The timing of sulphide mineralisation in the Rombaken Tectonic Window and their spatial relation to the Rombaken-Skjomen Shear Zone, northern Norway

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Abstract

The Rombaken Tectonic Window (RTW) is a Paleoproterozoic inlier within the Caledonian nappes of northern Norway. The bedrock consists of Svecofennian granites intruded into metasedimentary and metavolcanic rocks, which appear as N-S trending parallel belts widening and thickening along strike. Sulphide mineralisations in the RTW, including As-Au, Cu and Pb-Zn, have long been explored for gold in the area and the need for a better understanding of the geological evolution of the area has increased. Recent tectonic and structural models have verified a large scale Svecofennian Rombaken-Skjomen shear zone (RSSZ), which can be traced across the whole window and into Sweden. The model consists of four deformation events that includes two N-S striking, east verging fold-thrust (D_1-D_2) and two oblique-slip events with steep ductile N-S striking (D_3) and NE-SW (D_4) striking shear zones. Several known sulphide mineralisations are found along, within and near this regional shear zone. In the present study we have studied several of these for their genesis, timing and spatial relationship to the RSSZ. We found at least four stages of mineralisation including; 1) syngenetic bedding parallel Zn-Pb SEDEX deposits (D_0), 2) syntectonic metasomatic As-Au-Fe deposit (D_3-D_4) and 3) orogenic gold, both along the regional shear zone, including remobilisation of the SEDEX mineralisations (D_3-D_4) and as 4) Cu-Au in late Svecofennian quartz veins (D_3-D_4). The formation of most of the sulphide mineralisations in RTW is very complex with several stages of remobilisation and deformation, that are spatially and temporally linked to the development of RSSZ

Keywords: Rombaken Tectonic Window, Orogenic gold, SEDEX, Metasomatic, sulphides, Rombaken-Skjomen Shear zone.

1.0 Introduction

The Fennoscandian Shield is dissected by a network of major shear zones containing associated economic important deposits of gold and/or base metals (Eilu et al., 2003; Sundblad, 2003; Martinsson, 2004). In the northern part of the shield these regional fault structures developed and were reactivated during several tectonothermal events in conjunction with the Paleoproterozoic Svecofennian orogeny (1920-1790 Ma; Lahtinen et al., 2012). Recently, an additional member of this network has been defined in the Rombaken Tectonic Window (RTW) where the N-S trending Rombaken-Skjomen Shear Zone (RSSZ) intersects Paleoproterozoic basement rocks overthrusted during the Ordovician to early Devonian by Caledonian nappe complexes close to the eastern margin of the Caledonian orogen (Fig.1). The RTW is endowed with partly auriferous polymetallic sulphide mineralisations which are the theme of the present paper.

The RSSZ developed during the Svecofennian orogeny and is situated close to the boundary between the Karelian Craton with Archean-Paleoproterozoic granite-greenstone terrains (e.g. Rutland et al., 2001) and the Svecofennian arc-related volcano sedimentary sequences to the west and south. The boundary between these terrains is largely obliterated by the emplacement of granitic plutons comprising possibly the eastern margin of northern extension of the Transscandinavian Igneous Belt (TIB; Gorbatschev 2004). Thus the RSSZ may represent an important suture zone between crustal segments in the Fennoscandian shield. Several sulphide mineralisations have been known in this area for more than a century (Foslie, 1916; Korneliussen & Sawyer, 1986; Coller, 2004; Blomlie, 2011). However, the knowledge of their genesis has not been well understood. The importance of the present study is to show how the sulphide mineralisation in the Paleoproterozoic supracrustals in the RTW and along RSSZ may be part of a complex story involving several genetic types. The understanding of the metallogeny of the RSSZ is largely based on field and structural relationship as well as microscopic studies and geochemical analysis of the host rocks and the hydrothermal alteration associated with the mineralisations. The ultimate aim of the present paper is to place the development of the sulphide mineralisations in time and space within the geotectonic framework of the RSSZ.

