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OXYGEN AND CARBON ISOTOPE COMPOSITIONS OF CARBONATES IN THE ALTERATION ZONES OF OROGENIC GOLD DEPOSITS IN CENTRAL FINNISH LAPLAND

by
Pentti Hölttä and Juha Karhu*

Geological Survey of Finland, P.O. Box 96, FIN-02151 ESPOO, FINLAND
E-mail: Pentti.Holtta@gsf.fi
*present address: Department of Geology, FIN-00014 HELSINGIN YLIOPISTO
E-mail: Juha.Karhu@helsinki.fi

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Introduction

In Central Finnish Lapland there are ca. thirty known gold mineralisations in an area covering ca. 4000 km^2, some of those being economicly viable. The deposits are mostly associated with late shear zones in a greenschist facies metamorphic environment. A Pb isotope study of some of these gold mineralizations and their country rocks has given ages, indicating syn to late-orogenic ore formation during the Svecofennian orogeny (Mänttäri 1995). Therefore the gold mineralisations in Central Lapland seem to represent the orogenic ore type following the classification by Groves et al. (1998). According to Groves et al. (1998), orogenic gold deposits are ores that were formed during compressional to transpressional deformation processes at convergent plate margins in accretionary and collisional orogens.

Most of the gold mineralisations in Central Lapland are hosted by mafic and ultramafic volcanic rocks, and they are surrounded by alteration zones characterised by K-metasomatism with abundant biotitization and sericitization. Albitization and carbonation are also typical features of the alteration zones. There are several interpretations for the origin of the fluids causing such alteration, the main alternatives being premetamorphic sea-floor hydrothermal and synmetamorphic fluid system connected with shear zones, as proposed for Central Lapland by Korkiakoski (1992) and Eilu (1994). Different rock types and formation environments have different oxygen and carbon isotope signatures and so stable isotope studies can be used as a tool for constraining the origin of fluids causing the alteration. In the case of the gold deposits, large quantities of fluid is needed to infiltrate the rock to precipitate gold in economic abundance. The high fluid-rock ratio should be reflected in the stable isotope compositions of host rocks. In this work, a test set of samples was analysed from carbonated rocks in the alteration zones of gold deposits (and also similarly altered rocks without gold) in Central Lapland (Fig. 1). For comparison, carbonates were also analysed from unaltered rocks at the neighbourhood of the alteration zones.

Analytical method

Carbonate was sampled from the fresh surface of a sawed rock using a dentist drill. From unaltered tholeiitic volcanite specimens carbonate was sampled from carbonate-bearing vesicles or veinlets. Isotope analytical methods were chosen according to the carbonate species in question. An aliquot of the sample powder was used to determine the proportion of calcite, dolomite and magnesite in the total carbonates by a semi-quantitative X-ray diffraction method described by Karhu (1993). Carbon and oxygen isotope ratios in carbonates were measured using the

