmi and Ward, 1989). Gold occurs in quartz ± tourmaline veins and also disseminated in pervasively altered

quartz-sericite schists, typically containing Fe-sulfides and minor Te and Bi minerals (Johanson and Kojonen, 1989).

Although these belts have significant economic potential and are currently focus for exploration, only a few showings have as yet been evaluated by drilling. The Rämepuro deposit has been assessed as containing some 0.25 Mt at 5 ppm to a depth of 50—70 m and over a strike length of 500 m (Pekkarinen, 1988).

Gold mineralization in the Lapland greenstone belt

The Lapland greenstone belt covers a vast area (>50,000 km^2) in the northern Fennoscandian Shield from the Kuusamo area in northeastern Finland into northern Norway and Sweden (Fig. 1; Table 1). It developed by episodic extension and rifting of an Archean ensialic substrate between 2.5—2.0 Ga (Lehtonen et al., 1985; Ward et al., 1989). Deposition started with bimodal volcanic rocks, which are overlain by a quartzite — metapelite association and voluminous subaqueous tholeiitic — komatiitic volcanic rocks. High heat flow and permeability associated with rifting caused circulation of seawater and sediment-hosted brines leading to widespread, synvolcanic albite — carbonate dominated alteration, which may be locally intense along linear belts. Deposition of massive sulfides accompanied the process, as indicated by the copper deposits of Viscaria, Pahtavuoma, Saattopora and Riikonkoski (Godin, 1976; Inkinen, 1979).

Compressive deformation and associated greenschist facies metamorphism did not take place until the Svecokarelian orogeny at about 1.9 Ga ago. It resulted from the emplacement of the allocthonous Lapland granulite terrain from the NE, combined probably with coeval thrusting of opposite vergence (Ward et al., 1989). Ductile shear zones developed subparallel to the thrusting direction and later deformation caused progressive shortening, rotation of earlier structures and granitoid intrusion.

Epigenetic gold mineralization occurred along tectonic zones in a diverse of geological settings including quartz-carbonate vein systems and disseminations associated with: 1) altered mafic — ultramafic lithologies; 2) altered granitoids and porphyry dikes; and 3) pervasively altered epiclastic metasediments (Ward et al., 1989). Although many occurrences exhibit a close spatial relationship to early albite-carbonate altered rocks, it is evident that gold mineralization accompanied the late and typically brittle stages of deformation, and a metamorphic fluid source was involved. This is manifested for instance, by a distinct tectonic control of mineralized veins cross-cutting earlier structures and a well-developed potassic alteration in initially K-deficient albite-carbonate-dominated and ultramafic lithologies. Syndepositionally altered sequences have probably been structurally favorable units for fluid flow and compositionally suitable for effective fluid/rock interaction and gold precipitation.

Known gold occurrences are concentrated in the Kuusamo area in southeastern part and in the Kittilä — Sodankylä region at the center of the greenstone belt (Fig. 1; Table 1). The Bidjovagge Au-Cu mine, in northern Norway, belongs to the same province (Söderholm and Nixon, 1988). Most mineralization in the Kittilä — Sodankylä area consists of quartz-carbonate veins and disseminations in mafic — ultramafic lithologies. Pyrite and/or pyrrhotine are typical sulfides, occurring in varying amounts, together with chalcopyrite and arsenopyrite. In the Kuusamo area, as well as in Bidjovagge, gold is disseminated with abundant Fe-sulfides in pervasively altered albite-carbonate-quartz-sericite-chlorite rocks, which were originally subarkosic sediments intruded by mafic — ultramafic sills. Typical metal associations in the Kuusamo area include Fe-Au-Co-U-Cu-W-Mo-Pb-Te-Bi-As and average grade

varies between 0.5—10 ppm for Au and 0.1—0.3% for Co (Pankka, 1989; Pankka and Vanhanen, 1989).

The Lapland greenstone belt is currently the target of several gold exploration projects and many occurrences have yet to be properly delineated. The Saattopora mine, being the first gold mine to enter production in Finnish Lapland, contains 1 Mt ore in situ grading 3.6 ppm (T. Korkalo, pers.commun., 1990). The Juomasuo Au-Co deposits have geological reserves of over 0.7 Mt at 5 ppm Au (Pankka and Vanhanen, 1989).

Gold mineralization in the Svecofennian complex

The Svecokarelian terrain can be subdivided into: 1) an intracratonic part, which is largely coeval with the Lapland greenstone belt, but comprises mainly epiclastic sediments and late orogenic granites and migmatites with only minor tholeiitic — komatiitic volcanic rocks; and 2) the juvenile Svecofennian part, which contains all the currently known gold occurrences (Fig. 1). The latter was formed during a short period (about 1.90—1.86 Ga) in an active continental margin environment and consists predominantly of calc-alkaline volcanic rocks along with their sedimentary derivatives and voluminous I-type granitoid complexes (see, Gaál and Gorbatchev, 1987). Multiphase deformation and medium grade metamorphism took place soon after the peak of magmatic activity, but was subsequently widely overprinted by higher-grade metamorphism, related to the formation of migmatites and S-type granites during a later orogenic phase about 1.83—1.80 Ga ago (Korsman et al., 1984; Nurmi and Haapala, 1986).

Gold deposits have been found throughout the juvenile Svecofennian complex, but distinct clusters occur around Ylivieska and Rantasalmi in Finland and Skellefte in Sweden (Fig. 1). Mineralization seems to have a close spatial relationship with synorogenic tonalites and subvolcanic intermediate intrusions, because most deposits are either hosted by or occur adjacent to intrusive rocks (Mäkelä et al., 1988; Kontoniemi and Ekdahl, 1990; Nurmi, 1991; Table 1). Gold occurs typically in discrete quartz vein systems with limited alteration halos and less commonly as disseminations in shear zones. Alteration minerals include quartz, sericite, biotite and K-feldspar, but carbonates are notably lacking. Sulfides are fairly abundant usually consisting of Fe-sulfides, chalcopyrite, arsenopyrite and less commonly scheelite, sphalerite, galena and minor Te- and Bi-minerals.

Only some of the deposits have been fully evaluated. The Björkdal deposit contains about 10 Mt at 2.8 ppm Au; the Laivakangas deposit has reserves of 0.7 Mt grading 4 ppm (Mäkelä et al., 1988); Osikonmäki 4.5 Mt at 2 ppm (Kontoniemi and Ekdahl, 1990); and Pirilä, 0.15 Mt at 8 ppm (Makkonen and Ekdahl, 1988).

SAMPLING OF FINNISH GOLD OCCURRENCES

Previous geochemical studies have shown that the composition of gold deposits can vary considerably even within a particular camp (e.g., Kerrich, 1983; Nurmi et al., 1989). On the other hand, mesothermal gold mineralization does not exhibit the same kind of geochemical zoning as is found, for example in lower-T epithermal gold, massive sulfide and porphyry deposits, but may instead be fairly homogeneous from bottom to top (Colvine et al., 1988). For this reason, it was

considered necessary to include almost all known occurrences in this study in order to reach reliable conclusions concerning the possible geochemical differences between various provinces. Each deposit included in the survey was required to have at least one ore-grade drill intersection, but the overall tonnage was not considered important, since many of the deposits have not been evaluated in detail, nor are geochemical characteristics necessarily related on the deposit size. Altogether 6 targets from the Archean greenstone belts in eastern Finland, 17 from the Lapland greenstone belt in northern Finland and 19 from the Svecofennian complex in southwestern Finland were sampled (Fig. 1; Table 1). Of these 42 occurrences 24 have been investigated by the Geological Survey of Finland, 16 by Outokumpu Oy (with Lapin Malmi Oy) and one each by Kajaani Oy and by Malmikaivos Oy (Table 1; Nurmi, 1991).

By using representative bulk sampling the total number of samples was kept to a reasonable minimum. Drill-core material was deemed preferential to other sample types and was exclusively used for the deposits. Moreover, the use of drill-core material offered flexibility in selection of the sample sites, with the further advantage that samples could be delineated and defined accurately, material is unweathered, and all samples are of the same type.

In addition to ore-grade samples, altered wall rocks were also sampled, since gold does not necessarily have any systematic correlation with elements whose abundances may have changed considerably during the mineralization process and which may form geochemical halos around ore zones. Thus these elements are as essential components of mineralization as gold itself and may be useful pathfinders in exploration.

The most representative drill core from each deposit was carefully selected on the basis of exploration reports and in most cases together with local company staff. The most important criteria were: good gold assays over an adequate depth interval, unimodal gold distribution, most typical ore type and host rock, and location at the center of the deposit. In a few cases, unimodal ore intersections did not exist but ore horizons were separated by intervening barren portions or by post-mineralization dikes, which were therefore excluded (see, Table 1). At Lokkiluoto and Kopsa it was possible to analyse only one side of the alteration zone.

Drill-core reports and gold contents were used to delineate three intervals from the selected cores, representing both the ore and altered wall rocks on either side. The ore samples were delineated purely on the basis of gold assays produced in association with exploration, using a cut-off value of about 1 ppm. The longest ore

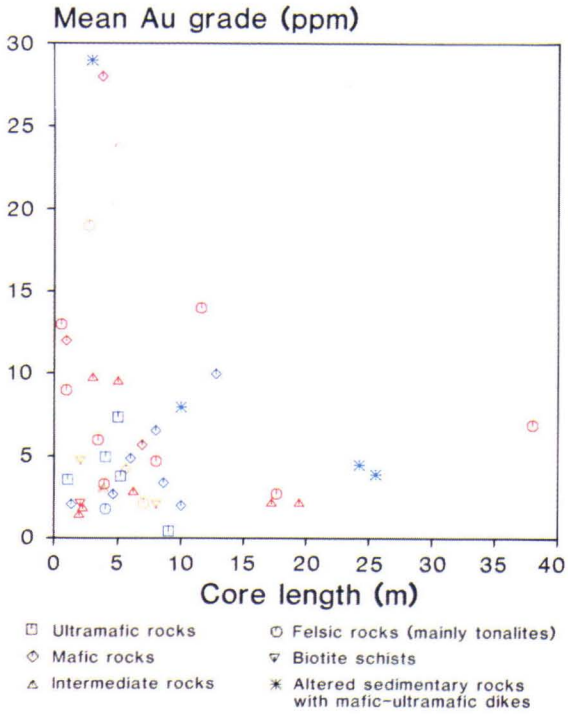


Fig. 2. Drill-core lengths and average grades (according to exploration analyses of subsamples) of the bulk ore samples of this study from the Finnish gold deposits. Gold provinces: brown represents Archean deposits; blue, deposits in the Lapland greenstone belt; and red, deposits in the Svecofennian complex.

intersection sampled in the material is 38 m (averaging 6.9 ppm) from Osikonmäki E, the shortest 0.6 m (13 ppm) from Kangaskylä, the best average grade (according to original exploration analyses) is 29 ppm (over 3 m) from Konttiaho and poorest 1.4 ppm (1.9 m) from Isovesi (Fig. 2, Table 1). The wall-rock samples were delineated on the basis of drill-core reports and analytical results, and usually represent 2 to 15 m intervals of the dominant host rock, from the ore outwards to unaltered rock.

Bulk samples for this study were combined from the drill-core material. During exploration, the 35 or 45-mm drill cores had been halved by splitting, generally in 0.3—2 m intervals, and crushed with portions weighing approximately 100 g milled for analysis. Original coarsely-crushed material was in most instances still available for use in this study. Where this was not the case, half of the remaining drill core was taken in about 2-m intervals. Wall-rock samples were often not analysed for their whole length, in which cases the core was also halved in 2-m sections specifically for this study. This guaranteed the same crushing and milling procedures for all samples, which are described in detail below.

GEOLOGY AND SAMPLING OF GOLD MINES OUTSIDE FINLAND

Samples from 11 mines/ore bodies in well-known Late Archean mesothermal gold provinces in Canada and Western Australia (Table 2) were included in the study for reference purposes as well as two samples from other parts of the Fennoscandian Shield (Table 1). The mines were selected to represent different host-rock lithologies and ore types.

Data from the Björkdal and Bidjovagge mines are considered together with the Finnish deposits, because the former is situated within the Svecofennian complex in Västerbotten, northern Sweden and the latter is located within the Lapland greenstone belt in Finnmark, northern Norway. The Björkdal deposit is hosted by a series of quartz-tourmaline veins, which developed in a shear zone at the contact of a tonalite and felsic volcanic and carbonate rocks (Larsson, pers. commun., 1989). Native gold occurs as coarse, up to 1 mm sized flecks, in the quartz veins and is, in part, associated with pyrite. Minor chalcopyrite, scheelite, and Bi and Te minerals are common. The sample provided by the mine geologist represents a 5 kg portion of the refinery feed.

The Bidjovagge Au-Cu deposit comprises sev-

Table 2. Location, geology and reserves (produced and present) of sampled mines in Canada and Australia.

Target No	Mine	Location	Company	Host rock	Ore type	Reserves (t Au)
1	Mt. Charlotte	Kalgoorlie, Australia	Kalgoor. Min. Ass.	Gold. Mile Doler.	qtz veins	53
2	New Celebration	-"-	Newmont Australia	qtz-feldsp. porph.	py veins	23
3	Macassa	Kirkland Lake, Canada	Lac Minerals	alkalic intrusives	qtz veins	81
4	Hoyle Bond	Timmins, Canada	Falconbridge Gold	thol. basalt	qtz veins	12
5	Owl Creek	-"-	-"-	thol. basalt	disseminated	7
6.1	Kerr Addison	Kirkland Lake, Canada	Golden Shield Res	thol. basalt	py dissemination	317
6.2	"	-	-	graph. basalt	py dissemination	-
6.3	"	-	-	ultramafic rock	dissemination	-
7	Renabie	Wawa, Canada	Royex Gold Min. Co.	tonalite	qtz lenses	34
8	Ferderber	Val d'Or, Canada	Belmoral Mines	tonalite	qtz-py veins	9
9	Page Williams	Hemlo, Canada	Lac Minerals	felsic volcanics	py dissemination	283

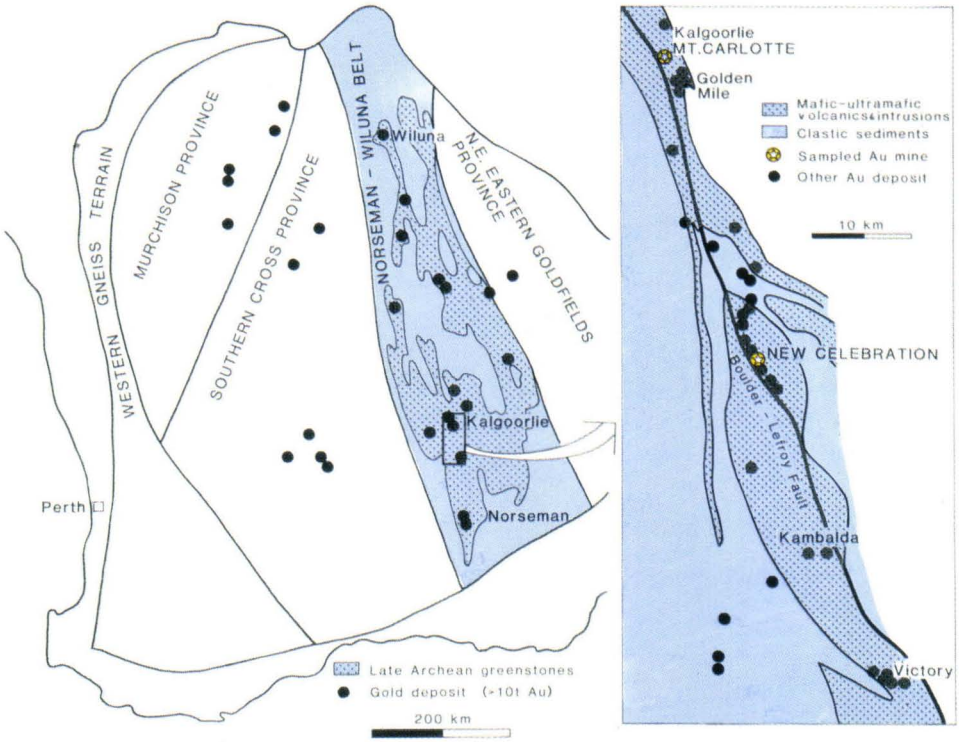


Fig. 3. Major Archean provinces of the Yilgarn block in Western Australia showing transcrustal fault zones, major gold deposits (> 10 t Au), and distribution of gold deposits in the Kalgoorlie — Kambalda district, with the location of the mines included in this study. Modified from Groves and Barley (1988).

eral small ore bodies in a pervasively albitized and sheared, graphite-bearing, epicontinental sedimentary suite with dolerite dikes (Björlykke et al., 1987; Söderholm and Nixon, 1988). Gold contents have a clear correlation with radioactivity and tellurides. A chip-channel sample weighing about 10 kg was taken by the mine geologist across the Au-rich Eva lode for this study. It grades > 10 ppm Au and 1.5—2.0% Cu over intersections up to 40—50 m.

Samples from the Norseman — Wiluna belt in western Australia are from the New Celebration and Mt. Charlotte mines (Fig. 3), located adjacent to the Boulder — Lefroy Fault, which controls the major gold deposits in the belt (see, Groves and Barley, 1988). The New Celebration mine is situated between Kalgoorlie and Kambalda and the sample is from the Hampton Boulder ore body. Mine geology is dominated by a quartz-feldspar porphyry body in contact with a mafic hanging wall sequence and ultramafic footwall rocks, intruded by thinner felsic dikes (Cullen and Norris, 1988). Gold ore comprises several tabular bodies within a sheared and pervasively altered porphyry and in its contact zones. The sample provided by the mine geologist represents an approximately 5 kg chip-channel sample across a lode within pyrite-bearing, silicified and sericitized porphyry.

The Mt. Charlotte mine at Kalgoorlie is one of the mines within the Golden Mile Dolerite, which, as host to the most important gold mines in the Norseman — Wiluna belt, has a cumulative production of 1200 Mt to 1988 (Groves and Barley, 1988). Economic mineralization in Mt. Charlotte is mainly confined to the granophyric

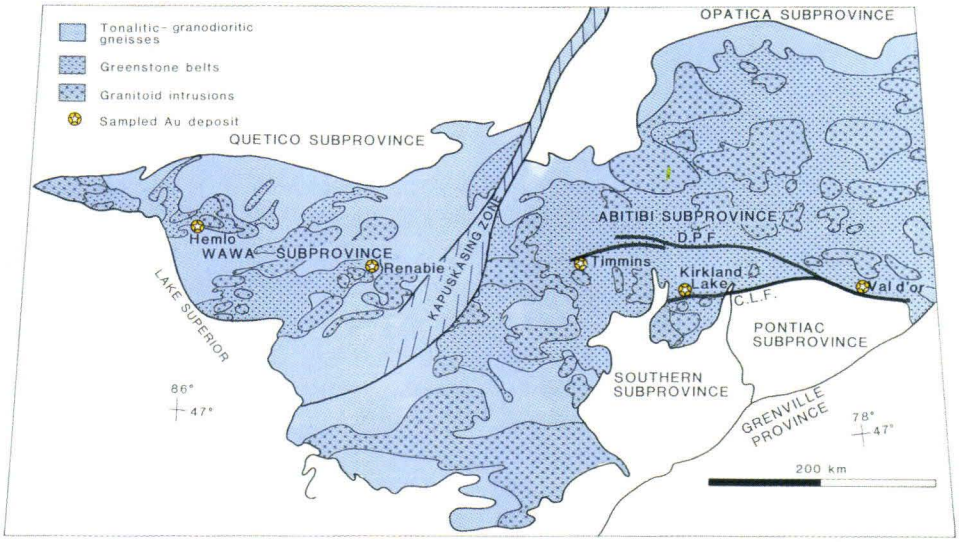


Fig. 4. Principal geological complexes in and around the Superior Province in Canada, with the location of the gold camps included in this study (see, Table 2). Modified from Percival and Card (1985).

unit of the differentiated tholeiitic sill (Clout et al., 1988). Mineralization occurs in quartz veins in a bleached host rock, dominated by albite, sericite, ankerite, magnetite and pyrite. A chip channel sample (about 5 kg) across a typical quartz lode was taken by H. Pankka during a visit to the mine.

Samples from the Canadian Shield were selected from typical gold mines representing different geological settings and host rocks throughout the Superior Province (Fig. 4, Table 2). The deposits from the Abitibi greenstone belt include Owl Creek and Hoyle Pond from the Timmins gold camp, associated with the Destor — Porcupine fault zone, Kerr Addison and Macassa from Kirkland Lake, and Ferderber in Val d'Or all occurring adjacent to the Cadillac — Larder Lake fault zone. These two fault zones control the majority of gold deposits in the Abitibi belt. The Page Williams mine in Hemlo and the Renabie mine near Missanabie belong to the Wawa subprovince.

Kerr Addison, Owl Creek and Hoyle Pond are largely hosted by tholeiitic metabasalts, the most common wall-rock type for Archean mesothermal gold deposits world wide. The ore bodies of the huge Kerr Addison mine are located along the Larder Lake break which, in addition to being an important tectonic break, is also a major lithological boundary between tholeiitic — alkalic volcanics and sediments, and komatiitic — tholeiitic volcanics (see, Kishida and Kerrich, 1987, and references therein). Gold occurs in two main ore types. The green carbonate ore is hosted by a highly altered ultramafic rock composed of Cr-mica, quartz and carbonate, and contains coarse-grained gold in quartz veinlets. Gold in the flow ore is associated with fine-grained, disseminated pyrite in altered pillow basalts, now dominated by a quartz-chlorite-carbonate assemblage. Three chip-channel samples (about 5 kg each) across typical ore bodies representing the flow ore (No 6.1, Table 2), graphitic flow ore (No 6.2) and green carbonate ore (No 6.3, Table 2) were provided by the mine geologist.

At Hoyle Pond and Owl Creek, gold is mainly associated with quartz veins and disseminated pyrite in altered tholeiitic volcanics (Downes et al., 1984; Coad et al., 1986). From both mines chip-channel samples (about 5 kg each) across

typical lodes were provided by the mine geologists. The sample from Hoyle Pond represents coarse gold in quartz veins, whereas that from Owl Creek fine-grained gold in disseminated pyrite.

The Macassa mine has a complex geological setting dominated by clastic sediments and trachytic volcanics intruded by a composite alkalic rock, which is the principal host rock (Kerrich and Watson, 1984). Fine-grained gold together with pyrite, molybdenite and tellurides occurs in structurally controlled quartz veins, lenses and in lesser amounts in quartz breccias. Hydrothermal alteration includes silicification, carbonation and potassic alteration revealed by the abundance of K-feldspar and sericite. Sample included in this study is from an international gold-ore standard (MA-1a) prepared and supplied by the Canada Centre for Mineral and Energy Technology. The sample is supposed to be a well-homogenized bulk sample from a typical lode, and it is composed mainly of quartz, feldspar, dolomite, muscovite and chlorite. Pyrite, chalcopyrite, sphalerite, hematite, magnetite, altaite and melonite are present in minor to trace amounts.

Page Williams is one of the three mines in the giant Hemlo deposit within the Schreiber — White River greenstone belt. Local geology is dominated by calc-alkaline intermediate to felsic volcanic, volcanoclastic and sedimentary rocks, which occur as fault-bounded sheets (Valliant and Bradbrook, 1986). The mine comprises three ore bodies hosted by amphibolite-grade volcanic and sedimentary rocks. For this study a bulk sample (about 10 kg) was taken by the authors from the main B zone. It comes from a thick lense of pyritic quartz-sericite schist at the contact zone between a quartz-crystal tuff and sedimentary rock, and between two fault zones. Fine-grained native gold and enriched Mo, Sb, As, Hg, Tl, V and Ba contents are characteristic for the ore (Harris, 1986).

The Ferderber and Renabie mines are both hosted entirely within biotite tonalites. Gold occurs in quartz lenses controlled by shear zones (Vu et al., 1987; Callan and Spooner, 1989). The bulk samples, collected by the authors, comprise 5 to 10 kg of chips from typical lodes.

REFERENCE SAMPLES OF ROCK TYPES

The abundances of many rare elements are inadequately documented for common rock types, and for example, there exist no complete geochemical data for international rock standards. Hence, it was deemed necessary to analyse a set of commonly occurring host rock types in order to obtain better assumptions for background levels of all elements analysed. Furthermore, this also acted as a rough check for any possible bias in the results.

Table 3. Location and rock types of background samples (see, Backman, 1991).

Sample code	Rock type	Sampling site	Map sheet	Grid coordinates X	Y
RS 131	basaltic komatiite	Sattasvaara, Sodankylä	3714 05	7502.51	473.21
RS 11	gabbro	Usmi, Hyvinkää	2044 02	6726.14	543.37
RS 101	diorite	Karpioniemi, Viitasaari	3311 02	6997.20	428.29
RS 91	phyllite	Häkkisenmäki, Karunki	2542 02	7326.70	501.87
M863883	tonalite	Kuittila, Ilomantsi	4244 08	6967.66	561.64

It was not possible to analyse the host rocks of all targets, since in most cases unaltered equivalent host rocks are absent, or difficult to define and sample, and moreover the number of samples required would have markedly increased. For this reason, a set of analytical reference samples prepared at the Geological Survey of Finland (Backman, 1991), representing commonly occurring host rock types from felsic to ultramafic, was included as a reference suite (Table 3). This was supplemented with a tonalite, which is a carefully selected drill-core sample (1 m) from the Late Archean Kuittila stock in Ilomantsi, eastern Finland.

ANALYSIS

Sample preparation

The samples from each target were selected carefully as described in the sampling section. Primary samples consisted of coarse crushed drill core material, chips and uncrushed drill core material. The coarsely crushed samples were then recrushed with a jaw crusher (Table 4) to give a sample with a grain size of 95% <2 mm. The uncrushed drill-cores were firstly halved and then crushed along with the chip samples (Table 4) followed by fine crushing as above. Each sample was split to give a subsample of which at least 100 g was milled (Table 4). For the Finnish targets, from which drill-core material was available, three separate composite samples (the ore and wall-rock samples on both sides of the ore) were combined from these subsamples. The composite samples were coded so that two numbers represent the target and a third number describes the section within the target. Number one refers to the upper wall rock, number two the ore and number three the lower wall rock.

Table 4. Equipment used in sample preparation.

Equipment	Usage
Humbold Wedag AG MN 931/10	Jaw crusher for coarse crushing.
Retch BB2	Jaw crusher for fine crushing
Retch PKZ/2	Rotatory Tube Sample Divider for representative sample splitting
Siebtechnic	Swing mill with carbon steel pans (steel CK 45) for sample milling
Turbula T 52C	Shaker Mixer for homogenization of composite samples

Combination of the subsamples was carried out by calculating the weight of each subsample in proportion to the length of the subsample with respect to the length of the composite sample. At least 250 g of composite sample was prepared. From eleven selected ore samples, 2000 g of composite sample was prepared for quality control and further use. These samples were used as duplicates to control the precision of analysis and homogenization. After weighing, the composite samples were mixed thoroughly (Table 4). Each sample was separated into three identical fractions and distributed for analysis. A total of four preparation blanks were included to check for preparation contamination at each stage of preparation. Blanks consisted of quartzite samples prepared using the same equipment as used in this study.

The whole research material consisted of 137 research samples, of which 13 samples are from gold deposits outside Finland, and a further five

background samples, eleven duplicates of ore samples and four preparation blanks.

The total number of subsamples was 780, which means that the bulk samples (excluding the chip samples) contained on average 6.4 subsamples.

Analytical methods

The samples were distributed to three laboratories for analysis. A summary of the analytical methods and the detection limits are shown in Fig. 5.

X-Ray Assay Laboratories Ltd (XRAL) in Toronto, Canada analyzed the samples using their research analysis package employing various analytical methods. Gold, Pd and Pt were determined after Fire Assay preconcentration with a direct current plasma-atomic emission spectrometer (DCP-AES), using 20 g of sample. Major elements and Cl, Cr, Rb, Nb, Sn, Zr and Ba were determined by X-ray fluorescence (XRF). $HF/HClO_4$ digestion was used for the determination of Li, Sc, Mn, Co, Cu, Ni, Zn, Ga, Sr, Y, Mo, P and low Mg with an inductively coupled plasma-atomic emission spectrometer (ICP-AES), and La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Tl and Bi with inductively coupled plasma mass spectrometer (ICP-MS). Silver, Cd and In (low K) were determined from the same digest with a flame atomic absorption spectrometer (FAAS) and Se with a graphite furnace atomic absorption spectrome-

Analytical methods

ICP Inductively coupled plasma atomic emission spectrometry
DCP Direct current plasma atomic emission spectrometry
PMS Inductively coupled plasma mass spectrometry
XRF X- ray fluorescence spectrometry
NAA Neutron activation analysis
FAA Flame atomic absorption spectrometry
GAA Graphite furnace atomic absorption spectrometry
W Wet chemical and other methods

H (H_2O) W																
Li ICP 1	Be DCP 1											B NAA 0.5	C (C,Co_2) W100			F W 20
Na XRF NAA10	Mg XRF ICP10											Al XRF 50	Si XRF 50	P XRF ICP10	S ICP 10	Cl W 50
K XRF FAA10	Ca XRF 70	Sc ICP 0.05	Ti XRF 60	V DCP 2	Cr XRF NAA1	Mn ICP 2	Fe XRF	Co ICP 1	Ni ICP 1	Cu ICP 0.5	Zn ICP 0.5	Ga ICP 0.1	Ge DCP 10	As NAA 0.5	Se GAA 0.02	
Rb XRF 2	Sr XRF ICP1	Y XRF ICP1	Zr XRF 1	Nb XRF 2	Mo ICP 1				Pd GAA 0.0001	Ag GAA 0.001	Cd FAA 0.2	In FAA 0.5	Sn XRF 2	Sb NAA 0.2	Te GAA 0.001	
Cs NAA 1	Ba XRF 10	La PMS 0.1	Hf NAA 0.5	Ta NAA 1	W NAA1 W0.5				Pt GAA 0.004	Au GAA 0.001	Hg W 0.005	Tl PMS 0.1	Pb ICP 2	Bi PMS 0.1		

Ce PMS 0.1	Pr PMS 0.1	Nd PMS 0.1		Sm PMS 0.1	Eu PMS 0.05	Gd PMS 0.1	Tb PMS 0.1	Dy PMS 0.1	Ho PMS 0.05	Er PMS 0.1	Tm PMS 0.1	Yb PMS 0.1	Lu PMS 0.05
Th NAA 0.5		U NAA 0.1											

Fig. 5. Chemical components analysed in this study with main analytical method used and detection limits (in ppm) for elements often having low abundances.

ter (GFAAS) after MIBK-extraction. Beryllium, V and Ge were determined with DCP-AES after KOH-fusion. Neutron activation analysis (NAA) was used for Th, U, Hf, Ta, W, Cs, Sb, As, Cr and low Na. Prompt-gamma spectrometry was used for B, while Hg was determined with cold vapor atomic absorption spectrometry. Ion specific electrodes were used for F, and H_2O^+, H_2O^- and CO_2 were determined gravimetrically.

Gold, Te, Se, Ag, Pd and Pt were determined in the Chemical Laboratory of the Geological Survey of Finland (GSF) with low detection limits (Niskavaara and Kontas, 1990). Twenty grams of sample were digested with aqua regia and the elements analysed were separated by reductive coprecipitation using Hg as a collector and stannous chloride as a reductant. The elements were determined with GFAAS. This method has been widely used at GSF and has been shown to be applicable for the determination of trace concentrations of Au, Ag, Se, Te, Pd and Pt by analyzing international geological reference samples (Kontas et al., 1986, 1990). In addition to the rare elements above, S was determined with ICP-AES after aqua-regia digestion. Because of the mode of occurrence and low concentrations of these Au-affiliated rare elements, the aqua-regia dissolution is sufficient for yielding results very close to the total abundances.

Total carbon was determined in the Chemical Laboratory of the Geological Survey of Finland (GSF) in Espoo. Graphitic carbon was calculated from the difference of total carbon and CO_2. In addition Au determinations exceeding 10 ppm concentrations, which were not reported by XRAL in the package used, were determined with FAAS after Fire Assay preconcentration from 25 g samples. Magnetic susceptibility was also measured at GSF in Rovaniemi.

Comparison of analytical methods

Since Au was determined with two considerably different methods a comparison of results was carried out. The results Au_{FA} are from fire assay/DCP or FAAS and results Au_{AR} are from aqua regia/Hg-coprecipitation/GFAAS. Sample 3 (Macassa), which is a reference gold ore MA-1a distributed by Canada Centre for Mineral and Energy Technology gave 19.6 and 23.0 ppm respectively (certified value 21.4 ppm). Both analytical methods gave equally accurate results for this particular sample. In Fig. 6 a plot of Au_{FA} vs. Au_{AR} is shown for 137 samples. The correlation coefficient is 0.93 and there is no systematic difference between the results. This contrasts with the results reported by Hall et al. (1989), which show that values obtained for Au using aqua-regia dissolution were systematically low by 24—42% compared to INAA results.

In order to increase the reliability of the Au results of this study, the mean of these two results is further used in processing for all wall-rock

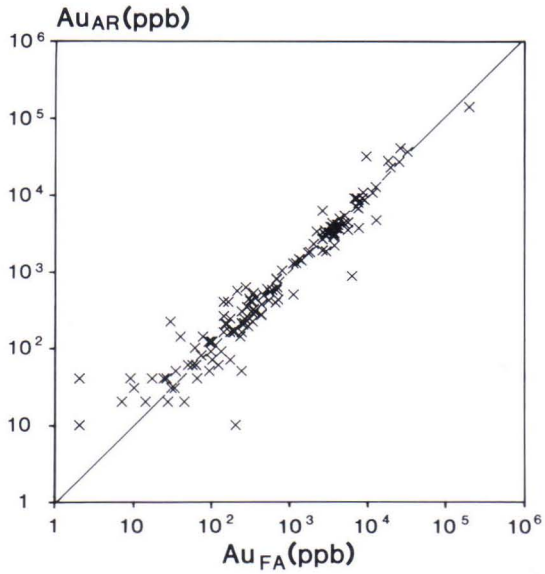


Fig. 6. Comparison of Au results analysed with graphite furnace atomic absorption spectrometry (GFAAS) after aqua-regia dissolution (Au_{AR})and direct current plasma atomic emission spectrometry (DCP) after fire-assay concentration (Au_{FA}). Both analyses are from 20 g samples.

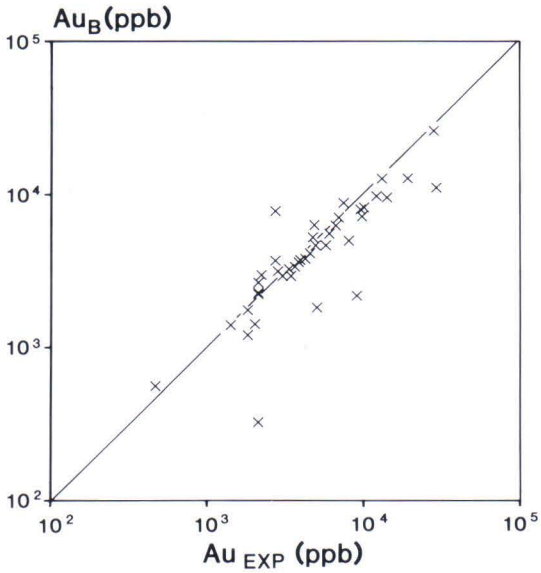


Fig. 7. Comparison between Au contents of the bulk samples analysed in this study (Au_B) and the mean of exploration analyses (Au_{EXP}) of respective subsamples.

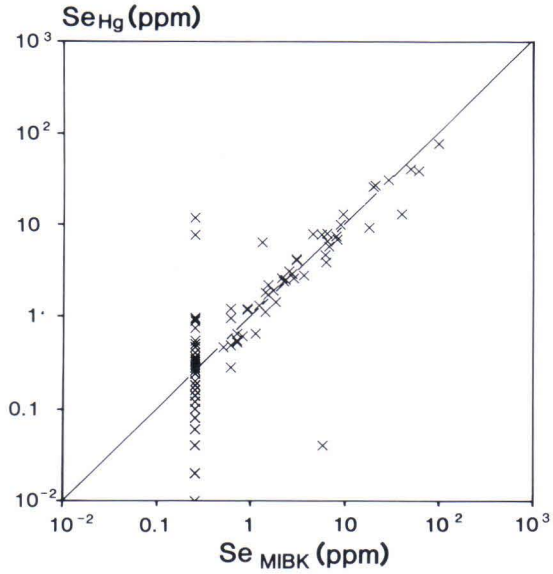


Fig. 8. Comparison of Se results analysed with graphite furnace atomic absorption spectrometry after aqua-regia dissolution and Hg co-precipitation (Se_{Hg}), and after HF-$HClO_4$ digestion and MIBK extraction (Se_{MIBK}).

samples and for the ore samples when the results deviate less than 30%. In other cases, the result which is closer to the mean content according to the exploration analyses for the particular core interval is used.

In Fig. 7 the Au values used in this study are plotted against the values of exploration analyses which were calculated as a mean of analyses of subsamples. The analyses used in the exploration stage seem to be highly reliable and show a good correlation with the results of this study, the only prominent exception being Hirvilavanmaa (sample 222). This good correlation also indicates the success of combination and homogenization procedures used in this study.

Selenium was also determined by two methods, one with a significantly lower detection limit (Se_{Hg}: Aqua regia/Hg-coprecipitation/GFAAS). In Fig. 8 a plot of Se_{MIBK} (total digestion/MIBK-extraction/GFAAS; results not reported) vs. Se_{Hg} is shown. Excluding one deviant sample (sample 223) and using only values higher than detection limits, the correlation coefficient is 0.96. Due to the considerably lower detection limit, the results of Se_{Hg} are used.

Silver, Pd and Pt were determined with two methods. The results of Hg-coprecipitation/GFAAS are used in further processing because of the lower detection limits of this method. Tungsten was also determined with two methods. The higher values reported here are NAA results and the lower (<3 ppm), colorimetric analyses performed at GSF.

For most elements the lowest reported values of the methods used were sufficiently low to cover the total variation of concentrations in the whole research material (Fig. 5), exceptions being Bi, Cd, Pb, Mo, Sb, Hg and Sn. The detection limits for Ta, Ge, Pt, In and some volatiles were also insufficiently poor but these elements are not of essential importance to this study. For elements determined with INAA the detection limits varied depending on sample matrix, which makes the data handling somewhat difficult for Sb and U.

Precision of gold analyses

Eleven of the ore samples were included as duplicate samples in order to test the precision of analytical methods and the homogeneity of samples. For Au four consecutive analytical results of these samples are available. The mean values of duplicate analyses of both analytical methods are comparable with only three exceptions: sample 142 (means $Au_{FA} = 3050$; $Au_{AR} = 5400$), sample 212 (means $Au_{FA} = 6500$; $Au_{AR} = 1600$) and sample 432 (means $Au_{FA} = 9600$; $Au_{AR} = 23{,}000$).

Due to insufficient number of replicate analyses, the evaluation of precision is difficult, so that the relative difference of duplicate analyses is used as an estimate of precision. In Fig. 9 a plot of mean values vs. the relative difference of the duplicate analyses is presented for both analytical methods. Excluding three prominent outlying samples, good precision (estimate $< 40\%$) is typically achieved in concentrations higher than 1000 ppb. The precision of Au_{FA} seems to be slightly better than Au_{AR} which has been developed in particular for mineralized samples with trace concentrations of elements. In addition, heterogeneity of samples may contribute to the outlying values.

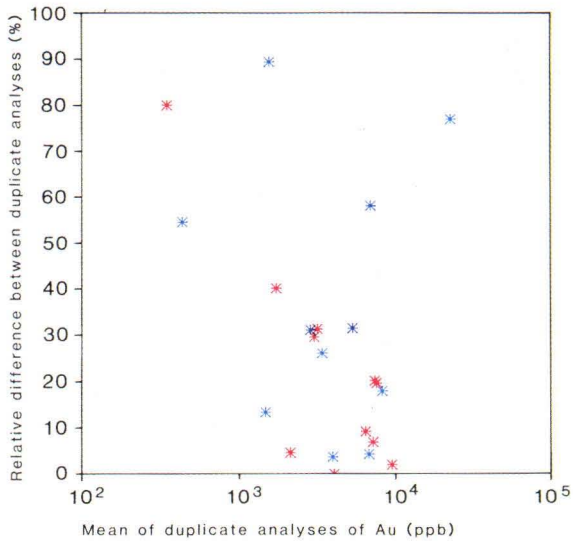


Fig. 9. Means of duplicate Au analyses of the bulk samples vs. relative difference. Red symbols refer to aqua-regia dissolution (Au_{AR}) and blue to fire assay concentration (Au_{FA}).

Contamination during sample preparation

Contamination tests were carried out to establish contamination sources in preparation stages.

Sample 1 is a quartzite sample milled in an agate pan. This will give the actual uncontaminated concentrations of the test sample. Sample 2 was crushed using a jaw crusher and milled in an agate pan (Table 4). Sample 3 was crushed with both jaw crushers and milled in agate pan. Sample 4 was crushed with both crushers and milled in a steel pan.

A slight contamination from equipment during preparation was observed for elements Fe (max 0.23%), Mn (max 0.017%), Cu (max 8.7 ppm) and Mo (max. 3 ppm). This contamination can be considered negligible as the regular samples are softer than quartzite so that the actual contamination will be less.

A minimal contamination of Au, Ag and Te was also observed. This contamination was found to be an unfortunate carry over from previously prepared ore samples, but is insignificant compared to the contents of the mineralized samples.

RESULTS

In the following discussion, emphasis is laid on those elements that seem to be involved in mineralization processes, as revealed by highly variable contents in the samples. Numerous elements exhibit either only a small overall variation in the total data set or else variation closely related to host lithologies and therefore affected only by the mass and volume changes related to wall-rock alteration (e.g., Be, Hf, REE, Sc and Zr). Cadmium, Ge, In and Ta were mostly below the analytical detection limits and do not show individual peak values. Hence, those elements are not discussed further in this context.

Because the Au content of the drill intersections was used in delineating the ore samples in such a way that the mean Au content should correspond to grade of ore that is economic at current Au prices (1 ppm cut-off value, average Au mostly >2 ppm), the contents of the other elements likewise represent mean abundances in typical gold ore and, as Au itself, may be at times orders of magnitude lower than individual peak values in smaller samples.

Sampling of the wall rocks was usually done recording visible alteration and although these samples are also anomalous for Au, the Au content was not the primary delineation criteria. Hence, the wall-rock samples record element abundances adjacent to a gold ore lode more independently than those of the ore itself.

Location of the deposits studied and analysed drill cores are shown in Figs. 1—3 and Tables 1—2, and descriptions of analysed samples are given in App. 1. Complete analytical results and magnetic susceptibilities of the samples are given in App. 2 for the deposits in the Fennoscandian Shield, in App. 3 for the deposits in Canada and Australia, and in App. 4 for the reference set of rock types. The elements are listed in the Appendices in alphabetical order, according to their chemical symbols, except for respectively Au analyses, major elements, volatile elements and rare earth elements — which are grouped together. In the Tables, Appendices and Figures, deposits within each province are arranged in a general order according to dominant host rock lithology from mafic — ultramafic to felsic.

Gold and affiliated rare elements

On the basis of mineralogical and geochemical studies, gold deposits have for a long time known to contain elevated abundances of a number of rare elements. Boyle (1979) gives a general list for associated elements in all types of hypogene and supergene deposits, including S, Se, Te, As, Sb, Bi, Cu, Ag, Zn, Cd, Hg, Sn, Pb, Mo, W, Fe, Pt, Pd, Co and Ni. Archean greenstone belt-hosted, mesothermal gold deposits have been reported to be generally enriched in the order of $>10^3$ times compared to background values for Au, Ag, B and W; and more locally for As, Sb, Se, Te, Bi and Pd, but not for the base metals, which show contents between 10 and 0.1 times background (Kerrich, 1983; Kerrich and Fyfe, 1988). Epithermal gold deposits are invariably enriched in Ag, Hg, As, Sb, Tl, Se, Te, Bi, W, Pb, Zn, Cu, Co, S, Ba and F (e.g., Berger, 1985; Berger and Bethke, 1985; Clarke and Govett, 1990). The Au-affiliated elements are here defined as rare elements enriched in a number of targets by several orders of magnitude compared to background values.

Although an increasing number of geochemical studies on gold deposits have recently been published, the variations in content and mean abundance of many important rare elements (e.g., Bi, Te, Se, B, Hg and Sb) are still poorly known. This is mainly due to analytical difficulties related to the extremely low natural abun-

dances of these elements. Knowledge concerning their occurrence in gold ores is mainly of a qualitative nature, since the presence of tellurides, selenides as well as Bi minerals has commonly been reported.

Knowledge concerning the background levels for many rare elements in common rock types is likewise insufficiently known. Hence, except for the mean contents available from the literature, which are usually based on rather old data and seem to be somewhat high for many elements, we have established ranges shown by geochemical reference samples of common rock types. These samples represent homogeneous rocks containing only small amounts of volatiles, cavities and inclusions of foreign components.

Gold

Gold abundances in primary igneous rocks are highly variable, but average contents do not show marked differences between various rock types. Ultramafic rocks tend to have somewhat lower Au (0.75 ppb) than basalts, which contain on average 2 ppb Au (Tilling et al., 1973; Anhausser et al., 1975; Kwong and Crocket, 1978; Saager and Meyer, 1984; Kerrich and Fyfe, 1988) and the mean Au content of granitoids in southern Africa is about 1 ppb (Saager and Meyer, 1984). Kwong and Crocket (1978) demonstrated that all unaltered Archean igneous and sedimentary rocks contain <2 ppb Au. Kontas et al. (1986, 1990) report values for individual geostandard samples from 0.2 to 0.8 ppb for ultramafic rocks (5 samples), mostly 0.5 to 0.9 ppb for mafic rocks (14 samples), generally 0.2 ppb for granitoids (6 samples) and 0.2—0.4 ppb for schists (5 samples). GFAAS analyses of our reference samples show values from <1 ppb to 2 ppb (App. 4), which are in good agreement with previous studies.

Gold is present in all types of gold deposits in principally metallic form, which is alloyed with Ag (generally 5—15%) and with smaller amounts of Cu, platinum group elements and Bi (see, Boyle, 1979). In hydrothermal deposits, native gold occurs mostly as small to submicroscopic inclusions in sulfides and silicates. Tellurides, such as calaverite ($AuTe_2$), krennerite ([Au,Ag]Te), sylvanite ([Au,Ag]Te_4), petzite (Ag_3AuTe_2), nagyagite ($Pb_5Au[Te,Sb]_4S_{5-8}$); antimonides, such as aurostibite ($AuSb_2$); and selenides, as, for example, fischesserite (Ag_3AuSe_2), may be locally important carriers of Au. Gold is also present in trace amounts in native metals such as Ag, As, Cu and Sb, and in many sulfides, tellurides and arsenides. Concentrations of invisible gold (<0.1 μm) range from <0.5 to >1000 ppm, and high invisible gold contents are typically found in arsenopyrite and As-bearing pyrite (Cook and Chryssoulis, 1990).

The minimum acceptable Au grade of economic gold deposits is highly variable, depending on factors such as deposit type, tonnage, byproducts, location and political circumstances, but is generally in the range of 1 to 10 ppm at current Au prices; this means that Au is enriched 10^3—10^4 times above background values. The somewhat fortuitous, random occurrence of Au as isolated native grains and the low overall grade needed for economic gold ore makes the evaluation of average Au contents difficult. However, the mean Au contents for the homogenized bulk samples in this study mostly show a good correlation with the mean contents of the original exploration analyses (Fig. 7), indicating the success of the homogenization procedures.

Gold contents of the ore samples in this study exceed 1 ppm, except for Rovaselkä (0.33 ppm) and Hirvilavanmaa (0.56 ppm) in the Lapland greenstone belt, and New Celebration (0.58 ppm) in Australia (Fig. 10, Apps. 2 and 3). The subsamples from Hirvilavanmaa were reanalysed, and the mean of these new results is very close to that obtained for the bulk sample of this study, indicating some kind of confusion in the original exploration analyses. The 5 kg chip-channel sample from New Celebration was taken across a typical lode; although this does not correspond to the mean Au grade of the deposit, the sample

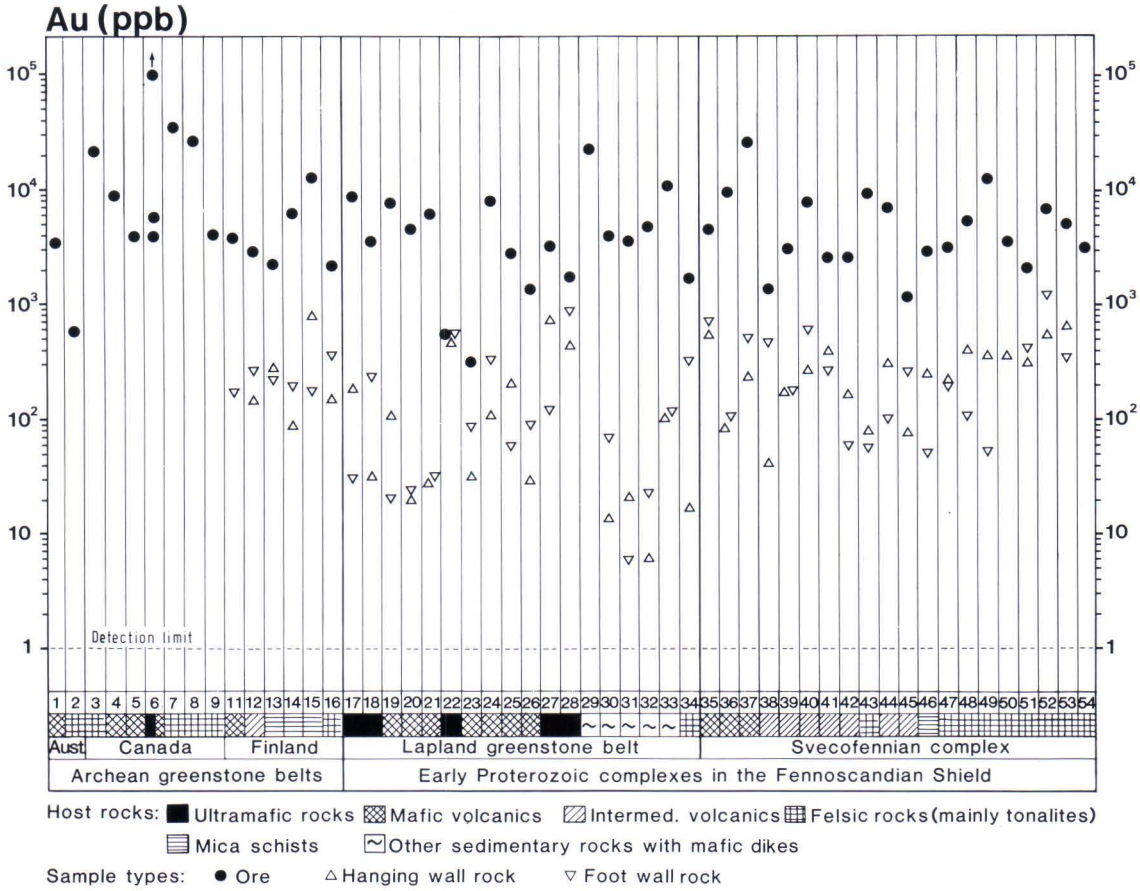


Fig. 10. Variations in Au content in mesothermal gold deposits and their altered wall rocks (detailed information on the deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 5. Statistical data for Au (ppb) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	25700	5010	5440	6080
Standard deviation	49400	4050	5320	5650
Median	5650	3340	3900	4140
Maximum	171000	12700	23100	26200
Minimum	580	2200	325	1190
Number of samples	11	6	18	20

may still nevertheless be representative for the other elements.