2.0 Geological setting

The RTW consists mainly of Paleoproterozoic rocks exposed as an inlier surrounded by Caledonian thrust sheets of Phanerozoic rocks, and is a result of deep erosion and removal of the overlying Caledonian nappes. The geology of the area has previously been described by Gustavson et al. (1974), Priesemann (1984 a, b), Skonseng (1985), Korneliussen & Sawyer (1986) and Bargel (1995).

The RTW consists of plutonic rocks, comprising intrusions of granites and subordinate gabbros and several N-S trending belts of metasupracrustal rocks (Fig. 1). The oldest dated rock in the area is represented by a tonalitic basement rock found in the Sjangeli area (Sweden). It yields a U-Pb age of 2709 Ma and occurs as xenoliths in the Sjangeli granite (Romer et al., 1992) (Fig. 1). The metasupracrustal rocks in the Sjangeli area are dominated by mafic to ultramafic volcanic and volcano sedimentary units intercalated with metasedimentary rocks. The metasupracrustal rocks in the Sjangeli and Kopperåsen areas are assumed to have a depositional age of 2300-2000 Ma (Romer & Boundy, 1988; Romer, 1989), but is uncertain. They have previously been correlated to the Gautelis supracrustal belts in the southern part of the studied area (Fig. 1) (Romer, 1987). The metasedimentary rocks in Gautelis are assumed to be of younger age. The tonalite in the Gautelis area is the lowermost basement rock and is overlain by sedimentary breccias and conglomerates containing pebbles of the underlying tonalitic basement. Romer et al., (1992) dated a Paleoproterozoic tonalite, yielding an age of 1949±26 Ma (U-Pb). The basal conglomeratic sequence is overlain by marbles and metagreywacke with an assumed age of 1900-1880 Ma (Korneliussen & Sawyer, 1989). These metasedimentary rocks are thought to be deposited in a basin in an Andean-type setting and show large similarities to the supracrustal belts in the Haugfjellet-Sildvika and Norddalen areas (Fig.1.) (Korneliussen & Sawyer, 1989). The rocks in the RTW have undergone several stages of metamorphism. Peak metamorphism reached amphibolite-grade at 6kb and 575ºC, and is dated to ca. 1800 Ma (Sm-Nd) (Sawyer, 1986; Romer, 1989). Another metamorphic event was detected by U-Pb dating of zircons from a granite to the east of Gautelis giving an age of 1769.6±9.7Ma correlating with the Svecofennian orogeny (Romer et al, 1992). Uranitite, associated with Cu-Fe sulphides in Kopparåsen, have been dated and also associated to this age and metamorphic event (1780 Ma; Romer & Boundy, 1988). In the Sjangeli area (Fig. 1) the epigenetic Cu-Fe vein mineralisation is thought to be related to Proterozoic metamorphism with remobilsation of stratiform Fe-Zn sulphides during the Caledonian metamorphism (Romer, 1989). It has been furthermore documented that retrogression to greenschist facies metamorphism occurred in the Norddalen area (Fig. 1). Structure related gold occurrences have been documented locally from Haugfjellet (Fig. 1: Coller, 2004). The age of this event has both been interpreted as Proterozoic (Korneliussen & Sawyer, 1986) and as Caledonian (Romer, 1993). Korneliussen & Sawyer (1986) suggested that the retrogradation was linked to steep N-S trending shear zone and fold structures in Norddalen, whereas Romer (1993) argued that the presence of upright folds in combination with Pb-Pb isotope data suggested a Caledonian tectonothermal event. However, recent investigations show that the structures are Paleoproterozoic with approximately the same age as the Rombak granites in the Haugfjellet and Gautelis area (1786 ± 8 – 1790 ± 8 Ma; Angvik et al., 2014 included manuscript). They are found both to be segmented by and also crosscut the shear zone (Larsen et al., 2013). The shear zone cuts through variably deformed gabbros and metasupracrustal rocks, and it is interpreted as a dynamic and continuous transpressional event with strain partitioning (Larsen et al, 2013). The strain was first dominated by two events of N-S striking, upright and east verging folding and thrusting (D_1-$D_{2)}$ which progressively turned into thrust parallel, sub vertical, N-S orientated, mainly sinistral and slightly dextral oblique-slip shear zones (D_3) which were later drag folded and cut by a NE-SW dextral oblique-slip shear zone (D_4). The greenschist facies retrogression is strongly related to the transpressive RSSZ structures carrying associated sulphide mineralisation (Larsen et al., 2010; Larsen et al., 2013). Nevertheless, Caledonian reactivation cannot be entirely excluded (Larsen et al., 2013).