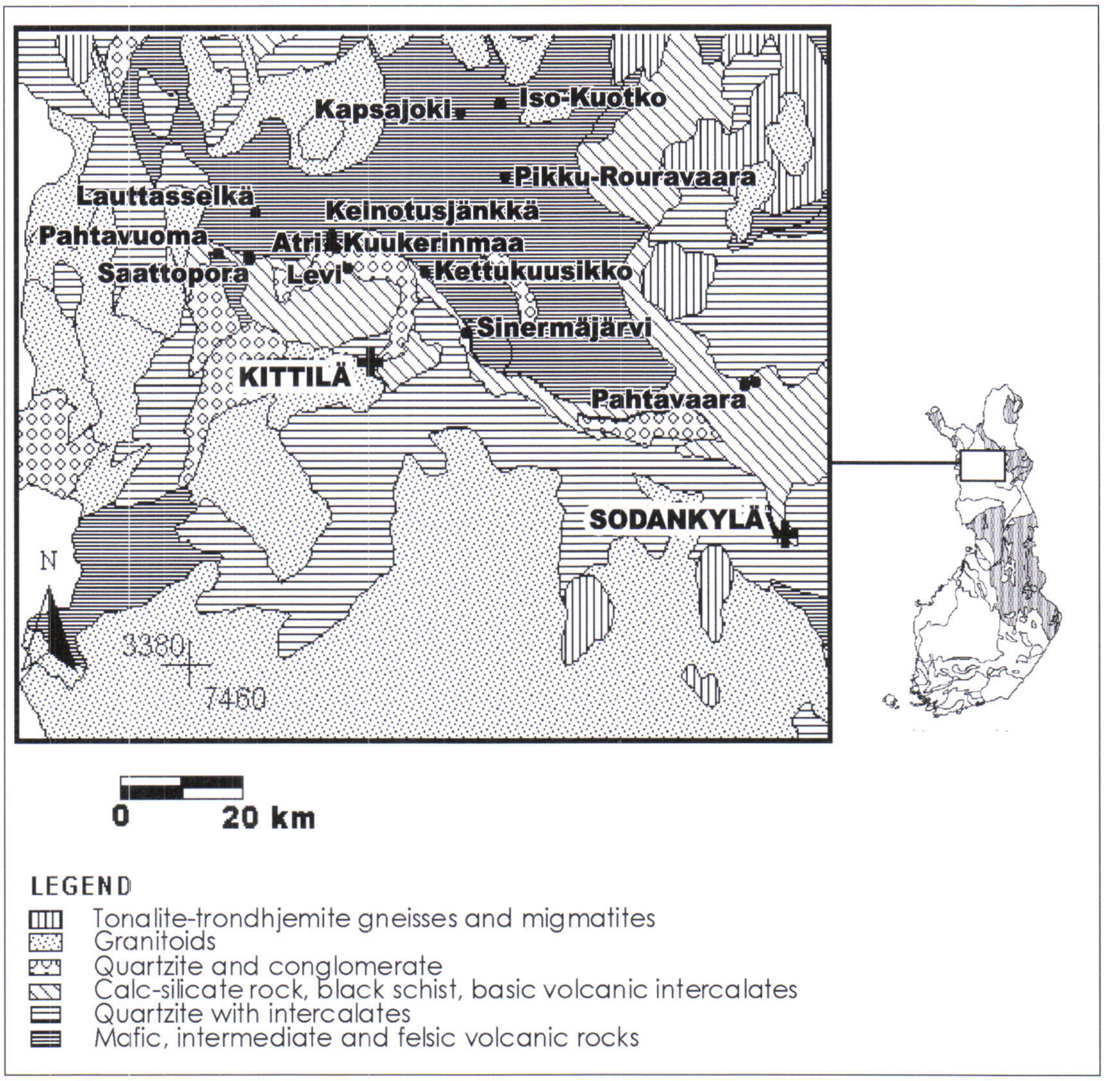

Fig. 1. Simplified lithological map of Central Finnish Lapland (after Korsman et al. 1997). Sample locations are marked with small black dots.

conventional phosphoric acid method at 50°C for calcite and 100°C for dolomite and magnesite. The analytical methods are described in detail by Karhu (1993).

Results and discussion

Oxygen isotopes

The isotope ratios of oxygen and carbon in carbonates are given in Table 1 and illustrated in Figure 2. The $\delta^{18}O$ values in altered rocks fall in a narrow range from 11 to 13 ‰ (SMOW), with a few outliers at lower and higher values. The small variation in oxygen isotope composition contrasts with the pattern observed in Archean hydrothermal carbonates associated with gold mineralizations in eastern Finland. There the variation in $\delta^{18}O$ values is considerably larger relative to the variation observed in $\delta^{13}C$ (Karhu et al. 1993). The variable $\delta^{18}O$ values in Archean deposits have been interpreted to be related to Proterozoic metamorphic overprinting (Karhu et al. 1993).

Unaltered carbonate bearing volcanic rocks in greenschist facies areas do not show any marked deviations from the isotopic composition of carbonates in the alteration zone. These regions include Saattopora, Iso-Kuotko and Atri. However, regions with peak metamorphic conditions in amphibolite facies show a different pattern. The volcanic host rocks of the Pahtavaara deposit have been metamorphosed in lower amphibolite facies with hornblende-plagioclase assemblages, whereas the gold-related metasomatic alteration took place in upper greenschist facies conditions (Korkiakoski 1992). The carbonates in the gold-related alteration zone are tightly grouped with $\delta^{18}O$ values between 11.2 and 12.8 ‰, but both altered and unaltered rocks outside the immediate vicinity of the gold ore have distinctively lower $\delta^{18}O$

Table 1. Analytical data. Mineral abbreviations: cal=calcite, dol=dolomite, ank=ankerite, mgs=magnesite. Locations of the sample sites are presented in Figure 1.