Gold distribution in the analysed samples is shown in Fig. 10 and average contents of the ore samples from different provinces in Table 5. Average Au contents of ore samples from different provinces are very similar, the median values varying from 3.3 to 5.6 ppm, although Ar-

chean samples from other shield areas do include some anomalously high contents. This evidently makes the comparison of abundances of various Au-affiliated elements between the provinces easier than would data containing highly disparate Au contents.

Silver

Silver abundances in unaltered igneous and sedimentary rocks vary generally from a few tens to over 100 ppb. Ultramafic rocks have been reported to contain 40—50 ppb, basalts 100—110 ppb, felsic rocks 50 ppb and Archean graywackes 80 ppb Ag (see, Kerrich, 1983; Govett, 1983; and references therein). Recommended working values for individual geostandards vary from about 30 to 110 ppb for both mafic and felsic rocks (19 samples) (Govindajaru, 1989). Compared to the above average values, results from the reference set of this study exhibit somewhat lower abundances ranging from 1 ppb in komatiitic basalt to 55 ppb in phyllite, but occur well within the range of the geostandards (App. 4).

Silver is an ubiquitous rare element in all types of gold deposits. Kerrich (1983) report Ag contents from 0.1 to 54 ppm (mostly 1 to 10 ppm) for 18 Archean mesothermal gold deposits in the Abitibi greenstone belt. Epithermal deposits contain generally higher Ag and the ore types vary from Au to Ag predominated types (e.g., Hayba et al., 1985). Carlin-type deposits are typically low in Ag, showing contents mostly between 0.7 to 3 ppm, but may occasionally contain up to 100 ppm (Bagby and Berger, 1985; Radtke, 1985). Hot-spring gold deposits exhibit Ag abundances from <0.5 to 2000 ppm (mostly <10 ppm) (Berger, 1985). Correlation between Au and Ag is highly variable. Epithermal deposits show a very wide range in Au/Ag ratios from 20:1 to 1:100 but are generally higher in Ag, whereas Archean mesothermal deposits have Au/Ag ratios generally from 3:1 to 20:1 (Hutchinson, 1987). Deposits in the Abitibi greenstone belt exhibit Au/Ag ratios between 15:1 and 1:1 (Kerrich, 1983).

Silver forms a number of its own minerals and may be present in minor to trace amounts in, for example, sulfides, sulfosalts, tellurides and selenides (Boyle, 1979). Silver is a constant component in native gold, and there is probably a complete substitutional series from native gold to native silver. Typical Ag-bearing minerals in Precambrian gold deposits belong to the tetrahedrite series ($Cu_{12}Sb_4S_{13}$), whereas argentite (Ag_2S) is common in some Phanerozoic deposits (Boyle, 1979).

Our data shows that Ag is markedly enriched in mesothermal gold deposits, and although there is a wide variation of contents, different provinces show characteristic ranges of abundances (Fig. 11, Table 6, Apps. 2 and 3). Archean deposits in Canada and Australia typically contain from 1 to 4 ppm Ag. The highest values were obtained for the green carbonate ore from Kerr Addison (19.4 ppm), and from the tonalite hosted Ferderber (11.9 ppm) and Renabie (7.7 ppm) mines. Anomalously low contents are shown by New Celebration (0.15 ppm) and Page Williams (0.43 ppm). Archean deposits in Finland seem to be rather low in Ag (0.15 to 0.52 ppm), except for the Kuittila (4.7 ppm) and Rämepuro (4.1 ppm) deposits, both hosted by felsic intrusive rocks. In the former, Ag has been observed to occur in three phases: in gold, electrum and metallic silver (Johanson and Kojonen, 1989). Although the data do not allow definite generalizations, high Ag contents seem to be typical for tonalite-hosted deposits in the Archean.

The deposits of the Lapland greenstone belt are, in general, low in Ag (0.02 to 2 ppm). This is especially the case for the deposits associated with highly altered sedimentary rocks (Kuusamo and Bidjovagge) which show consistently low (<0.4 ppm) concentrations of Ag. The Saattopora mine also has anomalously low Ag (0.021 ppm). The highest contents are shown by Kivimaa (2.0 ppm), Suurikuusikko and Soretiavuoma (both 1.4 ppm).

Deposits in the Svecofennian complex are invariably high in Ag (mostly 0.5 to 4 ppm) and

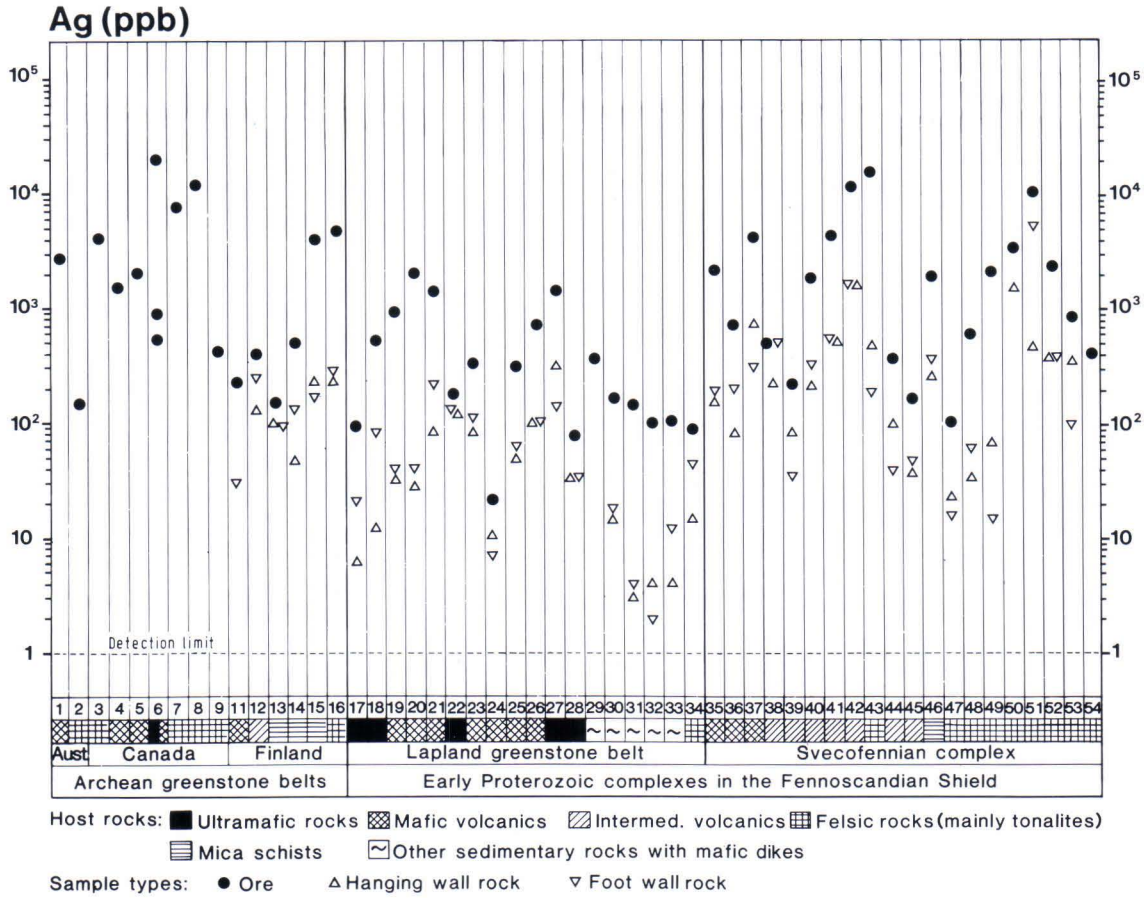


Fig. 11. Variations in Ag content in mesothermal gold deposits and their altered wall rocks (detailed information on the deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 6. Statistical data for Ag (ppb) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	4660	1680	493	3150
Standard deviation	6080	2120	574	4250
Median	2000	462	238	1850
Maximum	19400	4700	2000	15200
Minimum	145	152	21	101
Number of samples	11	6	18	20

there is no preferential tendency of enrichment according to host-rock type, since high and low abundances occur both in volcanic- and intrusive-hosted deposits. The peak contents were encountered at Pirilä S (15.2 ppm), Kiimala (11.2 ppm) and Kangaskylä (10.7 ppm).

Wall-rock samples from the deposits within the Archean and Svecofennian terrains generally

show some enrichment compared to typical background values. In contrast, wall-rock samples from the Lapland greenstone belt usually have Ag contents near to background levels.

Silver exhibits a distinct correlation with Au, indicating a close association between Ag and Au deposition (Fig. 12). Ratios of Au/Ag are scattered, but the median ratios of ore samples are 3 (mostly between 1.3 and 6.2) for the Archean deposits, 2.9 for the mafic — ultramafic-hosted and 11.8 for the sedimentary-hosted deposits in the Lapland greenstone belt, and 2.1 (range 0.63—5.6) for the deposits in the Svecofennian complex.

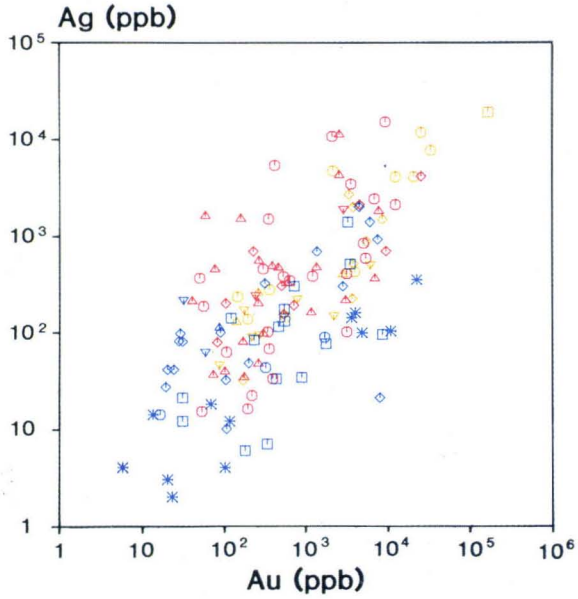


Fig. 12. Ag — Au relationships for ore and wall-rock samples from the mesothermal gold deposits. Symbols as in Fig. 2.

Arsenic

The average content of As is rather uniform in primary igneous rocks, being 0.5—1.0 ppm in ultramafic rocks, 2 ppm in basalts and 1.5—2 ppm in granitoids (see, Govett, 1983; Kerrich, 1983; and references therein). Shales have higher average contents (c. 6 ppm) and a higher variation from 3 to 18 ppm. These values are quite comparable to the results from our reference suite, which exhibits contents from <0.6 to 2.2 ppm for igneous rocks and 4.0 ppm for the phyllite (App. 4).

Arsenic shows remarkable enrichment in all types of hydrothermal gold deposits, but As contents and their correlation with Au are, in detail, highly variable. Archean gold deposits in the Abitibi greenstone belt have As contents ranging from typical background values up to 9600 ppm, the most common values being between 20 and 1000 ppm (Kerrich, 1983). Carlin-type deposits have a general range between 100 to 1000 ppm and an average value of 500 ppm (Bagby and Berger, 1985; Radtke, 1985), whereas hot-spring deposits are lower in As (4 to 100 ppm) (Berger, 1985).

Arsenic usually occurs in arsenopyrite (FeAsS) (for example, in deposits of the Svecofennian complex), tennantite ($[Cu,Fe]_{12}As_4S_{13}$) and various other sulfosalts (Boyle, 1979). Realgar-orpiment ($AsS—As_2S_3$) is common in epithermal and Carlin-type deposits (Hutchinson, 1987) and cobaltite (CoAsS) is an important As carrier in some deposits (e.g., the Kuusamo area, Pankka and Vanhanen, 1989). Pyrite, being generally abundant in gold deposits, may contain some thousands of ppm As and thus alone explain slight enrichments in As.

This study confirms that As is a typical element associated with mesothermal gold mineralization, and in spite of considerable scatter, average ranges seem to be characteristic for each province (Fig. 13, Table 7, Apps. 2 and 3). Archean deposits typically contain As from a few tens to hundreds of ppm, but there are also deposits showing contents close to background (New Celebration, Renabie and Kuittila). It is perhaps worthy of note that all these deposits are hosted by felsic intrusives. Lokkiluoto is the only Archean deposit to show extreme As enrichment (8500 ppm).

Sediment-hosted deposits at Kuusamo and Bidjovagge in the Lapland greenstone belt consis-

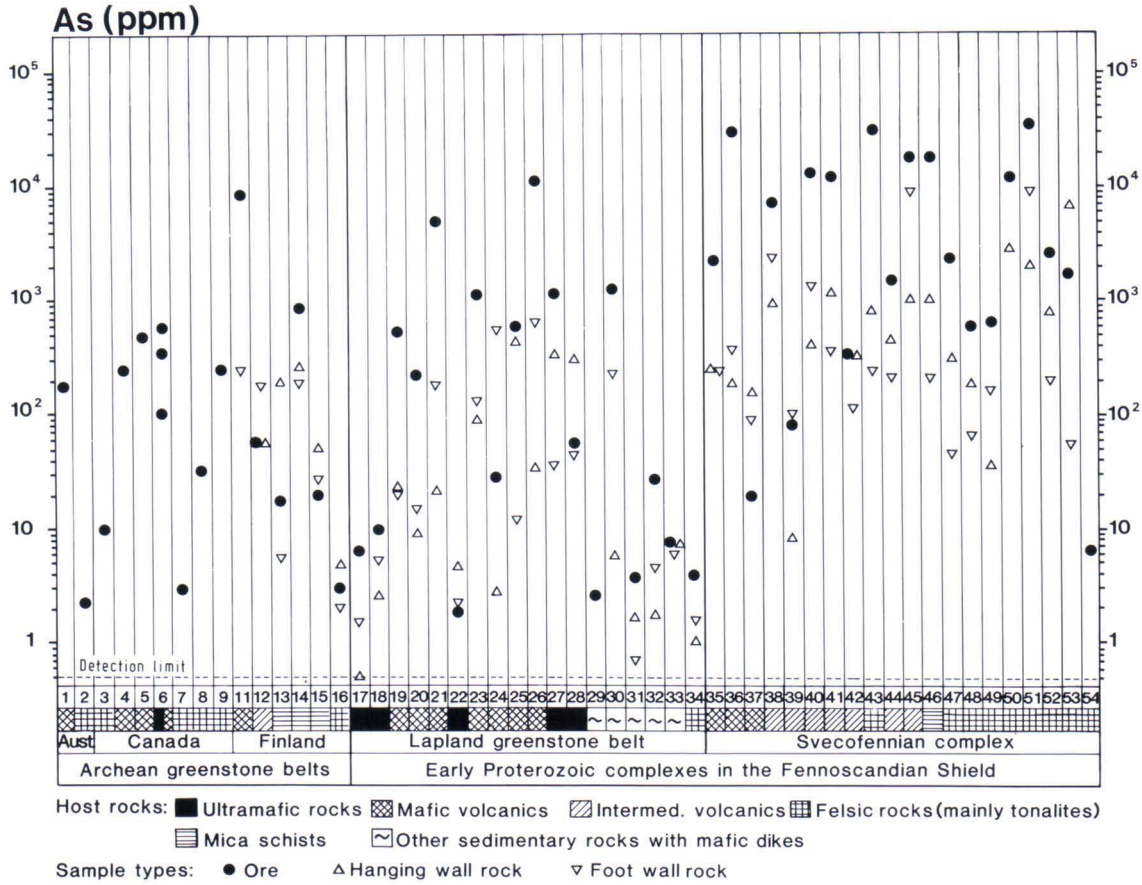


Fig. 13. Variations in As content in mesothermal gold deposits and their altered wall rocks (detailed information on the deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 7. Statistical data for As (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	194	1580	1150	9410
Standard deviation	191	3410	2720	11500
Median	170	39.0	41.0	2450
Maximum	550	8500	11000	35000
Minimum	2.2	3.0	1.8	6.3
Number of samples	11	6	18	20

tently show low As (2.5 to 27 ppm), excluding Juomasuo (1200 ppm). Arsenic contents of the mafic-ultramafic-hosted deposits are scattered from <10 to >1000 ppm, Iso-Kuotko showing the peak content (11,000 ppm).

The deposits in the Svecofennian complex are almost invariably very high in As, reflecting the abundance of arsenopyrite. Arsenic contents generally exceed 1% and irrespective of host rock, As is always enriched compared to back-

ground abundances. Anomalously low contents were encountered from Björkdal (6.3 ppm), Jokisivu (19 ppm) and Antinoja (80 ppm).

Generally, correlation between Au and As is poor, and As contents are often higher in the wall-rocks than in the ore (Fig. 14). This suggests that, although Au occurs in some deposits as small aggregates and also in the crystal lattice of arsenopyrite (Cathelinau et al., 1989), deposition of these elements occurred separately in most cases.

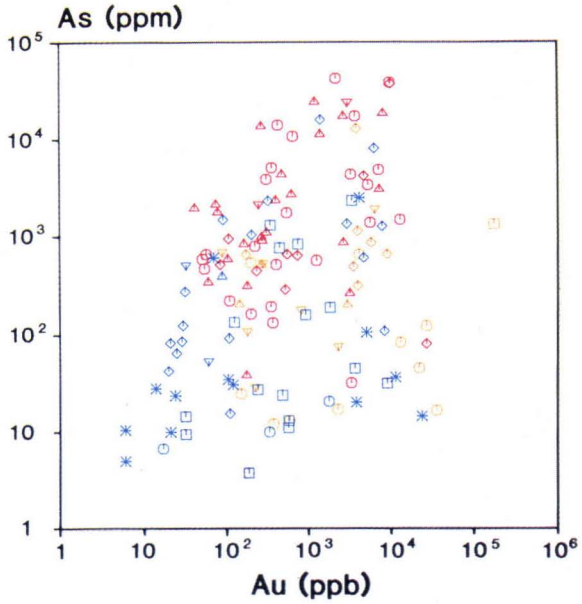


Fig. 14. As — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Tellurium

Average abundances of Te in common rock types are incompletely known. Recent analyses of a series of international rock standards (22 samples) by Kontas et al. (1990) and recommended working values of some other geostandards (8 samples) (Govindajaru, 1989) indicate that Te contents in ultramafic to felsic igneous rocks are mostly between 1 and 7 ppb, but shales show higher values, between 12 and 65 ppb. The reference suite of this study gave contents from 2 to 8 ppb for the igneous rocks and 48 ppb for the phyllite (App. 4).

Tellurium has been found to be almost universal in all types of gold deposits, including epithermal and mesothermal varieties (Boyle, 1979; Afifi et al., 1988; Clarke and Govett, 1990). The close association of Te and Au is mainly based on the qualitative observation of tellurides in gold deposits, with analytical data being very scarce. According to Boyle (1979), Te contents vary generally between <0.2 and 2200 ppm. Carlin-type deposits tend to exhibit low Te, from <20 to 40 ppb (Radtke, 1985).

Tellurium may be present in a number of Au, Pb, Ni, Co, Fe, Ag, Hg and Bi tellurides and telluride sulfides, in metallic form and in other sulfides and sulfosalts (Boyle, 1979). Typical Te minerals, in addition to the Au-bearing varieties listed above, include tetradymite (Bi_2Te_2S), tellurobismuthite (Bi_2Te_3), joseite ($Bi_3Te[Se,S]$), hedleyite (Bi_7Te_3), altaiete (PbTe), hessite (Ag_2Te), frohbergite ($FeTe_2$), melonite ($NiTe_2$), rickardite ($Cu_{2-x}Te$) and coloradoite (HgTe). In the Fennoscandian Shield, tellurides have been reported from the Bidjovagge mine, and Ilomantsi and Kuusamo areas (Söderholm and Nixon, 1988; Johanson and Kojonen, 1989; Pankka and Vanhanen, 1989). According to Afifi et al. (1988), deposition of Te always follows the initial deposition of sulfides and is often closely related to that of Au, though having, however, a tendency to precipitate simultaneously or slightly earlier.

The present study indicates that Te is one of the most uniformly associated elements in mesothermal gold deposits, being enriched in almost all targets from 10 to 10^4 times typical background values, regardless of host-rock lithology (Fig. 15, Table 8, Apps. 2 and 3). There are, however, considerable differences between provinces and also between adjacent deposits. In the Archean deposits, Te is invariably enriched (from 120 to 49,000 ppb), the Macassa and Renabie mines showing the peak values. Tellurium occurs

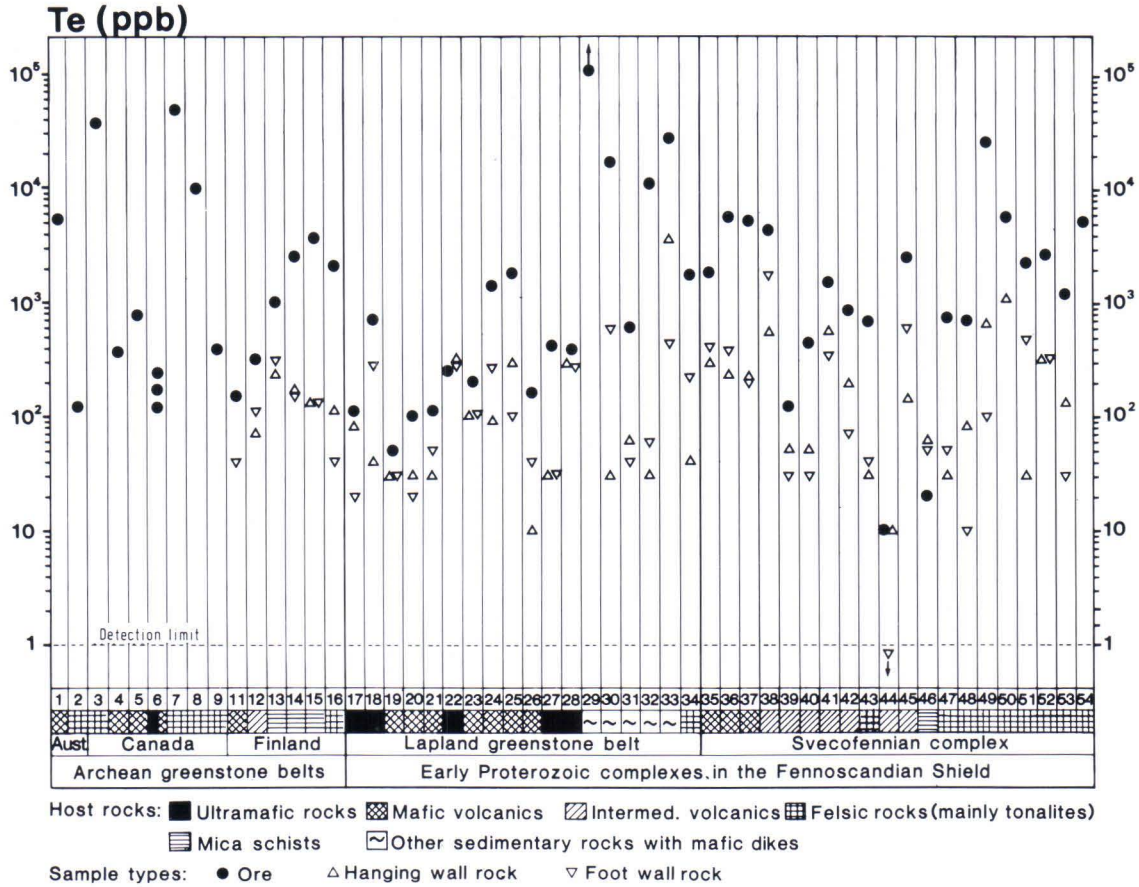


Fig. 15. Variations in Te content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 8. Statistical data for Te (ppb) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	9410	1640	15200	3390
Standard deviation	17100	1390	49200	5680
Median	390	1600	520	1700
Maximum	49000	3700	210000	26000
Minimum	120	150	50	10
Number of samples	11	6	18	20

in the former as altaite and melonite (Can. Inst. Miner. Energy Technol., description of sample MA-1a). Although the deposits at Ilomantsi are only moderately enriched in Te (320 to 3700 ppb), tellurides (altaite, tellurobismuthite, hessite, frohbergite and petzite) are commonly observed (Johanson and Kojonen, 1989), demonstrating the strong tendency of Te to form its own minerals even when present in trace amounts.

The deposits of the Lapland greenstone belt

fall into two main groups according to Te abundances. Mineralizations hosted by sedimentary rocks at Kuusamo and Bidjovagge are, with the exception of Säynäjävaara (610 ppb), very high in Te (11,000 to 210,000 ppb). In these deposits, tellurides show an intimate association with Au (Söderholm and Nixon, 1988; Pankka and Vanhanen, 1989). This contrasts with the mafic — ultramafic-hosted deposits in central Lapland which typically show only a moderate (50 to 700 ppb) enrichment of Te. The Saattopora deposits, hosted by carbonate-albite rocks, which may at least in part have originally been sedimentary rocks, lie between the major groups (1400 and 1800 ppb Te).

The majority of the deposits in the Svecofennian domain contain >1000 ppb Te, the peak value being obtained from the quartz-vein occurrence of Pöhlölä (26,000 ppb). Anomalously low Te abundances are exhibited by the minor Pirilä N (20 ppb) occurrence and Kalliosalo (10 ppb), which is actually an antimony deposit containing only sporadically ore grade Au values.

Tellurium generally shows a fairly good correlation with Au (Fig. 16), and in individual Te-enriched deposits (Fig. 15). This is in accordance with the commonly observed close association between gold and tellurides in many types of gold deposits (e.g., Afifi et al., 1988), and suggests that Au and Te were deposited roughly simultaneously in mesothermal gold mineralization. Median Au/Te ratios are 2.5 (general range 1—9) for the ore samples from the Archean deposits, 1.6 for the mafic-ultramafic-hosted and 0.27 for the sedimentary-hosted deposits in the Lapland greenstone belt, and 2.5 (0.7—5.7) for the deposits in the Svecofennian terrain.

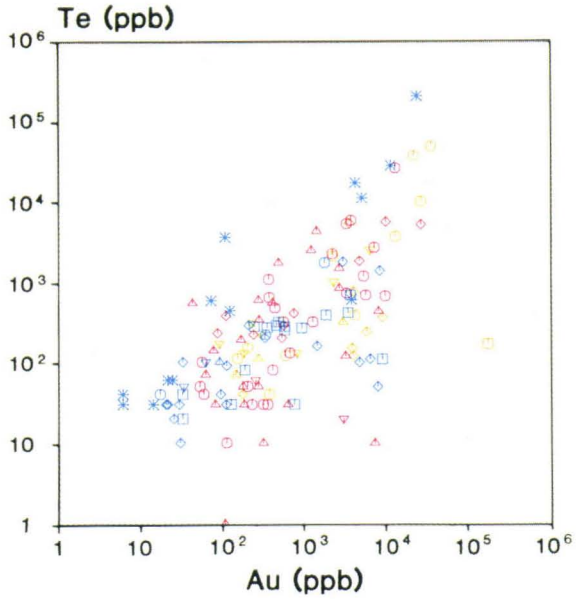


Fig. 16. Te — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Bismuth

Various sources give slightly different average contents for Bi in common rock types. Mean values reported by Govett (1983) are, for ultramafic rocks 1 ppb, for basalts 7 ppb and for granitoids 100 ppb, but shales exhibit a wider range of 0.15—2 ppm. On the basis of the recommended working values of individual geostandards, mafic rocks have contents mostly from 15 to 50 ppb (8 samples), felsic rocks from 40 to 500 ppb (8 samples) and shales from 230 to 940 ppb (4 samples) (Govindajaru, 1989). According to geostandard analyses by Terashima (1984), ultramafic rocks (6 samples, 4—12 ppb) and mafic rocks (9 samples, 9—45 ppb) are low in Bi, while felsic rocks (9 samples, 32—652 ppb) and shales (3 samples, 241—930 ppb) exhibit systematically higher abundances. Our reference suite gave, except for the gabbro (0.5 ppm) and the phyllite (1.2 ppm), contents below the 0.1 ppm detection limit (App. 4).

Bismuth is a characteristic element in association with many types of hydrothermal gold deposits, but analytical data are notably scarce. Boyle (1979) suggests that Bi is generally <5 ppm, but at least some epithermal deposits contain abundant Bi minerals (Hutchinson, 1987) and accordingly higher contents.

Bismuth is typically present in metallic form, as

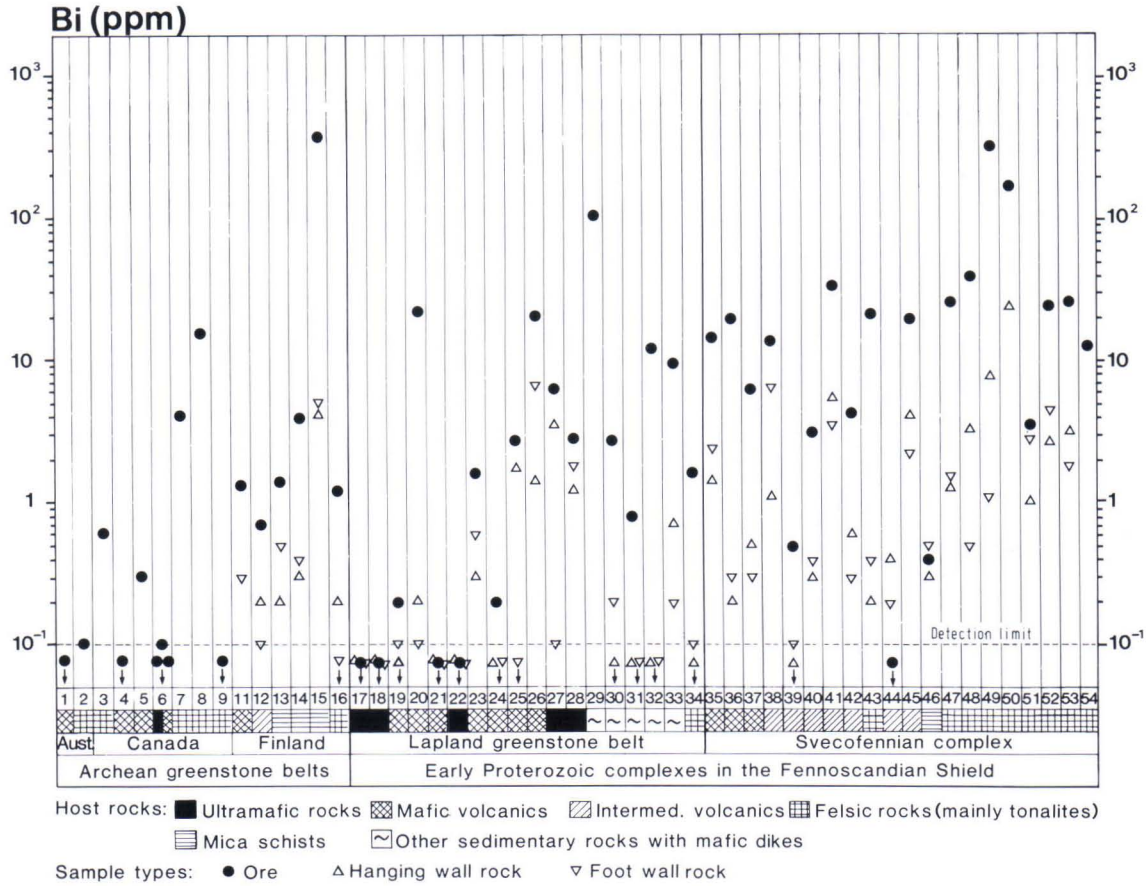


Fig. 17. Variations in Bi content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 9. Statistical data for Bi (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	1.8	61.6	10.3	37.2
Standard deviation	4.5	147	24.3	74.4
Median	0.1	1.4	2.2	16.6
Maximum	15.0	361	104	314
Minimum	<0.1	0.7	<0.1	<0.1
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

bismuthinite (Bi_2S_3), galenobismutite ($PbBi_2S_4$), Bi-bearing tetrahedrite-tennantine series ($Cu_{12}Sb_4S_{13}$-$[Cu,Fe]_{12}As_4S_{13}$), wittichenite (Cu_3BiS_3), as well as forming a number of Bi tellurides and selenides (Boyle, 1979). Traces of Bi may also be found in other sulfides and sulfosalts. The com-

mon association with tellurides and selenides suggests a close genetic correlation with Au.

According to the present study, Bi is commonly enriched in mesothermal gold deposits, although concentration varies markedly between the provinces (Fig. 17, Table 9, Apps. 2 and 3). Of the Archean deposits in Canada and Australia, Bi is considerably enriched only in the tonalite-hosted deposits of Ferderber (15 ppm) and Renabie (4.0 ppm), but is also distinctly anomalous (0.6 ppm) in the Macassa mine, within the alkalic intrusives. The Archean deposits in Finland seem to be more uniformly enriched in Bi, exhibiting contents from 0.7 to 3.9 ppm, except for the peak value of 361 ppm in the Rämepuro deposit, which contains abundant metallic bismuth (L. Pekkarinen, pers. commun., 1989).

Deposits of the Lapland greenstone belt frequently show Bi contents >1 ppm. Peak contents were encountered from Bidjovagge (104 ppm), Kivimaa (22 ppm) and Iso-Kuotko (20 ppm), representing both sedimentary- and volcanic-hosted mineralization types. However, mafic-ultramafic-hosted deposits in central Lapland often exhibit Bi contents below the detection limit (0.1 ppm). In the Iso-Kuotko deposit, Bi is mainly present in metallic form and as maldonite (Au_2Bi) (I. Härkönen, pers. commun., 1990).

Bismuth contents of the deposits in the Svecofennian terrain are roughly an order of magnitude higher than those in the other provinces, and there is no distinct difference between volcanic- and tonalite-hosted mineralizations, although the latter do contain the maximum abundances (Pöhlölä 314 ppm and Kopsa 168 ppm). Only the Kalliosalo deposit has Bi content below the detection limit.

Bismuth shows a fairly good correlation with Au, especially in the Svecofennian province (Fig. 18). This refers to roughly coeval deposition of the elements. Median Au/Bi ratios of the ore samples are 2.3 (general range 0.6—30) for the Archean deposits, 0.4 for the mafic-ultramafic-hosted and 0.6 for the sedimentary-hosted deposits in the Lapland greenstone belt, and 0.26 (0.1—0.6) for the deposits in the Svecofennian province.

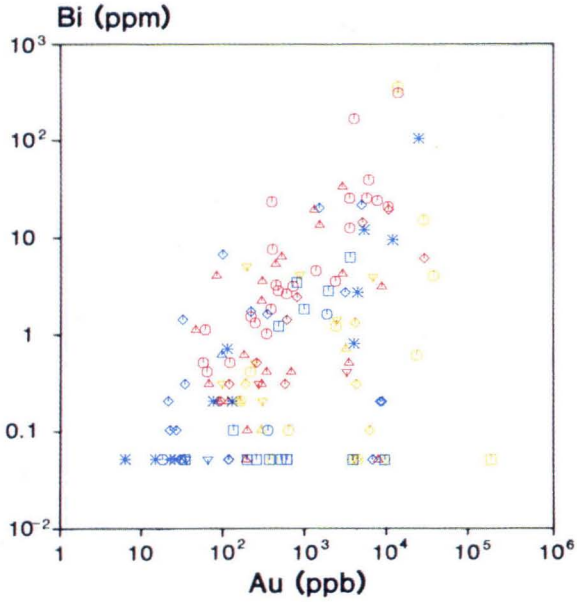


Fig. 18. Bi — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Antimony

Reported mean contents of Sb are 100 to 200 ppb for ultramafic to felsic igneous rocks, but shales exhibit generally higher values, from 0.1 to 3 ppm (see, Govett, 1983; Kerrich, 1983; and references therein). Recommended working values of individual geostandards vary mostly from 150 to 350 ppb for mafic rocks (11 samples) and from 60 to 400 ppb for felsic igneous rocks (10 samples) (Govindajaru, 1989). Our reference suite has Sb contents from <0.2 to 0.4 ppm for igneous rocks and 1.2 ppm for the phyllite, corresponding to typical background abundances (App. 4).

Antimony is a commonly associated element in all types of hydrothermal gold deposits and often shows coherence with Au (Boyle, 1979). It is particularly enriched in epithermal deposits (Hutchinson, 1987), the Carlin type showing a

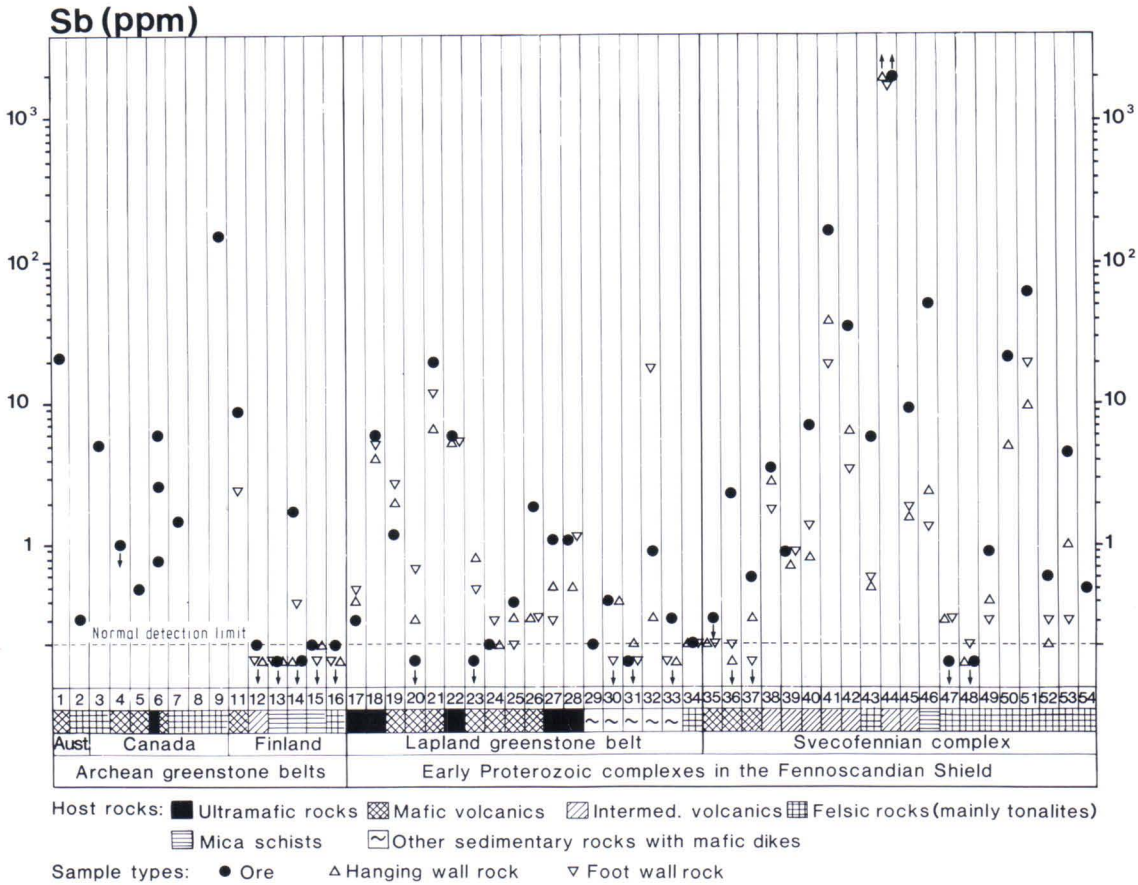


Fig. 19. Variations in Sb content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1). Detection limit varies from 0.2 up to 1 ppm, depending on sample matrix.

Table 10. Statistical data for Sb (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland green-stone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	17	1.6	2.2	450
Standard deviation	44	3.6	4.8	1900
Median	1.5	0.2	0.4	4.0
Maximum	150	8.9	20	8700
Minimum	<0.2	<0.2	<0.2	<0.2
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

general range from 50 to 150 ppm (Radtke, 1985), and hot-spring types from 3 to 150 ppm (Berger, 1985). Archean mesothermal gold deposits in the Abitibi belt are also usually enriched in Sb, but typically show somewhat lower contents, between 1 and 20 ppm, only locally

having up to 100 ppm (Kerrich, 1983).

Antimony is commonly present in gold deposits as stibnite (Sb_2S_3), tetrahedrite-tennantine series, aurostibite ($AuSb_2$) and other sulfosalts (Boyle, 1979). Pyrite, marcasite and arsenopyrite may contain a few hundred ppm Sb.

The present study indicates that Sb is rather commonly associated with mesothermal gold deposits in all provinces (Fig. 19, Table 10, Apps. 2 and 3). In contrast to Bi, Sb is commonly enriched in the Canadian and Australian Archean deposits, but is low in the Finnish occurrences, except for Lokkiluoto (8.9 ppm). The range of contents in the Canadian and Australian deposits (< 0.2 to 21 ppm) is about the same as that reported by Kerrich (1983) for deposits in the Abitibi belt. The Page Williams mine, from which a number of Sb minerals have been observed (Harris, 1986) is, however, considerably higher in Sb (150 ppm) than the others. The low Sb contents of the deposits in the Ilomantsi area have also been confirmed by mineralogical studies, since no Sb-bearing tellurides or other phases have been encountered (K. Kojonen, pers. commun., 1990).

The highest Sb abundances in the Lapland greenstone belt were, in contrast to Te and Bi, encountered within mafic — ultramafic-hosted deposits, whereas the sedimentary-hosted mineralizations are conversely only slightly anomalous. The peak values were recorded from the adjacent occurrences of Suurikuusikko (20 ppm), Lälleävuoma (6.0 ppm) and Hirvilavanmaa (5.9 ppm).

Antimony is invariably enriched in the deposits of the Svecofennian complex, which in general show higher contents than those in the other provinces. There is no apparent correlation with host rock, since low and high contents occur both in the volcanic- and tonalite-hosted mineralizations. Except for the Kalliosalo antimony deposit (8700 ppm), the most anomalous contents were encountered at Ängesneva (160 ppm) and Kangaskylä (60 ppm).

Contrasts between ore and wall-rock samples for Sb are less pronounced than, for example, for Te and Bi (Fig. 19), and there is in general,

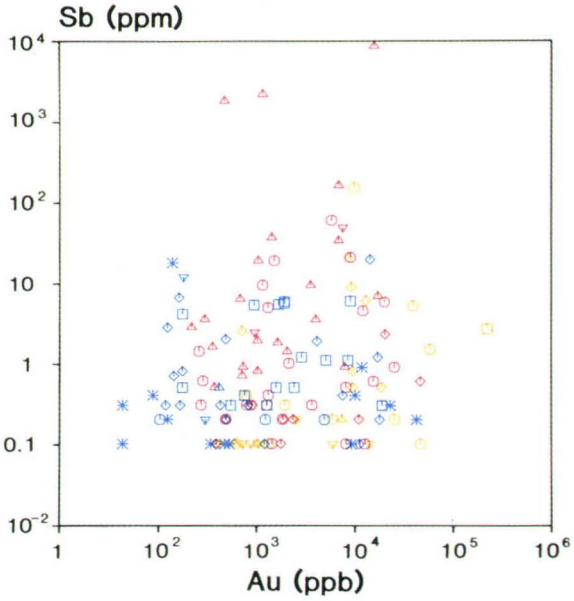


Fig. 20. Sb — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

no distinct correlation between Sb and Au (Fig. 20). This demonstrates that in broad terms, these metals behave in somewhat different ways during mineralization.

Selenium

The average Se content in ultramafic to felsic primary igneous rocks and shales is estimated to be ca. 50 ppb (see, Govett, 1983; and Kerrich, 1983; and references therein). Suggested working values for individual geostandards vary from 8 to 190 ppb for mafic rocks (10 samples) and from 3 to 70 ppb for felsic rocks (8 samples) (Govindajaru, 1989). According to analyses of a suite of geostandards by Chan (1985), ultramafic rocks (4 samples) contain 6 to 125 ppb Se, mafic rocks (5 samples) 11 to 195 ppb, felsic rocks (5 samples) < 5 to 26 ppb and shales (2 samples) 30 to 930 ppb. Aqua regia soluble Se contents from our reference suite are below or near the detection limit (20 ppb) except for the phyllite, which contains 200 ppb Se (App. 4), in

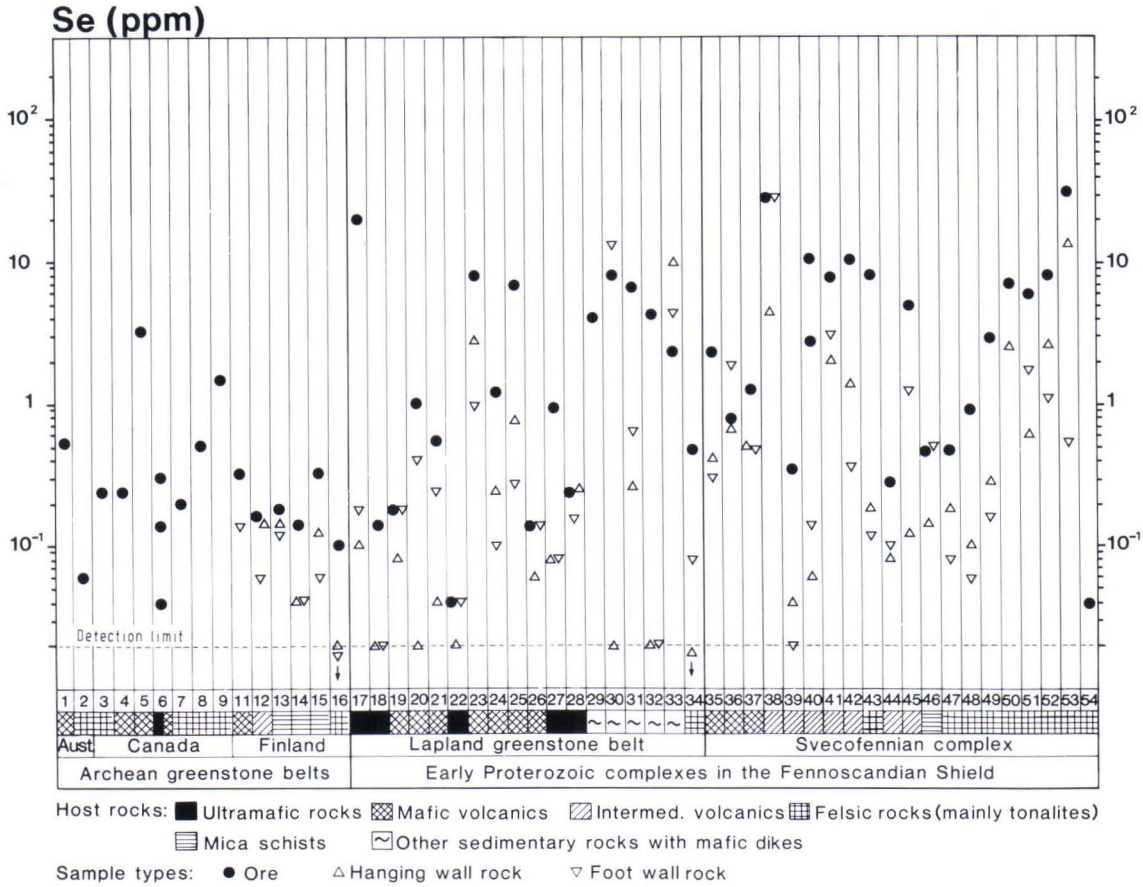


Fig. 21. Variations in Se content in mesothermal gold deposits and their altered wall rocks (detailed information on the deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 11. Statistical data for Se (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland green-stone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	0.62	0.20	11.1	6.4
Standard deviation	0.91	0.09	20.8	8.4
Median	0.24	0.17	1.1	3.8
Maximum	3.1	0.32	78	31
Minimum	0.04	0.10	0.04	0.04
Number of samples	11	6	18	20

rough agreement with previously published average abundances.