3.0 Sulphide mineralisation

Several sulphide deposits have been known in this area for more than a century (Foslie, 1917; Korneliussen & Sawyer, 1986; Skyseth, 1995; Coller, 2004; Blomlie, 2011). The genetic aspects of the deposits have not been treated in any detail including their relation to the RSSZ. The sulphide occurrences along the shear zone include a variety of polymetallic deposits. The supracrustal belts are generally very rusty in appearance as an indication of their contents of Fe-sulphides. There are several areas of interest in regard to auriferous sulphide deposits (Fig. 1), and two of these, the Haugfjellet-Sildvika and Gautelis areas have been emphasised in the present study (Fig. 1).

3.1 Haugfjellet-Sildvika area

The Haugfjellet-Sildvika area is located in the northern part of the RTW where the bedrock consists of granites with two large belts of metasedimentary rocks (Fig. 1). The bedrock in Sildvika is similar to Haugfjellet and consist of metagreywacke, marble, metatuffite, metasiltstone, graphitic schist and quartzitic rock (Fig. 2). The eastern part of the metasupracrustal belt at Haugfjellet is dominated by siltstones interbedded with metagreywacke, sandstones, volcanites and graphitic schists whereas the western part is mainly composed of metatuffite interbedded with metagreywackes, quartzites and graphitic schists (Bargel, et al. 1995; Coller, 2004). There are also some marble beds forming thin lens-shaped units elongated parallel to and within oblique-slip shear zones (Fig. 2). In the western part of Haugfjellet, some lenses of marble and metagreywacke are even found within a shear zone in the coarse-grained Rombak granite (Fig. 2). The Sildvika metasupracrustal belt is located SW of Haugfjellet (Fig. 1) and comprises the same type of lithologies as in the western part of the Haugfjellet belt. The rocks are less deformed than at Haugfjellet, and primary structures are commonly observed. The Haugfjellet metasupracrustal belt show more deformation with a pronounced N-S striking cleavage dipping steeply to the west (D_3). The surrounding Rombak granites are more or less undeformed with a slight foliation developed except along localised shear zones. The metasedimentary rocks at Haugfjellet are affected dominantly by steep to subvertical folds (D_3), plunging both to NNW and SSE (Larsen et al., 2013).The folds are bounded by steep ductile shear zones where low angle thrust planes being refolded (D_1-D_2), have only been identified by microscopy (Larsen et al., 2013). Several sub vertical N-S, NE-SW and NW-SE orientated (D_{3}-D_4) oblique-slip ductile shear zones cut and drag fold the primary sedimentary bedding. The shear zones are mm to several meters wide and seem to spread out and slightly bend of towards the NNW (Fig. 2). They show both dextral and sinistral shear senses as well as a pronounced moderate dipping lineation towards NW (Larsen et al., 2013). The structures of the Haugfjellet belt have been interpreted to be part of a pure-shear-dominated domain in a transpressive orogen with ductile strain partitioning developing from a fold-thrust belt (D_1-D_2) into steep oblique-slip (D_{3}-D_4) shear zones (Larsen et al., 2010).

Sulphide-rich metasedimentary rocks with a reddish brown, rusty colour appear frequently in the Haugfjellet supracrustal belt. Since the rocks in this area have been strongly deformed and segmented, the distribution of the sulphide mineralisation appears very irregular and complex. There is a visual difference between the eastern part of Haugfjellet, dominated by metasiltstones and the western part composed of oxidised red-coloured metatuffite and metagreywacke with more Fe sulphides (Fig. 2). There are several old showings in the Haugfjellet-Sildvika area from earlier exploration. Three main types of mineralisation can be differentiated: 1) Bedding parallel Fe and Zn-Pb sulphide mineralisations (D_0), 2) Shear-zone-hosted Cu-Au-As mineralisation, including remobilisation of Zn-Pb (D_3-D_4), and 3) quartz-vein-hosted Cu-Au mineralisation (D_3-D_4).