Outcrop	Sample no.	Site	northing	easting	Analysed mineral	$\delta^{18}O$ SMOW	$\delta^{13}C$ PDB	Rock type, a = altered, u = unaltered
PSH-98-102		Keinotusjänkkä	7527580	2531360	cal	11.50	-2.74	mafic volcanic rock, u
PSH-98-103		Levi	7522280	2534390	dol/ank	14.05	-1.80	schistose mafic volcanic rock brecciated by brown carbonate veins, u
PSH-98-113	1	Kuukerinmaa	7525400	2532130	dol/ank	11.58	-5.15	chlorite schist brecciated by Fe-carbonate veins, a
PSH-98-113	1	Kuukerinmaa	7525400	2532130	mgs	12.07	-3.14	chlorite schist brecciated by Fe-carbonate veins, a
PSH-98-113	2	Kuukerinmaa	7525400	2532130	dol/ank	12.08	-5.17	chlorite schist brecciated by Fe-carbonate veins, a
PSH-98-113	2	Kuukerinmaa	7525400	2532130	mgs	12.78	-2.83	chlorite schist brecciated by Fe-carbonate veins, a
PSH-98-113	3	Kuukerinmaa	7525400	2532130	mgs	12.04	-5.01	chlorite schist brecciated by Fe-carbonate veins, a
PSH-98-120		Pahtavuoma	7523480	2512090	cal	12.88	-8.35	chlorite schist brecciated by Fe-carbonate veins, a
PSH-98-64	1	Pahtavaara	7505400	3477040	cal	10.26	-8.74	pillow lava, 1.83 km NE from the main ore, u
PSH-98-64	2	Pahtavaara	7505400	3477040	cal	10.06	-4.78	pillow lava, 1.83 km NE from the main ore, u
PSH-98-64	4	Pahtavaara	7505140	3475360	dol/ank	10.44	-1.23	talc breccia, 200 m N from the main ore, a
PSH-98-64	8	Pahtavaara	7505140	3475360	dol/ank	10.19	-1.76	tremolite rock, 200 m N from the main ore, a
PSH-98-65	1	Pahtavaara, open pit of the main ore	7504950	3475280	mgs	11.78	-2.08	barite vein with grey Fe-carbonate, main ore, a
PSH-98-65	1.1	Pahtavaara, open pit of the main ore	7504950	3475280	mgs	11.36	-1.83	barite vein with grey Fe-carbonate, main ore, a
PSH-98-65	2	Pahtavaara, open pit of the main ore	7504960	3475280	dol/ank	11.62	-4.11	komatiite brecciated by talc, main ore, a
PSH-98-65	3	Pahtavaara, open pit of the main ore	7504960	3475280	dol/ank	11.86	-1.18	komatiite brecciated by talc, main ore, a
PSH-98-65	4	Pahtavaara, open pit of the main ore	7504960	3475280	mgs	11.52	-1.62	komatiite brecciated by talc, main ore, a
PSH-98-65	4	Pahtavaara, open pit of the main ore	7504960	3475280	dol/ank	11.24	-2.39	komatiite brecciated by talc, main ore, a
PSH-98-65	7	Pahtavaara, open pit of the main ore	7504970	3475280	dol/ank	12.13	-3.77	biotite-amphibole schist brecciated by talc, 9 m N from the ore, a
PSH-98-65	8	Pahtavaara, open pit of the main ore	7504985	3475280	dol/ank	11.68	-4.13	biotite-amphibole schist brecciated by talc, 22 m N from the ore, a
PSH-98-65	9	Pahtavaara, open pit of the main ore	7504967	3475273	dol/ank	12.19	-1.66	Fe-carbonate vein with blue amphibole, 6 m N from the ore, a
PSH-98-65	10	Pahtavaara, open pit of the main ore	7504990	3475270	dol/ank	12.84	-4.42	biotite-amphibole schist, 30 m N from the ore, a
PSH-98-66	2	Pahtavaara	7505150	3475270	dol/ank	10.24	-1.97	komatiite, 200 m N from the main ore, u
PSH-98-76	1	Atri, open pit	7525590	2531070	dol/ank	12.50	-5.84	carbonate breccia, a
PSH-98-76	1b	Atri, open pit	7525590	2531070	dol/ank	12.83	-5.97	carbonate breccia, a
PSH-98-76	2	Atri, open pit	7525590	2531070	dol/ank	11.95	-5.20	carbonate breccia, a
PSH-98-76	2b	Atri, open pit	7525590	2531070	dol/ank	12.38	-4.83	carbonate breccia, a
PSH-98-76	3	Atri, open pit	7525590	2531070	cal	11.81	-6.70	folded carbonate breccia, a
PSH-99-106	1	Iso-Kuotko	7550340	2559050	cal	19.79	-4.86	chlorite-carbonate rock, a
PSH-99-106	3	Iso-Kuotko	7550340	2559050	dol/ank	11.02	-7.43	albite-carbonate rock, a
PSH-99-107		Iso-Kuotko	7550300	2558780	cal	11.26	-3.91	mafic volcanic rock with crb-filled veinlets, u
PSH-99-109		Lauttasselkä	7530670	2518030	cal	10.31	-2.85	mafic volcanic rock rock with crb-filled vesicles, u
PSH-99-113	2	Sinermäjärvi	7512680	2554690	mgs	11.90	-6.86	chromian marble, without Au, a
PSH-99-113	4	Sinermäjärvi	7512680	2554690	dol/ank	11.66	-5.85	chromian marble, without Au, a
PSH-99-73	1	Kettukuusikko	7522280	2547440	dol/ank	11.42	-5.03	mafic volcanic rock with Fe-carbonate, a
PSH-99-80	2	Pikku Rouravaara	7538380	2560350	cal	13.75	-0.77	mafic volcanic rock with crb-filled veinlets, u
PSH-99-82	1	Kapsajoki	7548400	2552350	cal	12.05	-3.58	mafic volcanic rock with crb, ab and ep-filled veinlets, u
PSH-99-95		Saattopora	7523560	2517130	cal	12.10	-6.87	mafic volcanic rock with crb-filled veinlets, 700 m north of the mine, u
PSH-98-111	1	Saattopora, open pit	7522810	2517210	dol/ank	12.63	-6.85	Fe-carbonate breccia, a
PSH-99-96	1	Saattopora, open pit	7522910	2517380	dol/ank	13.18	-7.22	banded and deformed Fe-carbonate rock, a
PSH-99-96	2	Saattopora, open pit	7522910	2517380	dol/ank	12.36	-7.68	coarse grained Au-bearing Fe-carbonate veins in N-S direction, cutting 96.1, a
PSH-99-96	3	Saattopora, open pit	7522910	2517380	dol/ank	12.19	-6.87	coarse grained Au-bearing Fe-carbonate veins in N-S direction, cutting 96.1, a
PSH-99-96	4	Saattopora, open pit	7522910	2517380	dol/ank	12.44	-7.37	coarse grained Au-bearing Fe-carbonate veins in N-S direction, cutting 96.1, a