Selenium closely follows S in nature and is usually present in trace amounts in hydrothermal gold deposits (1—10 ppm), except within specific mineralized zones that can have contents up to 200 ppm (Boyle, 1979). Analytical data for Se in gold deposits is, however, particularly scarce. The

Carlin-type deposits show a wide range, from <1 to 20 ppm, with a mean value of 1.5 ppm (Radtke, 1985). Pyrites from Archean mesothermal deposits generally show Se contents between 1 and 10 ppm, and only sporadically up to 80 ppm, indicating low total abundances (Kerrich, 1989; King and Kerrich, 1989).

Selenium is present in practically all S minerals in varying amounts, and may be especially enriched in pyrite, chalcopyrite, bismuthinite, tetrahedrite and other sulfosalts (Boyle, 1979). Selenides combine readily with Cu, Ag, Pb, Bi and Hg, forming minerals such as umangite (Cu_3Se_2), klockmannite (CuSe), penroseite ($[Ni,Cu]Se_2$), naumannite (Ag_2Se), guanajuatite ($Bi_2[Se,S]_3$) and junoite ($Bi_8Pb_3Cu_2[S,Se]_{16}$).

Our study indicates that Se is invariably enriched in mesothermal gold deposits in the different provinces (Fig. 21, Table 11, Apps. 2 and 3). The Archean deposits show increased Se contents compared to typical background abundances, but they are mostly close to or less than 0.5 ppm, probably due to the introduction of S during mineralization. Peak values were encountered from Owl Creek (3.1 ppm) and Page Williams (1.4 ppm).

The mafic-ultramafic-hosted deposits in the Lapland greenstone belt are mostly fairly low in Se, but show anomalously high contents at Pahtavaara (11.8 ppm), Rovaselkä (7.7 ppm) and Saattopora S (6.6 ppm). In contrast, the sedimentary-hosted deposits at Kuusamo and Bidjovagge exhibit consistently high contents, from 4 to 80 ppm.

Gold deposits in the Svecofennian complex show much higher Se abundances than those in the other provinces, the contents varying mostly from 1 to 10 ppm. Peak values were encountered at Osikonmäki W (31 ppm) and Isovesi (27 ppm).

Selenium shows a rough correlation with Au (Fig. 22) and is, in Se enriched deposits, always higher in the ore compared to adjacent wall rocks indicating similar behavior during Au deposition. Median Au/Se ratios of the ore samples are 1.1

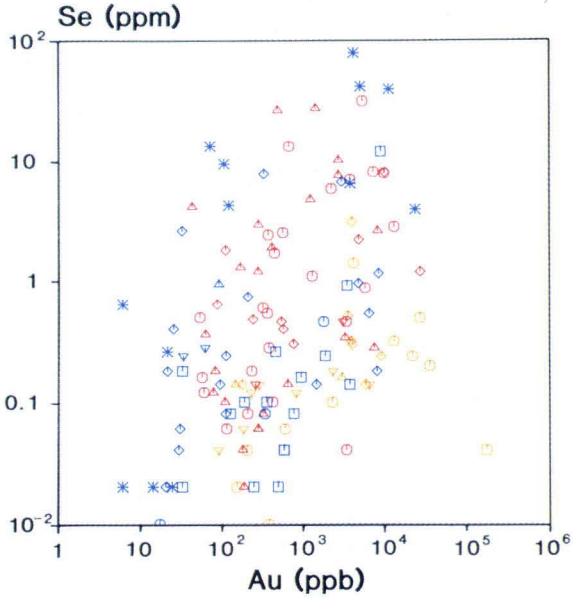


Fig. 22. Se — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

(general range 0.3—39) for the Archean deposits, 1.7 for the mafic-ultramafic-hosted and 0.12 for the sedimentary-hosted deposits in the Lapland greenstone belt, and 0.87 (0.2—3.5) for the deposits in the Svecofennian province.

Tungsten

Average W contents are about 0.1 ppm for ultramafic rocks, 0.4 ppm for mafic rocks, 1.5 ppm for felsic rocks and 2 ppm for shales (Govett, 1983; Kerrich, 1983; and references therein). Our reference suite gave <1 ppm for the mafic rocks, and 3 ppm for the tonalite and phyllite (App. 4).

Tungsten is a common associate in mesothermal and Carlin-type deposits, in which it is usually present as scheelite ($CaWO_4$) and less commonly as wolframite ($[Fe,Mn]WO_4$) (Boyle, 1979; Hutchinson, 1987). Boyle (1979) gives a general range from 2 to 5000 ppm in gold-quartz deposits, whereas Kerrich (1983) reported abundances between 5 and 50 ppm for mesothermal gold deposits in the Abitibi belt, while referring

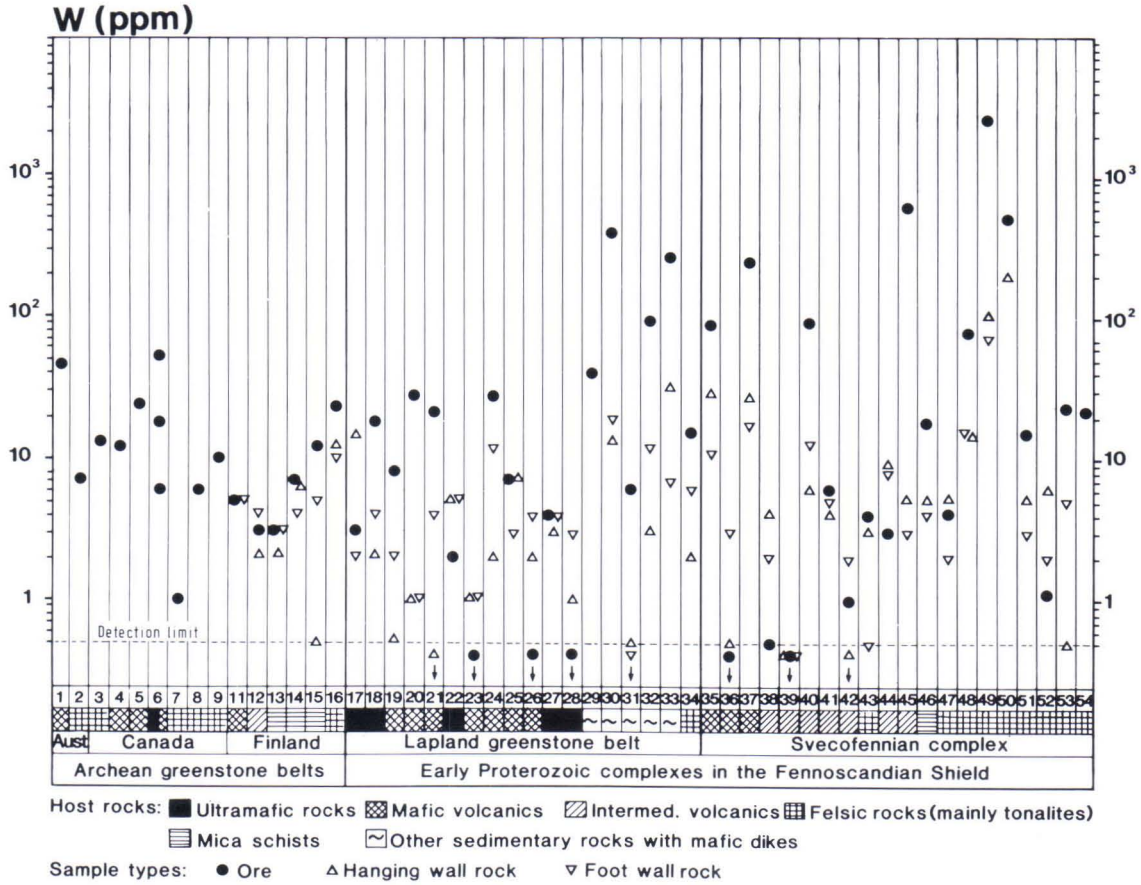


Fig. 23. Variations in W content in mesothermal gold deposits and their altered wall rocks (detailed information on the deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 12. Statistical data for W (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	18	9	51	205
Standard deviation	16	8	104	544
Median	12	6	12	16
Maximum	51	23	390	2400
Minimum	1	3	<0.5	<0.5
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

to the occurrence of scheelite enriched lodes in some mines. Carlin-type deposits have W contents from <20 to 400 ppm (Radtke, 1985).

Tungsten contents are typically slightly increased in most of the deposits studied, but only seldom attain contents of several hundred ppm (Fig. 23, Table 12, Apps. 2 and 3). Archean deposits in Finland and abroad mostly show

abundances between 5 and 50 ppm, consistent with results reported by Kerrich (1983). Only Renabie (1 ppm) and two of the deposits in Ilomantsi have W contents <5 ppm.

Mafic-ultramafic-hosted deposits in the Lapland greenstone belt have either very low W or are only slightly anomalous (c. 20 ppm). In contrast, the sedimentary-hosted deposits are typically enriched in W, with maximum concentrations occurring at Juomasuo (390 ppm) and Konttiaho (260 ppm).

Tungsten is commonly associated with gold deposits in the Svecofennian complex, the only province in which it exhibits a strong enrichment. Peak values are shown by the scheelite-bearing deposits of Pöhlölä (2400 ppm), Kurula (600 ppm) and Kopsa (500 ppm). Nevertheless, 8 of the 20 deposits studied have W content <5 ppm. Tungsten content does not appear to be related to host rock lithology.

Tungsten shows some general correlation with Au, which is an indication of a broad geochemical coherence during Au mineralization (Fig. 24). This becomes more evident when studying individual deposits high in W, where the ore sample is always highly enriched with respect to wall-rock samples (Fig. 23).

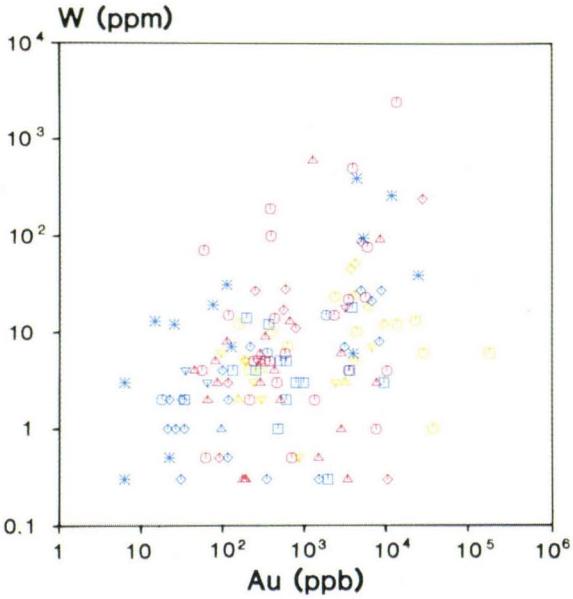


Fig. 24. W — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Molybdenum

Average Mo contents vary between about 0.2 ppm for ultramafic rocks, 1.4 ppm for mafic rocks, 1 ppm for felsic rocks and 2 ppm for shales (Govett, 1983; and references therein). Our reference suite gave contents from <1 to 2 ppm (App. 4).

Molybdenum is fairly common in many types of hydrothermal gold deposits, but is generally only slightly enriched. Boyle (1979) reports a general range from 2 to 840 ppm for Au-quartz deposits and from <2 to 100 ppm for Carlin-type deposits, whereas Radtke (1985) demonstrates that the mean Mo content in the Carlin-type deposits is only about 7 ppm. Contents within mesothermal deposits in the Abitibi belt given by Kerrich (1983) are consistently <30 ppm. Epithermal deposits show variable but occasionally high abundances (Hutchinson, 1987).

Molybdenum is mostly present as molybdenite (MoS_2), but traces may also occur in sulfides and scheelite, which forms an isomorphic series with powellite ($Ca[Mo,W]O_4$) (Boyle, 1979).

Molybdenum, although having analogical chemical properties to W, and often being associated with it in many types of deposits is, on the basis of present data, a far less common component of mesothermal gold deposits than W, and peak values occur mostly in different deposits (Fig. 25, Table 12, Apps. 2 and 3). The Mo contents seem to be either close to background or distinctly anomalous, contents in the range of 5 to 20 ppm being rare. The Archean deposits mostly contain <5 ppm Mo, except for the Page Williams deposit (3270 ppm), which typically contains about 1% molybdenite, and shows some broad correlation between Mo and Au (Valliant and Bradbrook, 1986). Other exceptions are Renabie (181 ppm) and Macassa (130

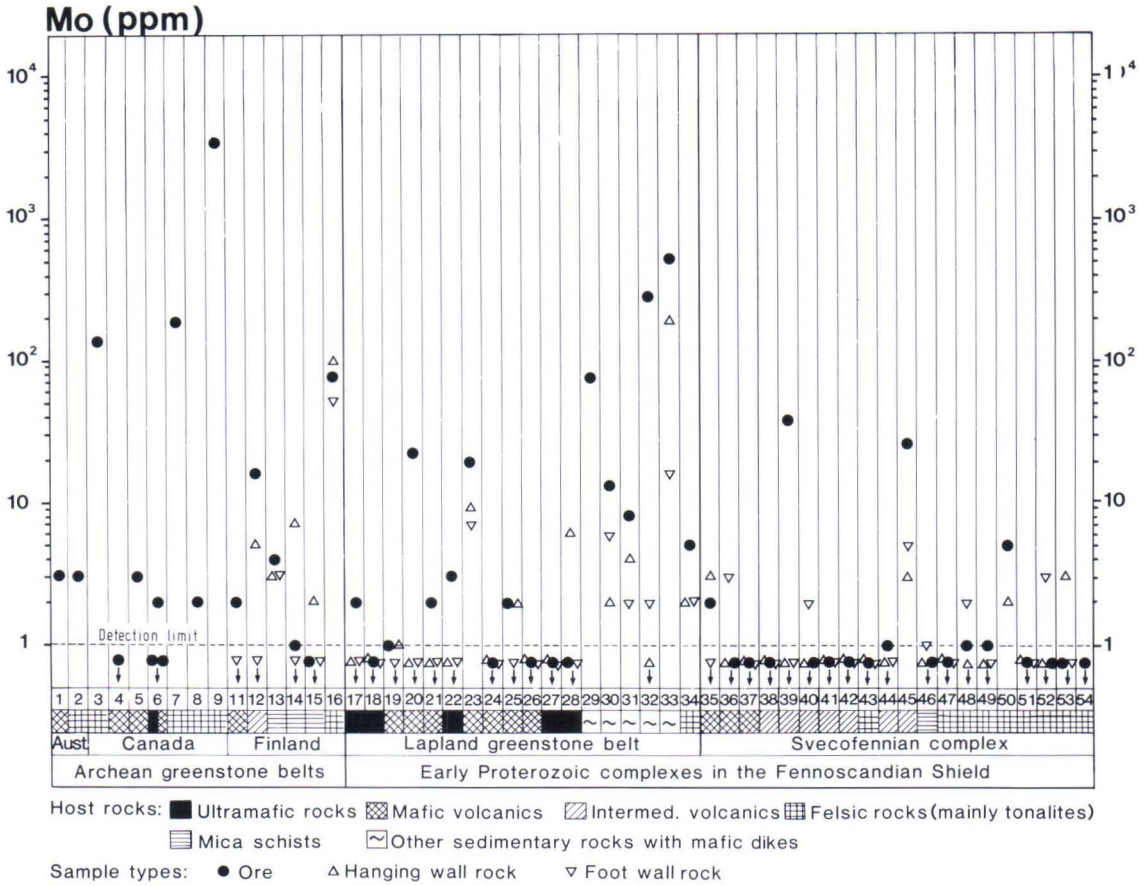


Fig. 25. Variations in Mo content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 13. Statistical data for Mo (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	327	16	52	4
Standard deviation	978	29	131	10
Median	3	3	3	1
Maximum	3270	75	510	38
Minimum	<1	<1	<1	<1
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

ppm) in Canada, as well as Kuittila (75 ppm) and Kelokorpi (16 ppm) within the Ilomantsi greenstone belt.

Mafic — ultramafic-hosted deposits in the Lapland greenstone belt are very low in Mo, excluding the anomalous deposits of Kivimaa (22

ppm) and Rovaselkä (19 ppm). In contrast, Mo is a typical associated element for the sedimentary-hosted deposits in Kuusamo and Bidjovagge, having contents up to 510 ppm at Konttiaho and 275 ppm at Sivakkaharju.

Molybdenum seems to be only rarely associated with the gold deposits in the Svecofennian province, although many of them are hosted by felsic intrusive rocks and are enriched in W. Only Antinoja (38 ppm) and Kurula (26 ppm) show contents >5 ppm.

Correlation between Mo and Au is generally weak, reflecting the fact that Mo is only rarely anomalous (Fig. 26). However, Mo seems to follow Au in deposits with increased Mo contents (Fig. 25) indicating, at least locally, broadly simultaneous deposition.

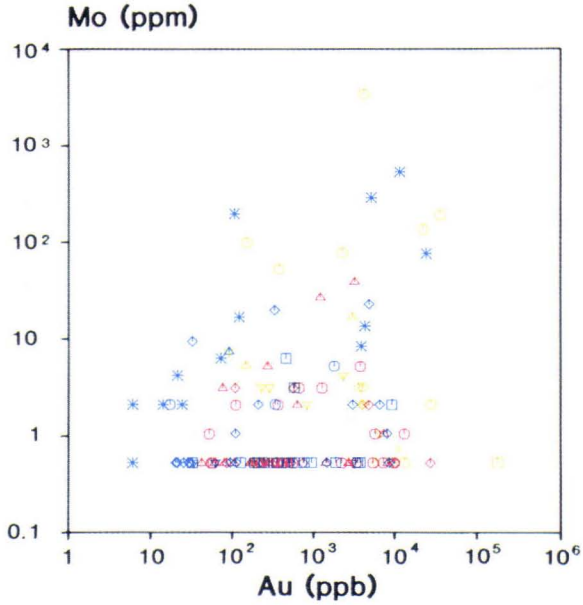


Fig. 26. Mo — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Boron

Average B contents in primary igneous rocks are 3 ppm in ultramafic, 5 ppm in mafic and 15 ppm in felsic rocks, whereas shales exhibit a wider range with an average content of about 100 ppm (Govett, 1983; Kerrich, 1983; and references therein). The gabbro (160 ppm) and phyllite (496 ppm) from our reference suite are enriched in B, while the others show more common values (App. 4).

Boron is usually present in hydrothermal gold deposits as tourmaline ($Na[Mg,Fe,Li,Al]_3 Al_6B_3Si_6O_{27}[OH,F]_4$) or axinite ($[Ca,Fe,Mg]_3 Al_2BSi_4O_{15}[OH]$), and is especially common in quartz-vein and Carlin-type gold deposits (Boyle, 1979; Hutchinson, 1987). The mean B content given by Radtke (1985) for the latter mineralization is, however, only 80 ppm, whereas the total range is from <7 to 200 ppm (Boyle, 1979). Boron is enriched from 100 to 5000 ppm in two thirds of the mesothermal gold deposits in the Abitibi belt, but the rest contain <20 ppm (Kerrich, 1983).

Boron is typically slightly enriched compared to typical background abundances in most of the gold deposits studied, but only occasionally shows considerable enrichment in different provinces, recording the sporadic presence of tourmaline (or axinite) in Au-bearing mineralization systems (Fig. 27, Table 14, Apps. 2 and 3). Archean deposits in Canada and Australia are generally fairly low in B (7.7 to 87 ppm), except for the tourmaline-bearing lode from Ferderber (508 ppm). Mineralization in the Ilomantsi area seems to be systematically high in B, which is probably due to the pyroclastic — sedimentary nature of the schist belt. The tonalite-hosted Kuittila occurrence in fact has the lowest B content, although it is still highly anomalous (163 ppm). The association of B and gold mineralization in this area is also evident on the basis of regional to local till geochemical studies, although there is no mutual correlation between the two elements at deposit scale (Nurmi et al., 1989).

Boron is only slightly anomalous or close to background levels in most Lapland greenstone belt deposits, such that the mafic — ultramafic-hosted mineralization generally has lower con-

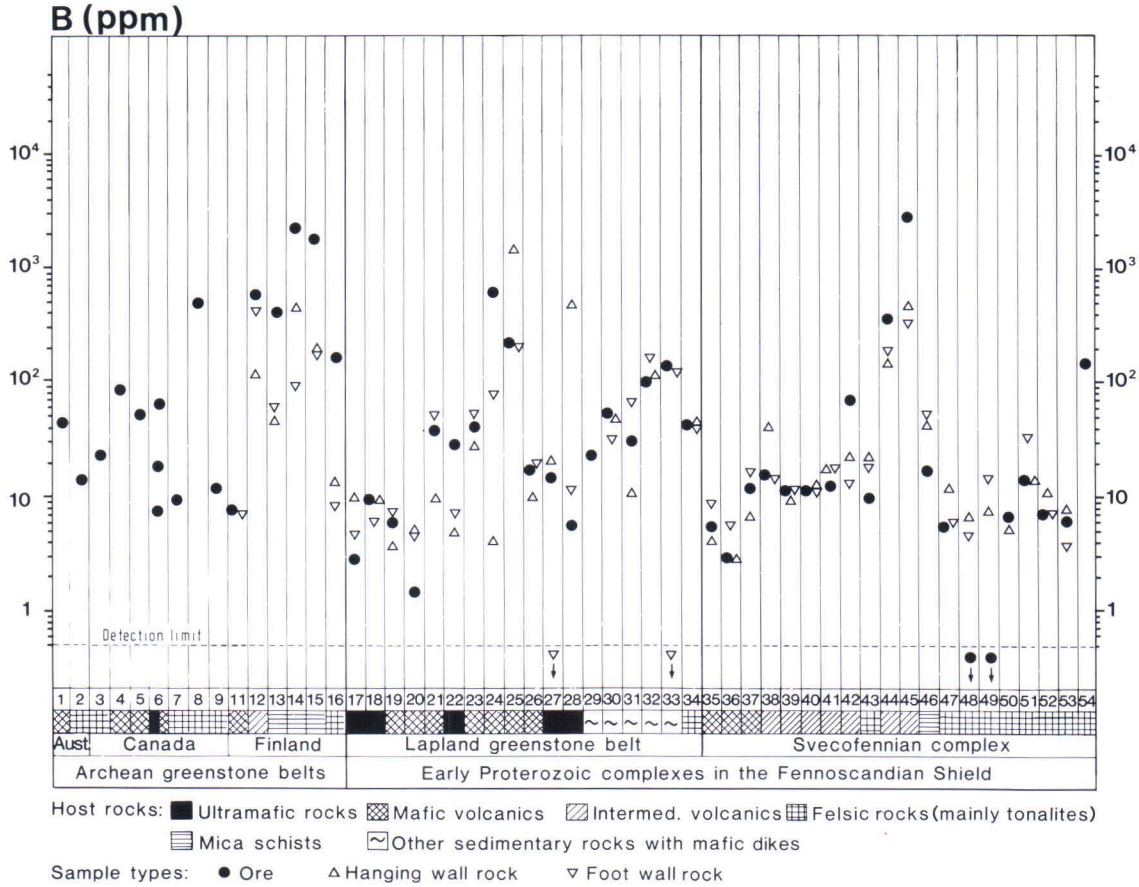


Fig. 27. Variations in B content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 14. Statistical data for B (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	76.5	880	77.7	181
Standard deviation	145	942	146	645
Median	23.0	502	30.2	11.6
Maximum	508	2280	621	2900
Minimum	7.7	7.5	1.5	<0.5
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

tents than those that are sedimentary-hosted. The Saattopora deposits (621 and 216 ppm), and Konttiaho (141 ppm) and Sivakkaharju (101 ppm) from the Kuusamo area show the most elevated abundances.

Data from deposits in the Svecofennian com-

plex indicate that B is not one of the most typical elements associated with this gold mineralization. Boron abundances are close to the background contents in the majority of the deposits, and exhibit high values only sporadically, as at Kurula (2900 ppm) which contains tourmaline-quartz veins, and at Kalliosalo (366 ppm).

The rather fortuitous distribution of B in the deposits studied implies that there cannot be any general correlation between B and Au (Fig. 28). Although B is at least locally involved in the hydrothermal processes leading to gold mineralization, it is usually deposited separately both in space and time, a conclusion supported by the general existence of higher contents in the wall-rock than the ore samples (Fig. 27).

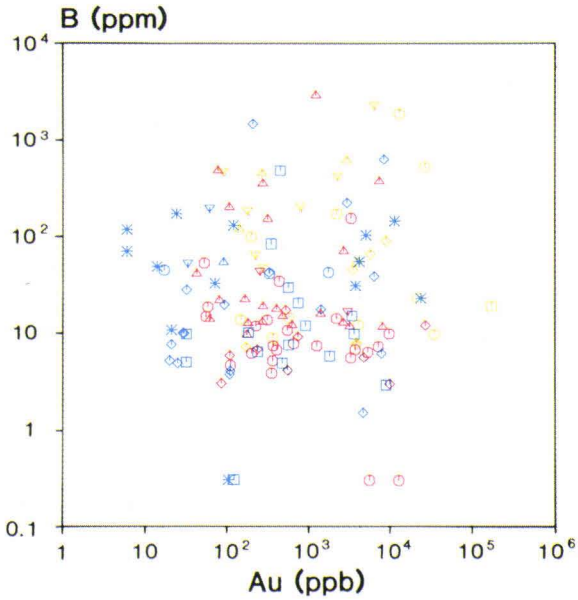


Fig. 28. B — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Mercury

Average Hg contents compiled from the literature by Govett (1983) are about 10 ppb for ultramafic rocks, 90 ppb to mafic rocks, 80 ppb for felsic rocks and 400 ppb for shales. These values are high compared to the suggested working values of individual geostandards, ranging from 2.1 to 28 ppb for mafic rocks (8 samples) and 0.2 to 51 ppb for felsic rocks (6 samples) (Govindajaru, 1989). Our reference suite has contents between 5 and 15 ppb, which are within the range of the geostandards (App. 4).

Mercury is commonly associated with hydrothermal gold deposits which, though invariably enriched, usually contain only small amounts (< 1 ppm) of Hg (Boyle, 1979). It seems to be especially abundant in Tertiary epithermal deposits (Hutchinson, 1987). Carlin-type deposits show a general range from 0.2 to 30 ppm (Bagby and Berger, 1985) and the hot-spring type from 0.06 to > 13 ppm (Berger, 1985). Radtke (1985) gives an average Hg content of 20 to 30 ppm and a mean Hg/Au ratio of 3:1 for the Carlin-type deposits. Archean mesothermal deposits typically contain several tens of ppb Hg, but may locally exhibit values up to several ppm (Boyle, 1979; Kerrich, 1983).

Mercury usually occurs in gold deposits as cinnabar (HgS), metacinnabar and livingstonite ($HgSb_4S_8$), and less commonly as Hg-bearing tetrahedrite-tennantine (Boyle, 1979). It may also be enriched in sphalerite, and at least some Hg-enriched deposits contain abundant sphalerite and sulfosalts. Mercury deposits fairly late and is often associated with stibnite and As minerals, and can also occur as a telluride (coloradoite) and selenide (tiemannite, HgSe).

Mercury seems to be sporadically anomalous in all provinces examined in this study but is nevertheless only seldom highly enriched (Fig. 29, Table 15, Apps. 2 and 3). Archean deposits mostly exhibit Hg contents close to background, with peak values at Page Williams (11,200 ppb), where a number of Hg minerals have been identified (see, Harris, 1986), and also Mt. Charlotte (2150 ppb) and Lokkiluoto (150 ppb).

Deposits in the Lapland greenstone belt are consistently low in Hg (< 50 ppb, mostly < 20 ppb), except for Suurikuusikko (580 ppb) and Kivimaa (180 ppb), and there is no difference be-

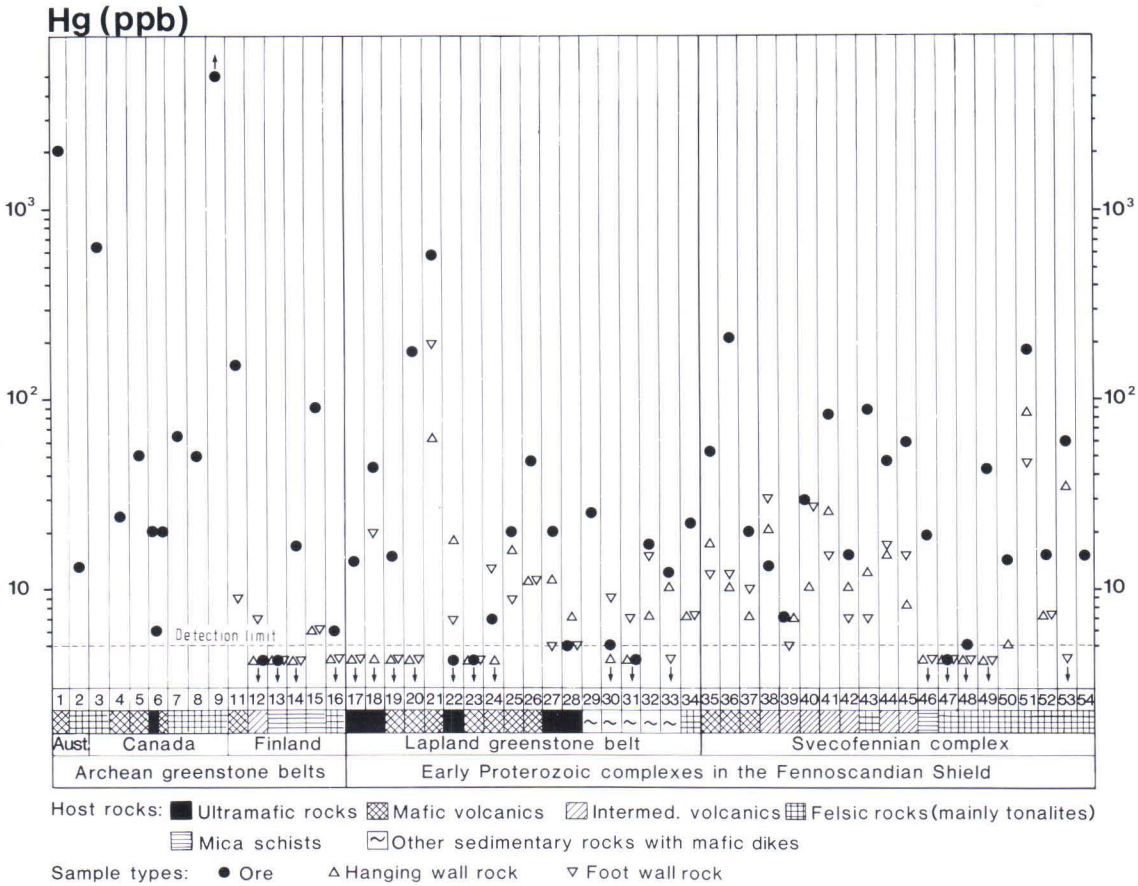


Fig. 29. Variations in Hg content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 15. Statistical data for Hg (ppb) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	1290	45	57	49
Standard deviation	3350	62	140	56
Median	50	12	16	25
Maximum	11200	150	580	210
Minimum	6	<5	<5	<5
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

tween deposits within different host rock lithologies. The deposits in the Svecofennian terrain are also generally low in Hg, excluding the peak contents at Sudenkylä (210 ppb) and Kangaskylä (180 ppb).

Correlation between Hg and Au is generally

poor as might be expected from the sporadic occurrence of Hg (Fig. 30). In Hg-enriched deposits, however, it is always concentrated sympathetically with Au, demonstrating roughly simultaneous deposition (Fig. 29).

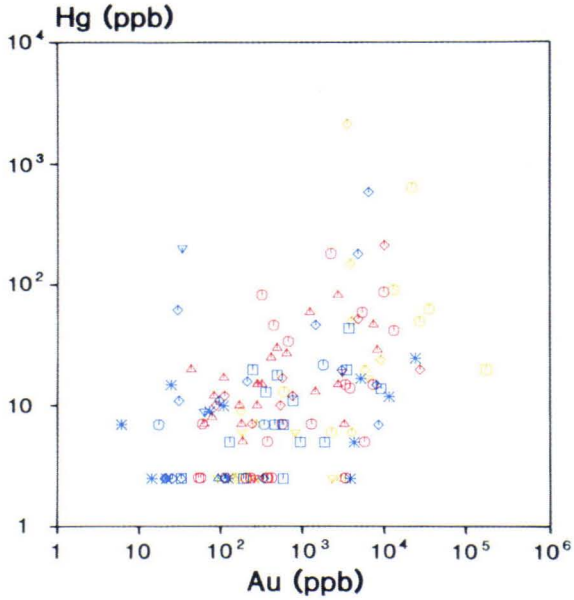


Fig. 30. Hg — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Rare elements with a weak or sporadic response to mineralization

Uranium and thorium

According to Boyle (1979), U and Th are uncommon in hydrothermal gold deposits, but are typically enriched in paleoplacer deposits. However, both Precambrian and Tertiary examples exist where U and Th are enriched up to some tens of ppm. Mesothermal deposits in Timmins, show U and Th contents that reflect host-rock abundances and imply approximately isochemical behavior of the elements (Kerrich, 1989). Common U minerals in hydrothermal deposits are pitchblende-uraninite (UO_2) and davidite ($[Fe,Ce,U]_2[Ti,Fe,V,Cr]_5O_{12}$).

Uranium and Th do not show any evident enrichment in the Archean deposits of this study, contents ranging from <0.1 to 3.4 ppm and <0.5 to 9.2 ppm, respectively (Fig. 31, Table 16, Apps. 2 and 3). Most of the deposits in the Lapland greenstone belt contain U and Th within the same ranges. However, U is strongly enriched at Saattopora N (9.9 ppm), Saattopora S (23 ppm), Bidjovagge (95 ppm), Juomasuo (284 ppm), Sivakkaharju (410 ppm) and Konttiaho (100 ppm), which are largely hosted by epicontinental sedimentary rocks intruded by mafic-ultramafic dikes, and were affected by pervasive synvolcanic Na-CO_2 alteration prior to Au mineralization. This context possibly indicates to a local source of U. Thorium does not show any apparent increase concomitant with U.

Uranium has a strong correlation with Au in these deposits, according to both our analyses and observations in the Bidjovagge mine, where radiation can be used in delineating gold ore (Söderholm and Nixon, 1988). The main U mineral at Bidjovagge is davidite (Björlykke et al., 1987) and uraninite in the Kuusamo area (Pankka and Vanhanen, 1989).

The deposits in the Svecofennian complex have U contents <5.4 ppm and Th <0.5 to 10 ppm, except for Jokisivu, where both elements are 12 ppm in the ore sample (App. 2).

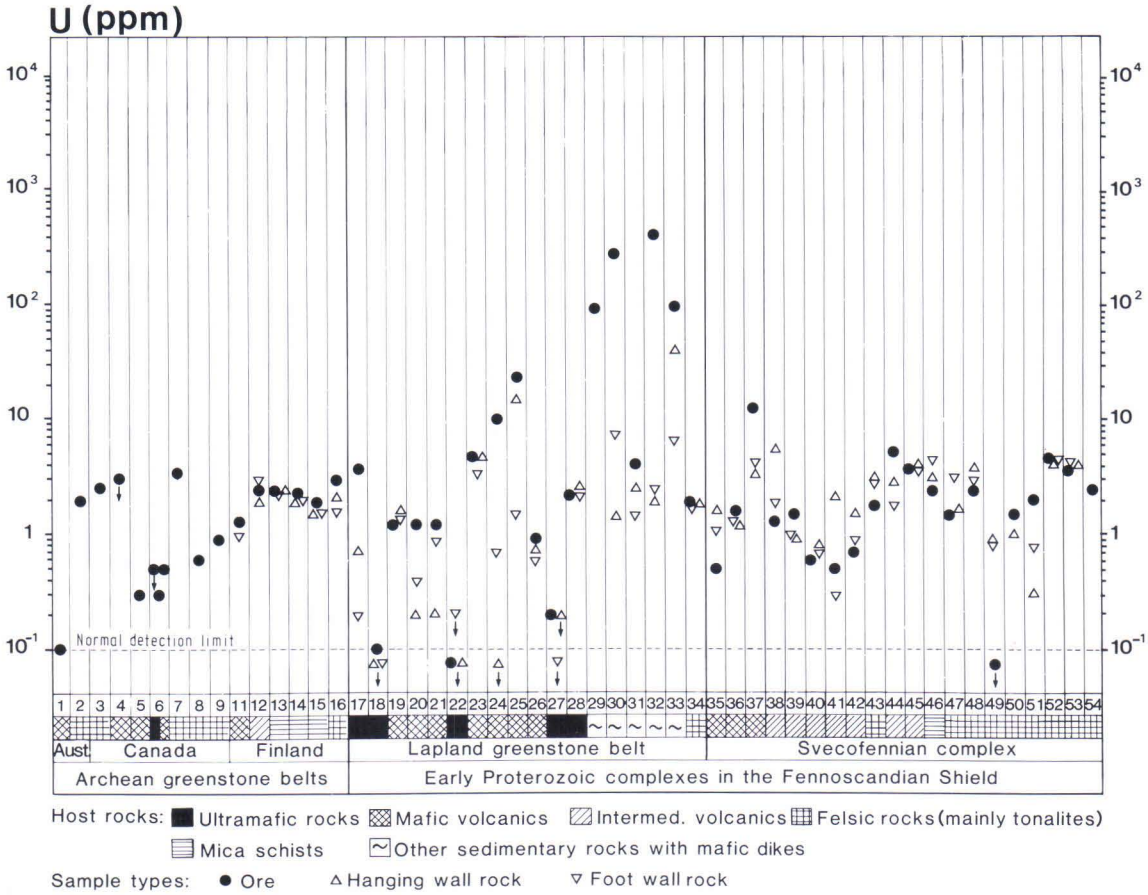


Fig. 31. Variations in U content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1). Detection limit varies from 0.1 up to 3 ppm, depending on sample matrix.

Table 16. Statistical data for U (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	1.1	2.2	52.4	2.5
Standard deviation	1.1	0.5	114	2.7
Median	0.5	2.3	2.9	1.7
Maximum	3.4	2.9	410	12.4
Minimum	0.1	1.3	<0.1	<0.1
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

Tin

Anomalous Sn contents have been noted for some hydrothermal gold deposits, but Sn is usually only slightly enriched (Boyle, 1979). Mesothermal deposits at Yellowknife contain <10 ppm and at Kirkland Lake 2 to 11 ppm Sn. The Carlin-

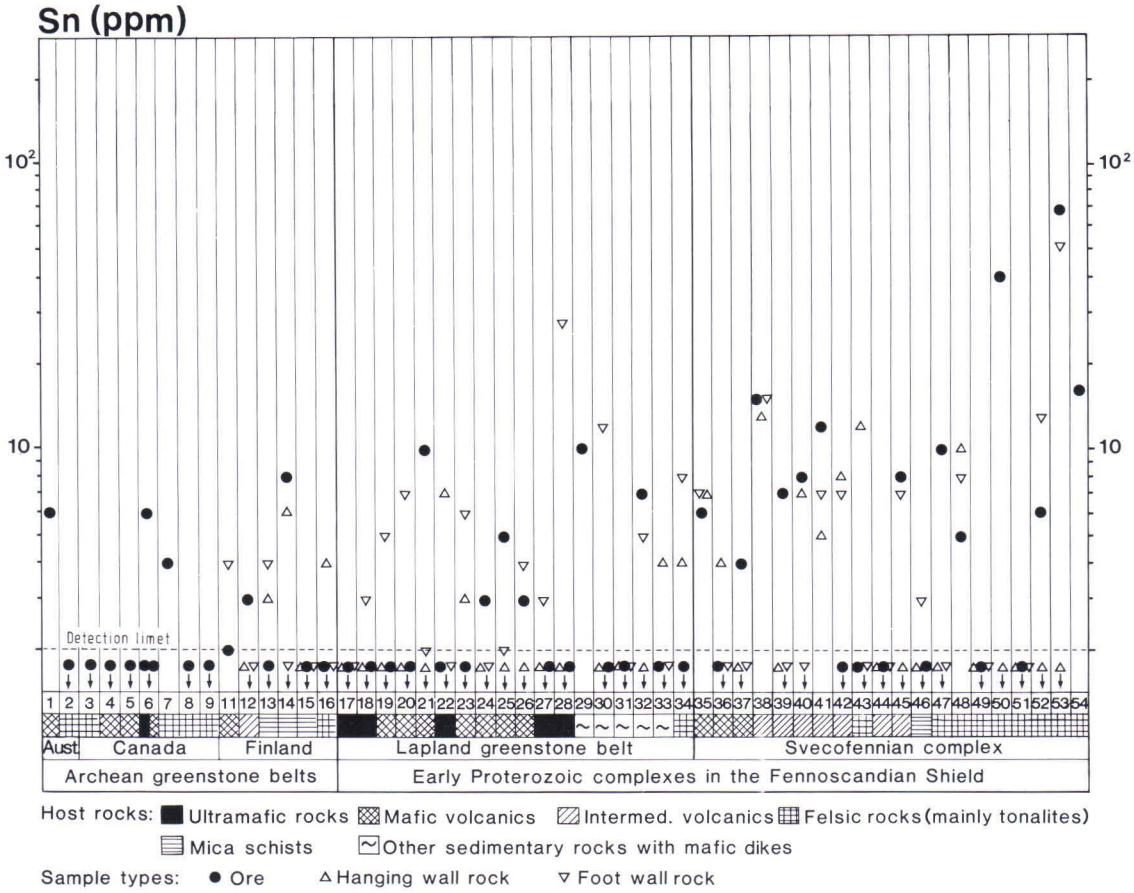


Fig. 32. Variations in Sn content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 17. Statistical data for Sn (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean[1]	2	2	3	11
Standard deviation	2	2	3	16
Median	<2	2	<2	6
Maximum	6	8	10	68
Minimum	<2	<2	<2	<2
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

type deposits have Sn contents from <7 to 20 ppm (Radtke et al., 1972).

The most typical Sn mineral in gold deposits is stannite (Cu_2FeSnS_4) and trace amounts may also be found in simple sulfides such as pyrite, galena and sphalerite (Boyle, 1979).

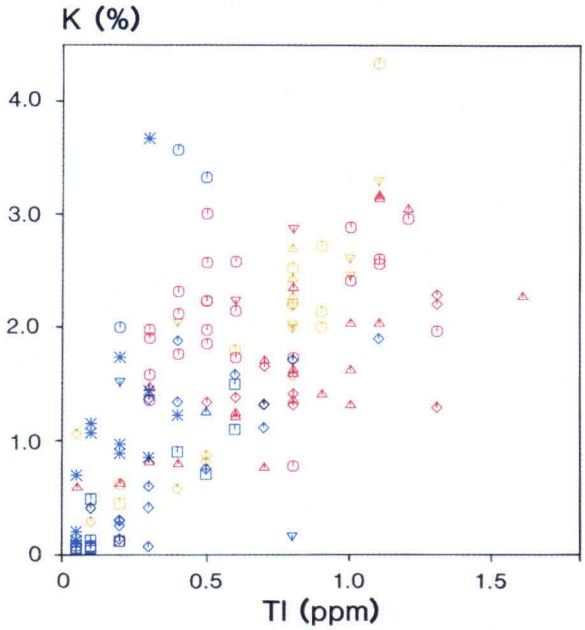


Fig. 33. K — Tl relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

The Archean deposits seem to be nearly devoid of Sn, showing typically contents from <2 to 4 ppm with only minimal enrichments of 6 ppm at Mt. Charlotte and in the flow ore of Kerr Addison, and 8 ppm at Korvilansuo (Fig. 32, Table 17, Apps. 2 and 3). In the Lapland greenstone belt seven deposits show Sn contents >5 ppm in either the ore or the wall rocks. The ultramafic foot wall rock of the Sirkka W deposit has the highest content (28 ppm), the other six anomalous samples being within the range of 6 to 12 ppm.

The deposits in the Svecofennian complex are commonly slightly enriched in Sn (App. 2). Eleven of the 20 deposits show in at least one of the samples Sn contents >5 ppm (mostly 6 to 16 ppm). The peak values are encountered in ore samples from the Osinkonmäki W (68 ppm) and Kopsa (40 ppm) deposits. Although these two mineralizations are tonalite-hosted, the other anomalous contents are not restricted to any specific host rock.

Thallium

Thallium is a trace component of hydrothermal gold deposits, which may form discrete minerals, such as lorandite ($TlAsS_2$) or be enriched, as, in galena, sulfosalts and orpiment or substitute for K in micas and alkali feldspar (Boyle, 1979). Thallium is commonly an associated element in epithermal deposits, and published analyses from hot-spring and Carlin type deposits show that Tl is enriched from several ppm up to some tens of ppm (Radtke et al., 1972; Berger, 1985). The average content for Carlin-type deposits is 40 to 50 ppm (Radtke, 1985). This contrasts with values for Archean mesothermal deposits which seem to mostly be from 0.05 to 2 ppm (Kerrich, 1989).

Data from the Fennoscandian Shield show no peak values and a total variation of Tl from <0.1 to 1.6 ppm (mostly <1 ppm), indicating that Tl was not markedly enriched in the mineralizing fluids, and most probably occurs in K-bearing minerals (App. 2). There is, however, no simple mutual correlation between K and Tl, and samples from the Lapland greenstone belt seem to be anomalously low in Tl (Fig. 33).

In our data from Canada and Australia, the Page Williams mine in the Hemlo deposit is the only one which is anomalous in Tl (31.5 ppm), the others showing contents within the limits established for the Fennoscandian Shield (App. 3). Harris (1986) has identified several Tl minerals from Hemlo, such as parapierrotite ($TlSb_5S_8$) and routhierite ($CuTlHg_2[As_{1.4}Sb_{0.6}]S_6$).

Base metals and sulfur

Copper, zinc and lead

Average abundances of Cu, Zn and Pb in ultramafic rocks are 15, 40 and 0.5 ppm; in mafic rocks 90, 120 and 7 ppm; in felsic rocks 30, 60 and 18 ppm; and in shales 60, 75 and 15 ppm, respectively (Govett, 1983; Kerrich, 1983; and references therein). These metals are commonly associated with gold mineralization and may be present in either minor or major amounts with contents varying markedly between different types of deposits (Boyle, 1979). The elements typically form simple sulfides such as chalcopyrite ($CuFeS_2$), enargite (Cu_3AsS_4), bornite (Cu_5FeS_4), sphalerite (ZnS) and galena (PbS), and a number of other compounds such as sulfosalts and tellurides. These base metals are notably enriched in epithermal Neogene — Quaternary deposits of the Circum Pacific Belt (Sillitoe, 1989). Porphyry Au-Cu deposits of this region show strong Cu enrichment and usually have a positive correlation between Cu and Au, whereas Zn and Pb are only locally enriched. Amongst the epithermal deposits, the acid-sulfate types are enriched in Cu, while the adularia-sericite types, which are in general somewhat poorer in base metals, show Zn and Pb as well as Cu enrichment.

The Carlin- and hot-spring-type deposits possess Cu, Zn and Pb abundances near background levels or only a slight enrichment. General ranges for Carlin type deposits are <5 to 200 ppm for Cu, 10 to 1500 ppm for Zn and <7 to 300 ppm for Pb (Bagby and Berger, 1985) and for the hot-spring deposits, <5 to 50 ppm for Cu, <5 to 35 ppm for Zn and <10 to 30 ppm for Pb (Berger, 1985). Archean mesothermal deposits typically have low Cu, Zn and Pb contents, within the range of 0.1—10 times their background values, but may show locally sporadic enrichments (Kerrich, 1983; Kerrich and Fyfe, 1988).

Copper is the only base metal which is commonly somewhat enriched in the mesothermal gold deposits sampled (Fig. 34, Table 18, Apps. 2 and 3). The Archean deposits typically have rather low Cu, except for the Cu enriched lode at the Ferderber mine (1.16%) and the Owl Creek deposit (0.064%). The same samples are also somewhat enriched in Zn and Pb, but in the other deposits these elements show contents close to the background abundances.

Deposits in the Lapland greenstone belt are typically anomalous in Cu but mostly rather low in Zn and Pb. The peak Cu values were encountered in the Kivimaa (1.84%), Bidjovagge (1.20%) and Saattopora S (0.84%) deposits, which are also past or present Cu producers. For the other showings, Cu content is variable, from <0.01 to 0.2%. Zinc is mostly <130 ppm and Pb <30 ppm. Anomalous Pb contents (up to 150 ppm) are mostly restricted to the deposits of the Kuusamo area, in which Pb may be largely of radiogenic origin, since sporadic higher Pb values have been demonstrated to be spatially associated with U anomalies (Pankka, 1989).

The deposits in the Svecofennian terrain are characteristically enriched in Cu, mostly showing contents between 0.03 and 0.3%. Zinc and Pb are only locally anomalous at Kiimala (Zn = 2920 ppm and Pb = 78 ppm), Kangaskylä (Zn = 496 ppm and Pb = 33 ppm) and Pirilä S (Zn = 432 ppm and Pb = 778 ppm). The latter deposit has been considered as syngenetic in origin mainly on the basis of elevated base metal contents (Makkonen and Ekdahl, 1988). Although sphalerite and galena are common accessory minerals in the deposits of the Svecofennian complex (Nurmi, 1991), Zn and Pb are usually only slightly enriched (up to 160 ppm and 50 ppm, respectively).

Copper shows a broad general correlation with Au, but both ore and wall-rock samples may exhibit anomalously high or low values on a local scale as well as in the bulk of the data (Figs. 34 and 35). For Zn and Pb there is no general correlation with Au, although the metals are enriched in the ore samples from some deposits.