3.1.1 Bedding parallel Fe and Zn-Pb sulphide mineralisations

Sulphide mineralisations along primary sedimentary beds have been observed in the supracrustal belts at Haugfjellet, Jernvann and Sildvika (Fig. 1-2). The sulphides are found in a few centimeters thick beds, either as single or multiple, parallel beds that can be followed up to hundreds of meters (Fig. 3A). They are either cut by steep oblique-slip (D_{3}-D_4) shear zones, thin out or the sulphide content gradually decreases. Both on Haugfjellet and Jernvann occur beds with a high content of sulphides (Fig. 3) in areas where the rocks are weakly deformed and frequently contain primary sedimentary structures such as cross-bedding and graded bedding (Fig. 3B and D). The sulphides are commonly found along distinct beds of the darker, fine-grained silty beds with high quartz and mica content. The sulphide mineralisation comprises three different types, dominated by disseminated to semi-massive 1) pyrrhotite (Fig. 3C, 2), pyrite (Fig. 3E) and 3) sphalerite and galena (Fig. 3D).

The types 1 and 2 are very similar in appearance and can sometimes coexist as separate pyrrhotite- and pyrite-dominated beds in the same outcrop. These two types are mainly found in the oxidised red-coloured metatuffite and metagreywacke units in the western part of Haugfjellet and Jernvann. Pyrite beds are more commonly encountered in the metatuffites, whereas the pyrrhotite is more evenly distributed in all the metasedimentary units especially along metagreywackes.

Type 1 is the most common and occurs as dissemination of very fine-grained (10-150 µm) pyrrhotite in silty beds. Locally the dissemination grades into semi-massive pyrrhotite bands. Pyrrhotite is also intergrown with minor amounts of chalcopyrite, sphalerite and pyrite, which appear to have copercipitated with the pyrrhotite (Fig. 3C). The metagreywacke host-rocks consist mainly of quartz and K-feldspar together with some biotite and chlorite. In beds with alternating high chlorite and biotite content, the sulphide is more abundant in the chlorite dominated beds. The type 2, pyrite mineralisation (Fig. 3D) occurs commonly as the only sulphide in the metatuffite (Fig. 3E), although minor pyrrhotite is locally observed. Pyrite has a grain size in the range 10-150 µm and commonly occurs as minor segregations and thin (5-10 mm) semi-massive bands together with quartz. The gangue is dominated by biotite, chlorite, larger but fewer quartz grains than type 1 (10-500 µm) and with epidote aggregates (100-150 µm).

Type 3 consists of bedding parallel sphalerite and galena mineralisation (Fig 3F). It is found along undeformed greywacke beds in the Sildvika area and partly at Haugfjellet, where the mineralised rocks frequently retain their primary sedimentary structures and occur adjacent to areas affected by strong shear deformation. The sulphide mineralisation is found in the finer grained silty beds with large amounts of quartz and biotite and less of plagioclase. The sulphide minerals occur as dissemination locally grading into massive bands and lenses (1-50m long, 1-20cm thick) in the outcrops. The sulphide minerals coexist with coarse chlorite (50-1500 µm), calcite (50-500 µm) and quartz grains (10-1000 µm) which define weak foliation or hairline veining. Mineralisation of Sphalerite dominates and has grain sizes of 10-500 µm with small pyrite inclusions (<50 µm) (Fig 3F).

3.1.2 Shear-zone-hosted Cu-As-Au with remobilised Pb-Zn mineralisation

Several of the old showings in the Haugfjellet area show a complex development of shear zone-hosted sulphide mineralisation (Fig. 2). The sulphides are mixed and are slightly anomalous with uncommon metal association such as Pb-Zn together with As. The sulphide minerals of this category consists of pyrrhotite, sphalerite, galena and chalcopyrite, and locally minor arsenopyrite (Fig. 4) which have been interpreted to be of two different genetic types with typical metal assemblages 1) Cu-As-Au and 2) remobilised Pb-Zn.