values, between 10.0 and 10.4 ‰. Similarly, the unaltered tholeiitic amphibolite facies rock from Lauttasselkä (PSH-99-109) has a slightly lower $\delta^{18}O$ value compared to the altered samples (Table 1). Sample PSH-99-106.1 differs from all other carbonate samples having a high $\delta^{18}O$ value of 19.8 ‰. Calcite in this sample may represent late fluid infiltration at lower temperatures, possibly during weak weathering.

Oxygen isotope ratios of carbonates depend on the temperature of formation and the isotopic composition of the fluid. The isotopic composition of the fluid is, in turn, related to the source of the fluid and to the water/rock (W/R) ratio during alteration. Relatively homogeneous $\delta^{18}O$ in alteration-related carbonates suggest large crustal scale processes with high W/R ratios. More variable $\delta^{18}O$ values outside the cores of the alteration zones may result from differences in any of these factors.

Carbon isotopes

Compared to oxygen, the carbon isotope composition of carbonates show more scatter, with $\delta^{13}C$ values varying from -8.7 to -0.8 ‰(PDB, Table 1). No clear differences in carbon isotope values can be observed between altered and unaltered volcanic rocks apart from Pahtavaara, where the altered rocks generally have higher $\delta^{13}C$ values compared to unaltered rocks (Fig. 2). The large spread in $\delta^{13}C$ may be related to the presence of black schists in the host rock association of most gold mineralizations. Sedimentary organic matter is characterized by carbon depleted in ^{13}C, and progressive additions of organic carbon to the fluid system will tend to shift the $\delta^{13}C$ values to more negative values. Black schists have not been observed to occur close to the Pahtavaara ore deposits, and accordingly the $\delta^{13}C$ values of the hydrothermal carbonates there are relatively high compared to other mineralizations.