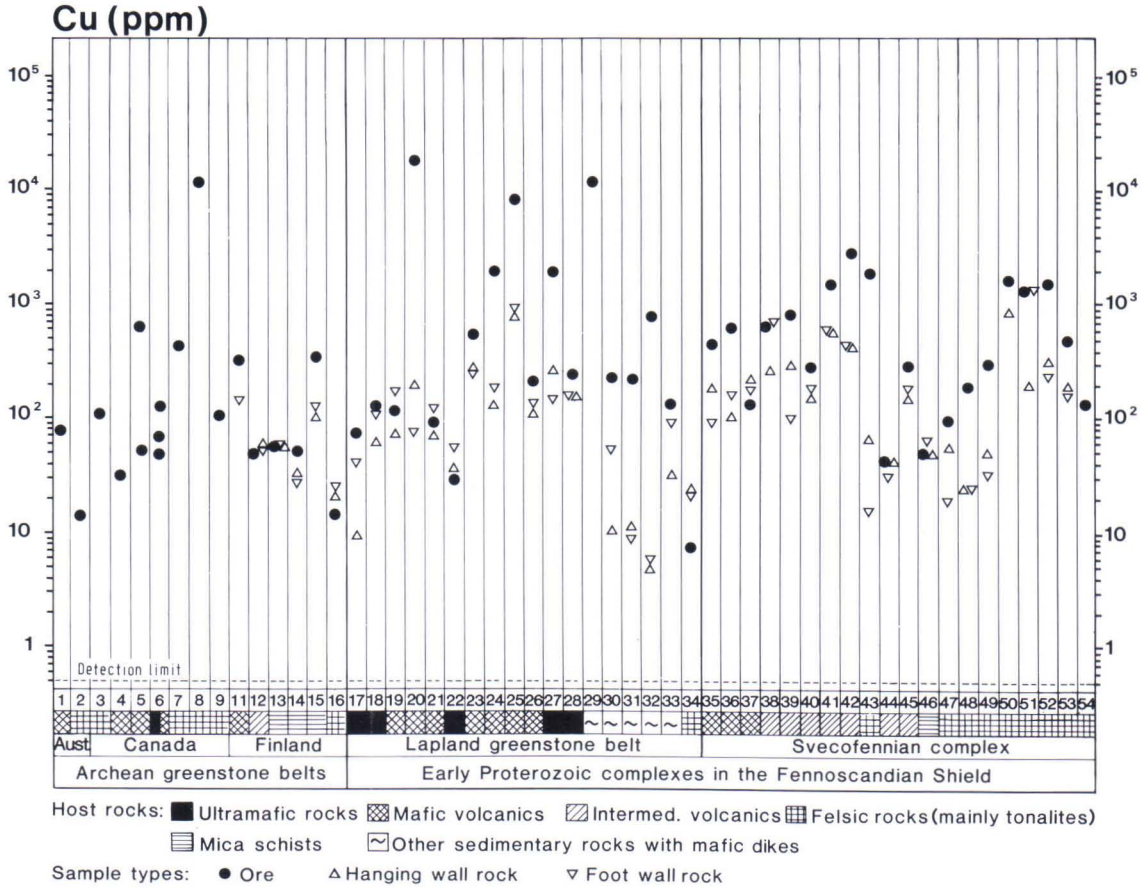


Fig. 34. Variations in Cu content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 18. Statistical data for Cu (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	1200	139	2520	763
Standard deviation	3450	151	5120	773
Median	103	53.2	223	465
Maximum	11600	346	18400	2860
Minimum	14.2	14.1	7.4	42.2
Number of samples	11	6	18	20

Cobalt, nickel and chromium

Cobalt, Ni and Cr are usually present in gold deposits in trace to minor amounts (Boyle, 1979). Cobalt and Ni occur in common sulfides, but where more abundant may locally form a number of discrete minerals. Chromium is a major component in Cr-mica and a number of rock-

forming minerals, and may also occur in lesser amounts in various ore minerals. In Archean mesothermal deposits, Cr and Ni show a strong dependence on host rock lithology, being abundant (Cr >2000 ppm and Ni 900 ppm) only in some ultramafic hosted deposits, although the possibility of hydrothermal concentration along with precious metals cannot be ruled out (Kerrich and Fyfe, 1988).

The Archean mesothermal deposits from Canada and Australia sampled for this study seem have rather low Co (mostly <50 ppm) (Fig. 36, Table 19), Ni (<70 ppm) and Cr (<200 ppm) (App. 3). The ultramafic-mafic-hosted deposits of Owl Creek and Kerr Addison do exhibit, however, somewhat higher contents for Ni (up to 515 ppm) and Cr (1990 ppm). The tonalite-hosted, Cu-rich Ferderber deposits has anomalous Co (124 ppm) and Ni (102 ppm). Compared to these deposits, the occurrences at Ilomantsi, hosted predominantly by intermediate supracrustal schists, are slightly anomalous with respect to Ni (121 to 155 ppm) and Cr (140 to 300 ppm) (App. 2). Nickel occurs in this area as pentlandite ($[Fe,Ni]_9S_8$) inclusions in pyrrhotine (Johanson and Kojonen, 1989).

Nickel and Cr exhibit roughly parallel behavior in the deposits of the Lapland greenstone belt, mostly being close to background values (<700 ppm), although showing distinct local enrichments in the ultramafic-hosted deposits of Lälleävuoma (Ni = 912 and Cr = 2260 ppm), Hirvilavanmaa (Ni = 802 and Cr = 2050 ppm) and Soretiavuoma (Ni = 2380 and Cr = 1900 ppm) (App. 2). Although some other ultramafic-hosted deposits show much lower contents, abundances of these metals are not necessarily controlled by the mineralization processes, since approximately similar contents are found in wall rocks and ore samples.

Cobalt behaves independently from Ni and Cr, and is particularly enriched in the deposits of the Kuusamo area (172 to 1820 ppm) (Fig. 36, Table 19, App. 2), where it is present in cobaltite (CoAsS) and pentlandite (Pankka, 1989). The

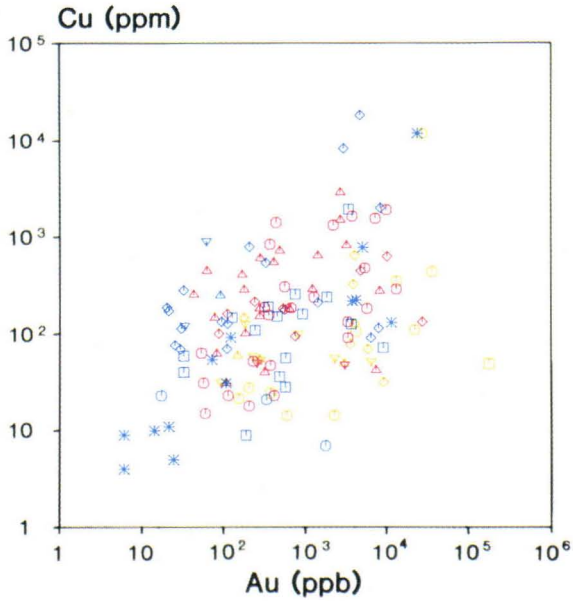


Fig. 35. Cu — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

mafic-ultramafic-hosted deposits contain in most cases <60 ppm Co, but locally content may exceed 400 ppm as, for instance, at Pahtavaara (472 ppm) and Soretiavuoma (428 ppm). Unlike Ni and Cr, Co is usually enriched in the ore samples (Fig. 36).

In the deposits of the Svecofennian province, Ni and Cr abundances are typically near background contents (<150 ppm for volcanic-hosted and <70 ppm for tonalite-hosted deposits) and the ore samples are usually depleted resulting from an increase in volume, attributed principally to quartz veining (App. 2). Only at Sudenkylä is Ni distinctly higher (775 ppm). Cobalt is in most cases <30 ppm, but locally shows distinct enrichments, up to 1590 ppm at Kurula and 999 ppm at Sudenkylä (Fig. 36, Table 19, App. 2).

Sulfur

Sulfur contents vary considerably according to lithology. Approximate average abundances are 100 ppm for ultramafic rocks, 300 ppm for mafic

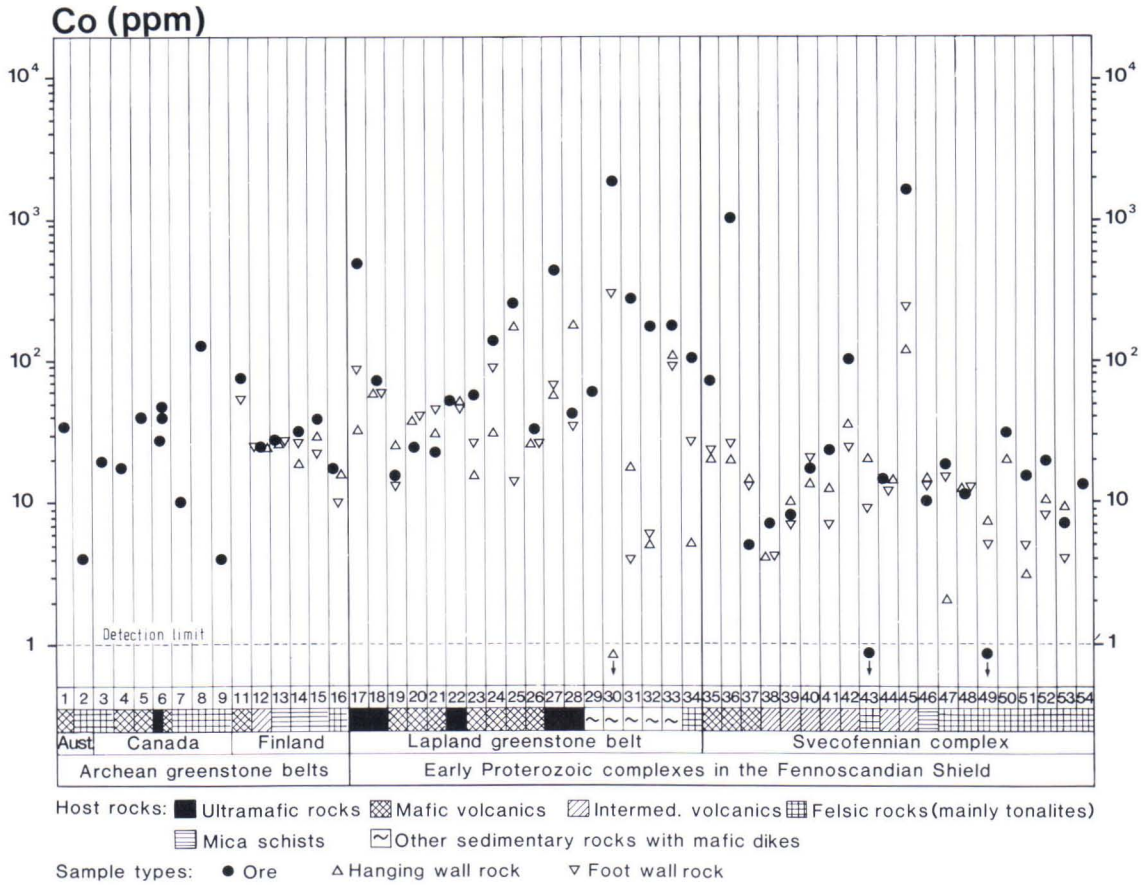


Fig. 36. Variations in Co content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 19. Statistical data for Co (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	33	35	233	148
Standard deviation	34	20	419	404
Median	27	29	87	15
Maximum	124	73	1820	1590
Minimum	4	17	15	<1
Number of samples	11	6	18	20

[1] A value of half the detection limit has been assigned to samples with content below the relevant limit.

rocks, 400 ppm for felsic rocks and 3000 ppm for shales (Govett, 1983; and references therein).

Sulfur, being the major component of sulfides, sulfosalts and sulfates (barite, gypsum, anhydrite and alunite), is an ubiquitous element in all types of hydrothermal gold deposits, and is always present in considerable but varying amounts (Boyle, 1979). In some deposits Au shows a

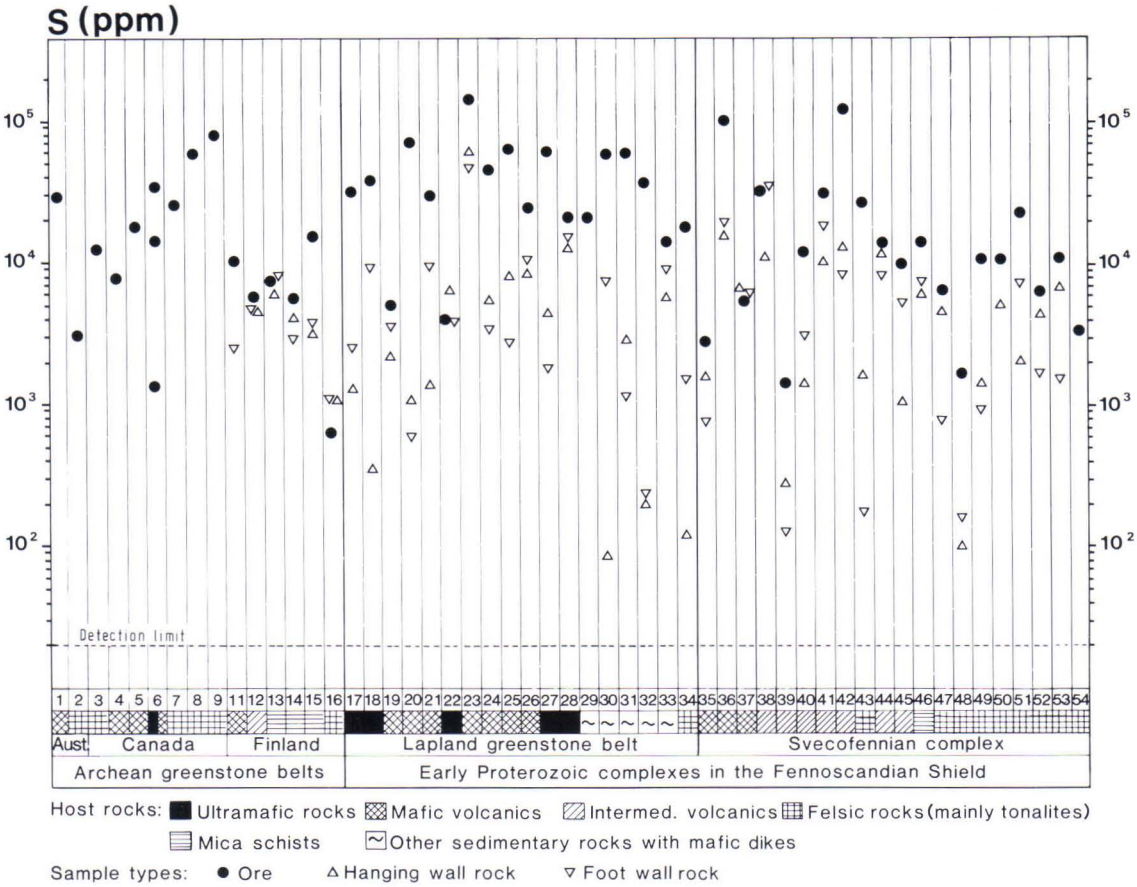


Fig. 37. Variations in S content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

Table 20. Statistical data for S (ppm) in ore-grade samples from gold deposits in various provinces.

	Archean deposits		Lapland greenstone belt	Svecofennian complex
	Australia & Canada	Finland		
Mean	25700	7530	41420	22270
Standard deviation	24200	4979	31960	32110
Median	17800	6600	34200	10900
Maximum	79600	15400	139000	120000
Minimum	1350	633	4060	1420
Number of samples	11	6	18	20

general correlation with S, whereas in others no such coherence exists. The main S carriers in all gold deposits are Fe-sulfides, which crystallize after the reaction of S-bearing fluid with Fe in the host rocks. Sulfate minerals in gold deposits are common only in epithermal systems (Hutchinson, 1987). In these deposits, the acid-sulfate type is commonly enriched in pyrite (up to >50%)

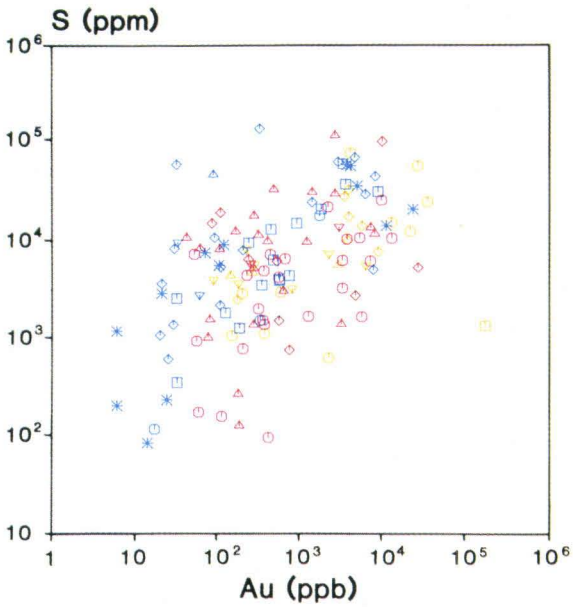


Fig. 38. S — Au relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

compared to the adularia-sericite type (Sillitoe, 1989). Archean mesothermal deposits of the Abitibi belt show a wide range of S from 0.1 to >20% in pyritic occurrences (generally between 0.4 to 3%), but high Au contents are found in both S-rich and S-poor types (Kerrich, 1983).

Our data indicates that the mesothermal gold deposits are invariably enriched in S, ranging from <0.1 to over 10% (Fig. 37, Table 20, Apps. 2 and 3). Although the overall variation is large and Au is not directly controlled by the abundance of sulfides (mainly Fe sulfides), there are nevertheless differences in average S abundances between the provinces. The Archean deposits most commonly contain from about 0.5 to 3.5% S, the peak content occurring in the sample from the Page Williams mine (8.0%) and the lowest content in the green carbonate ore at Kerr Addison (0.14%). The occurrences in the Ilomantsi area seem to exhibit somewhat lower S abundances (typically 0.6 to 1.5%), with the tonalite-hosted Kuittila deposit being anomalously low (0.063%).

The deposits in the Lapland greenstone belt are enriched in S compared to the other provinces, their contents being typically from 2 to 6%. The highest content (13.9%) was encountered in the minor Rovaselkä showing, in which gold occurs in association with abundant pyrrhotine. Anomalously low content occurs at Hirvilavanmaa (0.41%), which is also rather low in Au. In the Pahtavaara deposit, much of the S (3.2%) occurs in baryte and only minor pyrite dissemination exists. The data from the Lapland greenstone belt may be somewhat biassed, since geophysical methods (Slingram, IP and VLF-R) have been widely used in exploration, preferentially revealing more sulfide-rich occurrences (see, Nurmi, 1991).

The deposits in the Svecofennian complex generally contain from about 0.5 to 2.5% S. Anomalously low contents occur at Antinoja (0.14%) and Laivakangas S (0.17%), while the highest contents were found at Kiimala (12.0%) and Sudenkylä (10.4%). The former comprises fairly massive pyrrhotine zones and breccias, while the latter is principally pyrrhotine-rich quartz-vein mineralization.

Sulfur shows a broad general correlation with Au, the ore samples typically being enriched in S with respect to the wall rocks (Figs. 37 and 38). However, Au abundances are not directly related to the abundance of sulfides.

Elements related to wall-rock alteration

Hydrothermal gold deposits are presumably the result of extensive fluid flow through the parent rock, since that is the only conceivable mechanism for producing economic concentrations from hydrothermal fluids that have very low natural concentrations of Au (see, Kerrich and Fyfe, 1984; Seward, 1984). Hence, gold deposits are always related to hydrothermally al-

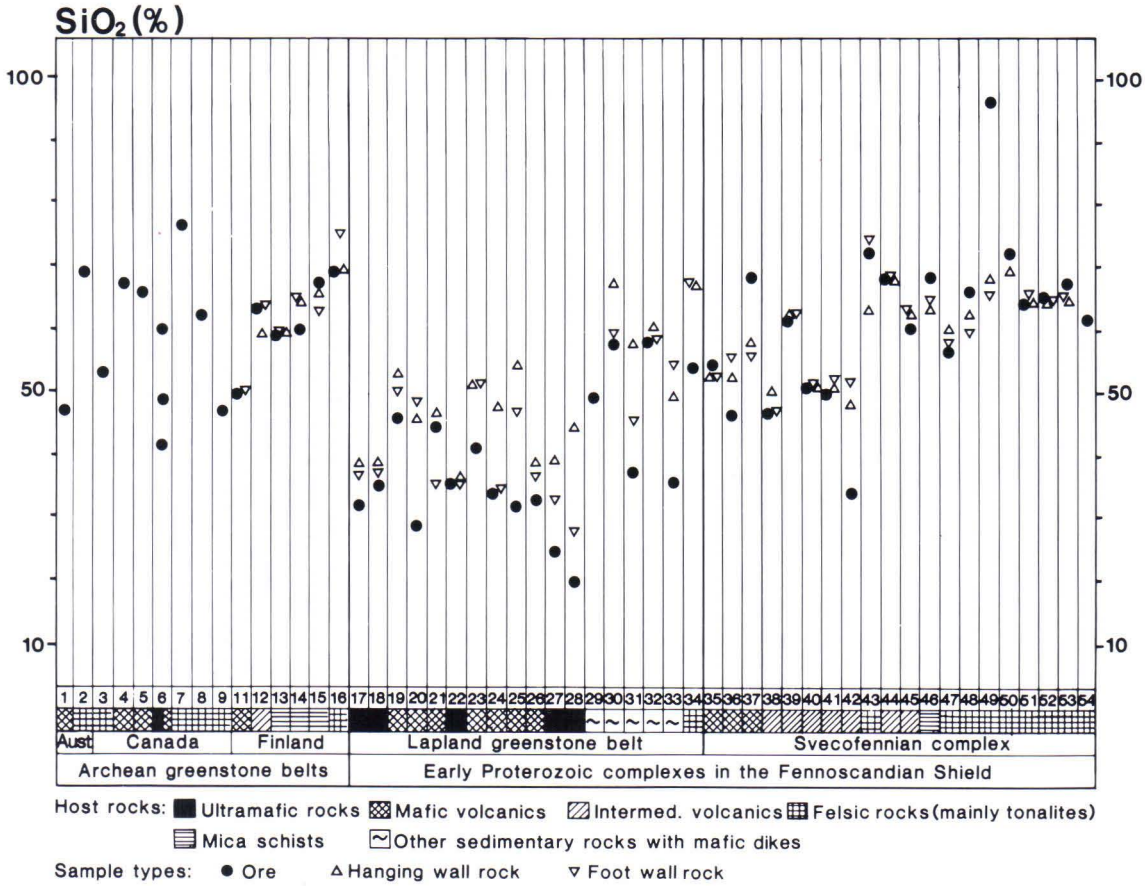


Fig. 39. Variations in SiO_2 content in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

tered wall rocks and in most instances alteration is both extensive and intense.

Epithermal mineralization systems tend to result in zoned alteration patterns, which include silicification and advanced argillic alteration at the top of the system, quartz-adularia-calcite veins associated with sericite-albite or argillic halos, and broad propylitic and argillic halos (e.g., Berger and Bethke, 1985; Groves, 1989). In mesothermal systems, zoning is not as well developed, and alteration generally produces patterns which indicate carbonation, hydration and potassic alteration, resulting typically in parageneses dominated by ferroan dolomitic, K-mica, alkali feldspar, chlorite and quartz (e.g., Colvine et al., 1988). Alteration is accompanied by removal of, amongst other elements, Ca, Sr and Na; and addition of Si, K, Rb, H_20 and CO_2.

Unlike the Au-affiliated rare elements and the base metals, elements recording wall-rock alteration are major components of common rock-forming minerals or trace elements substituting for major elements. Their contents generally change during mineralization processes by a factor of some tens of per cent to considerably less than an order of magnitude, and original lithological compositions and volume changes exert a strong influence on the analysed abundances of altered rocks. For example, a quartz-vein occurrence in tonalite may actually have an even

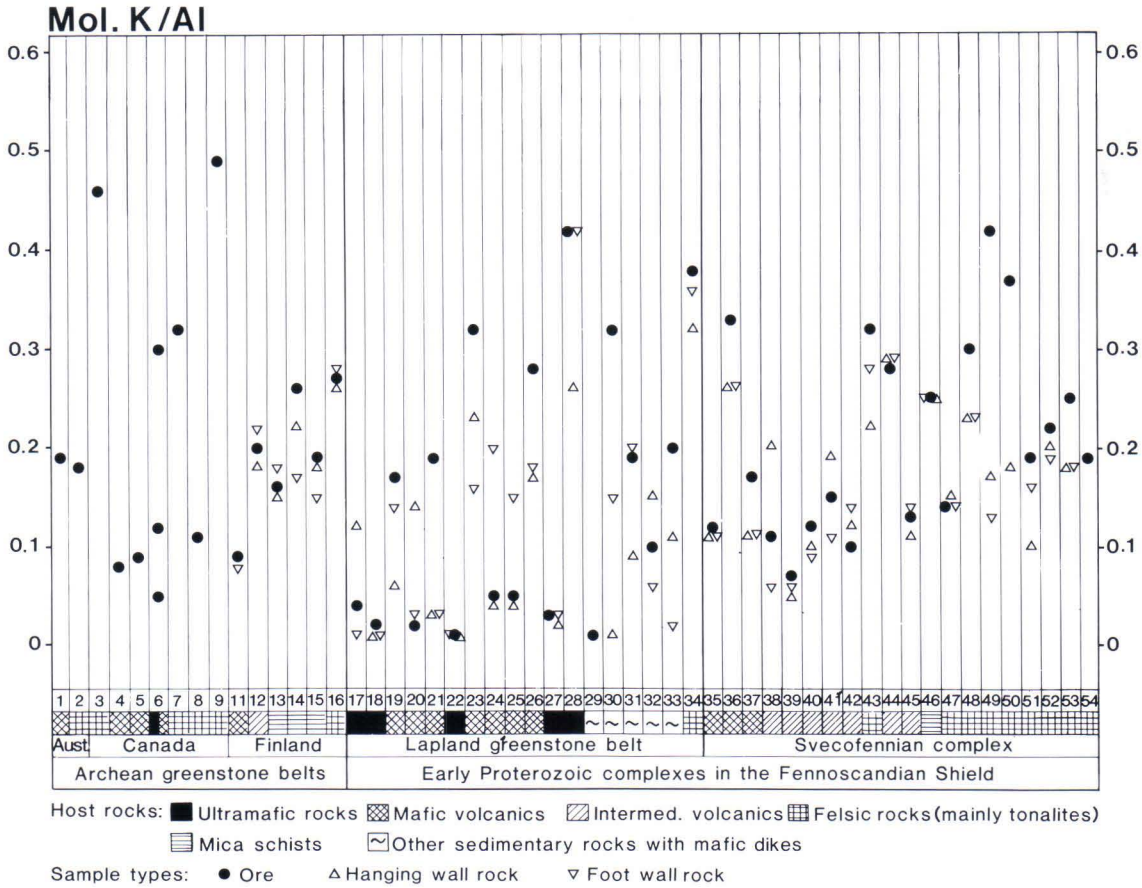


Fig. 40. Variation in mol. K/Al ratios in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

lower K content than its K-poor host rocks, although all Al would be bound in K-micas, because of the dilution effect of abundant silica. Likewise, a pervasively altered K-enriched ultramafic rock may still have a lower K content than a normal granodiorite.

Because the chemical components of rocks have a constant sum, changes in content of a particular element during alteration record a relative change, but not the true amount of element gained or loosed. Hence, detailed studies of wall-rock alteration should apply mass-balance calculations recording mass gains or losses of chemical components. For example, Kerrich and Fyfe (1988) present volume factors for mesothermal deposits, which range from 0.8 at the periphery of alteration domains to 7 at vein margins. The peripheral alteration domains are characterized by removal of Ca, Mn and Mg, and to some extent of Cr, Ni, Sr and S (Kerrich and Fyfe, 1988). The major and minor elements combine with CO_2 from the fluid and form carbonate minerals leading to considerably increased volume factors at the places of carbonate and vein precipitation.

Mass-balance calculations are, however, beyond the scope of this paper and difficult to compute without analyses for unaltered wall rocks from each locality. Results presented here are studied as ratios of geochemically similar ele-

ments and on a mineralogical basis using molecular ratios for determining relative saturation (see, e.g., Kishida and Kerrich, 1987). This also allows comparison between different host-rock lithologies.

From the above given facts, it can be concluded that it is neither relevant nor valid to compare major element abundances from different deposits. This can be demonstrated, for instance in the case of silica, which is a ubiquitous component of gold mineralization, precipitating from ore-forming fluids and being liberated in many reactions related to wall-rock alteration (see amongst others, Fournier, 1985; Colvine et al., 1988). The mafic-ultramafic-hosted deposits in the Lapland greenstone belt, for example, show a wide range of SiO_2 contents (19 to 52%) mainly reflecting the replacement of silicates by carbonates and the fortuitous presence of quartz-vein material in the analysed sections (Fig. 39). The basaltic — andesitic-hosted deposits have, in general lower SiO_2 than tonalite-hosted deposits in the Svecofennian complex, although the ranges of contents largely overlap.

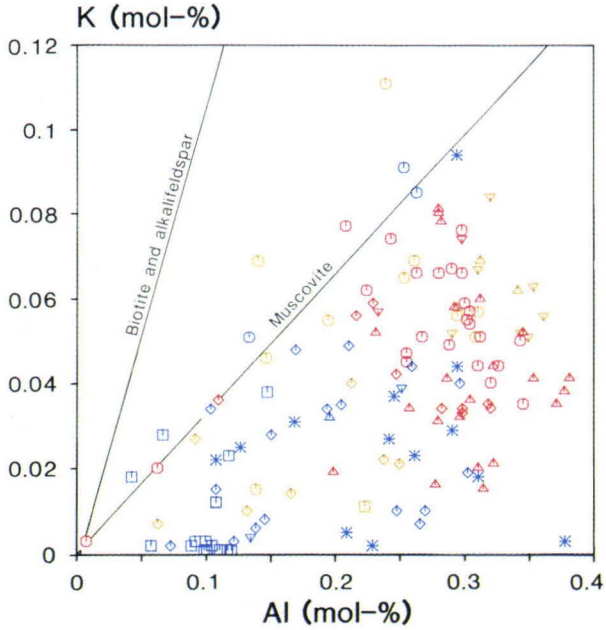


Fig. 41. Mol. K — Al relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Lithophile elements

Potassium addition is one of the most universal alteration phenomena associated with gold mineralization, and is studied here as a function of Al, Rb, Ba and Na contents. Potassium is bound in Al-bearing silicates, of which muscovite is most commonly associated with mesothermal gold mineralization. Biotite and alkalifeldspar are nevertheless also common in many deposits. The molecular K/Al ratio is 1/3 for muscovite, and accordingly 3K/Al ratio has a value close to one in completely altered rock, where all Al is bound in muscovite. Biotite and K-feldspar contain three times more K than muscovite such that mol.K/Al = 1.

Figures 40 and 41 show that K saturation is highly variable amongst the mesothermal deposits studied. This is particularly the case for the ultramafic- and sediment-hosted deposits in the Lapland greenstone belt, which were initially very poor in K, but locally show extreme K alteration associated with gold mineralization. For the deposits in the Svecofennian and Archean terrains, K saturation is also variable indicating increased saturation in association with mineralization. The mol.K/Al ratios are, on average, higher in initially K-rich rocks, but may attain high values irrespective of the host-rock lithology. The highest saturation values are not restricted to ore samples, which indicates that the degree of K alteration does not directly correlate with extent of gold deposition.

Rubidium closely follows K in geological processes, because Rb^{1+} can readily substitute for K^{1+} in K-bearing minerals (see, Shaw, 1968). Thus the K/Rb ratio may be diagnostic for the source processes of hydrothermal mineralization (see e.g., Kerrich, 1989). Our data indicate similar behavior for these elements in mesothermal gold mineralization with a mutual correlation coefficient of 0.93 when taking the whole data

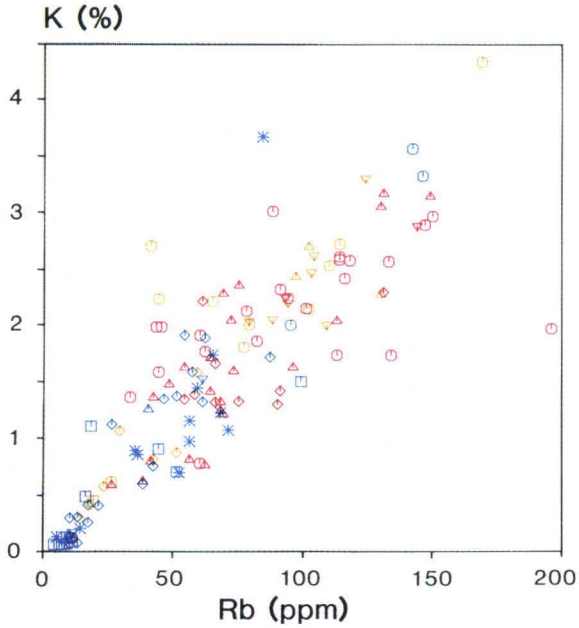


Fig. 42. K — Rb relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

set (Fig. 42). There are, however, marked differences between the provinces in average ratios and in the variation of the ratios (Figs. 42 and 43). The Archean deposits exhibit the most coherent pattern, the bulk of ratios falling between 230 and 270 and with a tendency towards higher values, up to 658 at Page Williams and 506 at New Celebration. Anomalously low values were obtained for Lokkiluoto and Kelokorpi. This pattern closely resembles that reported from the Abitibi belt by Kerrich (1989), where most values are between 230 and 380, close to the crustal average of 285 (Taylor and McLennan, 1985).

Deposits in the Svecofennian complex and especially in the Lapland greenstone belt show a wide variation in K/Rb ratios, lower average values and a tendency towards Rb enrichment. These kinds of patterns are typically formed during magmatic differentiation, but may also be formed as a consequence of granulite metamorphism in the source region (see, Kerrich, 1989).

Barium seems generally to follow K in the deposits in the Archean and Svecofennian terrains, whereas gold mineralization in the Lapland greenstone belt consistently shows low Ba contents lacking any distinct relationship to K abundances, thus demonstrating that Ba was not generally enriched in the ore-forming fluids in that area (Fig. 44).

Although Ba is commonly enriched in epithermal gold deposits, occurring in baryte veins, it is only seldom encountered in mesothermal deposits (Hutchinson, 1987). In our data, samples from the Page Williams mine (13.3%) and the Pahtavaara deposit (12.9%) are, however, distinctly anomalous for Ba, correlating with locally abundant baryte.

Potassium tends to replace Na in alteration associated with gold mineralization, such as when albite reacts with fluids to form muscovite. This is particularly evident in the data from the Lapland greenstone belt, where initially low-K ultramafic and mafic lithologies, which were typically highly enriched in Na due to early synvolcanic alteration, have subsequently been altered to muscovite and/or biotite predominated assemblages during gold mineralization. This has resulted in extreme variation in the K vs. Na diagram (Fig. 45). In the Archean and Svecofennian provinces, total variation is much less, although K enriched rocks are also typically present.

Carbon

Carbon, present mostly in carbonates, graphite or as hydrocarbon inclusions, is virtually ubiquitous in the alteration domains of both epithermal and mesothermal gold deposits, indicating that CO_2 was an important component of the ore-forming fluids (e.g., Boyle, 1979; Bodnar et al., 1985; Colvine et al., 1988). However, mesothermal deposits within amphibolite facies rocks often lack carbonation due to higher temperature mineralization conditions (Colvine et al., 1988). The maximum amount of carbonates in a rock

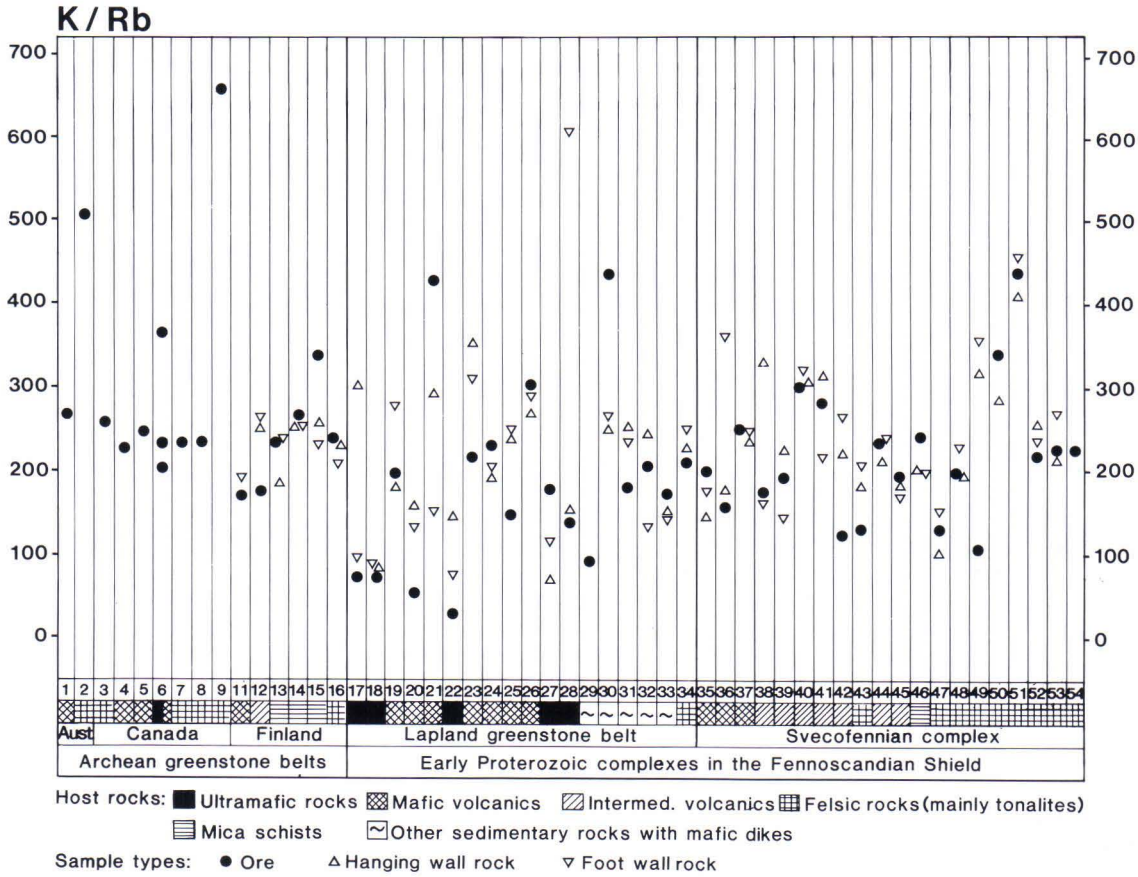


Fig. 43. Variation in K/Rb ratios in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

is a function of Ca, Mg and Fe contents, and carbonation is considered here as a molecular ratio $CO_2/(Ca+Mg+Fe)$, which gives a value close to zero in carbonate-deficient rocks and approaches unity in completely carbonated rocks, when all Ca, Mg and Fe are bound in carbonates (cf., Kishida and Kerrich, 1987).

The degree of carbonation differs markedly between provinces (Figs. 46 and 47). Both the volcanic and sediment-hosted deposits from the Lapland greenstone belt show the most pervasive carbonation. The Archean deposits likewise exhibit well-developed carbonation, except for the supracrustal-hosted deposits in the Ilomantsi area and the Page Williams mine, which are characterized by a total lack of carbonates, evidently due to a somewhat higher metamorphic grade. The deposits in the Svecofennian complex, excluding the Björkdal mine, do not in general contain carbonates, and the somewhat elevated CO_2 contents may be at least partly related to post mineralization alteration.

Graphite-bearing sedimentary rocks host a number of gold deposits, and graphite has evidently acted as the reducing agent in Au precipitation in certain occurrences (Groves and Barley, 1988; Naden and Shepherd, 1989). In addition, graphite may also have been precipitated from

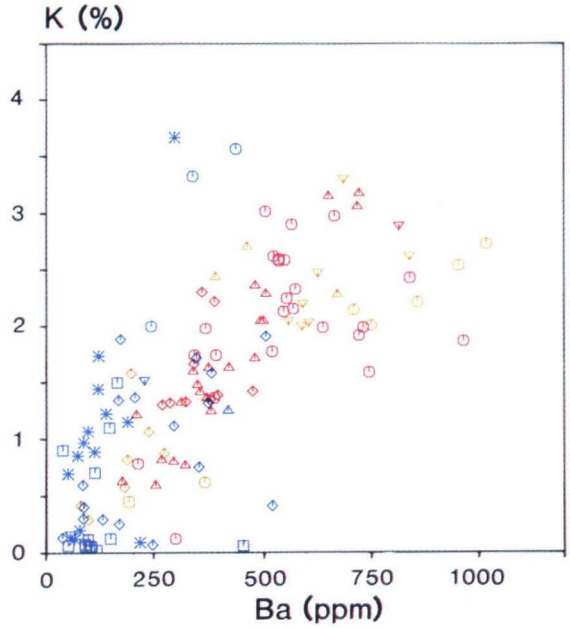


Fig. 44. K — Ba relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

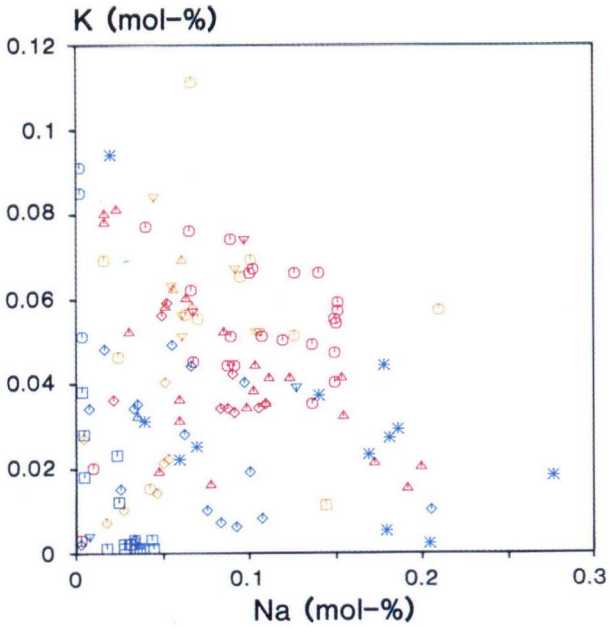


Fig. 45. Mol. K — Na relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

fluids in some gold deposits (Boyle, 1979). Graphite seems to be generally absent (<0.05%) in the deposits sampled here (Apps. 2 and 3). Hoyle Pond (0.06%), Owl Creek (0.33%) and the graphite flow ore at Kerr Addison (0.25%) are the only graphite-bearing Archean deposits. Of the deposits in the Svecofennian domain, one of the wall-rock samples from Pirilä N and from Kalliosalo, contain some graphite.

In the Lapland greenstone belt, only Suurikuusikko (0.82%), Rovaselkä (0.29%), Bidjovagge (0.23%) and Soretiavuoma (0.09%) exhibit elevated graphite contents in the ore (and wall-rock) samples, while Saattopora S shows enrichment in the wall-rocks but not in the ore. Graphite has been suggested as the reducing agent for Au deposition at Bidjovagge (Söderholm and Nixon, 1988). On the other hand, graphite-bearing sedimentary rocks are very common at many stratigraphic levels within the Lapland greenstone belt, particularly in comparison with the amount of graphite in the gold deposits, implying that this could not have been the most widespread deposition mechanism.

Water, chlorine and fluorine

Hydrolysis is one of the main alteration phenomena in hydrothermal gold deposits, leading to the ubiquitous presence of water-bearing silicates such as clay minerals, sericite, biotite, chlorite, talc and serpentine. Water content of a rock is mainly a function of Al such that for sericite the molecular ratio $3H/2Al = 1$, for chlorite $H/4Al = 1$, and for biotite $H/2Al = 1$. Since the ratio varies considerably between the different commonly occurring minerals, the exact degree of water saturation can only be estimated. Although the absolute water contents of different provinces largely overlap, the molecular H/Al ratio indicates that the degree of water saturation is characteristic for each province in that the mineralization in the Lapland greenstone belt is associated with the most extensive hydration, whereas it is somewhat less developed in the Ar-

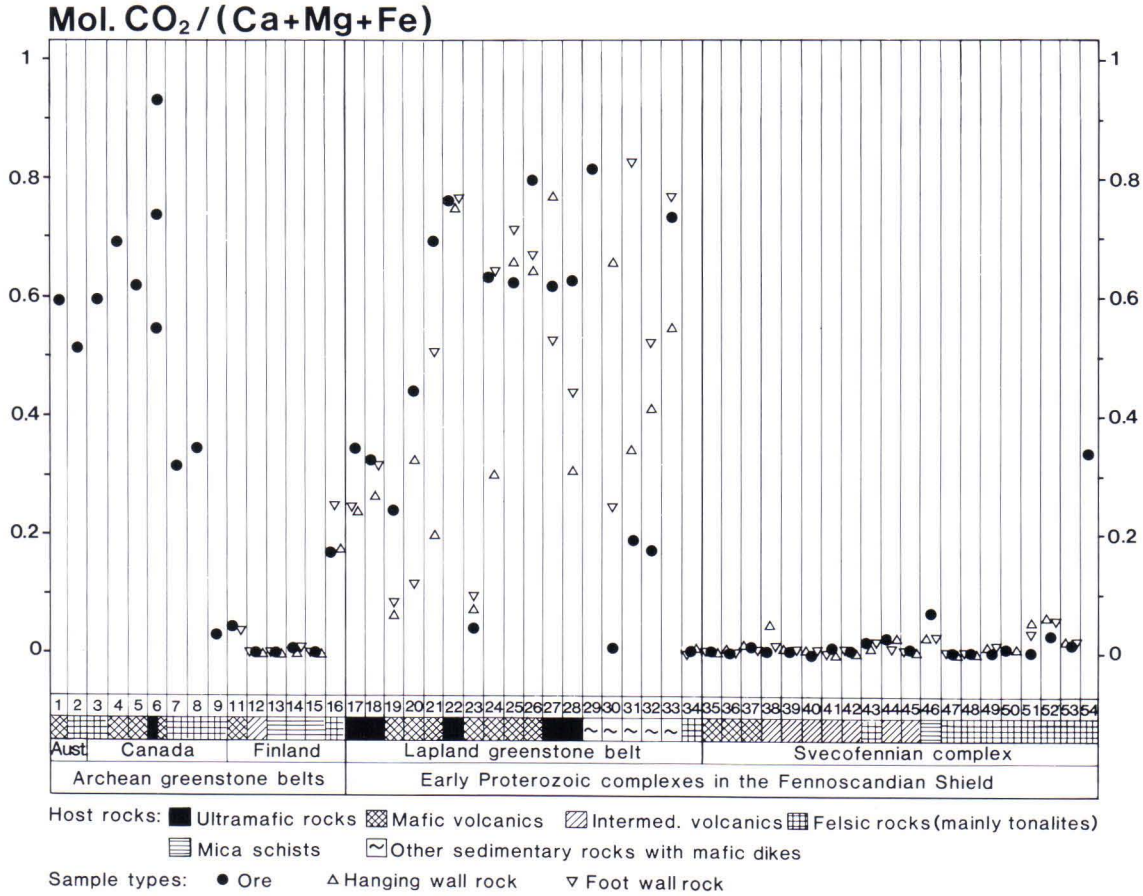


Fig. 46. Variation in mol. $CO_2/(Ca+Mg+Fe)$ ratios in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

chean deposits and weakest of all in the deposits within the Svecofennian terrain (Figs. 48 and 49). The clustering is partly due to the bias in host lithology, the ultramafic rocks, which are common in Lapland, exhibiting the highest saturation values, and granitoids, typical in the Svecofennian province, the lowest. In the former, water is commonly bound to Al-deficient minerals, such as talc and serpentine, in addition to Al

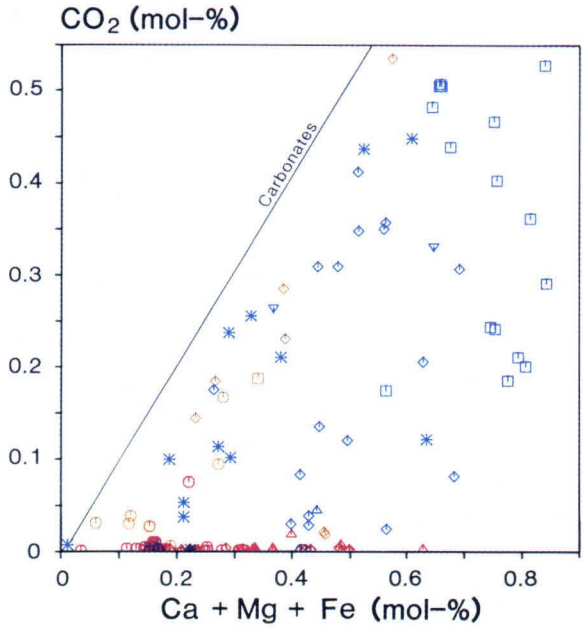


Fig. 47. Mol. CO_2 — $Ca+Mg+Fe$ relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

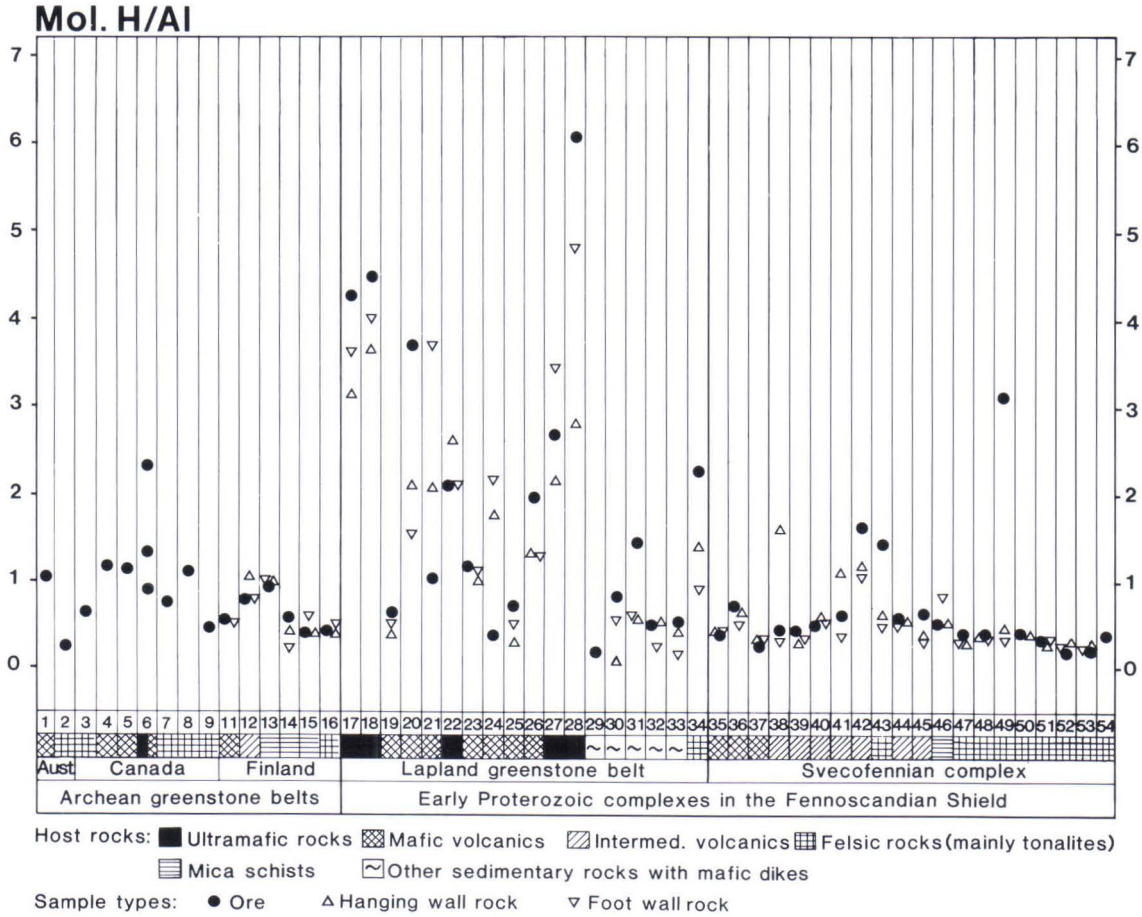


Fig. 48. Variation in mol. H/Al ratios in mesothermal gold deposits and their altered wall rocks (detailed information on deposits and samples are given in Figs. 1—3, Tables 1—2, and App. 1).

silicates, which may explain the high relative water contents of ultramafic-hosted deposits. However, mafic volcanic rocks for example, indicate that different degrees of water saturation in the provinces cannot be explained alone by lithological variations.