The sulphide mineralisation at locality HF-235, in the western part of Haugfjellet, occurs in a metagreywacke sequence sandwiched between the tuffite-dominated and siltstone-dominated units (Fig. 2). At this locality there are two exploration pits worked on a 1.5 m wide, ductile dextral shear zone (Fig. 4A), which has been intersected by two core holes. This steep dipping shear zone (D_3), with a red, purple and black coloured oxidised surface, can be traced for hundreds of meters along strike and have been observed to join or spread into several shear zones along strike in an anastomosing pattern (Fig. 6B). The different segments of the shear zone cut and fold the surrounding sedimentary beds with different frequency and intensity. The weakly deformed host rocks outside the shear zone consist of approximately 10-20 cm thick folded beds of upwards fining metagreywackes. The primary bedding of the greywacke has been totally erased in the shear zone and appears as steep, foliated, dark silty schist. The shear foliation is steep with a NW-SE strike direction. The fine-grained schistose tectonites within the shear zone contain up to 30 cm thick massive sulphide layers. Quartz-filled micro-fractures mainly occur along the shear foliation, but may locally form small clusters of non-directional veins or quartz-cemented breccias filling the shear zone (6C). The mineralised and sheared metagreywacke is characterised by large amounts of biotite and quartz which occur intergrown with epidote, muscovite and plagioclase. The minerals do not show any strong planar orientation and may be recrystallised. Biotite is partly to fully chloritised and occurs abundantly along quartz filled micro-fractures enveloped by fine-grained biotite aggregates dimishing in abundance away from the fractures. Chlorite is commonly intergrown with the sulphides which comprise pyrrhotite, galena, sphalerite and chalcopyrite, and minor arsenopyrite (Fig. 4D,F,G). The pyrrhotite appears as disseminated grains, whereas galena, sphalerite and chalcopyrite are confined to microfractures or to the shear zones (Fig. 4E). The latter sulphides appear locally to replace grains of pyrrhotite, but do also form aggregates together with pyrrhotite.

Geochemical data on three samples from pit 1 (Fig. 4A and C) show that they are enriched in Zn, Pb and Cu along the zones of high strain when compared with data for one sample from the unmineralised and weakly deformed layered metagreywacke host rock (Fig. 4). When the analytical values of the samples are normalised to the average value of unmineralised and weakly deformed metagreywacke in the Haugfjellet area they confirm that the mineralisation is enriched in a number of metallic elements and especially Pb, Zn, Cu and Hg (Fig. 4B). The gold contents of the shear zone are generally low, but higher than in the weakly deformed surrounding metagreywacke where no gold was detected.

Comparable observations were also done by logging the cores from a 140 m long drill hole, BH-1 (Figs. 4-5). The drill hole crosscuts several shear bands and high-strain zones, as well as weakly deformed to undeformed metagreywackes (Fig. 5). The core confirms the observations found in the prospects at the surface. The sulphides occur strongly associated with zones showing strong ductile deformation (Fig. 5). Pyrrhotite is the most abundant sulphide throughout the length of the cores and occurs both in areas of low and high strain. Abundant sphalerite and galena (Fig. 5) are found both in ductile shear bands and along the bedding of the weakly deformed metagreywacke. Arsenopyrite is only observed in zones showing strong ductile shearing, where it occurs along hairline thin quartz veinlets cutting the shear foliation (Fig. 5). These veinlets show both sinistral and dextral displacements of the metagreywacke bedding and the ductile shear bands that locally show tendencies of developing quartz breccias, similar to what is seen in Fig. 6C. In the log of BH-1 (Fig. 5), the Zn-Pb mineralisation show strong similar enrichment patterns relatable to the ductile shear zones, whereas Cu and As shows a different enrichment pattern though still confined to zones of ductile shearing with hairline veinlets.