Concluding remarks

Carbonates in gold related alteration zones in Central Lapland are characterized by relatively small

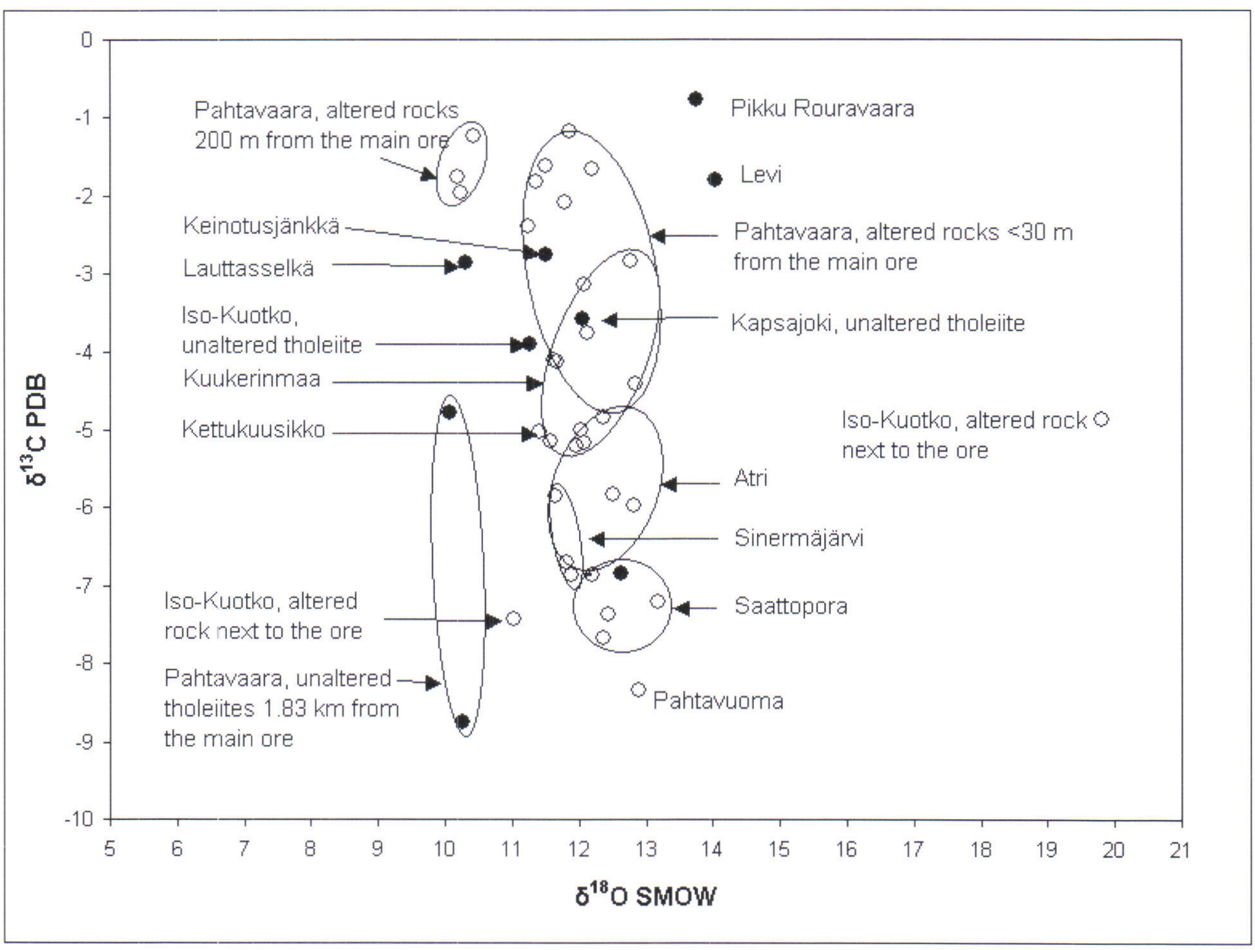

Fig. 2. Oxygen and carbon isotope compositions of carbonates from Central Lapland. Black dots = unaltered mafic volcanic rocks, open dots = altered rocks.

variation in $\delta^{18}O$ values compared to more spread in $\delta^{13}C$. Because oxygen isotope values are affected by both the fluid composition and the ambient temperature, it is difficult to draw any definitive conclusions about the source of the fluid. Furthermore, carbon isotope ratios seem to be more affected by local host rock lithologies. Nevertheless, in some study sites, such as Pahtavaara, the mineralized zone seems to have distinctive stable isotope characteristics, and stable isope ratios may therefore have potential as an exploration tool. Apparently, each local fluid system has its own characteistics and detailed studies are needed for each prospect.

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