Chlorine and F are common elements in hydrothermal gold deposits, but are seldom enriched to larger concentrations (Boyle, 1979). Except for fluorite/topaz-bearing epithermal deposits, which may contain F >5%, F content usually varies between 10 to 2100 ppm, with F occurring principally in mica, tourmaline, apatite and chlorite. Chlorine is not normally enriched in gold deposits, and the general range for gold-quartz deposits is from 100 to 500 ppm (Boyle, 1961, 1979).

Our data also indicate that abundances of these elements are, in the gold deposits sampled, close to background levels and are generally related to lithology (Apps. 2 and 3). Chlorine contents vary from <50 ppm in granitoid-hosted to >500 ppm in mafic-hosted deposits. The ultramafic footwall rock at Sirkka W in the Lapland greenstone belt (1840 ppm) and the Archean Lokkiluoto deposit (670 ppm) are the only anomalously enriched samples. Fluorine contents vary from <100 ppm in ultramafic-hosted to >800 ppm

in granitoid-hosted deposits, and the quartz dioritic foot-wall rock of the Kaapelinkulma deposit in the Svecofennian province is the only sample exhibiting a content > 1500 ppm (2800 ppm).

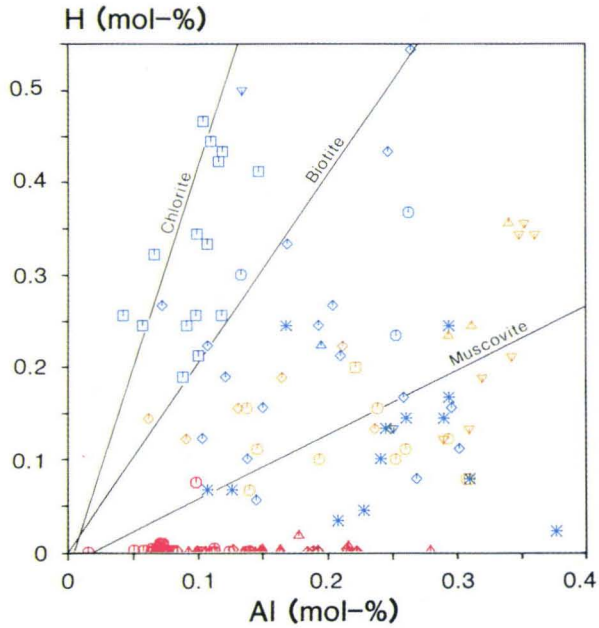


Fig. 49. Mol. H — Al relationships for ore and wall-rock samples from mesothermal gold deposits. Symbols as in Fig. 2.

Elements with no particular response to mineralization

Immobile elements

About one third of the determined elements exhibit effectively immobile behavior during the hydrothermal processes associated with gold mineralization. Their concentrations and interelement ratios in deposits and altered wall rocks are strongly related to those of the parent lithologies at all localities. This group includes Al, Ga, P, Sc, Ti, V, Zr, Hf and Nb (cf., Maclean and Kranidiotis, 1987; Kerrich and Fyfe, 1988; Kerrich, 1989).

The rare earth elements also seem to be practically immobile. Their contents are reduced in mineralized rocks, but their typical patterns are retained. This is demonstrated in Fig. 50, where basaltic komatiite-hosted mineralization at Pahtavaara, which is now characterized by tremolite-chlorite-biotite-talc-carbonate-quartz alteration show, REE patterns congruent with the exception of increased Eu in the ore sample, with that of unaltered komatiite (RS 131) from the nearby Sattasvaara area. The relative decrease in abundances indicates, however, considerable volume increase.

The very low values recorded from the Soretiavuoma mineralization are due to intense alteration to a carbonate-albite-quartz ± (talc-chlorite) lithology with abundant carbonate-quartz veining, although the protolith may have been a peridotitic komatiite having even lower original concentrations. Nevertheless, the ultramafic nature of the host rock can be unambiguously deduced from the characteristic REE patterns. Except for Eu, which could have been mobile in the hydrothermal systems, scattering observed in the other elements may largely be due to analytical uncertainties where concentrations are near or below chondritic abundances. Likewise, samples from the tonalite-hosted mineralizations in the Svecofennian province show parallel patterns, representing typical Svecofennian tonalites (see e.g., Nurmi and Haapala, 1986), regardless

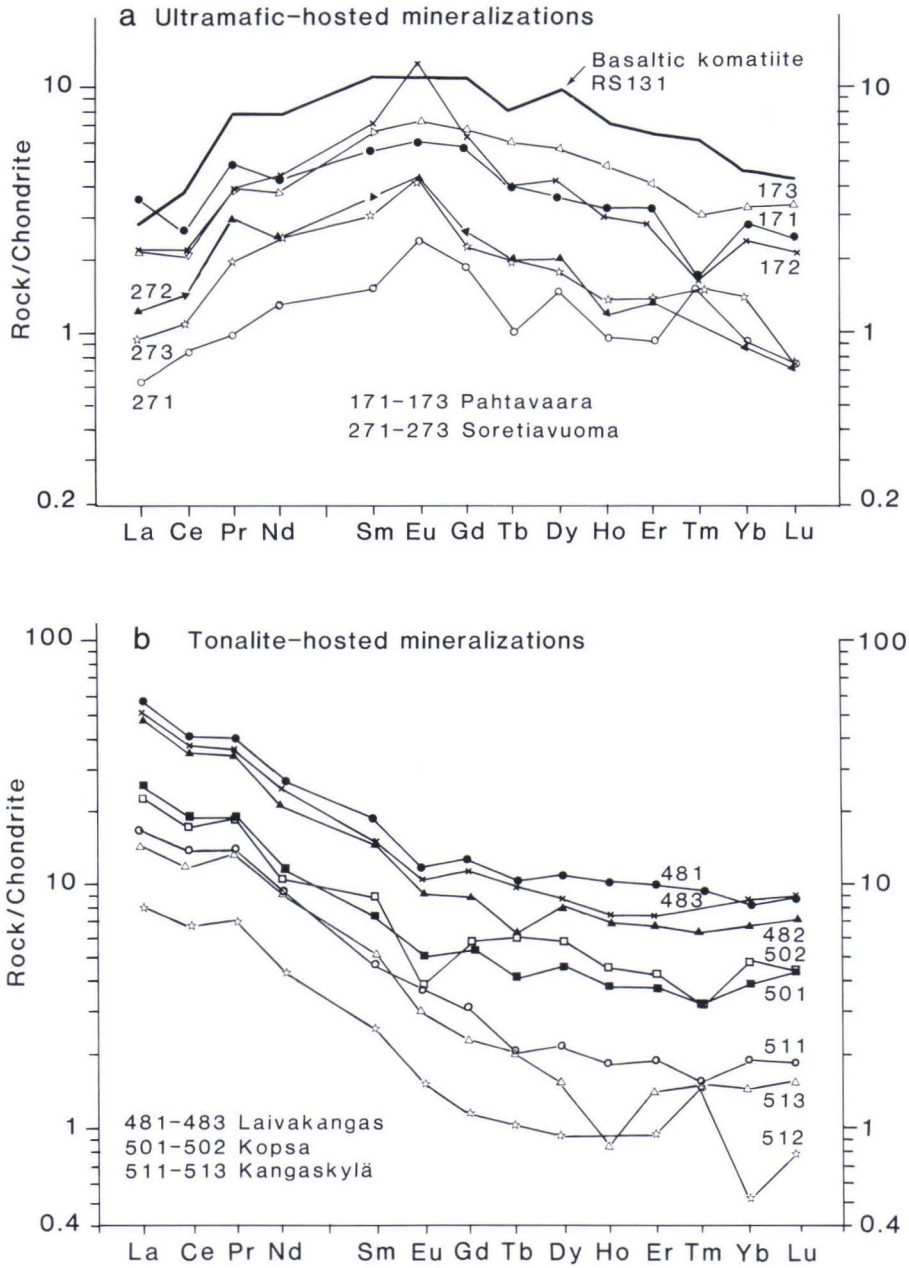


Fig. 50. Chondrite-normalized rare-earth element patterns for selected mesothermal gold deposits hosted by: a) ultramafic rocks in the Lapland greenstone belt; and b) tonalites in the Svecofennian complex.

of the intensity of silicification, potassic alteration or sulfidation (Fig. 50 b).

Palladium and platinum

Platinum group elements are locally encountered in hydrothermal gold deposits, and Pd is in particular alloyed with gold in some placer deposits (Boyle, 1979). Data in Kerrich (1983) show that Pd is enriched up to 180 ppb in a few Archean mesothermal deposits in Canada.

Platinum contents in our samples are systematically at or below the detection limit (4 ppb), indicating that Pt contents are close to background abundances in the gold deposits analysed (Apps. 2 and 3). Palladium contents in the Archean deposits vary from <0.1 to 8.3 ppb at the ultramafic-hosted ore of Kerr Addison. The range for the gold deposits in Proterozoic terrain is somewhat greater, from <0.1 to 19 ppb, the highest contents being observed in mafic-ultramafic-hosted deposits. Given that background values of Pd are around 5 to 20 ppb in mafic-ultramafic rocks (Kerrich, 1983; Kontas et al., 1986, 1990; Govindajaru, 1989), there is no apparent enrichment of Pd in the studied deposits.

DISCUSSION

The present study indicates that Archean and Early Proterozoic, mesothermal gold deposits are invariably enriched in a number of elements, which can be broadly classified as Au-affiliated rare elements, base metals and elements related to wall-rock alteration. Although individual deposits have their own geochemical characteristics, which may also differ from those in adjacent deposits within the same lithology and structural setting, the main gold provinces sampled here nevertheless exhibit typical general ranges for many elements and element ratios. This must be a consequence of the relationship between gold mineralization and crustal evolution being distinct for each province. The variation that is seen implies differences in fluid sources and deposition processes. Genetic aspects are not, however, dealt with any further in this paper.

The results demonstrate that the sampling procedure adopted, namely taking single, carefully selected and homogenized drill-core intersections from each deposit is representative enough to be used in defining general geochemical characteristics for the deposits and provinces. In addition to Au, the results of the other elements naturally also record average contents in bulk samples from typical gold ore, delineated using a cut-off value of 1 ppm, and from adjacent wall rocks. The use of the same cut-off value in all targets leads to similar median Au contents for the ore samples from different provinces, which makes possible a direct comparison of the results of Au-affiliated elements between the deposits and the provinces. Comparison of original Au assays with results from the bulk samples shows good coherence, indicating the success of sample homogenization. Repeated analyses and results for the suite of common rock types suggest that analytical accuracy is good for all relevant elements.

Enrichment of elements in gold deposits

Enrichment of the most important elements in gold deposits relative to background is illustrated in Fig. 51. Since the background contents were difficult to determine individually, all values were computed using a hypothetical basalt as the common reference sample (Table 21). Element abun-

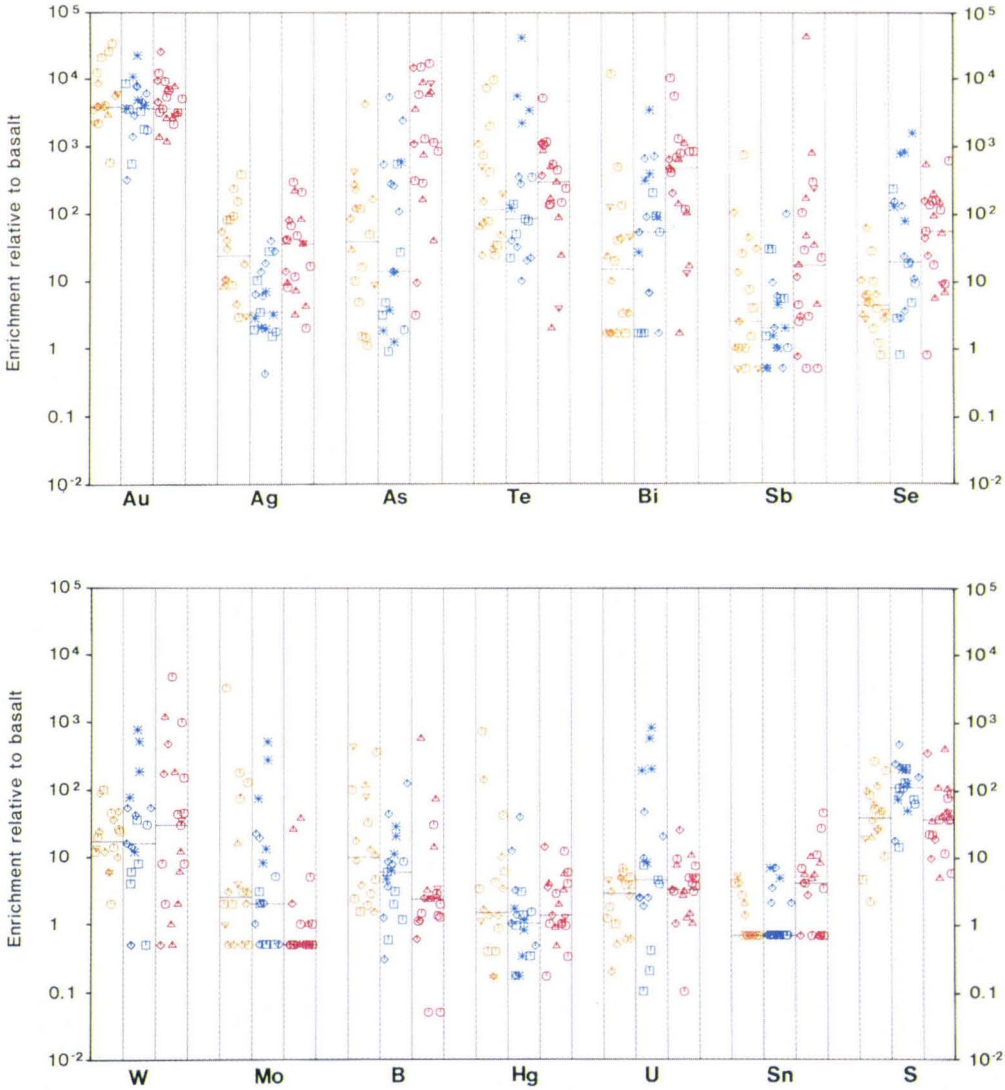
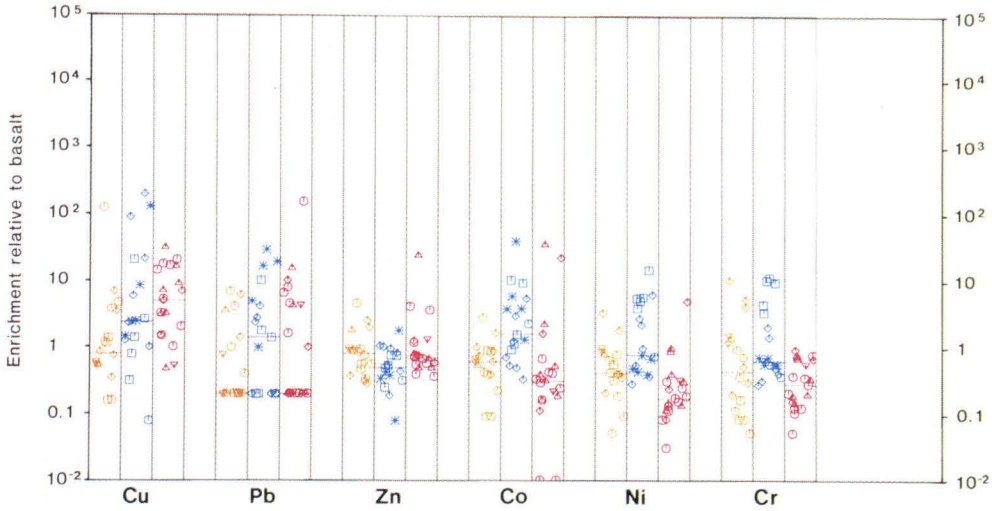


Fig. 51. Enrichments of selected elements relative to background abundances in basalts (see, Table 21) for ore samples from mesothermal gold deposits. Brown refers to deposits in the Late Archean greenstone belts; blue, to those in the Early Proterozoic Lapland greenstone belt; and red, to the Early Proterozoic Svecofennian complex. Symbols refer to principal host-rock lithology as in Fig. 2., and horizontal bars indicate median.

dances were selected according to literature values, supplemented by our own data for some rare elements in order to be representative of average contents for typical basalts. Basalt was selected as a reference, firstly because mafic rocks are the most common host rocks of mesothermal deposits world wide, but also because average abundances of rare elements are best known for basaltic rocks. The background contents for the Au-affiliated rare elements are very similar for all igneous rocks, although for the base metals at least, the usage of basalt values may cause some bias.

According to bulk samples from 17 deposits/



ore bodies in Archean greenstone belts in Finland, Canada and Western Australia, 18 deposits in the intracratonic Early Proterozoic, Lapland greenstone belt, and 20 deposits in the juvenile Early Proterozoic Svecofennian complex in the Fennoscandian Shield, element enrichment factors for Precambrian mesothermal gold deposits show extreme variation, from 1 to $>10^4$ for Au and many affiliated rare elements, but typically being between 0.1 and 10 for the base metals (Fig. 51).

Although the factors may attain extreme values in individual deposits, and with correspondingly high mean values, the median values offer a better indication of typical enrichment, and are much lower than those reported by Kerrich (1983) from mesothermal deposits in the Abitibi belt. This evidently results from different sampling strategy. Kerrich (1983) analysed samples mostly having extreme Au contents, whereas we used bulk samples showing typical economic grades of gold ore. Furthermore, our data indicate that although the results from the Archean deposits show a marked coherence with those by Kerrich (1983), the association of various elements with the Early Proterozoic gold provinces is unmistakably different from that in the Late Archean.

In general, Au is the only element that is systematically enriched $>10^3$—10^4 times the basalt background in ore-grade samples. Tellurium shows enrichment factors from 10 to 10^4; and As and Bi from 1 to 10^4. Selenium, W, Mo, B and S are enriched from <1 to 10^3, and Ag, Sb, Cu and Pb from 0.1 to 10^2 times the basalt values. Mercury, U, Co and Sn are either depleted or enriched <10 times the background. Zinc, Ni and Cr seem to be mostly somewhat depleted and generally do not exhibit enrichments other than those related to host-rock lithology.

The influence of host rock composition on the geochemistry of gold deposits cannot be statistically studied, because of the small number of samples. Nevertheless, there are no distinct indications that the abundances of rare elements

Table 21. Background contents (ppm) of selected elements in hypothetical basalt (based on Govett, 1983; Kerrich, 1983; Govindajaru, 1989; and our own data).

Ag	0.05	Cu	90	Se	0.05
As	2	F	370	Sn	1.5
Au	0.001	Hg	0.015	Te	0.005
B	5	Mo	1	Tl	0.2
Ba	300	Ni	160	U	0.5
Bi	0.03	Pb	5	W	0.5
Co	45	S	300	Zn	120
Cr	200	Sb	0.2		

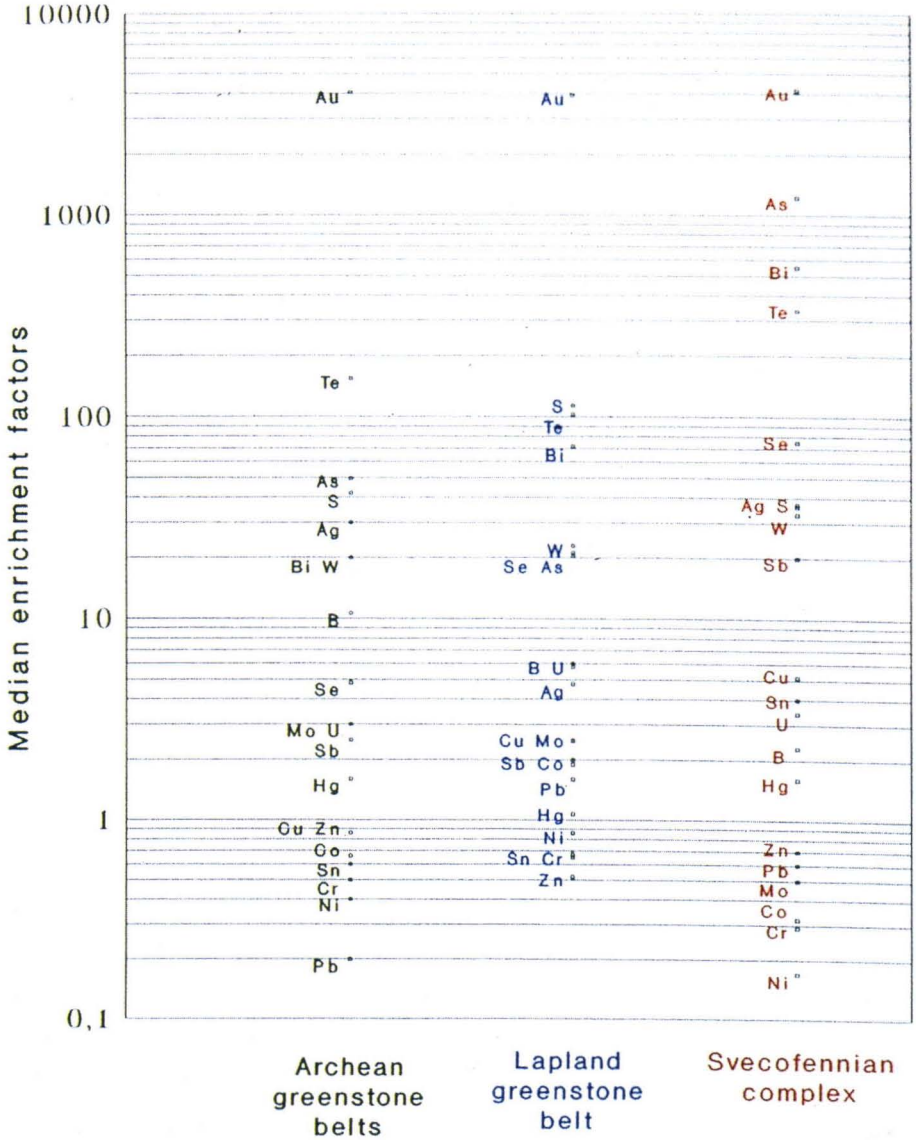


Fig. 52. Median enrichments of selected elements relative to background abundances in basalts (Table 21), for ore samples from mesothermal gold deposits in different provinces.

have been affected by lithological changes. The only lithological group that differs distinctly from the others in a particular province, is that of the sediment-hosted deposits in the Lapland greenstone belt, which are anomalously high in Te, Se, Bi, U and Mo. However, this is evidently more related to genetic and geographical factors than merely to lithology itself. There may be some tendency for the Archean tonalite-hosted deposits to be anomalously high in Ag and low in As. Likewise, the ultramafic-hosted deposits in the Lapland greenstone belt seem to be somewhat

deficient in both Ag and As compared with the other deposits.

Average enrichment factors of the elements and characteristic element associations in the provinces have been visualized in Fig. 52, showing the medians of enrichment factors for selected elements. The association of the elements with gold deposits is characteristic for each province, revealed by one to two orders of magnitude differences in the median enrichment factors for many elements. Compared to the extreme enrichment of Au, the affiliated elements show, in most instances, only moderate median enrichment, of the order of 10 to 100 times average basaltic contents. However, the deposits in the Svecofennian domain are much more strongly enriched in As, Bi and Te, and less distinctly in Se, Ag, Sb, Cu and Sn than those in the other provinces. The only elements showing the opposite behavior are B and Mo.

In general, Te is the most consistently high in our data, median enrichment factors varying from 103 in the data from Lapland to 340 in these from the deposits in the Svecofennian complex. Arsenic and Bi attain enrichments up to 1200 and 550 times basalt values, respectively, in the deposits of the Svecofennian complex, compared to median factors 20 to 70 in the other provinces.

Silver, although ubiquitous in all types of gold deposits, generally shows weak enrichment factors of 30 and 37 times the basaltic background in the deposits of the Archean and Svecofennian terrains, and is even an order of magnitude lower in the deposits from the Lapland greenstone belt. In contrast, the latter are particularly enriched in S (median enrichment factor 110), compared to the other provinces (36 and 42). The median enrichment factor for Se varies from 75 in the deposits of the Svecofennian province through 21 in those of the Lapland greenstone belt to 5 in the Archean deposits.

Tungsten is steadily enriched from 20 to 33 times basaltic contents in all provinces. Antimony shows a median enrichment factor of 20 in the data from the Svecofennian complex, but in the other provinces it exhibits only weak enrichment (about 2). Boron seems to be most typically related to Archean deposits, and is rare in the Svecofennian data. On the contrary, Sn is anomalous in the deposits of the Svecofennian province, but low in other provinces. Uranium shows weak enrichment in all provinces, whereas median Hg contents are close to the basalt abundances.

The base metals are typically somewhat depleted in the Archean deposits. In contrast, Cu is typically enriched by a factor of 2.5 in the deposits of the Lapland greenstone belt and is 5 times the basaltic average in the deposits of the Svecofennian complex. The former also shows some enrichment in Co and Pb.

Comparison of geochemical characteristics between Precambrian mesothermal and Phanerozoic epithermal gold deposits is not straightforward, since systematic geochemical studies including a wide range of elements such as, Kerrich (1983) and this paper are few. However, published results and compilations from epithermal deposits (e.g., Radtke et al., 1972; Berger and Bethke, 1985; Berger, 1985; Radtke, 1985; Hutchinson, 1987; Sillitoe, 1989; Clarke and Govett, 1990) indicate that there are striking geochemical differences between the two deposit types.

Mercury, Tl, Sb and Ba are usually highly enriched in epithermal deposits but, according to present data, are only sporadically associated with mesothermal gold mineralization. Ratios of Au/Ag are variable in all mineralization types, the epithermal deposits, however, typically exhibiting higher Ag contents. Base metals are markedly enriched in many epithermal deposits, especially in the southwest Pacific, but except for Cu in the Early Proterozoic mineralization, they appear to be low in the mesothermal deposits. Fluorine is often anomalously abundant in epithermal mineralization in contrast to mesothermal types. Tellurium and Bi are enriched in many epithermal deposits just as in mesothermal deposits, but the paucity of available analytical data preclude making quantitative comparisons.

Element associations of gold deposits

Element associations for individual deposits have been examined by calculating the maximum enrichment of all important elements, excluding those related to wall-rock alteration, relative to the hypothetical basalt. Discrimination between sample types was not considered necessary in this case, since there are number of elements, which although essential components of the mineralizing systems, do not correlate systematically with Au itself. Although each province has its own geochemical characteristics, the element associations are unique for each deposit, and may also differ significantly between adjacent deposits with the same structural setting and host-rock lithology.

Archean mesothermal gold mineralization is characterized by enrichment of a limited number of elements, only 15 of which are enriched by >10 times average basalt in at least one deposit. Of these only 11 elements show enrichment

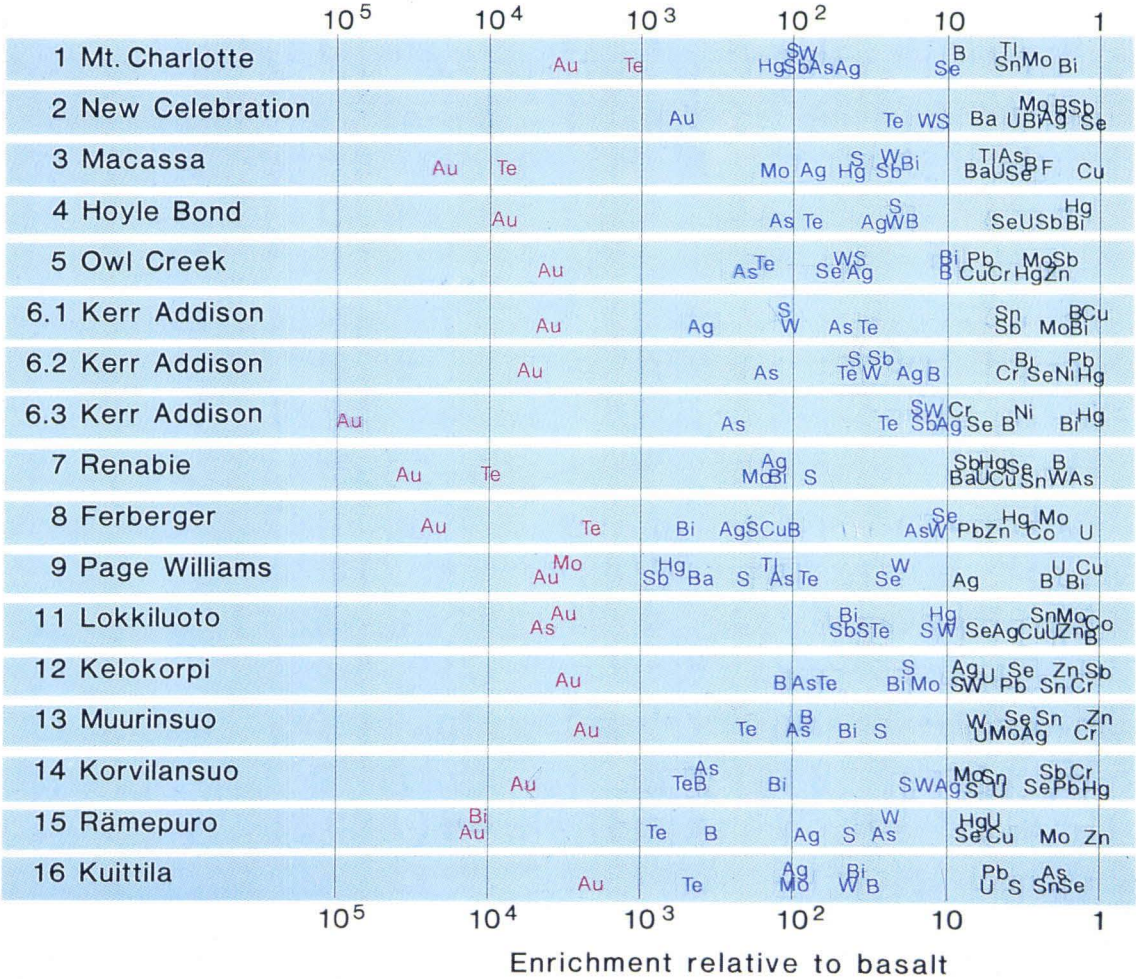


Fig. 53. Element associations for Archean mesothermal gold deposits, based on the maximum enrichment of selected elements in the ore or altered wall-rock samples relative to background abundances in basalts (Table 21)

to the same degree in at least three targets, and the element associations include on average 7.3 elements. In addition to Au, Te is uniformly present, and commonly also S, W and As (Figs. 53 and 54). Silver and Bi are enriched >10 times basaltic abundances in about half of the deposits. Boron, Sb, Mo and Hg are enriched in a few deposits, and Se, Cu, Tl and Ba only in one or two cases. Tellurium, As and Bi often show strong contrasts relative to background values, whereas S, W, Ag and the others show only moderate enrichment.

The Page Williams mine at Hemlo exhibits a unique association including Mo, Sb, Hg, Ba, Tl and Se which are either poorly or not at all enriched in the other deposits sampled. Mt. Charlotte is characterized by high Hg, Sb and Se; Ferderber by Cu; and the deposits in the Ilomantsi area by B which, in the latter region, is evidently a reflection of sedimentary host rocks.

The deposits in the Lapland greenstone belt exhibit a stronger multielement nature than their Archean counterparts. Twenty elements are enriched at least in one deposit by >10 times the mean basalt content, 15 elements are enriched in at least three deposits, and the associations comprise on average 8.7 elements (Figs. 55 and 56). Gold, Te and S are uniformly present at all targets. Tungsten, Se, Bi, As and B are concentrated in at least half of the targets, and As shows especially high enrichment factors. Uranium, Mo, Ag, Sb, Cu, Cr and Pb are associated elements in about one third of the deposits, whereas the rest of the elements appear only occasionally. The sediment-hosted deposits are characterized by strong enrichments in Te, Se, Bi, U and Mo, which are not typical or are only moderately enriched in the mafic-ultramafic-hosted deposits.

The number of elements associated with the deposits in the Svecofennian province (9.0 in

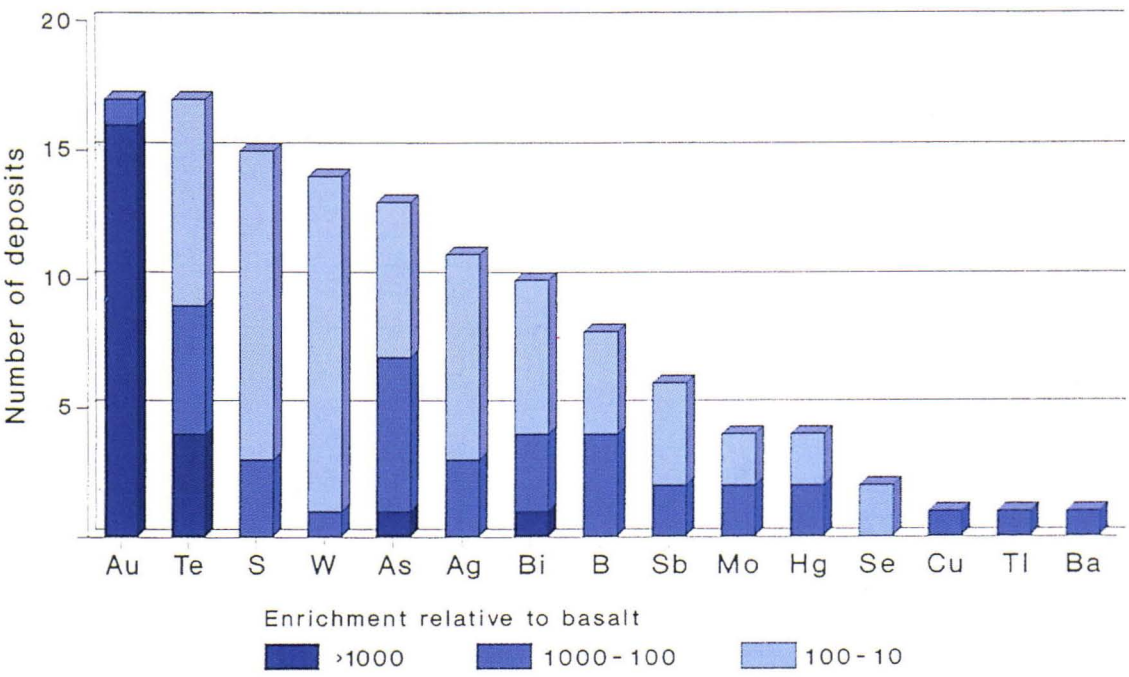


Fig. 54. Frequency and contrasts of concentration (relative to background abundances in basalts) of those elements enriched in Archean mesothermal gold deposits.

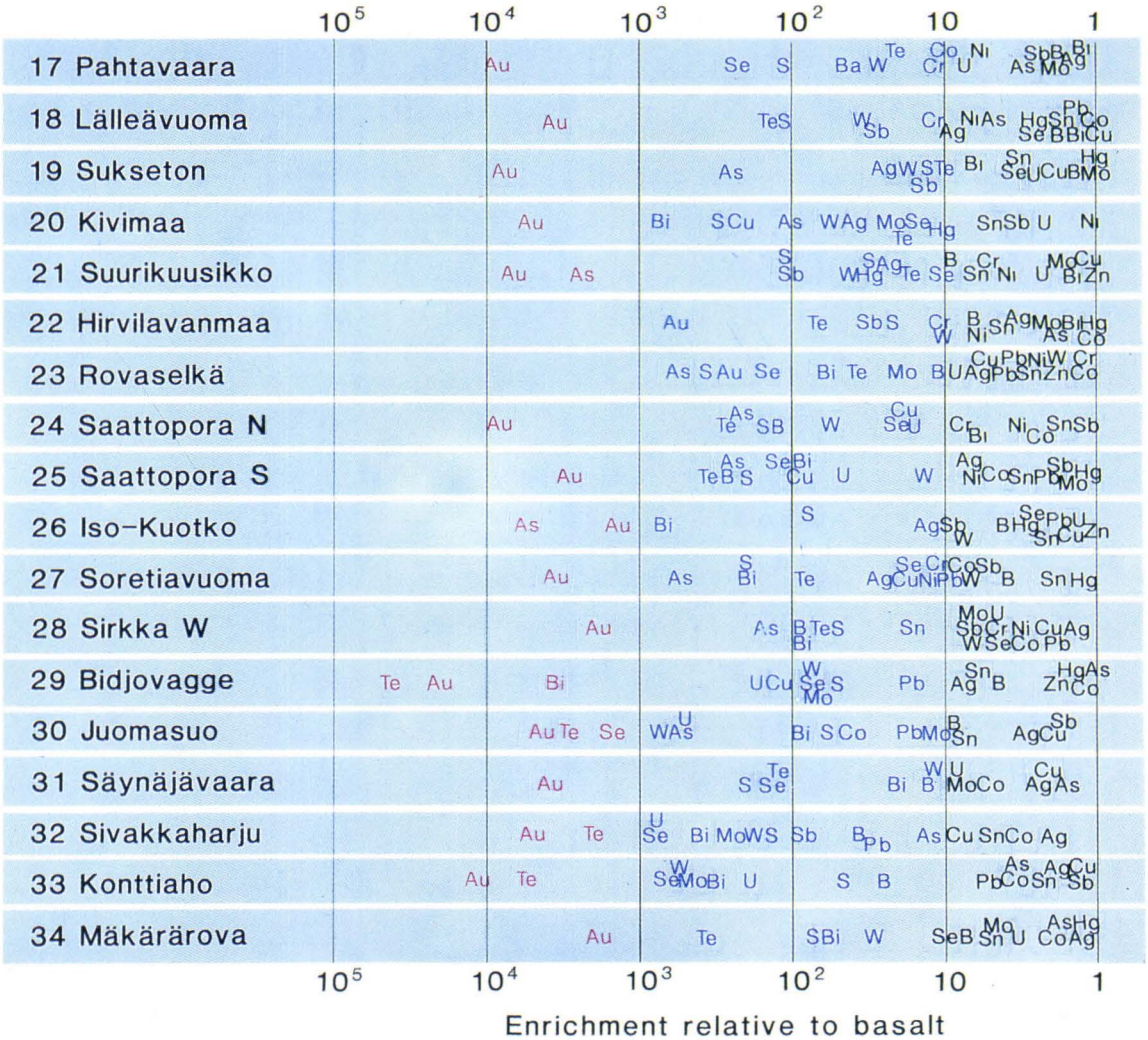


Fig. 55. Element associations for mesothermal gold deposits in the Lapland greenstone belt, based on the maximum enrichment of selected elements in ore or altered wall-rock samples relative to background abundances in basalts (Table 21).

average) is about the same as in those of Lapland, but many of the components commonly show extreme enrichments (Figs. 57 and 58). Bismuth, As and Te are present at practically all targets, and S, Se, W, Ag and Sb in more than half. The semimetals and W show the strongest contrasts with respect to background levels, whereas Ag and S are only moderately enriched. Copper, B and Sn are present in high amounts in some deposits, but the other elements are encountered only exceptionally.

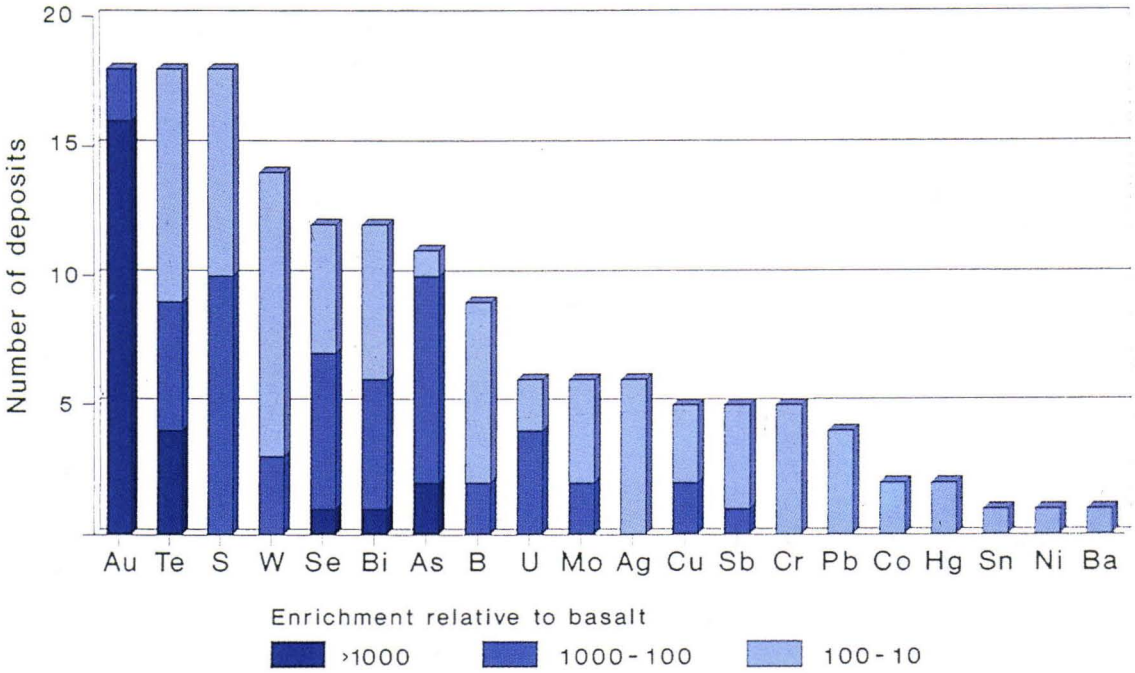


Fig. 56. Frequency and contrasts of concentration (relative to background abundances in basalts) of those elements enriched in mesothermal gold deposits of the Lapland greenstone belt.

Geochemistry of wall-rock alteration

Wall-rock alteration cannot be studied simply by comparing the absolute data, both because of the variations in host-rock lithology, from ultramafic to felsic, causing large ranges in the initial abundances of chemical components, and also the highly variable degree of volume change in individual deposits. Furthermore, alteration is not only a consequence of mineralization processes but have a complex history, unique for each province.

The Archean greenstone belts included in this study can all be regarded as of the extensional type (cf., Groves et al., 1987) meaning rapid crustal evolution at around 2.7 Ga ago with the formation of gold deposits shortly after peak metamorphic conditions (Colvine et al., 1988; Kerrich and Fyfe, 1988). However, mineralization was preceded by synvolcanic, spilitic alteration of varying intensity and by metamorphism typically at upper greenschist or lower amphibolate grade, in comparison to which, mineralization was generally retrogressive.

In contrast, the Lapland greenstone belt developed on a sialic Archean basement during a time interval of several hundred million years, but compressive deformation and metamorphism, typically attaining medium to upper greenschist conditions, occurred at about 1.9 Ga ago. Gold deposition occurred relatively late in this province, typically under brittle tectonic regimes. Premetamorphic alteration in the Lapland greenstone belt is widespread and locally very intense leading to pervasively altered albite-carbonate dominated assemblages (Pankka, 1989; Ward et al., 1989).

Gold deposits in the Svecofennian complex

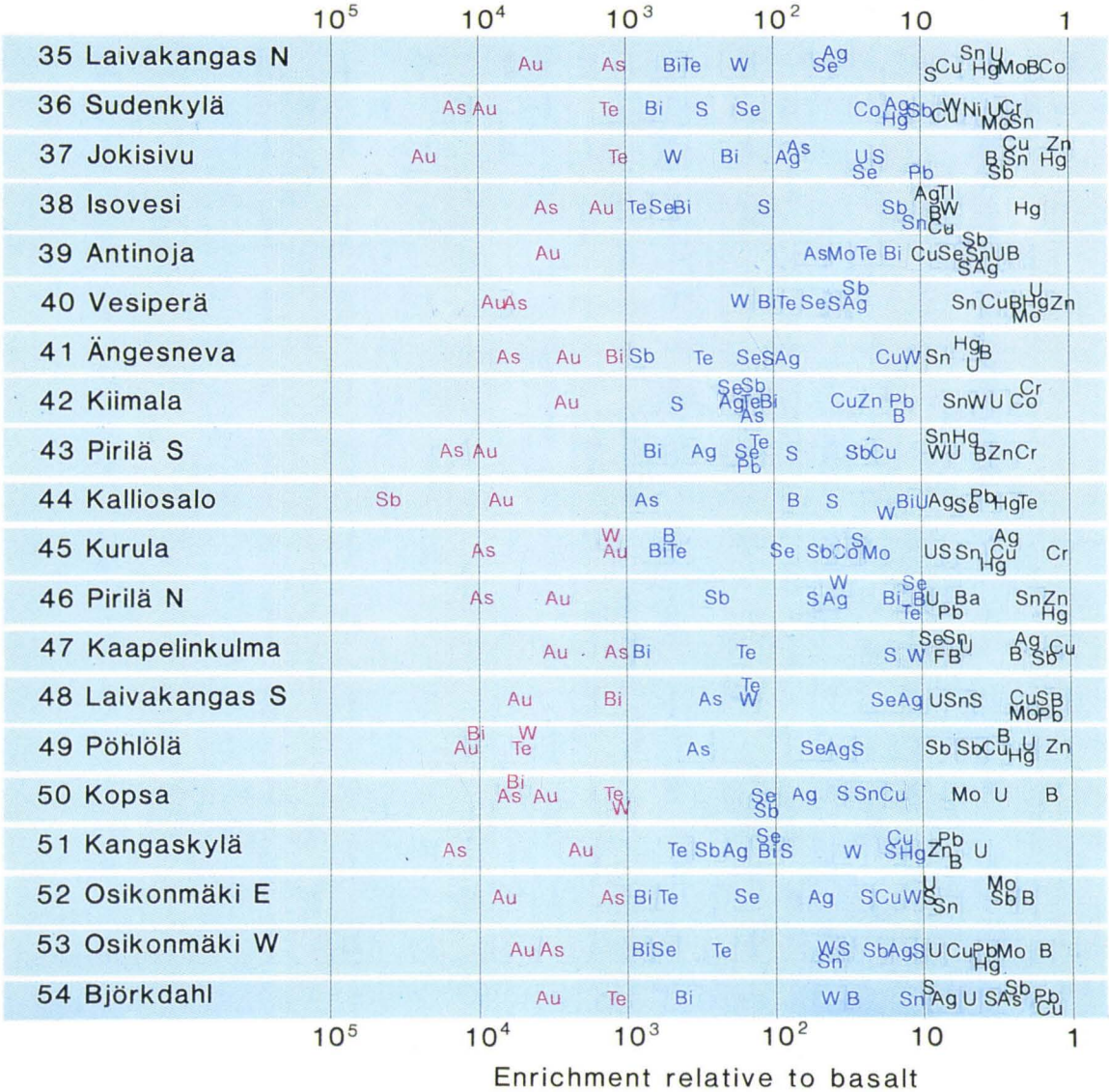


Fig. 57. Element associations for mesothermal gold deposits in the Svecofennian complex, based on the maximum enrichment of selected elements in ore or altered wall-rock samples relative to background abundances in basalts (Table 21).

probably formed simultaneously with or closely followed the major crust building processes. Mineralization is deformed and masked in wide areas by late Svecofennian medium to high grade metamorphism.