Locality HF-232 is located near HF-235 (Fig 2) within metagreywacke and also within a similar shear zone enriched in sulphide minerals. The sulphides in this locality are dominated by pyrrhotite, sphalerite and arsenopyrite. Pyrrhotite and sphalerite occur in micro shear zones filled with quartz as micro veins and lesser amounts of arsenopyrite. The arsenopyrite is intergrown with sericite and epidote. The normalised values of the analytical data for the samples from this locality (Fig. 6D,E) also confirm the general enrichment of most of the heavy metals when normalised to the weakly deformed and unmineralised metagreywacke wall rock, and especially Zn, Pb, As, Ag, Hg, Sb, and Mo.

The Varden locality is situated in the middle of a highly structurally segmented area in the metatuffite near the contact to metasiltstone (Fig. 2.). The sulphide mineralisation is found in a 2x1 meter blasted pit and is similar to the two other localities described above. The mineralisation occurs in metagreywacke and is located along a one meter wide ductile shear zone (D_3) that can be followed for at least tens of meters, and contains arsenopyrite, sphalerite, galena and minor chalcopyrite. Similar to the drill core at locality HF-235, the mineralisation contains clusters of non-directional quartz veins crosscutting and brecciating the shear zone (Fig. 6C). The geochemical data of these veins are marked with a green line, and the normalised values for the samples from the shear zone show that the mineralisation is enriched in W, Bi, Ag, Cd, Pb, Zn and to a less extent also Au (Figs. 6F, G).

3.1.3 Quartz-vein hosted Cu-Fe-Au mineralisation

Sulphide mineralisations are also found in quartz veins in the Haugfjellet area. The sulphide mineralised brittle-ductile quartz veins consist mainly of quartz (80%) some carbonate (2%) and 5-10% sulphides (Fig 7A). Only some veins contain sulphides. The veins are 1mm-1m thick and 10cm-5m long and occur widespread and occasionally in swarms (Fig 8). The brittle-ductile subvertical veins strike NW to NNE (Fig. 8) which suggests a NE-SW compression. They are found within the supracrustal rocks and in less extent within the coarse grained Rombak granite. Some quartz veins appear as an array of tension gashes which again have been sheared by the oblique-slip shear zones and some veins are also sheared along the boundary to the host rocks, which show that they are a late stage (D_3-D_4) of the development of the RSSZ (Fig.7; Larsen et al., 2010).

The sulphides are mainly comprised of chalcopyrite and pyrite (Fig. 7C) with minor arsenopyrite and accessory galena. Some veins contain epidote, chlorite and Mg-rich biotite (Fig 7B and 7D) which occur most abundantly along the walls of the veins and may even form separate veins of biotite and epidote. The geochemical data, normalised to the average host rock in the Haugfjellet area, shows that the quartz veins are enriched in Cu, Au, Bi, Ag and W (Fig. 7G; appendix 1). The gold content in the samples from the mineralized veins is up to 10ppm, but no gold grains have been observed in the microscopic studies and are probably refractory grains.

3.2 Gautelis area

The Gautelis area is located in the southernmost part of the RTW (Fig. 1). The metasediments rocks comprise metagreywacke, sedimentary breccia/conglomerate and dolomitic marble which are truncated by sub-parallel bodies of sub-volcanic metadolerite, as well as coarse- and fine-grained granites (e.g. Korneliussen & Sawyer, 1986) (Figs. 1 and 9). The metasupracrustal rocks are deposited on a tonalitic basement dated to 1940 Ma (Romer et al. 1992). Korneliussen & Sawyer (1989) and Korneliussen et al. (1986) have previously described this granite/tonalite as part of the Gautelis Tonalite Complex. The supracrustals have been intruded by metadolerite and granites (Korneliussen & Sawyer, 1986). The basal metasedimentary breccias and conglomerates comprise the lowermost unit. The rock fines upwards from coarse grained breccias with fragments of the underlying tonalite to metaconglomerates and metasandstones. The basal succession is about 5-8m thick and varies laterally. Locally the basal breccia/conglomerate is missing, and metasandstone, green bedded metatuffite or marble lie directly on top of the tonalitic complex. The basal marble is locally strongly deformed with thinning and thickening and occurs especially in areas with detachment folds. It may indicate the existence of a former thin continuous marble unit that has thinned out caused by a detachment horizon at the base. The metabreccia/conglomerate/sandstone sequence is overlain by another marble succession (Fig. 9) that varies from a few cm to several 100m thick. The marble is strongly deformed with formation of tight, isoclinal folds which lead to increased thickness of the unit. In areas with low deformation, and primary bedding have been preserved, the marble is about 2-3m thick. Korneliussen et al. (1986) describes two different types of marble from this area. The stratigraphically lower member comprises impure, brownish dolomitic marble that is overlain by an upper member of pure white calcitic marble (Korneliussen et al., 1986). The dolomitic marble contains widespread bands and veins of pale green tremolite which decrease in abundance as moving upwards through the stratigraphy. Metagreywacke comprises the uppermost unit in the metasedimentary belt and consists of an upwards fining metaturbidite sequence with bedding in 2-20 cm scale (Korneliussen & Sawyer, 1986; Korneliussen et al., 1986; Sawyer & Korneliussen, 1989). The metagreywacke sequence at Gautelis is very similar in composition to that occurring further north at Haugfjellet and the sediments are assumed to be derived from the mafic to intermediate metavolcanites rocks occurring in the Ruvsott and Sjangeli area of the RTW (Korneliussen et al., 1986; Sawyer & Korneliussen, 1989).

The metasedimentary sequence and its tonalitic basement are intruded by granites and gabbroic dolerite. The granites comprise two major bodies of coarse-grained S-type Rombak granites (Korneliussen et al., 1986). The granite along the eastern margin of the tonalites (Fig. 9) has been dated to 1769 Ma (Romer et al., 1992). The porphyritic, high-K granite dominating the area to the north (Fig. 9) of the tonalite and the supracrustal rocks, is medium- to coarse-grained (Korneliussen et al., 1986). This granite, which cuts across the supracrustal belt and the ductile shear zones, yields U-Pb isotope ages in the range 1.786-1.790 Ga (Larsen et al., 2010; Larsen et al., 2013). This slightly older granite can be followed from the main body developing into dykes parallel to the shear zones, i.e. comparable to observations at Haugfjellet (Fig. 2 and 10). These dykes are a few cm to several meters thick and are partly affected by shear deformation. The major granite massif, crosscutting the ductile shear zone in the northern part of Gautelis, appears very little deformed with only weak foliation. The gabbroic intrusions are dominated by coarse-grained metadolerites intruding the supracrustals parallel to the ductile shear zones. They are 0.2-1m thick and 2-50m long, sub vertical dykes which intersect the tonalite, supracrustals and also the younger coarse-grained granite in the east part of the area. However, in some localities the metadolerites are also intruded by the same coarse grained Rombak granite, which makes the granite, shear zones and metadolerite to be more or less of the same age. The conflicting contact relationships between the granite and metadolerites is possibly caused by the presence of several generations of dykes as suggested by Korneliussen et al. (1986).

The approximately 4 km wide belt of individual shear zones cutting the tonalite complex and the overlying supracrustal rocks developed during several tectonic events giving rise to shear zones with different shear senses and strain regimes in the wall rocks. Thus the general NE-SW trending foliation and bedding of the wall rocks is on a local scale variably orientated and the foliation in the rocks is somewhat dependent on lithology. The micaceous metagreywacke is commonly penetratively foliated, and the marble is highly internal deformed with development of flow-banding with associated multi-directional plunging folds. The strongest deformation is found associated with the mylonite zone along the eastern part of the Gautelis supracrustal belt (Fig. 9) where the zone is approximately 800m wide and comprising a mélange of variably mylonitised sedimentary and intrusive rocks (Fig. 10). A characteristic feature for all the lithologies is that they form elongated lens shaped bodies bordered by high strain zones (Figs. 9 and 10).