Nevertheless, in spite of the complexity of geologic history and alteration processes, mesothermal gold mineralization is clearly characterized by hydration and K alteration of varying intensity, as well as in most instances carbonation. Hydration and carbonation, expressed as mol.H/Al and mol. $CO_2/(Ca+Mg+Fe)$ ratios (Figs. 46 and 48), are better developed in Lapland than in the Archean greenstone belts, although gold

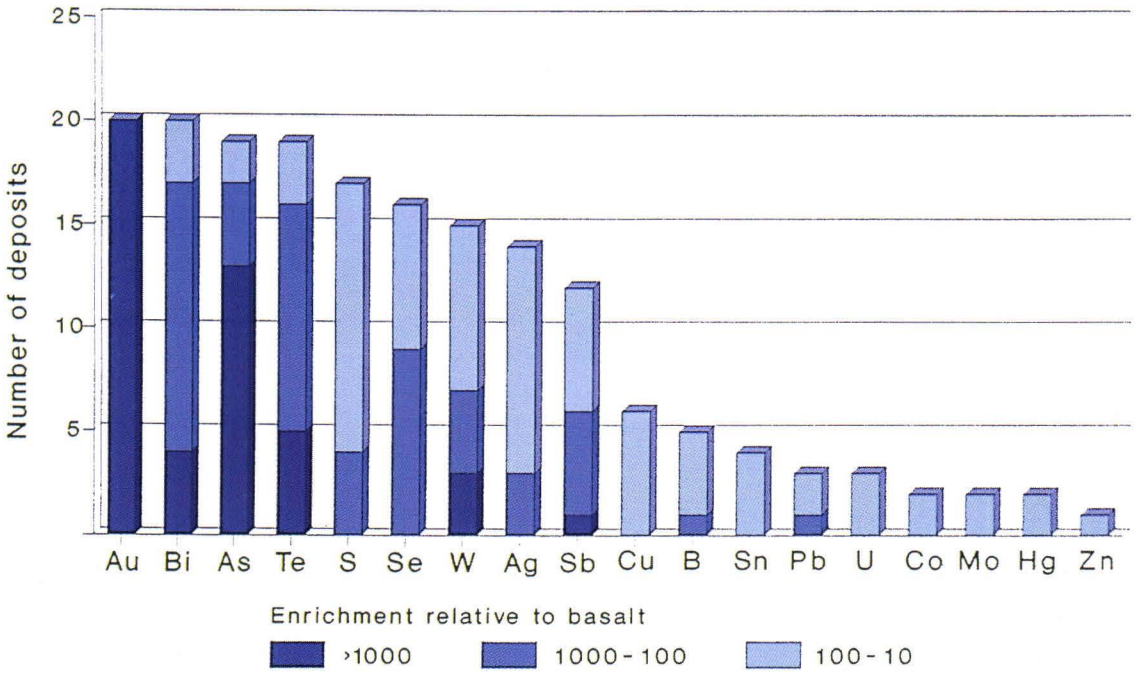


Fig. 58. Frequency and contrasts of concentration (relative to background abundances in basalts) of those elements enriched in mesothermal gold deposits in the Svecofennian complex.

mineralization is in both cases related to extensive fluid flow along major zones of weakness. The more extensive alteration in the former area is obviously due to more pervasive synvolcanic alteration and lower metamorphic grade. Furthermore, many of the deposits in the Lapland greenstone belt are hosted by ultramafic rocks, which also contain Al-deficient H-bearing minerals (talc and serpentine), explaining in part the anomalously high H/Al ratios.

The gold deposits in the juvenile Svecofennian domain do not show such an association with large-scale mineralized zones as the greenstone belt-hosted deposits, occurring instead typically as discrete quartz-vein systems or within small-scale shear zones adjacent to intrusive contacts. Wall-rock alteration is usually weakly developed and limited from a few tens of centimetres to some metres around the lodes, thus accounting for the low H/Al ratios. The post mineralization medium to high-grade metamorphism that affected the deposits in many areas may have caused further devolatilization. Although the virtual absence of carbonation may be in part due to the same process, the general lack of calc-silicates still indicates that gold mineralization in the Svecofennian province was not generally accompanied by carbonation.

Potassic alteration seems to be almost ubiquitously associated with Precambrian mesothermal gold mineralization, although no simple spatial correlation with Au exists, indicating dissimilar conditions of formation for alteration and Au deposition (Fig. 40). It is most distinct in initially K-deficient lithologies within the greenstone belts, where secondary sericite and/or biotite crystallized during the mineralization processes. The gold deposits in the Svecofennian domain are largely hosted by felsic and intermediate rocks, and accordingly the relative change in K is not as pronounced. Alteration is in general more weakly developed and K occurs in alkali feldspar

as well as within phyllosilicates. Post mineralization metamorphism could have locally caused some remobilization of K, and masked the alteration patterns related to mineralization.

There is an extreme variation of K/Na ratios in the deposits of the Lapland greenstone belt, demonstrating the pervasive nature of early Na- and synmineralization K-predominated alterations. However, on the basis of sampling from both Au lodes and their wall rocks, some deposits appear to lack obvious signs of K-alteration, although this do not preclude the possibility of alteration at slightly different spatial locations.

Implications for exploration

Prospecting for gold deposits is one of the most difficult tasks for an exploration geologist. Although mesothermal gold mineralization typically has a close association with structural zones and hydrothermally altered rocks, individual deposits may have a complex structural setting and no direct correlation with either the intensity of alteration or the abundance of sulfides. Ore zones are typically heterogeneous and often impossible to visually delineate or even identify, unrelated to any particular lithology or stratigraphic horizon and not characterized by any distinct physical properties that might allow direct delineation by geophysical techniques. Therefore, irrespective of the methods used in early stages of exploration, geochemical methods including extensive sampling and analytical procedures are inevitably necessary, at the latest, in detailed exploration as well as in the delineation and mining of proven deposits.

The low abundances of Au in economic ore deposits and the heterogeneous occurrence of Au as native gold grains of highly variable size does make geochemical studies difficult, although special attention should be given to sampling and analytical techniques. However, these problems could be partly overcome with a multielement approach including a set of pathfinder elements in addition to Au. These elements may form halos around gold deposits thus making the target larger, or may correlate well with Au yet be more homogeneously distributed, aiding the delineation of individual lodes. A multi-element approach may also give information on the economic potential of different targets and reduce the risk of erroneous interpretations.

Analysis of pathfinder elements may be straightforward, using common laboratory facilities or may demand special techniques, but in any case, the extra expenditure required is minimal compared to total exploration or mining budgets.

This study indicates that, although a number of elements are typically related to gold mineralization, each province or deposit has its own distinctive trace element pattern. Therefore, a pilot study is necessary to define the most useful pathfinder elements for any new area in which multielement geochemical exploration is planned. This is most reliable when done on mineralized rock material, if available, even though the aim would be in the utilization of secondary media, such as soil, drainage sediments or vegetation, because any meaningful anomalies in these materials are necessarily reflections of primary geochemistry. In detailed exploration stages, knowledge of the patterns of primary halos and correlations with Au become essential.

Differences in geochemical characteristics between the provinces and deposits are discussed above, but on the basis of this study we can conclude that the most important elements in exploration for Precambrian mesothermal gold deposits are, in approximate order of importance, as follows: Au, Te, Bi, As, Ag, W and Se (Fig. 59). The semimetals Te, As and Bi are often enriched >1000—100 times the basaltic average, whereas Se, W and Ag show most typically en-

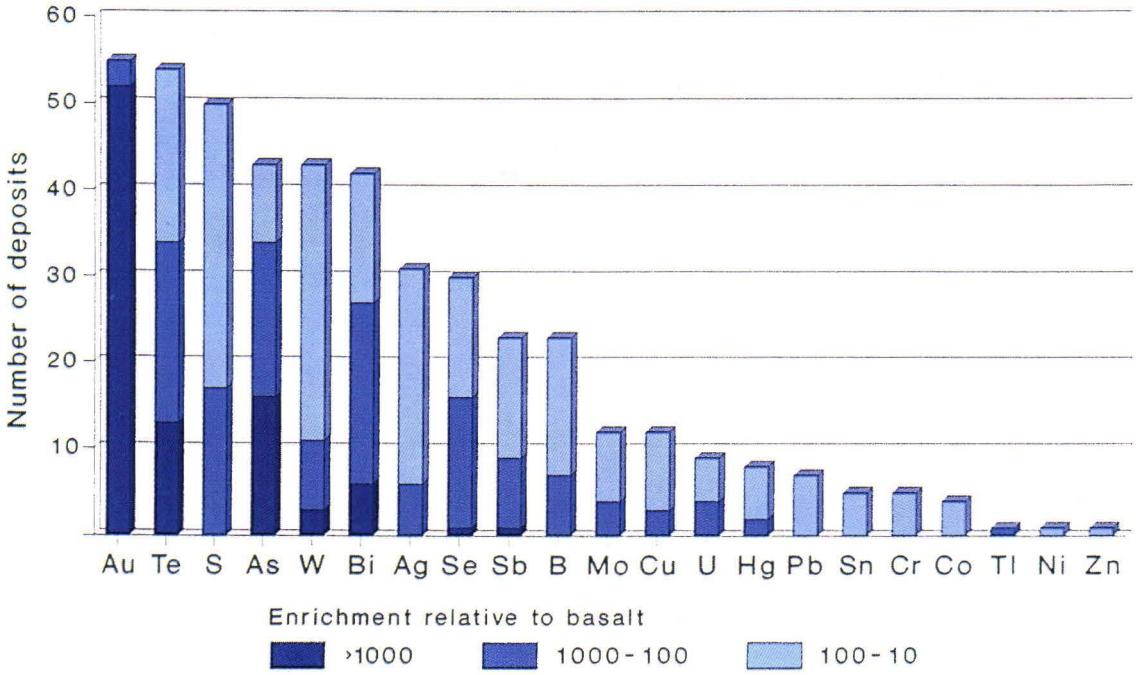


Fig. 59. Frequency and contrast of concentration (relative to background abundances in basalts) of those elements enriched in mesothermal gold deposits in both Late Archean and Early Proterozoic provinces included in this study.

richment factors between 100 and 10. Sulfur, although distinctly enriched in mesothermal gold deposits, is not a characteristic element for gold mineralization only, which restricts its use as a pathfinder element in exploration. Other elements of occasional or more local importance are: Sb, B, Mo, Cu, U, Hg, Pb, Sn, Cr and Co. In addition to trace elements related to the gold deposit itself, exploration may also be aided by components recording wall-rock alteration, such as K, Rb, Na, Ca, Sr, Si, CO_2 and H_2O.

There are only a few elements which seem to generally follow Au closely, and therefore have application to exploration at detailed scales. These elements, deposited roughly simultaneously with Au, are Te, Bi, Ag and Se, when showing distinct enrichment. Other elements may occasionally correlate with Au (e.g., As, S, W, Cu, Co, B and U), but are more generally related to the mineralization processes, and to a large extent deposited either before or after Au. They may form extensive halos around gold deposits and indicate zones of mineralization and are thus useful in regional scale exploration. Elements related to wall-rock alteration show, in a general sense, pathways of hydrothermal fluids.

ACKNOWLEDGEMENTS

The authors wish to thank P. Fuller (Newmont Australia Ltd.), A. Kusic (Renabie Gold Mines Ltd.), R.J. Labine (Falconbridge Gold Corporation), C. Löfgren (Terra Mining Ab), F.R. Ploeger (Gold Shield Resources Ltd.), K. Söderholm (As Bidjovagge Gruber), L. Vu (Bel-

morals Mines Ltd.), and the staff of Mt. Charlotte mine (Kalgoorlie) and Page Williams mine (Hemlo) for providing sample material from outside Finland.

We are grateful to M. Ketola, J. Nuutilainen, L. Grundström, R. Hugg, T. Huhtala and R. Sarikkola from Outokumpu Oy; P. Huopaniemi from Malmikaivos Oy; T. Kopperoinen from Kajaani Oy and our numerous colleagues at the Geological Survey of Finland, for providing sample material from the Finnish gold deposits.

We are grateful to the staff of the X-Ray Assay Laboratories Ltd. (Canada) and the laboratory staff of the Geological Survey of Finland in Rovaniemi and Espoo for the chemical analyses; M. Partanen and E. Eronen for assisting in data handling; and P. Kurki, T. Kinnunen and H. Moberg for drafting the figures.

R. Salminen and Mr. P. Noras critically read the manuscript, and P. Sorjonen-Ward revised the language.

REFERENCES

Afifi, A.M., Kelly, W.C. & Essene, E.J., 1988. Phase relations among tellurides, sulfides, and oxides: II. Applications to telluride-bearing ore deposits. Econ. Geol. 83, 395—404.

Anhauesser, C.R., Fritz, K.; Fyfe, W.S. & Gill, R.C.O., 1975. Gold in 'primitive' Archean volcanics. Chem. Geol. 16, 129—135.

Anttonen, R., Korkalo, T. & Oravainen, H., 1989. Lapin kultaa Saattoporan kaivoksesta. Summary: Gold from Lapland — Outokumpu Oy's Saattopora mine. Vuoriteollisuus — Bergshanteringen 47, 104—108.

Backman, C., 1991. Sampling and data evaluation of 13 rock samples for internal quality control. Bull. Geol. Soc. Finland, in press.

Bagby, W.C. & Berger, B.R., 1985. Geologic characteristics of sediment-hosted, disseminated precious-metal deposits in the western United States. In: B.R. Berger & P.M. Bethke (eds.), Geology and Geochemistry of Epithermal Systems. Reviews in Economic Geology 2, Soc. Econ. Geol., 169—202.

Berger, B.R., 1985. Geologic — geochemical features of hot-spring precious-metal deposits. U.S. Geol. Surv., Bull. 1646, 47—53.

Berger, B.R. & Bethke, P.M., (eds.), **1985.** Geology and Geochemistry of Epithermal Systems. Reviews in Economic Geology 2, Soc. Econ. Geol., 298 p.

Björlykke, A, Hagen, R. & Söderholm, K., 1987. Bidjovagge copper-gold deposit in Finnmark, northern Norway. Econ. Geol. 82, 2059—2075.

Bodnar, R.J., Reynolds, T.J. & Kuehn, C.A., 1985. Fluid inclusion systematics in epithermal systems. In: B.R. Berger & P.M. Bethke (eds.), Geology and Geochemistry of Epithermal Systems. Reviews in Economic Geology 2, Soc. Econ. Geol., 73—98.

Boyle, R.W., 1961. The geology, geochemistry, and origin of the gold deposits of the Yellowknife district. Geol. Surv. Can., Mem. 310, 193 p.

Boyle, R.W., 1979. The geochemistry of gold and its deposits. Canadian Geol. Surv., Bull. 280, 584 p.

Bursnall, J.T. (ed.), 1989. Mineralization and shear zones. Geological Association of Canada, Short Course Notes, Vol. 6, 299 p.

Callan, N.J. & Spooner, E.T.C., 1989. Archean Au quartz vein mineralization hosted in a tonalite-trondhjemite terrane, Renabie mine area, Wawa, North Ontario, Canada. In: R.R. Keays, W.R.H. Ramsay & D.I. Groves (eds.), The Geology of Gold Deposits: the Perspective in 1988. Econ. Geol., Monograph 6, 9—18.

Cathelineau, M., Boiron, M.-C.; Holliger, P.; Marion, P. & Denis, M., 1989. Gold in arsenopyrites: crystal chemistry, location and state, physical and chemical conditions of deposition. In: R.R. Keays, W.R.H. Ramsay & D.I. Groves (eds.), The Geology of Gold Deposits: the Perspective in 1988. Econ. Geol., Monograph 6, 328—341.

Chan, C.C.Y., 1985. Semiautomated method for determination of selenium in geological materials using a flow injection analysis technique. Anal. Chem. 57, 1482—1485.

Clarke, D.S. & Govett, G.J.S., 1990. Southwest Pacific gold: a rock-geochemistry perspective. J. Geochem. Explor. 35, 225—240.

Clout, J.M.F., Cleghorn, J.H. & Watt, R.D., 1988. Geology of Kalgoorlie Mining Associates leases, Kalgoorlie. In: D.I. Groves, M.E. Barley, S.E. Ho & G.M.F. Hopkins (eds.): Western Australian Gold Deposits. Bicentennial Gold 88, Excursion Guidebook. Geol. Dept. — Univ. Extension, Univ. W. Australia, Publ. 14, 70—77.

Coad, P.R., Labine, R.J. & Caron, D., 1986. Owl Creek mine. In: J. Pirie & M.J. Downes (eds.): Gold 86, Excursion Guidebook. Gold 86, Toronto, 34—36.

Colvine, A.C., Fyon, J.A., Heather, K.B., Marmont, S., Smith, P.M. & Troop, D.G., 1988. Archean lode gold deposits in Ontario. Ontario Geol. Surv., Miscellaneous Paper 139, 136 p.

Cook, N.J. & Chryssoulis, S.L., 1990. Concentrations of »invisible gold» in the common sulfides. Can. Mineral. 28, 1—16.

Cullen, I. & Norris, N., 1988. Gold deposits of the New Celebration mine. In: D.I. Groves, M.E. Barley, S.E. Ho

& G.M.F. Hopkins (eds.): Western Australian Gold Deposits. Bicentennial Gold 88, Excursion Guidebook. Geol. Dept. — Univ. Extension, Univ. W. Australia, Publ. 14, 87—90.

Downes, M.J., Hodges, D.J. & Derweduwen, J., 1984. A free carbon- and carbonate-bearing alteration zone associated with the Hoyle Bond gold occurrence, Ontario, Canada. In: R.P. Foster (ed.): Proc. Gold 82, the Geology, Geochemistry and Genesis of Gold Deposits. Geol. Soc. Zimbabwe, Spec. Publ. 1, 435—448.

Fournier, R.O., 1985. The behaviour of silica in hydrothermal solutions. In: B.R. Berger & P.M. Bethke (eds.), Geology and Geochemistry of Epithermal Systems. Reviews in Economic Geology 2, Soc. Econ. Geol., 45—54.

Gaál, G. & Isohanni, M., 1979. Characteristics of igneous intrusions and various wall rocks in some Precambrian porphyry copper-molybdenum deposits in Pohjanmaa, Finland. Econ. Geol. 74, 1198—1210.

Gaál, G. & Gorbatchev, R., 1987. An outline of the Precambrian evolution of the Baltic Shield. Precambrian Res. 35, 15—52.

Gaál, G. & Sundblad, K., 1990. Metallogeny of gold in the Fennoscandian shield. Mineral. Deposita 25, S104—S114.

Godin, L., 1976. Viscaria — en ny kopparmineralisering i Kiruna grönnstenen. 12th Winter Meeting of Nordic Geological Societies, Gothenburg, Jan. 7—10, Abstracts, p. 17.

Govett, G.J.S., (ed.), **1983.** Rock Geochemistry in Mineral Exploration. Handb. Explor. Geochem. 3. Elsevier, Amsterdam, 461 p.

Govindajaru, K., (ed.), **1989.** 1989 compilation of working values and sample description for 272 geostandards. Geostand. Newslett. 13, Spec. Vol., 113 p.

Groves, D.I. & Barley, M.E., 1988. Gold mineralization in the Norseman — Wiluna belt, Eastern Gold Fields Province, Western Australia. In: D.I. Groves, M.E. Barley, S.E. Ho & G.M.F. Hopkins (eds.): Western Australian Gold Deposits. Bicentennial Gold 88, Excursion Guidebook. Geol. Dept. — Univ. Extension, Univ. W. Australia, Publ. 14, 47—66.

Groves, D.I., Phillips, N., Ho, S.E., Houstoun, S.M. & Standing, C.A., 1987. Craton-scale distribution of Archean gold deposits: predictive capacity of the metamorphic model. Econ. Geol. 82, 2045—2058.

Groves, I.M., 1989. Epithermal gold and porphyry copper deposits: end members of a continuum? In: S.E. Ho & D.I. Groves (eds.): Advances in Understanding Precambrian Gold Deposits, Vol. II. Geol. Dept. & Univ. Extension, Univ. Western Australia, Publ. 12, 321—334.

Hall, G.E.M.; Vaive, J.E.; Coope, J.A. & Weiland, E.F., 1989. Bias in the analyses of geochemical materials for gold using current methods. J. Geochem. Explor. 34, 157—171.

Härkönen, I. & Keinänen, V., 1989. Exploration of structurally controlled gold deposits in the central Lapland greenstone belt. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 79—82.

Harris, D.C., 1986. Mineralogy and geochemistry of the main Hemlo gold deposit, Hemlo, Ontario, Canada. In: A.J. Macdonald (ed.): Proc. Vol. Gold 86. Gold 86, Ontario, 297—310.

Hayba, D.O., Bethke, P.M., Heald, P., & Foley, N.K., 1985. Geologic, mineralogic, and geochemical characteristics of volcanic-hosted epithermal precious-metal deposits. In: B.R. Berger & P.M. Bethke (eds.), Geology and Geochemistry of Epithermal Systems. Reviews in Economic Geology 2, Soc. Econ. Geol., 129—168.

Hedenquist, J.W.; White, N.C. & Siddley, G., (Editors), 1990. Epithermal Gold Mineralization of the Circum-Pacific; Geology, Geochemistry, Origin and Exploration, I. J. Geochem. Explor., Spec. Issue, 35, 447 p.

Ho, S.E. & Groves, D.I., (eds.), **1987.** Recent Advances in Understanding Precambrian Gold Deposits. Geol. Dept. & Univ. Extension, Univ. Western Australia, Publ. 11, 368 p.

Ho, S.E. & Groves, D.I., (eds.), **1988.** Advances in Understanding Precambrian Gold Deposits, Volume II. Geol. Dept. & Univ. Extension, Univ. Western Australia, Publ. 12, 360 p.

Hutchinson, R.W., 1987. Metallogeny of Precambrian gold deposits: space and time relationships. Econ. Geol. 82, 1993—2007.

Inkinen, O., 1979. Copper, zinc and uranium occurrences at Pahtavuoma in the Kittilä greenstone complex, northern Finland. Econ. Geol. 74, 1153—1165.

Johanson, B. & Kojonen, K., 1989. Ore mineralogy of gold occurrences in the Hattu schist belt, Ilomantsi, eastern Finland. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 49—52.

Keinänen, V., Johansson, P. & Lehmuspelto, P., 1988. Soretiavuoman volframi- ja kultatutkimuksista. In: V. Lappalainen & H. Papunen (eds.): Tutkimuksia geologian alalta. Univ. Turku, Annales Universitatis Turkuensis C 67, 69—77.

Kerrich, R., 1983. Geochemistry of gold deposits in the Abitibi greenstone belt. Canadian Inst. Min. Metall., Spec. Paper 27, 75 p.

Kerrich, R., 1989. Source processes for Archean Au-Ag vein deposits: evidence from lithophile-element systematics of the Hollinger — McIntyre and Buffalo Ankerite deposits, Timmins. Can. J. Earth Sci. 26, 755—781.

Kerrich, R. & Fyfe, W.S., 1984. Gold: natural concentration processes. In: R.P. Foster (ed.): Proc. Gold 82, the Geology, Geochemistry and Genesis of Gold Deposits. Geol. Soc. Zimbabwe, Spec. Publ. 1, 99—128.

Kerrich, R. & Watson, G.P., 1984. The Macassa mine Archean lode gold deposit, Kirkland Lake, Ontario; geology, patterns of alteration and hydrothermal regimes. Econ. Geol. 79, 1104—1130.

Kerrich, R. & Fyfe, W.S., 1988. The formation of gold deposits with particular reference to Archean greenstone belts and Yellowknife. Part I. Geological boundary conditions and metal inventory & Part II. Source of hydrothermal fluids, alteration patterns and genetic models. Contrib. Geol. Northwest Territories 3. NWT Geol. Div., INAC, Yellowknife, 37—95.

Keays, R.R., Ramsay, W.R.H. & Groves, D.I., (Editors), 1989. The Geology of Gold Deposits: the Perspective in 1988. Econ. Geol., Monograph 6, 667 p.

King, R.W. & Kerrich, R., 1989. S/Se and trace element systematics of auriferous pyrite in Abitibi mesothermal Au deposits. Geol. Assoc. Can. — Miner. Assoc. Can., Annu. Meet., Program with Abstracts 14: A3.

Kishida, A. & Kerrich, R., 1987. Hydrothermal alteration zoning and gold concentration at the Kerr-Addison Archean lode gold deposit, Kirkland Lake, Ontario. Econ. Geol. 82, 649—690.

Kontas, E., Niskavaara, H. & Virtasalo, J., 1986. Flameless atomic absorption determination of gold and palladium in geological reference samples. Geostand. Newslett. 10, 169—171.

Kontas, E., Niskavaara, H. & Virtasalo, J., 1990. Gold, palladium and tellurium in South African, Chinese and Japanese geological reference samples. Geostand. Newslett., in press.

Kontoniemi, O. & Ekdahl, E., 1990. Tonalite-hosted Early Proterozoic gold deposit at Osikonmäki, southeastern Finland. Bull. Geol. Soc. Finland 62, 61—70.

Korkiakoski, E.A., Karvinen, A. & Pulkkinen, E, 1989. Geochemistry and hydrothermal alteration of the komatiite-hosted Pahtavaara gold mineralization, Finnish Lapland. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 83—90.

Korsman, K., Hölttä, P., Hautala, T. & Wasenius, P., 1984. Metamorphism as an indicator of evolution and structure of the crust in eastern Finland. Geol. Surv. Finland, Bull. 328, 40 p.

Kwong, Y.T.J. & Crocket, J.H., 1978. Background and anomalous gold in rocks of an Archean greenstone assemblage. Kakigi Lake Area, Northwestern Ontario. Econ. Geol. 73, 50—63.

Macdonald, A.J., (ed.), **1986.** Gold'86 — An International Symposium on the Geology of Gold Deposits. Proceedings Volume, Gold'86, Toronto, 517 p.

Lehtonen, M., Manninen, T., Rastas, P., Väänänen, J., Roos, S.I. & Pelkonen, R., 1985. Keski-Lapin geologisen kartan selitys. Summary and disscussion: Explanation to the geological map of Central Lapland. Geol. Surv. Finland, Rept. Invest. 71, 56 p.

Luukkonen, E.J., 1988. The structure and stratigraphy of the northern part of the Late Archean Kuhmo greenstone belt, eastern Finland. In: E. Marttila (ed.): Archean Geology of the Fennoscandian Shield. Geol. Surv. Finland, Spec. Paper 4, 71—96.

Maclean, W.H. & Kranidiotis, P., 1987. Immobile elements as monitors of mass transfer in hydrothermal alteration: Phelps Dodge massive sulfide deposits, Matagami, Quebec. Econ. Geol. 82, 951—962.

Mäkelä, M., Sandberg, E. & Rantala, O., 1988. Proterozoic, gold-bearing vein occurrences associated with the granitoids in western Finland. Bicentennial Gold 88, Extended Abstracts Vol. 1, Geol. Soc. Australia, Abstracts 23, 153—155.

Makkonen, H. & Ekdahl, E., 1988. Petrology and structure of the Early Proterozoic Pirilä gold deposit in southeastern Finland. Bull. Geol. Soc. Finland 60, 55—66.

Naden, J. & Shepherd, T.J., 1989. Role of methane and carbon dioxide in gold deposition. Nature 342, 793—795.

Niskavaara, H. & Kontas, E., 1990. Reductive coprecipitation as a separation method for the determination of gold, palladium, platinum, rhodium, silver, selenium, and tellurium in geological samples by graphite furnace atomic absorption spectrometry. Anal. Chim. Acta 231, 273—282.

Nurmi, P.A., 1991. Geological setting, history of discovery and exploration economics of Precambrian gold occurrences in Finland. J. Geochem. Explor. 39, in press.

Nurmi, P.A. & Haapala, I., 1986. The Proterozoic granitoids of Finland: granite types, metallogeny and relation to crustal evolution. The Centennial Volume, Bull. Geol. Soc. Finland 58, 203—233.

Nurmi, P.A. & Ward, P., 1989. Geology and gold mineralization in the Hattu schist belt, Ilomantsi, eastern Finland. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 45—48.

Nurmi, P.A., Hartikainen, A., Damsten, M. & Rasilainen, K., 1989. Sampling strategies and pathfinder elements in till and rock geochemical gold exploration, Hattu schist belt, Ilomantsi, eastern Finland. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 53—58.

Pankka, H., 1989. Epigeneettiset Au-Co-U-malmiesiintymät Kuusamon liuskealueella. Unpubl. Ph. Lic. Thesis, Univ. Turku, Dept. Geol., 126 p.

Pankka, H.S. & Vanhanen, E.J., 1989. Aulacogen related epigenetic Au-Co-U deposits in northeastern Finland. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 91—94.

Pekkarinen, L.J., 1988. The Hattuvaara gold occurrence, Ilomantsi; a case history. In: V. Lappalainen & H. Papunen (eds.): Tutkimuksia geologian alalta. Univ. Turku, Annales Universitatis Turkuensis C 67, 79—87.

Percival, J.A. & Card, K.D., 1985. Structure and evolution of Archean crust in central Superior Province, Canada. In: L.D. Ayres; P.C. Thurston; K.D. Card & W. Weber (eds.): Evolution of Archean Supracrustal Sequences. Geol. Ass. Canada, Spec. Paper 28, 179—192.

Piirainen, T., 1988. The geology of the Archean greenstone — granitoid terrain in Kuhmo, eastern Finland. In: E. Marttila (ed.): Archean Geology of the Fennoscandian Shield. Geol. Surv. Finland, Spec. Paper 4, 39—52.

Puustinen, K., 1991. Gold deposits in Finland. J. Geochem. Explor. 39, in press.

Radtke, A.S., 1985. Geology of the Carlin gold deposits, Nevada. U.S. Geol. Surv., Prof. Paper 1267, 124 p.

Radtke, A.S., Heropoulos, C.; Fabbi, B.P.; Scheiner, B.J. & Essington, M., 1972. Data on major and minor elements in host rocks and ores, Carlin gold deposits, Nevada. Econ. Geol. 67, 975—978.

Rouhunkoski, P. & Isokangas, P., 1974. The copper-gold vein deposit of Kivimaa at Tervola, N-Finland. Bull. Geol. Soc. Finland 46, 29—36.

Saager, R. & Meyer, M., 1984. Gold distribution in Archean granitoids and supracrustal rocks from southern Africa: a comparison. In: R.P. Foster (ed.): Proc. Gold 82, the Geology, Geochemistry and Genesis of Gold Deposits. Geol. Soc. Zimbabwe, Spec. Publ. 1, 53—70.

Shaw, D.M., 1968. A review of K-Rb fractionation trends by covariance analysis. Geochim. Cosmochim. Acta 32, 573—601.

Seward, T.M., 1984. The transport and deposition of gold in hydrothermal systems. In: R.P. Foster (ed.): Proc. Gold 82, the Geology, Geochemistry and Genesis of Gold Deposits. Geol. Soc. Zimbabwe, Spec. Publ. 1, 165—182.

Sillitoe, R.H., 1989. Gold deposits in western Pacific island arcs: the magmatic connection. In: R.R. Keays, W.R.H. Ramsay & D.I. Groves (eds.), The Geology of Gold Deposits: the Perspective in 1988. Econ. Geol., Monograph., 6, 274—291.

Söderholm, K. & Nixon, F., 1988. Geology, exploration and exploitation of high grade gold zones, Bidjovagge mine, northern Norway. Bicentennial Gold 88, Extended Abstracts Vol. 1, Geol. Soc. Australia, Abstracts 23, 210—211.

Taylor, S.R. & McLennan, S.M., 1985. The Continental Crust: its Composition and Evolution. Blackwell Scientific, Oxford, 312 p.

Terashima, S., 1984. Determination of bismuth in eighty-three geochemical reference samples by atomic absorption spectrometry. Geostand. Newslett. 8, 155—158.

Tilling, R.I., Gottfried, D. & Rowe, J.J., 1973. Gold abundance in igneous rocks: bearing on gold mineralization. Econ. Geol. 68, 168—186.

Valliant, R.I. & Bradbrook, C.J., 1986. Relationship between stratigraphy, faults and gold deposits, Page-Williams mine, Hemlo, Ontario, Canada. In: A.J. Macdonald (ed.): Proc. Vol. Gold 86. Gold 86, Ontario, 355—361.

Vu, L., Darling, R., Beland, J. & Popov, V., 1987. Structure of the Ferderber gold deposit, Belmoral Mines Ltd., Val d'Or, Quebec. Can. Inst. Min. Metall., Bull. 80(907), 68—77.

Ward, P., Härkönen, I., Nurmi, P.A. & Pankka, H.S., 1989. Structural studies in the Lapland greenstone belt, northern Finland and their application to gold mineralization. Current Research 1988, Geol. Surv. Finland, Spec. Paper 10, 71—78.

Appendix 1. Numbering and description of analysed samples (* = ore sample). See App. 5 for abbreviations.

Target	Sample No/type	Original rock type	Alteration and mineralization
Fennoscandian Shield			
Lokkiluoto	112*	tholeiitic mafic tuffite	qtz veins; py, aspy
	113	tholeiitic mafic tuffite	crb alt., qtz veins
Kelokorpi	121	int. tuffite	qtz veins
	122*	int. tuffite	qtz veins; some py
	123	int. tuffite	-
Muurinsuo	131	graywacke	se-qtz schist; py dissemination
	132*	graywacke	se-qtz schist; py dissemination
	133	graywacke	se-qtz schist; py dissemination
Korvilansuo	141	graywacke	se alter.; po-py dissemination
	142*	graywacke	se alter.; po-py dissemination
	143	qtz-plag porphyry	se alter.
Rämepuro	151	graywacke-conglomerate	qtz veins
	152*	qtz-plag porphyry-graywacke	qtz-tour veins, se alter.; py-po dissemination
	153	graywacke-int. tuffite	minor qtz veins
Kuittila	161	tonalite	qtz veins, se-crb alter.; minor py-po
	162*	tonalite	qtz veins, se-crb alter; minor py-po
	163	tonalite	qtz veins, se-crb alter; minor py-po
Pahtavaara	171	basaltic komatiite	tre-chlo-bt-amph rock
	172*	basaltic komatiite	tre-talc-crb rock, qtz-bar veins; minor py
	173	basaltic komatiite	amph-chlo-talc rock
Lälleävuoma	181	basaltic komatiite	talc-chlo schist; crb-talc-py veins
	182*	basaltic komatiite	talc-chlo schist; abundant py-rich veins
	183	basaltic komatiite	talc-chlo schist; crb-talc-py veins
Sukseton	191	mafic volcanics-int. dike	po dissemination
	192*	mafic volcanics	po dissemination
	193	mafic volcanics	po dissemination
Kivimaa	201	differ. dolerite dike	-
	202*	differ. dolerite dike	qtz-crb breccia; abundant cp-py
	203	differ. dolerite dike	-
Suurikuusikko	211	mafic tuffite with graphite	chlo-ab alteration
	212*	mafic tuffite-graph. phyllite	chlo-ab alteration
	213	graphite phyllite	qtz breccia, ab alteration; abundant py-aspy
Hirvilavanmaa	221	ultramafic rock	chlo-crb alteration, qtz veins; py dissemination
	222*	ultramafic rock	chlo-crb alteration, qtz veins; py dissemination
	223	ultramafic rock	chlo-crb alteration, qtz veins; py dissemination
Rovaselkä	231	mafic tuffite	crb veins; po-cp
	232*	mafic tuffite	qtz-po breccia
	233	interm.tuffite-B.I.F.	qtz-po breccia, crb veins
Saattopora N	241	mafic tuffite	chlo-ab-crb alteration
	242*	mafic tuffite ?	crb-ab-qtz alter.; qtz-crb-po veins
	243	ultramafic rock	talc-chlo-crb schist
Saattopora S	251	mafic tuffite-phyllite ?	ab-crb schist
	252*	mafic tuffite-phyllite ?	ab-crb schist; qtz-crb-po veins
	253	phyllite	-
Iso-Kuotko	261	mafic volcanics	crb-se-chlo schist; py veins
	262*	mafic volcanics	crb-se-chlo schist; abundant qtz-crb-po-py veins
	263	mafic tuffite	crb alteration; py dissemination

App. 1, contd.

Soretiavuoma	271	ultramafic rock	crb-ab-qtz rock; qtz-crb-py-cp veins
	272*	ultramafic rock	qtz-crb veins; abundant py-cp
	273	ultramafic rock	crb-ab-qtz-talc-chlo rock
Sirkka W	281	ultramafic rock	crb-bt-chlo-talc alteration; po-py
	282*	ultramafic rock	crb-bt-chlo-talc alteration; cp-aspy
	283	ultramafic rock	crb-bt-chlo-talc alteration; po-py
Bidjovagge	292*	metasedim.-mafic dikes?	amph-crb-ab rock; cp-py-po
Juomasuo	301	arkosite ?	ab-qtz-crb rock; py
	302*	arkosite-mafic dikes ?	se-chlo-bt rock; abundant po-py dissemination
	303	mafic rock ?	ab-qtz-amph-se-chlo rock
Säynäjävaara	311	mafic rock ?	bt-chlo rock, abundant ab-crb veins
	312*	mafic rock ?	amph-chlo-bt-ab-crb-magn rock; po-py dissemination
	313	arkosite ?	alb-chlo alteration
Sivakkaharju	321	arkosite ?	alb-crb-bt-se schist
	322*	arkosite ?	qtz-ab-se schist; abundant py-cp dissemination
	323	arkosite ?	ab-crb-bt-se schist
Konttiaho	331	arkosite-mafic dikes ?	qtz-crb-bt-talc rock; py
	332*	arkosite ?	qtz-crb-bt rock; py-po
	333	arkosite ?	qtz-ab-crb rock; py
Mäkärärova	341	granitic gneiss	qtz-se alteration
	342*	granitic gneiss	qtz alteration; qtz-hem-py vein
	343	granitic gneiss	qtz-se alteration
Laivakangas N	351	mafic volcanics	qtz veins
	352*	mafic volcanics	qtz-po-py veins
	353	mafic volcanics	qtz veins
Sudenkylä	361	mafic volcanics	py
	362*	mafic volcanics	qtz-po-aspy veins
	363	mafic volcanics-granitic dikes	-
Jokisivu	371	mafic volcanics	qtz alteration
	372*	mafic volcanics	qtz-po-aspy veins
	373	mafic volcanics	qtz alteration
Isovesi	381	int. volcanics	epi-dio alteration
	382*	int. volcanics	epi-dio alteration; aspy-po dissemination
	383	int. volcanics	epi-dio alteration
Antinoja	391	int. plag-hornb porphyrite	cp
	392*	int. plag-hornb porphyrite	aspy-cp dissemination
	393	int. plag-hornb porphyrite	cp
Vesiperä	401	int. plag porphyrite	-
	402*	int. plag porphyrite	qtz alteration; aspy dissemination
	403	int. plag porphyrite	qtz alteration
Ängesneva	411	int. plag-hornb porphyrite	chlo alteration; py veins
	412*	int. plag porphyrite	chlo alteration; py-aspy veins
	413	int. plag porphyrite	chlo alteration
Kiimala	421	int. plag porphyrite	-
	422*	int. plag porphyrite	po-py-cp-sp breccia
	423	int. plag porphyrite	-
Pirilä S	431	int. volcanics minor pegmatite	-
	432*	qtz-plag gneiss	qtz-amph lenses; abundant aspy-po-py-cp dissemination
	433	qtz-plag gneiss	-
Kalliosalo	441	int. plag porphyrite	qtz-se alteration; sb-po dissemination
	442*	int. plag porphyrite	qtz-se alteration; sb-po dissemination
	443	int. plag porphyrite	qtz-se alteration; sb-po dissemination

App. 1, contd.

Kurula	451	qtz-plag schist	-
	452*	qtz-plag schist	tour; aspy dissemination
	453	qtz-plag schist & qtz diorite	-
Pirilä N	461	biotite gneiss	aspy-py dissemination
	462*	biotite gneiss	aspy-py dissemination
	463	qtz-plag gneiss	qtz lenses; py dissemination
Kaapelinkulma	471	qtz diorite	qtz veins
	472*	qtz diorite	qtz veins; aspy-po
	473	qtz diorite	qtz veins
Laivakangas S	481	tonalite	qtz veins
	482*	tonalite	qtz veins; aspy-cp
	483	tonalite	-
Pöhlölä	491	tonalite	-
	492*	tonalite	qtz vein
	493	tonalite	-
Kopsa	501	tonalite	qtz alteration
	502*	tonalite	qtz alteration; cp-aspy-po
Kangaskylä	511	tonalite	qtz veins; aspy
	512*	tonalite	qtz-aspy vein
	513	tonalite	qtz veins; aspy
Osikonmäki E	521	tonalite	aspy-po-cp dissemination
	522*	tonalite	aspy-po-cp dissemination
	523	tonalite	aspy-po-cp dissemination
Osikonmäki W	531	tonalite	aspy-po dissemination
	532*	tonalite	aspy-po dissemination
	533	tonalite	aspy-po dissemination
Björkdal	542*	granodiorite-schist	-
Australia			
Mt. Charlotte	1*	see text	-
New Celebration	2*	see text	-
Canada			-
Macassa	3*	see text	-
Hoyle Bond	4*	see text	-
Owl Creek	5*	see text	-
Kerr Addison	6.1*	see text	-
	6.2*	see text	-
	6.3*	see text	
			-
Renabie	7*	see text	-
Ferberger	8*	see text	-
Page Williams	9*	see text	-

Appendix 2. Abundances of analysed elements for mesothermal gold deposits in the Fennoscandian Shield.

		Lokkiluoto		Kelokorpi			Muurinsuo			Korvilansuo		
		112	113	121	122	123	131	132	133	141	142	143
Au1	ppb	3900.	190.	240.	2900.	140.	160.	2600.	250.	39.	2600.	240.
Au2	ppb	3650.	160.	50.	1850.	400.	400.	1900.	200.	140.	6250.	160.
Ag	ppb	225.	32.	129.	405.	258.	96.	152.	92.	47.	519.	138.
As	ppm	8500.	240.	59.0	58.0	180.	190.	18.0	5.7	260.	870.	190.
B	ppm	7.5	6.9	114.	594.	432.	46.4	410.	63.2	460.	2280.	94.2
Ba	ppm	271.	186.	391.	674.	464.	591.	593.	628.	841.	689.	752.
Be	ppm	4.	5.	4.	4.	4.	4.	4.	3.	3.	4.	3.
Bi	ppm	1.3	.3	.2	.7	.1	.2	1.4	.5	.3	3.9	.4
Cd	ppm	<.2	<.2	<.2	4.8	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	73.	53.	24.	24.	24.	25.	27.	26.	18.	31.	26.
Cr	ppm	57.	55.	310.	260.	250.	230.	230.	230.	170.	300.	110.
Cs	ppm	3.	2.	4.	8.	7.	2.	3.	4.	9.	12.	9.
Cu	ppm	319.	143.	58.3	48.4	53.4	53.6	55.4	58.1	31.5	51.1	27.2
Ga	ppm	34.2	33.7	26.3	23.2	22.5	27.4	30.0	28.1	22.8	22.1	24.1
Ge	ppm	<10.	10.	<10.	<10.	<10.	<10.	10.	10.	10.	<10.	<10.
Hf	ppm	5.8	4.7	3.6	2.5	3.1	3.9	4.1	3.8	3.4	3.1	3.0
Hg	ppb	150.	9.	<5.	<5.	7.	<5.	<5.	<5.	<5.	17.	<5.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	.5	.5	.5
Li	ppm	38.	38.	60.	72.	64.	52.	51.	59.	60.	72.	61.
Mo	ppm	2.	<1.	5.	16.	<1.	3.	4.	3.	7.	1.	<1.
Nb	ppm	15.	14.	14.	12.	14.	14.	12.	13.	14.	13.	14.
Ni	ppm	55.	45.	148.	123.	128.	134.	139.	142.	85.	155.	74.
Pb	ppm	<2.	<2.	4.	18.	5.	<2.	<2.	<2.	<2.	4.	9.
Pd	ppb	.1	.1	1.1	.4	1.9	1.7	2.0	2.9	.7	2.1	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	51.	42.	97.	130.	102.	109.	94.	103.	104.	124.	79.
Sb	ppm	8.9	2.5	<.2	.2	<.2	<.2	<.2	<.2	<.2	<.2	.4
Sc	ppm	32.4	35.0	22.1	18.2	18.1	23.2	24.0	24.0	12.5	19.2	10.2
Se	ppm	.32	.14	.14	.16	.06	.14	.18	.12	.04	.14	.04
Sn	ppm	2.	4.	<2.	3.	<2.	3.	<2.	4.	6.	8.	<2.
Sr	ppm	148.	174.	114.	135.	139.	286.	285.	227.	453.	213.	683.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
Te	ppb	150.	40.	70.	320.	110.	230.	1020.	310.	170.	2550.	150.
Th	ppm	2.6	3.2	5.3	5.9	6.7	7.2	7.0	6.2	5.6	5.2	5.9
Tl	ppm	.5	.5	.8	.8	.8	.8	.8	1.0	1.0	1.1	.9
U	ppm	1.3	1.0	1.9	2.4	3.0	2.5	2.4	2.2	1.9	2.3	2.0
V	ppm	280.	390.	200.	200.	190.	180.	200.	200.	120.	170.	94.
W	ppm	5.	5.	2.	3.	4.	2.	3.	3.	6.	7.	4.
Y	ppm	38.	40.	9.	13.	11.	16.	17.	15.	11.	15.	11.
Zn	ppm	235.	245.	155.	214.	120.	112.	120.	102.	110.	109.	101.
Zr	ppm	193.	200.	147.	120.	119.	132.	137.	140.	102.	128.	118.
SiO2	%	49.7	50.4	59.1	63.3	63.9	59.6	59.0	59.8	64.4	59.9	65.2
Al2O3	%	12.1	12.7	17.4	15.0	15.9	17.8	18.4	18.0	15.8	16.3	15.7
CaO	%	7.99	8.63	1.04	1.48	.97	1.43	1.40	1.17	2.05	1.25	2.86
MgO	%	3.25	3.44	4.12	3.87	3.19	3.48	3.50	3.35	2.51	4.02	1.99
Na2O	%	1.63	1.54	1.74	2.07	1.88	1.90	1.88	1.69	2.84	1.38	3.90
K2O	%	1.04	.97	2.92	2.73	3.24	2.40	2.64	2.97	3.15	3.97	2.40
Fe2O3*	%	18.6	17.5	8.45	7.11	6.68	7.46	7.77	7.17	5.77	8.56	4.94
TiO2	%	2.12	2.07	.84	.65	.64	.83	.89	.82	.59	.76	.51
MnO	%	.30	.31	.09	.09	.08	.07	.07	.06	.11	.11	.11
P2O5	%	.36	.24	.103	.085	.103	.15	.15	.13	.16	.110	.18
Loi	%	1.16	.31	3.08	2.08	2.31	3.47	3.23	3.16	1.08	1.93	.62
Total	%	98.3	98.2	98.9	98.5	98.9	98.7	99.1	98.4	98.6	98.3	98.6
H2O+	%	1.2	1.2	3.2	2.1	2.2	3.1	3.1	3.2	1.2	1.7	.7
H2O-	%	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
CO2	%	.90	.78	<.01	<.01	.01	<.01	<.01	<.01	<.01	.05	.08
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
S	ppm	10300.	2530.	4470.	5740.	4770.	5830.	7470.	8340.	4050.	5640.	2920.
F	ppm	360.	250.	230.	280.	250.	340.	340.	270.	480.	400.	550.
Cl	ppm	671.	685.	<50.	<50.	<50.	<50.	<50.	<50.	<50.	<50.	<50.
La	ppm	17.3	19.8	23.3	19.5	21.3	30.5	29.1	28.5	29.9	21.1	34.1
Ce	ppm	36.	39.8	45.2	37.9	40.2	58.6	56.2	55.9	60.5	41.2	69.5
Pr	ppm	4.7	5.2	5.3	4.5	4.8	7.1	6.8	6.5	7.3	4.7	8.7
Nd	ppm	20.0	23.5	20.6	16.9	18.5	28.1	26.8	27.4	30.8	20.6	34.7
Sm	ppm	5.9	6.2	4.3	3.7	3.4	5.2	5.3	5.2	5.1	3.8	6.0
Eu	ppm	1.49	1.96	1.04	1.08	.87	1.44	1.25	1.33	1.34	1.06	1.40
Gd	ppm	7.0	8.0	4.0	3.4	3.2	4.4	4.7	4.4	3.5	3.4	4.1
Tb	ppm	1.2	1.2	.5	.5	.5	.6	.6	.6	.5	.5	.4
Dy	ppm	7.4	7.7	2.6	2.6	2.4	3.2	3.1	3.2	2.6	3.1	2.4
Ho	ppm	1.64	1.62	.44	.49	.50	.66	.62	.63	.51	.62	.43
Er	ppm	5.0	5.3	1.0	1.4	1.3	2.2	1.9	1.6	1.4	1.7	1.1
Tm	ppm	.7	.8	.2	.2	.2	.3	.3	.2	.2	.3	.2
Yb	ppm	4.4	4.7	1.0	1.2	1.1	1.7	1.7	1.4	1.3	1.7	1.1
Lu	ppm	.68	.62	.12	.16	.16	.23	.24	.21	.17	.27	.19
Ms		800.	900.	520.	640.	620.	360.	340.	380.	630.	400.	650.

Au1: Fire Assay, DCP$_6$(20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Rämepuro			Kuittila			Pahtavaara			Lälleävuoma		
		151	152	153	161	162	163	171	172	173	181	182	183
Au1	ppb	1100.	12700.	190.	140.	2200.	300.	230.	8400.	33.	44.	3300.	290.
Au2	ppb	500.	4700.	170.	160.	3350.	440.	140.	9100.	30.	20.	3850.	190.
Ag	ppb	227.	4100.	175.	235.	4700.	280.	6.	95.	21.	12.	516.	83.
As	ppm	51.0	20.0	28.0	4.7	3.0	2.0	.5	6.3	1.5	2.5	9.7	5.3
B	ppm	197.	1830.	177.	13.4	163.	8.6	10.0	2.9	4.9	9.6	9.7	6.3
Ba	ppm	607.	859.	560.	955.	1020.	712.	2470.	12900.	454.	88.	49.	101.
Be	ppm	3.	4.	4.	4.	4.	3.	3.	3.	3.	3.	4.	3.
Bi	ppm	4.1	361.	5.0	.2	1.2	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	28.	38.	22.	15.	17.	10.	31.	472.	85.	56.	70.	57.
Cr	ppm	120.	140.	150.	71.	69.	46.	2070.	884.	2330.	2400.	2260.	2190.
Cs	ppm	8.	6.	6.	5.	5.	4.	<1.	<1.	<1.	<1.	<1.	<1.
Cu	ppm	98.5	346.	126.	21.	14.1	24.4	9.1	72.2	40.1	59.8	127.	109.
Ga	ppm	21.	21.4	25.5	16.5	19.1	13.7	13.9	12.7	15.8	12.3	5.3	14.4
Ge	ppm	<10.	10.	10.	10.	10.	<10.	20.	10.	10.	20.	10.	<10.
Hf	ppm	2.7	2.5	2.2	2.3	2.5	1.9	.7	<.5	.6	.5	.6	.8
Hg	ppb	6.	91.	6.	<5.	6.	<5.	<5.	14.	<5.	<5.	44.	20.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	86.	56.	67.	62.	71.	52.	6.	5.	10.	16.	13.	11.
Mo	ppm	2.	<1.	<1.	95.	75.	51.	<1.	2.	<1.	<1.	<1.	<1.
Nb	ppm	12.	14.	13.	13.	14.	12.	7.	8.	8.	8.	8.	10.
Ni	ppm	78.	121.	87.	45.	49.	30.	920.	878.	942.	913.	912.	960.
Pb	ppm	<2.	<2.	<2.	13.	21.	26.	2.	<2.	2.	<2.	9.	<2.
Pd	ppb	.2	2.8	1.2	<.1	<.1	.2	9.3	2.4	3.4	11.1	18.8	13.4
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	79.	65.	88.	110.	114.	102.	16.	11.	6.	7.	9.	6.
Sb	ppm	.2	.2	<.2	<.2	.2	<.2	.4	.3	.5	4.1	6.	5.3
Sc	ppm	14.8	13.6	15.7	8.56	8.33	6.55	19.7	11.	23.6	19.9	19.2	20.5
Se	ppm	.12	.32	.06	.02	.10	<.02	.10	11.80	.18	.02	.14	.02
Sn	ppm	<2.	<2.	<2.	4.	<2.	<2.	<2.	<2.	<2.	<2.	<2.	3.
Sr	ppm	424.	290.	293.	460.	485.	336.	158.	318.	76.	47.	72.	43.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
Te	ppb	130.	3700.	130.	110.	2100.	40.	80.	110.	20.	40.	700.	280.
Th	ppm	3.6	4.2	3.4	5.3	6.4	4.0	<.5	<.5	<.5	<.5	<.5	<.5
Tl	ppm	.8	.8	.4	.8	.9	.9	.1	<.1	<.1	.1	.1	.1
U	ppm	1.5	1.9	1.5	2.1	2.9	1.6	.7	3.6	.2	<.1	.1	<.1
V	ppm	140.	120.	150.	96.	90.	58.	130.	64.	140.	150.	210.	160.
W	ppm	.5	12.	5.	12.	23.	10.	14.	3.	2.	2.	18.	4.
Y	ppm	11.	8.	10.	8.	8.	7.	6.	5.	8.	2.	2.	1.
Zn	ppm	124.	89.6	87.0	52.2	55.4	80.7	23.6	30.4	53.2	84.2	92.8	74.0
Zr	ppm	89.	88.	102.	81.	92.	57.	22.	<1.	28.	33.	38.	35.
SiO2	%	65.5	67.2	63.0	69.4	68.9	75.2	38.6	32.0	36.9	38.7	35.2	37.5
Al2O3	%	14.8	15.0	17.5	12.9	13.3	9.91	5.43	2.92	6.07	5.92	5.29	5.63
CaO	%	2.80	.89	1.87	2.69	2.68	2.41	8.57	11.8	8.10	6.06	6.55	6.06
MgO	%	2.17	1.92	2.33	2.41	2.35	1.61	18.9	15.3	20.8	22.0	20.0	20.5
Na2O	%	3.21	1.95	3.30	2.94	3.12	2.16	.74	.93	.54	.83	.95	1.12
K2O	%	2.44	2.65	2.46	3.04	3.27	2.57	.58	.10	.07	.07	.08	.06
Fe2O3*	%	6.65	7.46	6.25	3.61	3.70	2.73	12.3	20.2	11.7	11.2	10.6	11.0
TiO2	%	.57	.57	.57	.40	.38	.28	.54	.27	.55	.61	.59	.62
MnO	%	.14	.06	.08	.07	.07	.06	.36	.34	.22	.16	.17	.19
P2O5	%	.115	.050	.12	.13	.13	.089	.053	.021	.034	.037	.030	.037
Loi	%	1.16	2.00	1.85	1.31	1.16	1.54	10.5	10.2	13.0	13.5	10.5	13.5
Total	%	99.6	99.8	99.5	99.1	99.3	98.6	97.1	95.6	98.3	99.4	90.2	96.5
H2O+	%	1.1	1.1	1.9	.9	1.0	.9	3.0	2.2	3.9	3.8	4.2	4.0
H2O-	%	<.1	<.1	<.1	<.1	<.1	.1	<.1	<.1	<.1	<.1	<.1	<.1
CO2	%	.01	<.01	<.01	1.19	1.15	1.30	8.14	12.8	8.82	9.25	10.7	10.6
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
S	ppm	3300.	15400.	3720.	1070.	630.	1130.	1280.	31800.	2570.	350.	38100.	9570.
F	ppm	210.	250.	260.	500.	420.	310.	100.	60.	26.	12.	94.	70.
Cl	ppm	<50.	<50.	81.	<50.	<50.	<50.	174.	126.	97.	78.	50.	50.
La	ppm	17.5	16.0	15.9	25.1	25.4	19.6	1.1	.7	.7	.6	.5	.5
Ce	ppm	33.7	33.7	33.2	50.1	49.2	35.2	2.1	1.8	1.7	1.8	1.6	1.6
Pr	ppm	4.1	4.1	4.0	5.8	5.8	4.1	.5	.4	.4	.4	.4	.4
Nd	ppm	16.5	17.3	17.1	22.9	23.8	16.4	2.6	2.7	2.3	2.0	2.2	2.6
Sm	ppm	3.2	3.1	3.3	3.6	3.6	2.5	1.1	1.4	1.3	.9	.7	.9
Eu	ppm	1.03	.77	1.05	.90	.93	.59	.45	.91	.54	.40	.28	.34
Gd	ppm	2.9	2.4	2.9	2.7	2.5	1.7	1.5	1.7	1.8	.7	.7	.6
Tb	ppm	.4	.3	.4	.3	.3	.2	.2	.2	.3	<.1	<.1	<.1
Dy	ppm	2.3	1.7	2.3	1.5	1.7	1.1	1.2	1.4	1.9	.5	.5	.5
Ho	ppm	.49	.41	.46	.32	.32	.25	.24	.22	.36	.07	.06	.05
Er	ppm	1.3	1.0	1.2	.9	.8	.6	.7	.6	.9	.2	.2	.1
Tm	ppm	.2	.1	.1	.1	<.1	<.1	<.1	<.1	.1	<.1	<.1	<.1
Yb	ppm	1.2	1.1	1.2	.9	.8	.6	.6	.5	.7	.2	.2	.1
Lu	ppm	.20	.14	.16	.15	.13	.08	.08	.07	.11	<.05	<.05	<.05
Ms		770.	830.	490.	630.	520.	610.	29400.	52500.	26300.	25500.	770.	7660.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Sukseton			Kivimaa			Suurikuusikko			Hirvilavanmaa		
		191	192	193	201	202	203	211	212	213	221	222	223
Au1	ppb	76.	7500.	<3.	10.	4900.	9.	17.	6200.	26.	530.	210.	700.
Au2	ppb	140.	7900.	40.	30.	4300.	40.	40.	880.	40.	420.	560.	430.
Ag	ppb	32.	927.	41.	27.	2000.	41.	81.	1400.	218.	114.	174.	130.
As	ppm	23.0	530.	20.0	9.0	220.	15.0	21.0	4900.	180.	4.5	1.8	2.2
B	ppm	3.7	6.1	7.5	5.1	1.5	4.8	9.9	38.6	53.	4.8	29.4	7.4
Ba	ppm	352.	347.	382.	83.	244.	36.	129.	294.	54.	97.	115.	102.
Be	ppm	3.	3.	3.	4.	6.	4.	5.	4.	4.	3.	3.	2.
Bi	ppm	<.1	.2	.1	.2	21.5	.1	<.1	<.1	<.1	<.1	<.1	<.1
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	24.	15.	13.	36.	24.	41.	29.	22.	45.	51.	51.	46.
Cr	ppm	110.	95.	100.	140.	62.	100.	77.	280.	1070.	1970.	2050.	1990.
Cs	ppm	1.	2.	1.	2.	<1.	1.	1.	1.	1.	<1.	<1.	<1.
Cu	ppm	70.6	115.	173.	188.	18400.	76.9	69.9	91.4	122.	36.0	28.9	56.4
Ga	ppm	23.4	21.7	22.2	18.3	25.7	18.0	29.8	18.0	17.5	14.0	14.5	13.2
Ge	ppm	<10.	10.	20.	10.	<10.	10.	<10.	<10.	<10.	<10.	<10.	<10.
Hf	ppm	2.0	1.7	2.0	1.6	1.3	2.0	3.3	1.1	1.4	.5	.5	.6
Hg	ppb	<5.	15.	<5.	<5.	180.	<5.	62.	580.	200.	18.	<5.	7.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	.5	.5	.5	.5
Li	ppm	13.	38.	10.	12.	2.	4.	30.	12.	20.	8.	6.	10.
Mo	ppm	1.	1.	<1.	<1.	22.	<1.	<1.	2.	<1.	<1.	3.	<1.
Nb	ppm	12.	13.	13.	10.	9.	14.	18.	11.	15.	9.	9.	10.
Ni	ppm	75.	57.	43.	197.	86.	190.	66.	153.	562.	809.	802.	820.
Pb	ppm	<2.	<2.	<2.	<2.	<2.	<2.	<2.	<2.	<2.	2.	<2.	<2.
Pd	ppb	10.0	14.4	4.1	3.0	1.9	2.4	.1	1.5	.4	4.9	5.4	5.0
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	42.	87.	57.	38.	13.	10.	10.	26.	11.	4.	8.	7.
Sb	ppm	2.0	1.2	2.8	.3	<.2	.7	6.6	20.0	12.0	5.4	5.9	5.6
Sc	ppm	27.2	28.9	23.9	44.2	30.0	42.2	32.1	21.1	20.5	16.9	17.1	16.8
Se	ppm	.08	.18	.18	.02	.96	.40	.04	.54	.24	.02	.04	.04
Sn	ppm	<2.	<2.	5.	<2.	<2.	7.	<2.	10.	2.	7.	<2.	<2.
Sr	ppm	389.	269.	490.	73.	75.	90.	59.	221.	236.	37.	44.	38.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	1.	<1.	<1.	<1.
Te	ppb	30.	50.	30.	30.	100.	20.	30.	110.	50.	320.	250.	280.
Th	ppm	2.0	1.3	2.7	1.3	1.1	1.5	1.1	.6	<.5	<.5	<.5	<.5
Tl	ppm	.5	.8	.6	.3	.3	.2	.2	.7	.8	<.1	<.1	.1
U	ppm	1.6	1.2	1.4	.2	1.2	.4	.2	1.2	.9	<.1	<.1	<.2
V	ppm	280.	340.	240.	220.	92.	240.	460.	270.	240.	190.	160.	160.
W	ppm	.5	8.	2.	1.	27.	1.	<.5	21.	4.	5.	2.	5.
Y	ppm	13.	17.	20.	10.	11.	13.	22.	10.	11.	1.	1.	1.
Zn	ppm	75.7	99.3	59.0	64.0	123.	62.5	143.	115.	103.	64.1	65.2	58.5
Zr	ppm	66.	55.	88.	79.	53.	74.	126.	62.	65.	29.	29.	30.
SiO2	%	52.7	45.8	50.2	45.5	28.8	48.7	46.6	44.5	35.6	36.5	35.4	35.8
Al2O3	%	15.4	13.2	15.1	5.43	3.66	6.16	13.5	7.63	6.85	5.01	5.12	5.08
CaO	%	10.9	13.6	12.0	11.2	15.4	13.6	4.49	9.34	10.0	4.88	5.44	4.83
MgO	%	5.48	5.72	4.64	10.4	3.50	10.8	5.86	6.25	13.0	17.4	17.8	18.2
Na2O	%	3.09	2.06	3.01	.78	.07	1.01	2.56	1.92	.22	1.05	1.19	1.36
K2O	%	.90	2.06	1.90	.71	.08	.16	.35	1.34	.20	.07	.03	.06
Fe2O3*	%	7.98	9.02	8.02	13.7	26.4	13.8	15.1	9.87	11.7	9.98	9.71	9.42
TiO2	%	1.0	1.17	.93	1.12	.73	1.23	2.14	.80	1.16	.57	.55	.57
MnO	%	.12	.17	.13	.25	.51	.26	.26	.26	.27	.17	.17	.17
P2O5	%	.13	.15	.24	.069	.018	.055	.19	.060	.13	.037	.032	.030
Loi	%	1.31	5.00	1.85	9.08	5.23	3.62	6.54	12.1	18.2	21.6	22.90	22.6
Total	%	99.1	98.0	98.1	98.2	84.3	99.4	97.6	94.1	97.5	97.5	98.6	98.3
H2O+	%	1.0	1.5	1.4	2.0	2.4	1.7	4.9	1.4	4.5	2.3	1.9	1.9
H2O-	%	<.1	<.1	<.1	<.1	<.1	<.1	.1	<.1	.1	.1	<.1	<.1
CO2	%	1.22	5.26	1.67	9.03	13.5	3.57	3.63	13.6	14.6	21.2	22.2	22.2
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	.16	.82	1.25	<.05	<.05	<.05
S	ppm	2190.	5080.	3660.	1070.	71400.	610.	1380.	30000.	9710.	6370.	4060.	3920.
F	ppm	520.	540.	420.	190.	70.	150.	300.	400.	290.	60.	30.	30.
Cl	ppm	475.	230.	188.	135.	155.	207.	<50.	196.	<50.	148.	91.	139.
La	ppm	14.9	8.5	17.4	7.0	7.2	7.7	12.2	5.6	7.8	.4	.4	.4
Ce	ppm	29.2	17.9	34.4	17.2	14.5	19.0	28.6	12.4	16.6	1.1	1.2	1.1
Pr	ppm	3.4	2.5	4.2	2.5	1.9	2.9	4.0	1.9	2.5	.4	.3	.2
Nd	ppm	13.7	11.5	17.6	11.9	9.5	13.8	18.2	8.0	11.3	1.9	1.9	1.9
Sm	ppm	3.0	3.3	3.7	3.2	2.4	3.6	5.0	2.0	3.2	.7	.9	.7
Eu	ppm	1.02	1.05	1.22	1.06	.60	1.19	1.54	.70	.93	.26	.23	.20
Gd	ppm	2.9	3.5	4.3	3.1	2.4	3.9	5.2	2.3	3.0	.5	.6	.5
Tb	ppm	.5	.6	.7	.4	.3	.5	.8	.4	.4	<.1	<.1	<.1
Dy	ppm	2.6	3.4	3.9	2.2	1.9	3.2	4.5	2.3	2.1	.4	.3	.3
Ho	ppm	.48	.72	.76	.44	.39	.61	.89	.48	.41	<.05	<.05	<.05
Er	ppm	1.4	2.0	2.3	1.2	1.1	1.7	2.6	1.4	1.3	<.1	.2	.1
Tm	ppm	.2	.2	.3	.1	.1	.2	.3	.2	.1	<.1	<.1	<.1
Yb	ppm	1.1	1.7	2.1	1.0	1.1	1.3	2.2	1.2	1.0	.1	.1	.1
Lu	ppm	.15	.21	.29	.13	.14	.16	.26	.16	.13	<.05	<.05	<.05
Ms		610.	600.	660.	21600.	68400.	9350.	340.	650.	470.	760.	780.	630.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Rovaselkä			Saattopora N			Saattopora S			Iso-Kuotko		
		231	232	233	241	242	243	251	252	253	261	262	263
Au1	ppb	24.	350.	120.	130.	7200.	420.	170.	2900.	62.	30.	1400.	96.
Au2	ppb	40.	300.	60.	90.	9100.	270.	240.	2900.	60.	30.	1400.	90.
Ag	ppb	80.	323.	111.	10.	21.	7.	48.	302.	63.	97.	693.	99.
As	ppm	86.0	1100.	130.	2.7	28.0	550.	420.	570.	12.0	33.0	11000.	640.
B	ppm	27.8	41.9	53.3	4.0	621.	81.6	1450.	216.	192.	9.8	17.5	19.5
Ba	ppm	508.	374.	420.	85.	84.	37.	522.	167.	226.	204.	171.	166.
Be	ppm	6.	8.	5.	3.	4.	2.	2.	5.	3.	5.	5.	5.
Bi	ppm	.3	1.6	.6	<.1	.2	<.1	1.7	2.7	<.1	1.4	20.	6.6
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	15.	56.	26.	30.	135.	88.	167.	248.	14.	25.	32.	25.
Cr	ppm	230.	120.	220.	130.	400.	1590.	100.	79.	93.	64.	53.	94.
Cs	ppm	<1.	<1.	<1.	1.	<1.	1.	1.	1.	1.	<1.	<1.	<1.
Cu	ppm	283.	544.	249.	127.	1980.	191.	794.	8350.	905.	113.	211.	133.
Ga	ppm	23.9	40.7	26.3	24.0	19.4	14.9	16.7	15.5	15.7	36.2	18.3	9.0
Ge	ppm	<10.	<10.	<10.	10.	<10.	20.	20.	10.	20.	<10.	<10.	<10.
Hf	ppm	1.9	.8	2.3	1.5	1.3	.8	2.1	2.1	1.6	4.5	3.1	3.7
Hg	ppb	<5.	<5.	<5.	<5.	7.	13.	16.	20.	9.	11.	47.	11.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	18.	9.	18.	11.	4.	11.	5.	10.	14.	11.	4.	11.
Mo	ppm	9.	19.	7.	<1.	<1.	<1.	2.	2.	<1.	<1.	<1.	<1.
Nb	ppm	15.	15.	15.	11.	12.	9.	15.	13.	13.	27.	24.	24.
Ni	ppm	165.	435.	158.	85.	346.	513.	159.	1000.	44.	41.	44.	46.
Pb	ppm	<2.	21.	<2.	<2.	<2.	<2.	<2.	14.	<2.	5.	12.	<2.
Pd	ppb	2.7	17.2	.1	11.4	3.7	10.6	.5	4.3	3.0	.3	.7	1.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	54.	61.	40.	21.	13.	44.	17.	17.	61.	51.	62.	46.
Sb	ppm	.8	<.2	.5	.2	.2	.3	.3	.4	.2	.3	1.9	.3
Sc	ppm	23.5	8.8	23.0	37.2	22.6	24.2	9.1	12.9	13.3	25.9	22.3	21.6
Se	ppm	2.60	7.70	.94	.24	1.16	.10	.74	6.60	.28	.06	.14	.14
Sn	ppm	3.	<2.	6.	<2.	3.	<2.	<2.	5.	2.	<2.	3.	4.
Sr	ppm	108.	30.	94.	49.	57.	51.	50.	52.	51.	128.	84.	90.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	1.	<1.	1.
Te	ppb	100.	200.	100.	90.	1400.	270.	290.	1800.	100.	10.	160.	40.
Th	ppm	2.9	1.9	2.2	.5	<.5	<.5	7.3	4.8	6.6	1.6	1.8	1.6
Tl	ppm	1.1	.7	.5	.1	.2	.4	.3	.2	.2	.3	.4	.4
U	ppm	4.5	4.7	3.4	<.1	9.9	.7	14.6	22.9	1.5	.7	.9	.6
V	ppm	330.	230.	330.	370.	270.	230.	200.	130.	140.	440.	320.	350.
W	ppm	1.	<.5	1.	2.	27.	12.	7.	7.	3.	2.	<.5	4.
Y	ppm	18.	8.	13.	13.	8.	5.	9.	13.	8.	10.	12.	54.
Zn	ppm	253.	65.5	99.8	44.7	23.0	16.9	11.7	52.7	18.2	75.2	128.	76.0
Zr	ppm	88.	70.	92.	57.	51.	35.	65.	67.	85.	203.	175.	166.
SiO2	%	51.0	41.1	51.2	47.4	33.8	34.9	54.1	31.8	47.1	38.6	32.8	36.8
Al2O3	%	10.7	5.27	9.96	12.6	7.37	5.99	13.7	7.02	12.8	10.4	8.63	9.84
CaO	%	4.18	1.42	5.07	7.53	10.3	12.4	5.85	10.2	8.4	8.96	8.07	9.66
MgO	%	4.10	1.70	4.49	6.47	6.80	15.0	4.55	6.52	6.11	5.29	6.22	6.55
Na2O	%	1.70	.22	1.08	2.33	3.31	.71	6.35	2.84	3.93	1.10	.50	1.03
K2O	%	2.29	1.58	1.50	.48	.36	1.08	.49	.30	1.83	1.64	2.26	1.61
Fe2O3*	%	17.8	39.7	19.3	12.2	16.8	6.59	3.76	17.30	5.29	15.1	17.3	14.5
TiO2	%	.92	.47	.96	1.16	.79	.61	.57	.44	.55	2.87	2.33	2.19
MnO	%	.13	.07	.19	.14	.16	.19	.10	.17	.20	.32	.29	.31
P2O5	%	.20	.13	.23	.092	.060	.046	.073	.034	.085	.46	.41	.40
Loi	%	5.0	8.47	4.16	7.70	6.43	19.7	7.62	10.1	11.9	12.7	13.8	14.1
Total	%	98.1	100.	98.2	98.0	86.1	97.4	97.2	86.7	98.2	97.5	92.7	97.0
H2O+	%	1.9	1.1	2.0	3.9	.5	2.3	.7	.9	1.2	2.4	3.0	2.2
H2O-	%	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	.1
CO2	%	1.29	1.05	1.93	5.93	15.7	19.3	7.67	15.4	11.6	13.6	18.1	15.3
Cgraph	%	.21	.29	.18	<.05	<.05	<.05	.24	<.05	.45	<.05	<.05	<.05
S	ppm	60800.	139000.	47700.	5390.	45800.	3530.	8060.	64300.	2800.	8360.	24800.	10800.
F	ppm	420.	140.	380.	180.	100.	310.	400.	210.	610.	510.	480.	480.
Cl	ppm	208.	85.	238.	341.	377.	367.	272.	527.	382.	<50.	<50.	<50.
La	ppm	14.1	8.0	14.1	4.9	28.0	7.0	34.0	31.4	24.1	21.4	17.2	16.3
Ce	ppm	27.9	14.6	28.7	10.6	46.3	11.7	58.2	55.3	44.5	49.3	39.7	37.9
Pr	ppm	3.7	2.0	3.6	1.6	5.4	1.5	6.6	6.6	5.1	6.9	5.5	5.3
Nd	ppm	15.0	9.1	14.9	7.6	20.2	5.9	23.0	26.8	19.5	31.2	24.7	24.2
Sm	ppm	3.9	1.8	3.5	2.4	4.3	1.5	4.1	4.8	3.6	7.0	5.5	5.5
Eu	ppm	.96	.64	1.11	.90	1.40	.71	.81	.95	.64	2.26	1.99	1.92
Gd	ppm	3.6	1.8	3.5	2.7	3.5	1.7	3.2	4.2	2.9	5.4	5.2	4.3
Tb	ppm	.6	.2	.5	.4	.5	.3	.4	.6	.4	.6	.6	.6
Dy	ppm	3.3	1.5	2.8	2.9	2.3	1.5	2.1	3.4	1.9	3.1	2.9	2.7
Ho	ppm	.71	.29	.57	.59	.36	.20	.38	.62	.38	.47	.52	.50
Er	ppm	2.1	1.1	1.8	1.6	.9	.6	1.1	1.7	.9	1.4	1.5	1.3
Tm	ppm	.3	.1	.2	.2	.1	<.1	.1	.2	.1	.2	.2	.2
Yb	ppm	1.9	.9	1.4	1.6	.8	.5	1.0	1.4	1.0	1.3	1.6	1.4
Lu	ppm	.24	.11	.21	.25	.12	<.05	.13	.19	.12	.20	.25	.19
Ms		2320.	1810.	1730.	320.	1810.	370.	510.	2790.	360.	1000.	920.	880.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Soretiavuoma			Sirkka W			Bidjovagge	Juomasuo		
		271	272	273	281	282	283	292	301	302	303
Au1	ppb	670.	3700.	29.	270.	1800.	790.	18200.	7.	4100.	92.
Au2	ppb	810.	3000.	220.	620.	1800.	1030.	28000.	20.	4100.	50.
Ag	ppb	302.	1400.	140.	33.	76.	34.	354.	14.	160.	18.
As	ppm	320.	1100.	36.0	290.	54.0	44.0	2.5	5.5	1200.	220.
B	ppm	20.4	15.	<.5	470.	5.7	11.8	23.1	48.1	54.6	32.4
Ba	ppm	88.	147.	95.	163.	111.	145.	215.	64.	298.	120.
Be	ppm	3.	4.	2.	6.	7.	6.	2.	2.	5.	3.
Bi	ppm	3.4	6.2	.1	1.2	2.8	1.8	104.	<.1	2.7	.2
Cd	ppm	<.20	<.20	<.20	<.20	<.20	<.20	<.20	<.20	1.20	<.20
Co	ppm	55.	428.	67.	170.	42.	34.	59.	<1.	1820.	295.
Cr	ppm	1890.	1900.	2380.	804.	655.	1100.	110.	120.	140.	120.
Cs	ppm	<1.	<1.	<1.	7.	4.	6.	<1.	<1.	<1.	1.
Cu	ppm	257.	1920.	147.	151.	241.	160.	12000.	10.3	226.	54.
Ga	ppm	9.	211.	11.40	14.50	9.	14.10	14.20	21.	26.70	21.50
Ge	ppm	10.	10.	<10.	<10.	10.	<10.	<10.	<10.	<10.	<10.
Hf	ppm	<.5	<.5	<.5	1.4	<.5	<.5	2.2	6.2	4.9	3.6
Hg	ppb	11.	20.	5.	7.	5.	5.	25.	<5.	5.	9.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	10.	9.	5.	18.	4.	7.	10.	2.	19.	18.
Mo	ppm	<1.	<1.	<1.	6.	<1.	<1.	74.	2.	13.	6.
Nb	ppm	7.	10.	8.	12.	7.	9.	10.	14.	12.	16.
Ni	ppm	819.	2380.	918.	374.	622.	501.	107.	3.	122.	57.
Pb	ppm	<2.	52.	<2.	<2.	7.	10.	99.	<2.	85.	<2.
Pd	ppb	7.7	9.3	3.8	2.5	2.0	.3	5.4	.5	.7	.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	11.	7.	10.	99.	51.	18.	10.	5.	84.	65.
Sb	ppm	.5	1.1	.3	.5	1.1	1.2	.2	.4	.4	.2
Sc	ppm	16.2	16.6	18.6	16.8	17.3	20.2	18.6	.48	5.80	10.7
Se	ppm	.08	.92	.08	.26	.24	.16	3.9	.02	78.	13.
Sn	ppm	<2.	<2.	3.	<2.	<2.	28.	10.	<2.	<2.	12.
Sr	ppm	51.	92.	106.	18.	30.	25.	64.	19.	10.	17.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	<1.	1.	<1.	<1.
Te	ppb	30.	420.	30.	290.	390.	270.	210000.	30.	7000.	590.
Th	ppm	<.5	<.5	<.5	2.2	<.5	<.5	7.2	5.0	8.1	7.9
Tl	ppm	.1	.1	.2	.6	.5	.6	<.1	<.1	.3	.2
U	ppm	<.2	.2	<.1	2.6	2.2	2.2	95.3	1.4	284.	7.5
V	ppm	130.	150.	130.	190.	120.	110.	170.	46.	130.	120.
W	ppm	3.	4.	4.	1.	<.5	3.	39.	13.	390.	19.
Y	ppm	2.	3.	2.	6.	8.	5.	27.	2.	23.	9.
Zn	ppm	49.0	90.8	92.4	56.7	58.6	50.7	217.	2.0	45.7	40.9
Zr	ppm	22.	24.	24.	60.	21.	16.	95.	257.	205.	170.
SiO2	%	39.0	24.7	33.1	44.2	19.9	28.0	49.1	67.2	57.5	59.6
Al2O3	%	4.48	4.65	5.06	7.48	2.14	3.39	11.6	19.2	15.0	15.0
CaO	%	5.09	7.09	7.75	4.10	8.17	5.97	9.26	.16	.04	2.25
MgO	%	17.7	16.5	20.0	10.1	14.8	15.3	2.61	.17	2.37	4.66
Na2O	%	.84	1.02	1.33	.09	.11	.11	6.31	12.4	.63	5.53
K2O	%	.09	.15	.14	1.80	.84	1.32	.11	.15	4.41	2.08
Fe2O3*	%	10.2	17.3	9.80	19.2	26.1	26.3	4.78	.29	13.1	4.48
TiO2	%	.32	.41	.36	.54	.24	.35	.62	.38	.45	.59
MnO	%	.24	.23	.21	.33	1.12	.82	.20	.012	.017	.025
P2O5	%	.027	.032	.023	.16	.007	.050	.071	.007	<.002	.105
Loi	%	22.2	18.8	20.1	7.16	19.8	15.2	7.00	.54	5.00	2.85
Total	%	101.	91.2	98.2	95.3	93.3	96.9	91.6	101.	98.6	97.1
H2O+	%	1.7	2.2	3.1	3.7	2.3	2.9	.4	.2	2.2	1.5
H2O-	%	.1	<.1	<.1	.1	.2	.1	.1	<.1	.1	<.1
CO2	%	22.3	20.5	17.7	7.64	23.2	15.9	10.4	.31	.08	2.32
Cgraph	%	.07	.09	<.05	<.05	<.05	<.05	.23	<.05	<.05	<.05
S	ppm	4430.	61400.	1830.	13200.	21200.	15200.	21000.	80.	58700.	7580.
F	ppm	270.	120.	140.	130.	60.	50.	40.	<20.	110.	310.
Cl	ppm	305.	206.	152.	554.	587.	1840.	118.	73.	61.	106.
La	ppm	.2	.4	.3	16.3	3.	4.3	39.9	7.8	34.2	9.4
Ce	ppm	.7	1.2	.9	29.	6.3	8.2	66.2	14.2	60.9	17.9
Pr	ppm	.1	.3	.2	3.4	.9	1.0	7.2	1.6	7.1	2.1
Nd	ppm	.8	1.5	1.5	14.8	4.2	4.5	27.3	5.3	28.5	8.0
Sm	ppm	.3	.7	.6	3.2	1.5	1.3	5.4	.9	7.6	1.7
Eu	ppm	.18	.33	.33	.90	.96	.68	.76	.16	1.00	.34
Gd	ppm	.5	.7	.6	2.8	2.0	1.5	5.7	.6	7.7	1.6
Tb	ppm	<.1	.1	.1	.3	.4	.3	.9	<.1	1.4	.3
Dy	ppm	.5	.6	.7	1.6	2.0	1.3	5.4	.3	7.7	1.7
Ho	ppm	.07	.10	.09	.22	.37	.23	1.17	.07	1.41	.39
Er	ppm	.2	.3	.3	.7	1.0	.7	3.6	.2	3.7	1.0
Tm	ppm	<.1	<.1	<.1	<.1	.1	.1	.5	<.1	.5	.2
Yb	ppm	.2	.3	.2	.6	1.0	.7	4.2	.4	2.7	1.2
Lu	ppm	<.05	<.05	<.05	.06	.10	.10	.67	.05	.29	.18
Ms		640.	420.	690.	960.	1650.	1080.	830.	970.	2480.	700.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6} SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Säynäjävaara			Sivakkaharju			Konttiaho			Mäkärärova		
		311	312	313	321	322	323	331	332	333	341	342	343
Au1	ppb	<4.	3700.	<4.	<4.	5500.	27.	200.	11400.	170.	14.	1700.	340.
Au2	ppb	40.	2200.	10.	10.	4400.	20.	10.	10700.	70.	20.	1760.	320.
Ag	ppb	3.	142.	4.	4.	99.	2.	4.	103.	12.	14.	89.	43.
As	ppm	1.6	3.7	.7	1.7	27.0	4.5	7.1	7.5	6.1	1.0	3.8	1.6
B	ppm	10.6	30.9	68.5	114.	101.	167.	<.5	141.	127.	44.1	42.0	40.5
Ba	ppm	110.	137.	71.	119.	187.	49.	95.	85.	76.	340.	242.	440.
Be	ppm	3.	7.	2.	3.	3.	3.	3.	3.	3.	5.	7.	4.
Bi	ppm	<.1	.8	<.1	<.1	11.9	<.1	.7	9.4	.2	<.1	1.6	.1
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	17.	267.	4.	5.	172.	6.	106.	174.	92.	5.	103.	27.
Cr	ppm	140.	110.	65.	130.	140.	150.	190.	110.	100.	110.	71.	32.
Cs	ppm	1.	2.	1.	<1.	<1.	<1.	<1.	1.	1.	1.	1.	1.
Cu	ppm	11.1	220.	9.0	4.9	783.	5.9	31.3	132.	92.1	23.6	7.4	21.1
Ga	ppm	17.8	23.8	8.2	16.3	20.6	21.1	17.2	14.4	11.7	27.2	29.2	29.3
Ge	ppm	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.
Hf	ppm	4.6	3.0	2.3	4.1	2.3	3.9	1.6	1.6	.8	11.0	3.4	7.7
Hg	ppb	<5.	<5.	7.	7.	17.	15.	10.	12.	<5.	7.	22.	7.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	28.	35.	14.	9.	9.	8.	12.	7.	2.	12.	1.	7.
Mo	ppm	4.	8.	2.	<1.	275.	2.	187.	510.	16.	2.	5.	2.
Nb	ppm	17.	15.	12.	15.	9.	15.	11.	11.	11.	22.	12.	19.
Ni	ppm	43.	69.	22.	46.	76.	50.	105.	63.	14.	50.	116.	34.
Pb	ppm	<2.	5.	<2.	<2.	150.	<2.	<2.	25.	<2.	<2.	<2.	<2.
Pd	ppb	<.1	<.1	1.7	1.1	6.3	2.1	11.4	10.7	1.5	<.1	.2	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	35.	68.	36.	59.	56.	52.	71.	56.	14.	146.	95.	142.
Sb	ppm	.2	<.2	<.2	.3	.9	18.0	<.2	.3	<.2	.2	.2	.2
Sc	ppm	11.4	6.40	4.40	11.8	14.0	7.87	22.2	29.8	19.1	11.1	5.47	14.8
Se	ppm	.26	6.4	.64	.02	41.	.02	9.3	39.	4.2	<.02	.46	.08
Sn	ppm	<2.	<2.	<2.	<2.	7.	5.	4.	<2.	<2.	4.	<2.	8.
Sr	ppm	26.	22.	120.	19.	19.	24.	27.	37.	24.	9.	10.	8.
Ta	ppm	1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	1.	<1.	1.
Te	ppb	60.	610.	40.	30.	11000.	60.	3600.	28000.	440.	40.	1750.	220.
Th	ppm	8.3	5.7	3.3	8.4	4.0	7.8	2.1	3.8	2.5	9.5	4.9	8.3
Tl	ppm	.2	.4	.3	.3	.1	<.1	.1	.2	<.1	.5	.2	.4
U	ppm	2.5	4.0	1.5	1.9	410.	2.5	39.7	99.7	6.7	1.8	1.9	1.7
V	ppm	96.	92.	52.	130.	170.	140.	240.	120.	64.	86.	86.	74.
W	ppm	.5	6.	<.5	3.	94.	12.	31.	260.	7.	2.	15.	6.
Y	ppm	8.	8.	6.	6.	31.	7.	8.	10.	9.	18.	10.	18.
Zn	ppm	32.7	51.9	6.1	10.3	41.2	9.8	11.5	9.0	9.0	32.4	38.6	26.3
Zr	ppm	165.	118.	89.	153.	102.	153.	67.	52.	55.	425.	187.	311.
SiO2	%	57.5	37.1	45.6	60.3	57.9	58.6	49.2	35.7	54.7	66.9	53.7	67.6
Al2O3	%	13.3	8.55	5.48	12.5	14.8	15.8	12.3	6.40	10.6	13.4	6.76	12.9
CaO	%	4.19	3.75	12.8	4.71	1.70	3.81	6.10	13.2	7.92	.43	.10	.58
MgO	%	7.04	8.42	10.6	5.99	3.86	3.94	8.36	10.4	5.06	2.76	.53	1.37
Na2O	%	5.23	1.20	1.82	4.34	5.77	8.54	5.61	2.15	5.56	.06	.08	.06
K2O	%	1.06	1.47	1.02	1.73	1.38	.83	1.28	1.16	.24	4.	2.40	4.29
Fe2O3*	%	3.51	28.7	2.71	3.17	6.86	1.73	5.19	9.26	4.97	7.33	32.2	8.64
TiO2	%	.57	.45	.22	.45	1.06	.76	.87	.45	.48	.85	.50	1.11
MnO	%	.030	.26	.08	.043	.026	.019	.06	.14	.10	.06	.020	.044
P2O5	%	.12	.066	.055	.096	.025	.094	.085	.094	.071	.21	.16	.35
Loi	%	4.77	5.93	18.4	5.47	4.31	4.46	7.47	15.	8.77	3.62	3.93	2.62
Total	%	97.3	95.9	98.8	98.7	97.7	98.5	96.5	93.9	98.4	99.7	100.	99.6
H2O+	%	1.3	2.2	.6	1.2	1.3	.7	.9	.6	.3	3.3	2.7	2.1
H2O-	%	1.1	.1	<.1	<.1	<.1	.1	<.1	<.1	<.1	.3	.1	.1
CO2	%	4.44	5.32	19.2	4.95	1.62	4.36	9.24	19.7	11.2	.06	.06	.01
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
S	ppm	2890.	60000.	1180.	210.	36600.	240.	5680.	14300.	9190.	120.	18100.	1530.
F	ppm	470.	280.	460.	280.	250.	510.	640.	350.	100.	1150.	260.	780.
Cl	ppm	<50.	<50.	<50.	<50.	<50.	<50.	60.	138.	71.	116.	92.	60.
La	ppm	27.2	23.7	13.5	6.2	26.0	21.5	38.2	37.9	84.3	57.6	45.4	37.8
Ce	ppm	53.6	46.8	24.7	12.8	53.5	42.3	71.4	69.0	164.	113.	89.4	76.5
Pr	ppm	6.10	5.30	2.80	1.50	6.70	4.80	8.50	7.80	19.	13.80	10.80	9.60
Nd	ppm	22.4	20.6	10.2	5.8	28.7	17.4	31.3	27.9	63.	55.1	43.2	39.1
Sm	ppm	3.8	4.3	1.6	1.3	7.8	3.4	7.0	5.9	9.8	9.6	9.0	8.0
Eu	ppm	.91	1.17	.48	.30	.91	.70	1.39	.86	1.69	1.96	2.51	2.45
Gd	ppm	2.8	3.4	1.6	1.2	8.6	2.2	4.8	4.8	5.7	7.3	6.1	6.6
Tb	ppm	.4	.5	.2	.2	1.9	.3	.6	.7	.6	.8	.6	.9
Dy	ppm	1.8	2.3	1.4	1.2	10.9	1.5	2.5	3.1	2.8	4.3	2.4	4.4
Ho	ppm	.32	.36	.23	.25	1.95	.28	.36	.54	.43	.78	.43	.88
Er	ppm	.9	.9	.7	.8	5.3	.8	.9	1.3	1.	2.5	1.2	2.3
Tm	ppm	.1	.1	<.1	.1	.7	<.1	.1	.2	.1	.3	.2	.3
Yb	ppm	.9	.8	.6	.8	4.3	1.0	.9	1.3	.9	2.3	1.3	2.1
Lu	ppm	.11	.10	.08	.11	.47	.15	.16	.18	.16	.33	.13	.33
Ms		580.	33700.	370.	670.	690.	490.	4960.	2440.	1140	690.	1500.	3070.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Laivakangas N			Sudenkylä			Jokisivu			Isovesi		
		351	352	353	361	362	363	371	372	373	381	382	383
Au1	ppb	510.	4300.	670.	100.	8600.	96.	260.	26200.	650.	34.	1300.	460.
Au2	ppb	590.	4950.	790.	70.	10800.	120.	210.	41000.	390.	50.	1460.	490.
Ag	ppb	153.	2100.	189.	78.	700.	198.	694.	4100.	302.	209.	472.	470.
As	ppm	240.	2200.	230.	180.	30000.	370.	150.	19.0	89.0	890.	7200.	2300.
B	ppm	4.1	5.6	9.1	3.0	3.0	5.8	6.7	12.1	17.3	40.9	15.8	14.9
Ba	ppm	265.	283.	320.	358.	475.	387.	394.	339.	376.	506.	205.	172.
Be	ppm	4.	4.	4.	5.	8.	4.	3.	3.	4.	7.	6.	6.
Bi	ppm	1.4	14.2	2.4	.2	19.2	.3	.5	6.1	.3	1.1	13.3	6.3
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	1.2	<.2	<.2	<.2	<.2
Co	ppm	20.	71.	23.	19.	999.	26.	14.	5.	13.	4.	7.	4.
Cr	ppm	180.	180.	130.	559.	130.	440.	29.	30.	31.	37.	28.	36.
Cs	ppm	6.	3.	3.	4.	1.	4.	2.	2.	2.	2.	2.	2.
Cu	ppm	178.	451.	94.	100.	632.	161.	215.	133.	182.	255.	645.	724.
Ga	ppm	22.8	21.2	20.4	24.9	22.2	16.4	14.5	12.0	15.0	17.5	23.5	19.9
Ge	ppm	<10.	10.	10.	<10.	<10.	30.	40.	30.	30.	30.	20.	30.
Hf	ppm	2.1	1.8	1.3	2.8	1.8	2.8	6.0	3.1	6.3	3.0	3.1	3.2
Hg	ppb	17.	52.	12.	10.	210.	12.	7.	20.	10.	20.	13.	30.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	106.	82.	97.	29.	12.	26.	32.	18.	26.	95.	17.	18.
Mo	ppm	3.	2.	<1.	<1.	<1.	3.	<1.	<1.	<1.	<1.	<1.	<1.
Nb	ppm	12.	14.	13.	17.	15.	14.	25.	17.	24.	14.	15.	17.
Ni	ppm	34.	36.	33.	136.	775.	106.	20.	13.	19.	21.	22.	25.
Pb	ppm	<2.	<2.	<2.	<2.	5.	<2.	<2.	51.	<2.	<2.	<2.	<2.
Pd	ppb	<.1	<.1	<.1	.9	14.1	1.5	<.1	<.1	<.1	<.1	1.0	.3
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	90.	66.	75.	131.	91.	61.	58.	66.	54.	69.	69.	38.
Sb	ppm	.2	<.3	.2	<.2	2.3	.2	.3	.6	<.2	2.8	3.5	1.8
Sc	ppm	36.2	33.7	34.9	29.4	10.1	25.2	15.2	10.9	18.3	16.1	11.4	12.1
Se	ppm	.40	2.2	.30	.64	7.9	1.8	.48	1.2	.46	4.1	27.	26.
Sn	ppm	7.	6.	7.	4.	<2.	<2.	<2.	4.	<2.	13.	15.	15.
Sr	ppm	241.	202.	210.	220.	82.	201.	265.	213.	269.	234.	416.	440.
Ta	ppm	<1.	<1.	<1.	1.	<1.	<1.	<1.	<1.	1.	<1.	<1.	<1.
Te	ppb	290.	1850.	410.	230.	5600.	380.	220.	5200.	200.	550.	4300.	1750.
Th	ppm	1.6	1.7	1.2	3.0	1.8	3.0	4.9	12.0	5.0	3.7	2.1	2.1
Tl	ppm	1.3	.8	.7	1.3	.8	1.3	.6	.7	.5	1.6	.6	.2
U	ppm	1.6	.5	1.1	1.2	1.6	1.3	3.4	12.4	4.2	5.4	1.3	1.9
V	ppm	280.	250.	290.	240.	120.	220.	130.	90.	180.	160.	130.	140.
W	ppm	28.	87.	11.	.5	<.5	3.	27.	240.	17.	4.	.50	2.
Y	ppm	18.	16.	17.	24.	10.	18.	28.	20.	26.	17.	17.	14.
Zn	ppm	88.8	91.7	85.5	100.	69.7	89.8	113.	147.	109.	60.0	83.3	96.8
Zr	ppm	64.	72.	66.	93.	45.	118.	235.	125.	191.	119.	113.	118.
SiO2	%	52.5	54.1	52.5	52.3	46.2	55.7	57.8	68.1	56.0	50.1	46.6	47.3
Al2O3	%	15.2	14.4	15.2	11.7	5.56	11.0	16.2	12.6	16.3	14.9	14.2	14.1
CaO	%	8.51	8.29	8.56	6.36	2.28	6.11	5.71	4.34	6.43	6.66	13.1	12.9
MgO	%	6.14	5.77	6.10	8.34	2.66	6.41	2.89	1.85	3.19	6.59	2.72	2.45
Na2O	%	2.82	2.57	2.71	1.60	.65	1.53	3.39	2.78	3.24	1.58	1.83	2.40
K2O	%	1.56	1.58	1.59	2.76	1.70	2.66	1.66	1.99	1.61	2.74	1.45	.74
Fe2O3*	%	10.4	9.90	10.3	13.0	31.5	12.5	9.02	5.22	9.87	9.41	15.9	15.6
TiO2	%	.80	.74	.78	1.01	.49	.91	.91	.58	1.08	.71	.60	.62
MnO	%	.18	.16	.17	.16	.07	.15	.15	.12	.16	.13	.20	.20
P2O5	%	.14	.13	.13	.22	.039	.20	.20	.12	.20	.18	.18	.18
Loi	%	.85	.77	.70	2.08	9.00	1.39	1.00	.85	.77	5.85	2.93	2.08
Total	%	99.2	98.5	98.8	99.7	100.0	98.6	99.0	98.6	99.0	99.0	99.8	98.7
H2O+	%	1.1	1.0	1.1	1.3	.7	1.0	.9	.6	1.0	4.2	1.1	.8
H2O-	%	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	.1	1.1	.2	.2
CO2	%	.04	.02	.07	.15	.05	.06	.13	.08	.06	.78	.05	.29
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
S	ppm	1540.	2800.	770.	15400.	104000.	19700.	6570.	5400.	6260.	11000.	32000.	34200.
F	ppm	450.	190.	400.	480.	70.	500.	370.	210.	380.	610.	420.	570.
Cl	ppm	<50.	<50.	<50.	166.	93.	172.	421.	201.	489.	67.	<50.	56.
La	ppm	9.0	8.4	9.3	17.8	5.6	17.5	31.0	22.0	27.1	17.4	23.5	19.5
Ce	ppm	18.3	17.7	19.6	37.5	11.9	36.0	60.5	45.9	54.5	33.8	47.0	38.5
Pr	ppm	2.6	2.3	2.7	5.0	1.6	4.5	7.5	5.8	6.7	4.6	5.9	4.9
Nd	ppm	10.9	10.5	11.2	21.7	6.8	18.7	31.9	24.0	28.6	17.3	23.5	20.5
Sm	ppm	2.9	2.7	2.8	4.8	1.8	3.8	6.2	4.8	6.2	3.7	4.8	4.1
Eu	ppm	.94	.92	.79	1.30	.48	1.11	1.63	1.	1.50	1.26	2.12	1.37
Gd	ppm	3.3	3.0	3.4	5.4	2.1	4.0	6.4	5.1	5.7	3.7	3.8	3.3
Tb	ppm	.6	.5	.5	.8	.3	.6	1.	.7	.9	.5	.5	.4
Dy	ppm	3.6	3.2	3.2	4.6	1.8	3.7	5.6	4.2	5.1	3.4	3.3	2.9
Ho	ppm	.72	.67	.70	.93	.34	.75	1.15	.79	1.	.75	.69	.61
Er	ppm	2.2	2.0	2.1	2.9	1.1	2.1	3.3	2.3	3.1	2.0	1.8	1.5
Tm	ppm	.3	.3	.3	.4	.1	.3	.5	.3	.4	.2	.2	.2
Yb	ppm	2.3	1.9	1.9	2.8	1.0	2.0	3.4	1.9	2.8	1.8	1.5	1.5
Lu	ppm	.34	.28	.29	.34	.11	.28	.46	.25	.37	.32	.27	.26
Ms		640.	610.	560.	2090.	12700.	2480.	660.	800.	800.	510.	2990.	3450.

Au1: Fire Assay, DCP (20g); Au2 Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Antinoja			Vesiperä			Ängesneva			Kiimala		
		391	392	393	401	402	403	411	412	413	421	422	423
Au1	ppb	150.	2800.	150.	300.	6700.	670.	430.	2600.	330.	170.	2600.	62.
Au2	ppb	200.	3450.	210.	240.	9100.	570.	370.	2650.	220.	160.	2650.	60.
Ag	ppb	79.	214.	34.	200.	1800.	321.	486.	4200.	554.	1500.	11200.	1600.
As	ppm	7.9	80.0	99.0	390.	13000.	1300.	1100.	12000.	350.	320.	330.	110.
B	ppm	9.5	11.7	12.6	13.0	11.6	12.0	17.7	12.8	18.8	22.3	70.0	13.8
Ba	ppm	249.	291.	263.	347.	373.	369.	481.	500.	337.	353.	318.	480.
Be	ppm	2.	3.	2.	2.	5.	4.	5.	4.	5.	5.	9.	4.
Bi	ppm	<.1	.5	.1	.3	3.1	.4	5.3	33.1	3.5	.6	4.2	.3
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	35.	<.2
Co	ppm	10.	8.	7.	13.	17.	20.	12.	23.	7.	34.	99.	24.
Cr	ppm	110.	64.	87.	36.	35.	36.	29.	38.	38.	390.	150.	120.
Cs	ppm	1.	3.	3.	3.	2.	2.	7.	5.	6.	3.	1.	2.
Cu	ppm	286.	819.	101.	152.	279.	180.	550.	1490.	602.	408.	2860.	447.
Ga	ppm	20.0	24.1	21.6	23.8	21.4	22.8	24.7	24.6	27.4	23.7	42.3	26.1
Ge	ppm	10.	40.	30.	20.	20.	<10.	<10.	<10.	<10.	30.	20.	<10.
Hf	ppm	2.1	2.5	2.6	1.5	1.4	1.7	2.2	1.3	1.6	1.2	1.2	1.9
Hg	ppb	7.	7.	5.	10.	29.	27.	25.	82.	15.	10.	15.	7.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	22.	23.	25.	36.	30.	38.	54.	35.	34.	50.	32.	38.
Mo	ppm	<1.	38.	<1.	<1.	<1.	2.	<1.	<1.	<1.	<1.	<1.	<1.
Nb	ppm	12.	13.	12.	12.	12.	11.	15.	12.	13.	12.	9.	10.
Ni	ppm	44,	46.	40.	21.	18.	21.	14.	20.	22.	91.	134.	49.
Pb	ppm	<2.	<2.	<2.	<2.	<2.	<2.	<2.	<2.	<2.	<2.	78.	<2.
Pd	ppb	<.1	<.1	.5	10.6	13.1	13.4	5.4	9.2	8.0	.7	.4	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	26.	41.	56.	48.	54.	42.	75.	72.	73.	64.	62.	64.
Sb	ppm	.7	.9	.9	.8	6.9	1.4	37.0	160.	19.0	6.3	34.0	3.5
Sc	ppm	12.9	11.5	13.0	18.5	17.2	18.1	27.4	19.0	16.6	23.8	11.9	21.8
Se	ppm	.04	.34	.02	.06	2.6	.14	1.9	7.5	2.9	1.3	10.	.36
Sn	ppm	<2.	7.	<2.	7.	8.	<2.	5.	12.	7.	8.	<2.	7.
Sr	ppm	528.	388.	543.	614.	551.	631.	278.	456.	563.	432.	126.	283.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
Te	ppb	50.	120.	30.	50.	440.	30.	560.	1500.	340.	190.	850.	70.
Th	ppm	1.3	1.0	2.1	.6	.7	.9	1.3	.9	.8	1.7	1.8	3.2
Tl	ppm	<.1	.4	.3	.3	1.0	.8	.8	1.1	.8	.9	.7	.7
U	ppm	.9	1.5	1.0	.8	.6	.7	2.1	.5	.3	1.5	.7	.9
V	ppm	110.	120.	100.	200.	200.	200.	320.	220.	180.	230.	130.	230.
W	ppm	<.5	<.5	<.5	6.	92.	13.	4.	6.	5.	<.5	1.	2.
Y	ppm	9.	9.	11.	16.	14.	15.	22.	16.	16.	10.	7.	12.
Zn	ppm	30.2	57.0	29.3	137.	95.2	112.	98.5	79.2	57.7	294.	2920.	346.
Zr	ppm	92.	84.	88.	62.	64.	58.	90.	65.	61.	60.	64.	61.
SiO2	%	62.6	61.3	62.4	50.8	50.6	51.4	50.8	49.7	51.9	47.9	33.9	51.8
Al2O3	%	16.0	15.8	16.4	19.2	18.0	18.9	15.9	17.6	19.4	15.5	10.1	16.4
CaO	%	4.83	3.75	4.95	7.44	6.74	7.59	3.87	5.80	6.34	7.73	3.33	6.32
MgO	%	3.24	3.21	3.11	3.48	3.28	3.25	5.31	2.93	2.74	7.93	3.79	5.48
Na2O	%	5.92	6.17	5.33	3.16	3.43	3.38	1.94	2.64	3.81	1.84	1.46	3.18
K2O	%	.70	.95	.97	1.77	1.95	1.63	2.83	2.45	1.91	1.69	.91	2.05
Fe2O3*	%	4.42	5.91	4.63	9.44	9.76	9.58	13.30	12.50	9.93	12.20	38.00	9.57
TiO2	%	.53	.51	.56	.86	.81	.87	1.35	.88	.86	.49	.40	.59
MnO	%	.07	.06	.07	.15	.13	.16	.12	.10	.08	.16	.17	.15
P2O5	%	.13	.15	.14	.25	.24	.25	.36	.26	.28	.085	.023	.14
Loi	%	.85	1.16	.77	1.85	2.08	1.47	4.00	3.62	1.62	3.31	8.16	3.16
Total	%	99.4	99.1	99.4	98.5	97.1	98.6	99.9	98.6	99.0	98.8	100.0	98.9
H2O+	%	.8	1.2	1.0	2.0	1.6	1.8	3.1	1.9	1.3	3.2	2.9	3.1
H2O-	%	.1	.2	.2	.3	.2	.1	.4	.1	<.1	.2	.2	.2
CO2	%	.05	.02	.02	.03	.01	.07	.03	.08	.02	.01	.08	.12
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
S	ppm	270.	1420.	130.	1400.	12000.	3110.	10100.	30800.	18400.	12700.	120000.	8490.
F	ppm	340.	330.	370.	410.	410.	320.	380.	320.	520.	260.	100.	300.
Cl	ppm	143.	132.	87.	149.	123.	174.	376.	314.	246.	101.	107.	67.
La	ppm	22.5	60.4	20.3	9.6	8.5	9.1	13.8	10.8	10.6	10.5	9.7	15.8
Ce	ppm	37.5	84.5	35.7	19.9	18.1	19.9	29.8	22.1	22.4	20.9	18.2	29.5
Pr	ppm	3.9	7.5	4.2	2.8	2.7	2.8	4.2	3.0	3.1	2.6	2.3	3.7
Nd	ppm	13.9	22.1	15.6	12.4	11.1	12.1	18.4	13.6	14.2	12.0	9.4	15.9
Sm	ppm	2.3	3.1	2.9	2.8	2.7	2.8	4.4	3.0	3.4	2.3	1.9	2.9
Eu	ppm	.71	.93	.83	1.16	1.04	1.17	1.41	1.13	1.13	.92	.71	1.16
Gd	ppm	2.1	2.3	2.3	2.9	2.5	3.1	4.3	3.2	3.3	2.4	1.7	2.7
Tb	ppm	.2	.3	.3	.4	.4	.4	.7	.5	.5	.3	.2	.4
Dy	ppm	1.7	1.8	2.3	3.3	2.8	3.5	4.3	3.4	3.3	2.1	1.4	2.2
Ho	ppm	.34	.37	.44	.69	.62	.64	.88	.68	.69	.42	.24	.41
Er	ppm	.9	1.1	1.2	1.9	1.7	1.9	2.7	2.0	2.2	1.2	.8	1.4
Tm	ppm	<.1	.1	.2	.2	.2	.3	.4	.3	.3	.1	.1	.2
Yb	ppm	.9	1.0	1.4	1.9	1.6	2.1	2.6	1.9	2.0	1.1	.7	1.3
Lu	ppm	.20	.22	.19	.31	.29	.28	.34	.27	.28	.14	.08	.12
Ms		690.	670.	630.	680.	430.	780.	530.	1590.	2330.	570.	11300.	390.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Pirilä S			Kalliosalo			Kurula			Pirilä N		
		431	432	433	441	442	443	451	452	453	461	462	463
Au1	ppb	60.	9500.	56.	340.	7500.	90.	72.	1100.	240.	260.	2800.	64.
Au2	ppb	100.	32000.	60.	280.	6700.	120.	80.	1280.	300.	240.	3100.	40.
Ag	ppb	450.	15200.	185.	96.	362.	39.	36.	160.	47.	244.	1900.	365.
As	ppm	790.	31000.	240.	440.	1500.	210.	990.	18000.	9100.	990.	18000.	210.
B	ppm	21.8	9.8	18.6	148.	366.	195.	473.	2900.	344.	43.9	17.0	52.5
Ba	ppm	493.	208.	840.	652.	719.	723.	378.	309.	420.	815.	1450.	666.
Be	ppm	4.	5.	3.	5.	3.	4.	3.	5.	4.	5.	5.	6.
Bi	ppm	.2	20.7	.4	.4	<.1	.2	4.0	19.1	2.2	.3	.4	.5
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	2.2	<.2
Co	ppm	19.	<1.	9.	14.	14.	12.	114.	1590.	238.	14.	10.	13.
Cr	ppm	430.	53.	120.	90.	130.	82.	220.	140.	160.	150.	110.	110.
Cs	ppm	5.	3.	4.	6.	1.	7.	5.	7.	6.	7.	5.	8.
Cu	ppm	62.8	1890.	15.5	40.	42.2	31.7	147.	291.	183.	50.1	48.9	63.4
Ga	ppm	17.1	14.9	14.8	19.8	21.4	21.4	22.5	20.4	23.9	23.0	17.6	25.4
Ge	ppm	10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.	10.	20.	<10.
Hf	ppm	2.2	.8	4.4	5.8	4.4	3.6	3.6	-	4.1	4.0	3.5	4.5
Hg	ppb	12.	87.	7.	15.	47.	17.	8.	59.	15.	<5.	19.	<5.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	58.	20.	54.	47.	50.	57.	16.	49.	59.	85.	44.	86.
Mo	ppm	<1.	<1.	<1.	<1.	1.	<1.	3.	26.	5.	<1.	<1.	1.
Nb	ppm	16.	11.	16.	17.	17.	16.	18.	13.	17.	17.	15.	18.
Ni	ppm	158.	38.	63.	58.	60.	46.	70.	151.	60.	67.	51.	62.
Pb	ppm	113.	778.	147.	2.	21.	<2.	<2.	<2.	<2.	28.	22.	16.
Pd	ppb	2.8	<.1	.6	.9	.3	<.1	.6	.7	.8	1.2	.8	.9
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	113.	60.	116.	149.	130.	131.	68.	68.	96.	144.	93.	150.
Sb	ppm	.5	5.8	.6	2200.	8700.	1800.	1.6	9.4	1.9	2.4	49.0	1.4
Sc	ppm	13.8	1.8	7.62	13.4	13.4	13.4	13.0	9.66	12.4	15.9	12.4	15.1
Se	ppm	.18	7.8	.12	.08	.28	.10	.12	4.7	1.2	.14	.46	.50
Sn	ppm	12.	<2.	<2.	<2.	<2.	<2.	<2.	8.	7.	<2.	<2.	3.
Sr	ppm	403.	45.	236.	115.	110.	155.	548.	272.	349.	246.	232.	150.
Ta	ppm	<1.	<1.	1.	<1.	<1.	<1.	1.	<1.	<1.	<1.	<1.	1.
Te	ppb	30.	680.	40.	10.	10.	<1.	140.	2500.	600.	60.	20.	50.
Th	ppm	4.1	1.9	9.1	10.0	6.9	10.0	5.8	5.4	7.7	10.0	8.0	10.0
Tl	ppm	1.0	.8	1.0	1.1	1.2	1.1	.6	1.0	.8	.8	.6	1.2
U	ppm	3.1	1.8	2.8	2.8	5.2	1.8	4.1	3.7	3.6	3.1	2.4	4.5
V	ppm	120.	18.	80.	110.	94.	98.	110.	110.	100.	130.	120.	130.
W	ppm	3.	4.	.5	9.	3.	8.	5.	600.	3.	5.	18.	4.
Y	ppm	10.	6.	8.	12.	10.	11.	16.	12.	16.	13.	13.	18.
Zn	ppm	209.	432.	124.	94.9	89.3	80.6	65.8	57.3	70.4	103.	158.	113.
Zr	ppm	99.	35.	175.	175.	131.	194.	162.	124.	171.	148.	127.	156.
SiO2	%	63.0	72.1	74.5	67.4	67.9	67.9	62.3	60.0	63.4	63.2	68.1	64.8
Al2O3	%	11.8	3.14	11.4	14.3	14.4	14.3	15.1	13.1	14.6	15.2	11.9	15.2
CaO	%	5.84	.74	1.17	2.21	1.58	1.63	4.18	1.62	2.50	1.44	1.83	.76
MgO	%	5.56	2.58	1.71	1.87	2.09	2.21	3.98	4.10	3.43	3.00	2.41	2.56
Na2O	%	.93	.29	2.06	.49	.51	.72	4.77	3.03	4.74	3.02	2.08	2.01
K2O	%	2.45	.93	2.91	3.78	3.67	3.81	1.49	1.58	1.95	3.47	2.70	3.57
Fe2O3*	%	7.59	14.0	4.08	5.41	5.67	5.27	5.19	7.49	6.23	6.22	5.45	6.77
TiO2	%	.49	.10	.40	.58	.59	.59	.63	.53	.63	.63	.51	.63
MnO	%	.20	.31	.07	.045	.06	.07	.07	.038	.037	.08	.08	.07
P2O5	%	.12	.014	.087	.13	.12	.14	.17	.15	.16	.14	.12	.15
Loi	%	1.00	4.00	.85	2.00	1.93	1.54	1.16	1.31	.85	1.62	3.00	2.70
Total	%	99.1	98.2	99.3	98.3	98.6	98.3	99.2	93.0	98.6	98.2	98.4	99.3
H2O+	%	1.3	.8	1.0	1.3	1.5	1.2	1.0	1.5	.8	1.4	1.1	2.3
H2O-	%	.1	<.1	<.1	<.1	<.1	<.1	.1	.1	<.1	<.1	<.1	.1
CO2	%	.14	.18	.10	.15	.15	.05	.05	.04	.04	.20	.49	.18
Cgraph	%	<.05	<.05	<.05	.12	<.05	<.05	<.05	<.05	<.05	<.05	<.05	.12
S	ppm	1590.	26300.	180.	11700.	13900.	8370.	1030.	9940.	5360.	5970.	14100.	7430.
F	ppm	1300.	950.	550.	520.	560.	580.	610.	680.	720.	590.	540.	750.
Cl	ppm	241.	181.	78.	<50.	<50.	<50.	243.	241.	326.	<50.	<50.	<50.
La	ppm	20.5	6.1	32.7	36.6	30.4	36.8	25.8	49.2	34.3	36.0	30.7	42.3
Ce	ppm	38.2	11.7	60.5	68.2	56.5	69.4	47.6	73.3	66.1	69.0	57.2	78.4
Pr	ppm	4.6	1.2	7.1	8.4	6.6	8.6	5.8	7.8	7.8	8.3	6.5	9.6
Nd	ppm	16.6	5.5	24.9	30.8	24.7	31.1	22.7	27.2	27.8	30.2	23.8	35.3
Sm	ppm	2.8	.9	4.2	5.7	4.5	5.4	4.3	4.7	4.9	5.3	4.6	6.0
Eu	ppm	.97	.23	.87	1.17	.91	1.15	1.23	.65	.98	1.26	.93	1.26
Gd	ppm	2.5	.7	3.2	4.2	3.4	3.9	3.8	3.3	4.0	4.2	3.5	4.6
Tb	ppm	.4	.1	.4	.5	.4	.5	.5	.4	.5	.5	.4	.7
Dy	ppm	2.2	1.0	2.2	3.0	2.3	2.7	2.9	2.3	3.6	3.4	2.7	3.7
Ho	ppm	.40	.16	.32	.43	.36	.43	.57	.44	.70	.57	.51	.72
Er	ppm	1.0	.8	.9	1.3	1.1	1.1	1.7	1.4	1.7	1.4	1.3	1.9
Tm	ppm	.1	.1	<.1	.2	.2	.1	.3	.2	.3	.2	.2	.3
Yb	ppm	1.2	.7	.9	.9	.9	1.0	1.6	1.4	1.8	1.2	1.1	1.7
Lu	ppm	.15	.08	.08	.14	.11	.12	.22	.20	.27	.17	.17	.28
Ms		900.	1990.	1070.	1210.	2050.	960.	490.	640.	520.	880.	1090.	530.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3; -: Not detected.

App. 2, contd.

		Kaapelinkulma			Laivakangas S			Pöhlölä			Kopsa	
		471	472	473	481	482	483	491	492	493	501	502
Au1	ppb	240.	3200.	140.	360.	5500.	100.	320.	12500.	49.	310.	3500.
Au2	ppb	210.	3250.	260.	450.	3500.	120.	410.	12800.	60.	410.	3800.
Ag	ppb	22.	101.	16.	33.	590.	62.	67.	2100.	15.	1500.	3400.
As	ppm	300.	2300.	45.0	180.	580.	65.0	35.0	630.	160.	2800.	12000.
B	ppm	11.7	5.5	6.1	6.6	<.5	4.6	7.3	<.5	14.7	5.1	6.7
Ba	ppm	366.	340.	390.	536.	566.	524.	722.	295.	745.	520.	505.
Be	ppm	17.	6.	6.	4.	4.	4.	4.	2.	4.	3.	2.
Bi	ppm	1.3	25.2	1.5	3.2	38.8	.5	7.5	314.	1.1	23.1	168.
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	2.	18.	15.	12.	11.	12.	7.	<1.	5.	19.	30.
Cr	ppm	59.	67.	97.	180.	150.	180.	40.	9.	47.	28.	24.
Cs	ppm	19.	9.	6.	6.	4.	5.	2.	<1.	3.	3.	2.
Cu	ppm	52.4	91.9	18.7	23.1	184.	23.2	47.2	293.	31.7	839.	1630.
Ga	ppm	24.1	24.7	23.8	21.2	19.5	21.9	21.6	3.2	22.8	14.5	14.0
Ge	ppm	<10.	<10.	20.	20.	20.	20.	40.	<10.	20.	10.	<10.
Hf	ppm	2.7	2.8	3.4	3.1	2.7	3.5	2.1	<.5	2.2	1.6	2.0
Hg	ppb	<5.	<5.	<5.	<5.	5.	<5.	<5.	42.	<5.	5.	14.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	57.	40.	31.	99.	64.	80.	33.	2.	41.	16.	11.
Mo	ppm	<1.	<1.	<1.	<1.	1.	2.	<1.	1.	<1.	2.	5.
Nb	ppm	15.	13.	14.	17.	14.	12.	12.	9.	14.	11.	12.
Ni	ppm	17.	24.	26.	33.	28.	35.	19.	5.	21.	20.	20.
Pb	ppm	<2.	<2.	<2.	7.	<2.	4.	<2.	40.	<2.	<2.	<2.
Pd	ppb	<.1	.5	.9	<.1	<.1	<.1	.3	<.1	<.1	<.1	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	196.	134.	113.	133.	147.	114.	60.	11.	44.	62.	88.
Sb	ppm	.3	<.2	.3	<.2	<.2	.2	.4	.9	.3	4.9	21.0
Sc	ppm	23.5	26.9	23.8	18.4	15.5	19.4	7.00	.13	7.88	10.9	9.06
Se	ppm	.18	.46	.08	.10	.88	.06	.28	2.8	.16	2.4	6.9
Sn	ppm	<2.	10.	<2.	10.	5.	8.	<2.	<2.	<2.	<2.	40.
Sr	ppm	217.	187.	186.	399.	344.	431.	744.	8.	861.	188.	130.
Ta	ppm	<1.	<1.	2.	1.	1.	<1.	<1.	<1.	<1.	<1.	<1.
Te	ppb	30.	740.	50.	80.	700.	10.	650.	26000.	100.	1090.	5800.
Th	ppm	3.4	3.8	4.4	6.5	5.8	5.4	1.5	<.5	1.7	2.4	1.8
Tl	ppm	1.3	.8	.6	1.1	1.0	1.1	.3	.2	.3	.4	.5
U	ppm	1.7	1.5	3.2	3.7	2.4	2.9	.9	<.1	.8	1.0	1.5
V	ppm	260.	220.	180.	140.	120.	180.	76.	4.	92.	90.	66.
W	ppm	5.	4.	2.	14.	77.	15.	100.	2400.	71.	190.	500.
Y	ppm	12.	20.	22.	19.	13.	15.	5.	<1.	6.	8.	9.
Zn	ppm	45.0	68.6	76.5	67.3	43.5	59.2	64.1	141.	64.2	59.9	64.9
Zr	ppm	94.	119.	124.	91.	87.	103.	58.	12.	62.	51.	40.
SiO2	%	60.0	56.4	58.2	62.4	65.9	59.7	68.0	96.2	65.7	69.3	72.0
Al2O3	%	17.5	16.6	15.8	14.3	12.4	14.8	14.7	.3	16.3	13.0	10.6
CaO	%	4.64	6.23	6.74	5.06	4.30	5.62	3.17	.19	3.86	4.18	2.33
MgO	%	3.12	3.38	3.68	3.62	3.40	3.99	1.98	.31	2.02	2.08	1.95
Na2O	%	3.70	2.70	2.83	3.11	2.76	3.15	4.22	.05	4.61	2.07	1.25
K2O	%	2.37	2.08	2.08	3.09	3.48	3.14	2.29	.14	1.90	2.12	3.62
Fe2O3*	%	7.12	9.03	8.17	5.90	5.58	6.39	3.41	1.85	3.87	4.33	4.29
TiO2	%	.86	.81	.77	.53	.49	.58	.42	.04	.48	.28	.24
MnO	%	.07	.11	.13	.11	.09	.10	.07	.020	.07	.06	.038
P2O5	%	.092	.12	.12	.15	.13	.16	.14	<.002	.15	.060	.041
Loi	%	1.08	1.16	.70	.47	.62	.54	1.08	.85	1.00	.70	1.54
Total	%	101.	98.7	99.3	98.9	99.3	98.3	99.7	100.	100.	98.2	97.9
H2O+	%	.9	1.2	.9	.9	.9	.9	1.2	.2	1.0	.9	.8
H2O-	%	<.1	<.1	<.1	<.1	<.1	<.1	.1	<.1	.1	<.1	<.1
CO2	%	.01	.01	.05	.01	.01	.02	.06	.01	.07	.03	.05
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
S	ppm	4510.	6420.	790.	100.	1690.	160.	1410.	10800.	940.	5030.	10600.
F	ppm	2800.	660.	870.	580.	580.	500.	300.	<20.	300.	330.	320.
Cl	ppm	412.	502.	479.	<50.	<50.	<50.	<50.	<50.	<50.	131.	88.
La	ppm	13.2	18.4	19.3	17.8	15.2	16.5	11.8	.7	14.7	8.0	7.2
Ce	ppm	23.1	36.1	37.5	33.0	28.8	30.5	22.4	1.0	28.3	15.4	13.9
Pr	ppm	2.8	4.4	4.7	4.0	3.4	3.7	2.9	.1	3.5	1.9	1.9
Nd	ppm	11.0	18.1	19.5	15.9	12.6	15.3	11.1	.4	13.4	6.8	6.4
Sm	ppm	2.2	4.2	4.2	3.6	2.8	2.9	2.0	< .1	2.2	1.4	1.7
Eu	ppm	.76	.98	1.03	.84	.65	.75	.61	<.05	.66	.36	.28
Gd	ppm	2.0	3.7	4.0	3.3	2.3	3.0	1.5	<.1	1.6	1.4	1.5
Tb	ppm	.3	.6	.6	.5	.3	.5	.1	<.1	.2	.2	.3
Dy	ppm	2.5	4.1	4.4	3.5	2.6	2.9	1.0	<.1	1.3	1.5	1.9
Ho	ppm	.46	.83	.90	.73	.49	.54	.17	<.05	.22	.27	.32
Er	ppm	1.4	2.4	2.7	2.1	1.4	1.6	.5	<.1	.6	.8	.9
Tm	ppm	.2	.3	.4	.3	.2	.2	.1	<.1	<.1	.1	.1
Yb	ppm	1.1	2.2	2.3	2.1	1.4	1.8	.4	<.1	.5	.8	1.0
Lu	ppm	.15	.31	.32	.26	.23	.29	.06	<.05	.07	.14	.14
Ms		610.	650.	570.	660.	890.	660.	690.	1140.	770.	900.	970.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6} SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 2, contd.

		Kangaskylä			Osikonmäki E			Osikonmäki W			Björkdal
		511	512	513	521	522	523	531	532	533	542
Au1	ppb	280.	2000.	340.	550.	7000.	1200.	680.	5000.	430.	3600.
Au2	ppb	340.	2300.	520.	540.	7000.	1280.	620.	5400.	270.	2850.
Ag	ppb	454.	10700.	5300.	379.	2400.	382.	344.	840.	100.	406.
As	ppm	2000.	35000.	9300.	770.	2600.	200.	6800.	1700.	55.0	6.3
B	ppm	13.6	14.2	34.3	10.6	7.2	7.3	7.7	6.3	3.8	151.
Ba	ppm	386.	732.	638.	574.	549.	554.	569.	535.	547.	964.
Be	ppm	2.	3.	2.	4.	4.	5.	5.	6.	3.	3.
Bi	ppm	1.0	3.5	2.8	2.6	23.8	4.5	3.1	25.3	1.8	12.4
Cd	ppm	9.6	3.8	.8	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	3.	15.	5.	10.	19.	8.	9.	7.	4.	13.
Cr	ppm	19.	40.	11.	28.	23.	30.	20.	20.	23.	71.
Cs	ppm	1.	1.	1.	3.	3.	3.	7.	5.	3.	3.
Cu	ppm	188.	1320.	1400.	306.	1540.	239.	185.	479.	156.	133.
Ga	ppm	16.7	16.4	15.4	22.4	23.0	22.2	23.4	20.4	24.8	23.2
Ge	ppm	<10.	10.	<10.	<10.	10.	<10.	10.	10.	<10.	20.
Hf	ppm	1.8	1.6	1.1	4.4	4.4	4.5	4.2	3.3	4.6	3.3
Hg	ppb	82.	180.	46.	7.	15.	7.	34.	59.	<5.	15.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	13.	12.	15.	39.	38.	39.	57.	37.	56.	19.
Mo	ppm	<1.	<1.	<1.	<1.	<1.	3.	3.	<1.	<1.	<1.
Nb	ppm	11.	11.	11.	17.	18.	16.	18.	16.	16.	14.
Ni	ppm	13.	13.	14.	27.	27.	21.	20.	18.	27.	48.
Pb	ppm	<2.	33.	37.	<2.	<2.	<2.	<2.	23.	<2.	8.
Pd	ppb	<.1	<.1	<.1	<.1	<.1	.4	.6	<.1	<.1	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	33.	45.	43.	91.	118.	94.	101.	114.	78.	82.
Sb	ppm	9.4	60.0	19.0	.2	.6	.3	1.0	4.5	.3	.5
Sc	ppm	5.83	4.67	5.17	6.39	6.49	6.61	6.48	5.18	6.56	9.89
Se	ppm	.60	5.8	1.7	2.5	8.0	1.1	13.	31.	.54	.04
Sn	ppm	<2.	<2.	<2.	<2.	6.	13.	<2.	68.	51.	16.
Sr	ppm	465.	259.	315.	549.	541.	609.	607.	355.	600.	1100.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.	3.	<1.	1.	<1.
Te	ppb	30.	2250.	480.	320.	2700.	320.	130.	1200.	30.	5300.
Th	ppm	.6	<.5	.8	7.5	7.9	8.2	7.1	6.7	7.4	9.8
Tl	ppm	.3	.5	.3	.4	.5	.5	.6	.6	.4	.5
U	ppm	.3	2.0	.8	4.0	4.6	4.4	4.0	3.6	4.3	2.4
V	ppm	42.	32.	34.	52.	56.	74.	70.	52.	52.	100.
W	ppm	5.	15.	3.	6.	1.	2.	.5	23.	5.	22.
Y	ppm	4.	2.	3.	13.	13.	13.	12.	10.	12.	12.
Zn	ppm	979.	496.	187.	54.5	80.8	54.1	45.6	46.9	61.3	85.0
Zr	ppm	54.	41.	48.	179.	153.	175.	146.	144.	157.	138.
SiO2	%	64.5	64.1	65.9	64.6	65.2	64.9	64.6	67.2	65.6	61.6
Al2O3	%	17.6	13.6	15.9	15.3	15.2	15.5	15.4	13.4	15.5	13.0
CaO	%	5.45	2.79	4.22	3.32	2.88	3.54	3.06	2.18	3.59	5.49
MgO	%	1.56	1.16	1.46	1.77	1.63	1.77	1.76	1.40	1.64	2.49
Na2O	%	4.20	2.76	3.33	4.69	4.35	4.67	4.63	3.90	4.64	4.61
K2O	%	1.63	2.38	2.38	2.79	3.10	2.69	2.58	3.11	2.55	2.23
Fe2O3*	%	2.19	6.84	3.52	4.48	4.26	4.51	4.47	4.47	4.18	4.88
TiO2	%	.23	.19	.22	.56	.52	.57	.51	.44	.53	.50
MnO	%	.07	.07	.09	.07	.040	.07	.06	.037	.07	.07
P2O5	%	.076	.044	.066	.18	.18	.18	.16	.15	.18	.26
Loi	%	.85	5.31	1.93	1.39	.85	.77	.85	1.93	.62	3.23
Total	%	98.4	99.3	99.1	99.3	98.3	99.3	98.2	98.3	99.3	98.6
H2O+	%	.9	.8	1.0	.8	.5	.7	.7	.5	.6	.9
H2O-	%	<.1	.1	<.1	<.1	<.1	<.1	<.1	.1	<.1	<.1
CO2	%	.37	.01	.24	.42	.18	.40	.13	.09	.15	3.28
Cgraph	%	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<05	<.05
S	ppm	2040.	22600.	7380.	4300.	6300.	1700.	6680.	10900.	1550.	3330.
F	ppm	160.	130.	140.	1100.	1400.	1000.	1200.	980.	750.	760.
Cl	ppm	118.	72.	80.	130.	165.	195.	68.	67.	139.	86.
La	ppm	5.4	2.5	4.7	34.9	34.1	36.9	33.8	29.2	34.4	65.5
Ce	ppm	11.3	5.4	9.8	63.0	62.9	66.3	61.4	52.1	62.3	128.
Pr	ppm	1.4	.7	1.4	7.2	7.1	7.4	6.6	5.9	7.1	15.5
Nd	ppm	5.6	2.6	5.4	26.7	25.5	25.9	24.2	20.9	26.2	57.0
Sm	ppm	.9	.5	1.0	4.6	4.1	4.5	3.9	3.5	4.3	8.3
Eu	ppm	.27	.11	.22	1.24	1.35	1.34	.98	.98	1.22	2.19
Gd	ppm	.8	.3	.6	3.3	3.4	3.6	2.9	2.9	3.2	5.4
Tb	ppm	.1	<.1	<.1	.5	.4	.4	.4	.4	.4	.6
Dy	ppm	.7	.3	.5	2.5	2.6	2.9	2.3	2.3	2.7	2.7
Ho	ppm	.13	<.05	.06	.46	.48	.50	.44	.40	.47	.40
Er	ppm	.4	.2	.3	1.3	1.2	1.3	1.1	1.0	1.3	1.0
Tm	ppm	<.1	<.1	<.1	.1	.2	.2	.1	.1	.2	.1
Yb	ppm	.4	.1	.3	1.1	1.1	1.1	1.1	1.0	1.1	.9
Lu	ppm	.06	<.05	.05	.14	.15	.17	.18	.15	.18	.13
Ms		720.	640.	600.	1040.	490.	1110.	690.	560.	690.	990.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

Appendix 3. Abundances of analysed elements for mesothermal gold deposits from Canada and Australia.

		Mt. Charlotte	New Celebration	Macassa	Hoyle Pond	Owl Creek
		1	2	3	4	5
Au1	ppb	3700.	590.	19600.	9000.	4100.
Au2	ppb	3200.	570.	23000.	8600.	3700.
Ag	ppb	2700.	145.	4100.	1500.	2000.
As	ppm	170.	2.2	9.7	240.	460.
B	ppm	44.3	14.1	23.0	86.8	53.1
Ba	ppm	195.	1970.	2040.	78.	179.
Be	ppm	4.	2.	5.	1.	2.
Bi	ppm	<.1	.1	.6	<.1	.3
Cd	ppm	<.2	<.2	<.2	<.2	<.2
Co	ppm	33.	4.	19.	17.	39.
Cr	ppm	38.	15.	180.	100.	1030.
Cs	ppm	9.	<1.	4.	<2.	<1.
Cu	ppm	77.0	14.2	108.	31.5	638.
Ga	ppm	22.8	21.7	21.1	5.3	14.9
Ge	ppm	20.	<10.	<10.	<10.	<10.
Hf	ppm	2.4	3.2	4.5	<2.0	1.1
Hg	ppb	2150.	13.	630.	24.	50.
In	ppm	<.5	<.5	<.5	<.5	<.5
Li	ppm	51.	9.	31.	11.	21.
Mo	ppm	3.	3.	130.	<1.	3.
Nb	ppm	11.	9.	14.	10.	10.
Ni	ppm	32.	29.	66.	63.	63.
Pb	ppm	<2.	<2.	5.	<2.	31.
Pd	ppb	<.1	<.1	<.1	2.3	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.
Rb	ppm	59.	44.	169.	18.	23.
Sb	ppm	21.0	.3	5.2	<1.0	.5
Sc	ppm	36.9	1.82	13.4	18.6	22.8
Se	ppm	.52	.06	.24	.24	3.10
Sn	ppm	6.	<2.	<2.	<2.	<2.
Sr	ppm	151.	652.	980.	47.	64.
Ta	ppm	<1.	<1.	<1.	<1.	<1.
Te	ppb	5400.	120.	37000.	370.	770.
Th	ppm	.5	9.1	9.2	<5.0	.9
Tl	ppm	.8	.5	1.1	.1	.4
U	ppm	.1	1.9	2.5	<3.0	.3
V	ppm	480.	14.	200.	80.	160.
W	ppm	45.	7.	13.	12.	24.
Y	ppm	8.	3.	18.	3.	4.
Zn	ppm	107.	39.1	102.	37.5	303.
Zr	ppm	90.	105.	162.	20.	43.
SiO2	%	47.1	69.0	53.0	67.2	65.7
Al2O3	%	10.8	15.8	12.2	6.68	8.41
CaO	%	6.84	1.26	5.49	6.95	4.63
MgO	%	3.64	.83	3.92	3.56	2.68
Na2O	%	1.57	6.52	2.09	.84	1.42
K2O	%	1.89	2.68	5.22	.49	.68
Fe2O3*	%	14.0	1.26	6.74	4.33	6.64
TiO2	%	1.43	.23	.65	.19	.53
MnO	%	.22	.026	.12	.14	.14
P2O5	%	.12	.14	.35	.005	.025
Loi	%	8.47	1.70	6.93	7.69	7.54
Total	%	96.1	99.7	97.1	98.1	98.5
H2O+	%	2.0	.7	1.4	1.4	1.7
H2O-	%	<.1	<.1	<.1	<.1	.1
CO2	%	10.1	1.33	7.31	8.08	6.31
Cgraph	%	<.05	<.05	<.05	.06	.33
S	ppm	28600.	3020.	12600.	7790.	17800.
F	ppm	180.	400.	860.	90.	150.
Cl	ppm	265.	160.	90.	125.	116.
La	ppm	4.9	37.0	55.1	1.0	4.3
Ce	ppm	12.3	67.2	112.	2.3	9.1
Pr	ppm	1.8	7.5	13.2	.3	1.2
Nd	ppm	8.8	25.3	48.6	1.7	5.4
Sm	ppm	2.3	4.0	8.9	.4	1.2
Eu	ppm	.66	1.09	2.19	.18	.42
Gd	ppm	1.9	2.2	6.9	.4	1.1
Tb	ppm	.3	.2	.8	<.1	.1
Dy	ppm	1.4	.8	3.6	.4	.7
Ho	ppm	.33	.11	.67	.11	.14
Er	ppm	1.0	.2	1.8	.3	.5
Tm	ppm	.1	<.1	.3	<.1	<.1
Yb	ppm	.9	.1	1.5	.4	.5
Lu	ppm	.17	<.05	.22	<.05	.07
Ms		7530.	650.	4160.	960.	2690.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

App. 3, contd.

		Kerr Addison			Renabie	Ferderber	Page Williams
		6.1	6.2	6.3	7	8	9
Au1	ppb	3500.	7600.	200000.	32400.	25300.	4000.
Au2	ppb	4300.	3700.	142000.	36500.	27000.	4100.
Ag	ppb	523.	890.	19400.	7700.	11900.	431.
As	ppm	99.0	330.	550.	2.9	32.0	240.
B	ppm	7.7	64.0	18.8	9.5	508.	11.9
Ba	ppm	189.	95.	235.	2620.	365.	133000.
Be	ppm	3.	2.	2.	3.	3.	3.
Bi	ppm	<.1	.1	<.1	4.0	15.0	<.1
Cd	ppm	<.2	<.2	<.2	<.2	<.2	<.2
Co	ppm	40.	27.	45.	10.	124.	4.
Cr	ppm	32.	792.	1990.	10.	21.	16.
Cs	ppm	<1.	<1.	2.	1.	<1.	2.
Cu	ppm	125.	68.1	48.0	434.	11600.	103.
Ga	ppm	20.1	8.2	10.7	19.0	14.2	9.6
Ge	ppm	10.	<10.	<10.	<10.	<10.	<10.
Hf	ppm	2.1	.6	<.5	1.6	.5	2.0
Hg	ppb	6.	20.	20.	63.	50.	11200.
In	ppm	<.5	<.5	<.5	<.5	<.5	<.5
Li	ppm	20.	16.	14.	16.	25.	14.
Mo	ppm	2.	<1.	<1.	181.	2.	3270.
Nb	ppm	11.	9.	10.	12.	11.	6.
Ni	ppm	87.	282.	515.	15.	102.	8.
Pb	ppm	<2.	7.	<2.	2.	35.	<2.
Pd	ppb	<.1	1.6	8.3	<.1	.5	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.	<4.
Rb	ppm	19.	14.	29.	77.	26.	41.
Sb	ppm	.8	6.1	2.7	1.5	<.2	150.
Sc	ppm	35.6	12.0	17.6	4.05	7.95	1.51
Se	ppm	.30	.14	.04	.20	.50	1.42
Sn	ppm	6.	<2.	<2.	4.	<2.	<2.
Sr	ppm	72.	113.	59.	371.	53.	564.
Ta	ppm	<1.	<1.	<1.	<1.	<1.	<1.
Te	ppb	120.	240.	170.	49000.	9900.	390.
Th	ppm	.6	.7	<.5	3.3	<.5	1.2
Tl	ppm	.2	.1	<.1	.6	.2	31.5
U	ppm	.5	.3	<.5	3.4	.6	.9
V	ppm	430.	98.	100.	76.	62.	460.
W	ppm	51.	18.	6.	1.	6.	10.
Y	ppm	5.	4.	2.	6.	6.	1.
Zn	ppm	66.	34.	43.8	67.30	557.	112.
Zr	ppm	77.	34.	21.	63.	32.	<1.
SiO2	%	48.9	60.0	41.7	76.2	62.1	47.1
Al2O3	%	11.30	3.17	4.63	7.42	7.06	7.16
CaO	%	5.80	8.73	4.65	2.17	5.39	2.23
MgO	%	4.12	6.45	16.0	.85	1.49	1.16
Na2O	%	4.46	.52	.11	.73	1.30	.49
K2O	%	.53	.34	1.27	2.16	.73	3.25
Fe2O3*	%	10.8	5.56	7.53	4.8	11.1	9.63
TiO2	%	1.51	.26	.31	.22	.42	.38
MnO	%	.25	.20	.14	.06	.10	.033
P2O5	%	.06	<.002	.025	.18	.071	.021
Loi	%	5.23	11.6	22.9	3.08	2.77	7.70
Total	%	92.9	97.0	99.5	98.2	92.5	94.0
H2O+	%	1.8	1.3	1.1	1.0	1.4	.6
H2O-	%	<.1	<.1	<.1	<.1	<.1	<.1
CO2	%	8.21	12.5	23.5	1.66	4.12	.25
Cgraph	%	<.05	.25	<.05	<.05	<.05	<.05
S	ppm	33900.	14300.	1350.	25100.	58600.	79600.
F	ppm	90.	110.	140.	790.	190.	140.
Cl	ppm	<50.	67.	<50.	176.	166.	<50.
La	ppm	4.2	3.5	.5	35.2	4.4	<.1
Ce	ppm	10.7	7.7	1.3	77.5	9.2	.2
Pr	ppm	1.6	.9	.3	9.7	1.2	<.1
Nd	ppm	8.8	4.2	1.2	38.0	6.5	1.4
Sm	ppm	2.3	1.0	.3	5.9	1.5	.4
Eu	ppm	.56	.30	.14	1.46	.48	.33
Gd	ppm	1.8	.9	.2	4.1	1.6	.4
Tb	ppm	.2	.2	<.1	.4	.2	<.1
Dy	ppm	1.0	.6	.4	1.6	1.1	.2
Ho	ppm	.20	.15	<.05	.23	.22	<.05
Er	ppm	.6	.4	.2	.5	.7	.2
Tm	ppm	.1	<.1	<.1	<.1	.1	<.1
Yb	ppm	.7	.4	.3	.3	.7	.2
Lu	ppm	.11	.05	<.05	<.05	.10	<.05
Ms		700.	1100.	660.	1280.	1040.	870.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

Appendix 4. Abundances of analysed elements in reference samples of common rock types.

		Basaltic komatiite	Gabro	Diorite	Phyllite	Tonalite
		RS131	RS11	RS101	RS91	M863883
Au1	ppb	9.	13.	<4.	<4.	<4.
Au2	ppb	2.	1.	<1.	<1.	1.
Ag	ppb	1.	18.	26.	55.	13.
As	ppm	1.8	2.2	.9	4.0	<.6
B	ppm	3.1	160.	<.5	496.	10.6
Ba	ppm	52.	149.	450.	598.	1100.
Be	ppm	4.	4.	6.	6.	4.
Bi	ppm	<.1	.5	<.1	1.2	<.1
Cd	ppm	<.2	<.2	<.2	<.2	<.2
Co	ppm	52.	31.	15.	29.	7.
Cr	ppm	2440.	300.	67.	180.	46.
Cs	ppm	<1.	7.	1.	4.	5.
Cu	ppm	80.2	64.9	35.2	137.	14.6
Ga	ppm	16.2	20.3	28.5	28.9	18.0
Ge	ppm	20.	40.	40.	10.	20.
Hf	ppm	.5	.8	3.9	3.6	2.4
Hg	ppb	15.	15.	7.	12.	5.
In	ppm	<.5	<.5	<.5	<.5	<.5
Li	ppm	2.	15.	21.	75.	47.
Mo	ppm	<1.	2.	1.	<1.	<1.
Nb	ppm	9.	11.	25.	17.	12.
Ni	ppm	915.	101.	37.	111.	32.
Pb	ppm	<2.	<2.	<2.	<2.	<2.
Pd	ppb	9.3	.7	<.1	2.9	<.1
Pt	ppb	<4.	<4.	<4.	<4.	<4.
Rb	ppm	4.	24.	30.	144.	81.
Sb	ppm	.2	.4	<.2	1.1	.2
Sc	ppm	21.8	34.0	18.9	27.2	6.19
Se	ppm	<.02	.02	<.02	.20	<.02
Sn	ppm	<2.	<2.	<2.	<2.	2.
Sr	ppm	12.	439.	911.	63.	878.
Ta	ppm	<1.	<1.	1.	1.	<1.
Te	ppb	2.	8.	2.	48.	5.
Th	ppm	<.5	<.5	1.9	9.8	2.8
Tl	ppm	.2	.2	.2	1.0	.6
U	ppm	.1	.1	1.1	4.4	1.1
V	ppm	200.	240.	230.	270.	64.
W	ppm	<1.	<1.	<1.	3.	3.
Y	ppm	11.	10.	21.	20.	6.
Zn	ppm	50.9	82.9	148.	163.	52.9
Zr	ppm	28.	46.	139.	145.	54.
SiO2	%	39.9	48.3	48.8	56.9	68.7
Al2O3	%	6.18	15.7	16.1	17.6	15.1
CaO	%	9.58	12.4	9.26	.39	2.67
MgO	%	22.3	8.82	4.08	4.04	1.45
Na2O	%	.07	1.83	2.70	1.57	4.72
K2O	%	.07	.53	1.17	3.47	2.65
Fe2O3*	%	10.7	9.01	11.1	9.97	2.64
TiO2	%	.51	.77	3.18	.93	.28
MnO	%	.15	.14	.13	.08	.06
P2O5	%	.037	1.12	.42	.12	.089
Loi	%	7.77	.85	.16	4.77	.85
Total	%	97.5	98.5	98.3	99.9	99.4
H2O+	%	5.5	1.4	.7	3.6	.5
H2O-	%	.1	<.1	<.1	<.1	<.1
CO2	%	2.64	.07	.10	<.01	.81
Cgraph	%	<.05	<.05	<.05	.44	<.05
S	ppm	130.	520.	1090.	9750.	30.
F	ppm	40.	250.	1300.	510.	390.
Cl	ppm	<50.	124.	120.	<50.	<50.
La	ppm	.9	7.2	39.0	33.6	17.5
Ce	ppm	3.2	15.7	86.6	61.7	32.0
Pr	ppm	.8	2.4	12.4	7.6	4.0
Nd	ppm	4.7	11.4	57.3	29.2	16.0
Sm	ppm	2.2	3.0	10.5	6.0	2.8
Eu	ppm	.83	1.13	3.0	1.35	.64
Gd	ppm	2.9	2.7	9.0	4.9	1.7
Tb	ppm	.4	.4	1.0	.6	.2
Dy	ppm	3.3	2.4	5.3	4.1	1.2
Ho	ppm	.53	.43	.88	.80	.20
Er	ppm	1.4	1.2	2.1	2.3	.6
Tm	ppm	.2	.2	.2	.3	<.1
Yb	ppm	1.0	1.1	1.6	2.5	.7
Lu	ppm	.14	.16	.18	.31	.08
Ms		30900.	560.	9660.	740.	860.

Au1: Fire Assay, DCP (20g); Au2: Aqua regia digestion, GAA (20g); Ms: Magnetic susceptibility (10^{-6}SI); Fe2O3*: Total Fe as Fe_2O_3.

Appendix 5. Explanations of abbreviations used in tables and appendices.

ab	albite
abcrbr	albite-carbonate rock
abcrbser	albite-carbonate-sericite rock
absechlor	albite-sericite-chlorite rock
amph	amphibole
aspy	arsenopyrite
bar	baryte
bt	biotite
btchloabr	biotite-chlorite-albite rock
chlo	chlorite
crb	carbonate
crbabr	carbonate-albite rock
cp	chalcopyrite
dio	diopside
epi	epidote
fgn	felsic gneiss
fvolc	felsic volcanogenic rock
grdr	granodiorite
grw	graywacke
hem	hematite
hornb	hornblende
ituf	intermediate tuffite
ivolc	intermediate volcanic/subvolcanic rock
magn	magnetite
mtuf	mafic tuffite
mvolc	mafic volcanic/subvolcanic rock
plag	plagioclase
po	pyrrhotine
py	pyrite
qtz	quartz
qtzdr	quartzdiorite
sb	antimony
se	sericite
sp	sphalerite
ton	tonalite
tour	tourmaline
tre	tremolite
umr	ultramafic rock

Tätä julkaisua myy

GEOLOGIAN
TUTKIMUSKESKUS (GTK)
Julkaisumyynti
02150 Espoo
☎ 90-46931
Teleksi: 123 185 geolo sf
Telekopio: 90-462 205

GTK, Väli-Suomen
aluetoimisto
Kirjasto
PL 1237
70701 Kuopio
☎ 971-205 111
Telekopio: 971-205 215

GTK, Pohjois-Suomen
aluetoimisto
Kirjasto
PL 77
96101 Rovaniemi
☎ 960-297 219
Teleksi: 37 295 geolo SF
Telekopio: 960-297 289

Denna publikation säljes av

GEOLOGISKA
FORSKNINGSCENTRALEN (GFC)
Publikationsförsäljning
02150 Esbo
☎ 90-46931
Telex: 123 185 geolo sf
Telefax: 90-462 205

GFC, Mellersta Finlands
distriktsbyrå
Biblioteket
PB 1237
70701 Kuopio
☎ 971-205 111
Telefax: 971-205 215

GFC, Norra Finlands
distriktsbyrå
Biblioteket
PB 77
96101 Rovaniemi
☎ 960-297 219
Telex: 37 295 geolo SF
Telefax: 960-297 289

This publication can be obtained
from

GEOLOGICAL SURVEY
OF FINLAND (GSF)
Publication sales
SF-02150 Espoo, Finland
☎ 90-46931
Telex: 123 185 geolo sf
Telefax: 90-462 205

GSF, Regional office of
Mid-Finland
Library
P.O. Box 1237
SF-70701 Kuopio, Finland
☎ 971-205 111
Telefax: 971-205 215

GSF, Regional office of
Northern Finland
Library
P.O. Box 77
SF-96101 Rovaniemi, Finland
☎ 960-297 219
Telex: 37 295 geolo SF
Telefax: 960-297 289

ISBN 951-690-403-3
ISSN 0367-522X