The Gautelis area comprises two different structural styles, which include one with remnants of an early fold-thrust belt and another characterised by several oblique-slip ductile shear zones segmenting the fold-thrust belt (Fig.9; Larsen et al., 2013). The rocks of the fold-thrust domain are affected by upright folds with low angle thrust structures. The folds are usual open SE verging and plunging at a low angle towards the NNE and SSW. These folds can be found at several levels in the stratigraphy from the basal conglomerate resting on lower marble detachment horizon on top of the tonalitic basement, and to higher levels where the upper marble and metagreywacke sequences show bedding repetitions in conjunction with folds above low angle thrusts. The SSE-striking thrusts are parallel to the hanging wall beds which show moderate dips towards the NW. These fold-and-thrust belts are typically found in areas of weak deformation and are bound by steep oblique-slip ductile shear zones (Priesemann, 1984b; Larsen, 2010). The oblique-slip shear zones are cutting and segmenting the sedimentary beds and are therefore good indicators of displacement and movement directions. The main foliation developed during the ductile oblique-slip shearing is N-S to NE-SW (Fig. 9) and forms an anastomosing pattern with zones of higher and lower strain including the supracrustals and the mylonite zone. The high strain zones comprise lens-shaped rocks of metagreywacke, conglomerate, marble and igneous dykes separated by mylonites. The rocks in the low strain zones still retain their original sedimentary structures and textures (Larsen et al., 2013). The oblique-slip shear sense is mainly reverse dextral, but in some outcrops both reverse sinistral and dextral shear sense can be observed (Larsen et al., 2010). The orientation of the oblique-slip shear zones can be separated into N-S striking (D_3), moderate to sub vertical, equal sinistral, and dextral shear zones, dipping towards the west and are found most frequently within the tonalite complex, or NE-SW striking (D_4), steep to sub vertical, predominantly dextral shear zones. The latter type of shear zones are the dominating regional structures in Fig. 1 and are oriented parallel to the main foliation of the area, especially along the major mylonite zone (Larsen et al., 2010). They are also closely related to the dolerite that follows the shear zones and to the sulphide mineralisation mainly observed in the localities of this set. The shear zone lineation is similarly orientated in both directions of shear zones where the lineation plunges moderately to steeply NNW to NW in a reverse oblique slip manner. Within the mylonite zones, the folds comprise tight to isoclinal asymmetric drag folds with hinge thickening and limb thinning and multidirectional plunge. In the low-strain domains of the shear belt, the folds are open to tight similar folds with slight limb thinning and steep plunge. The belt of oblique-slip shear zones extends into Sweden in the south, whereas to the north they are abruptly cut by the coarse-grained granite with the exception of the eastern mylonite zone which appears to continue northeastwards along the eastern margin of the northern granite towards the Swedish border (Fig.2; Skonseng 1985; Larsen et al., 2010).

Two main types of sulphide mineralisations are found within the two sets of structures and are either hosted or related to the steep oblique-slip shear zones (D_3-D_4): 1) Shear zone hosted Au-As mineralisation and 2) Metasomatic As-Au-Fe mineralisation.

3.2.1 Shear zone-hosted Au-As mineralisation

Numerous up to 2 meter wide and hundreds of meters long rusty sulphidic bands occur along a number of the individual high strain zones among the large anastomosing system of shear zones (D_3-D_4) in the Gautelis belt. These rust bands are strongly developed in the greywacke, but similar bands can also be found in the marble and the granite dykes (Fig. 11A). The rusty bands commonly represent mylonite zones, characterised as D_3-D_4 by Angvik et al. (included manuscript I), in the greywacke or occasionally in the granite lenses. The sulphides are especially enriched in areas where dilation has occurred within the individual shear zones (Fig. 11B). For example in zones where the shear zones bifurcate in duplex structures (Fig. 9A) and along shear bands following the boundary of two lithologies like metagreywacke/metadolerite or metagreywacke/granite. The mylonite bands in the metagreywacke follow the finer grained silty beds when the orientation of the bedding is parallel to the shear zone, these beds tend to be enriched in sulphides. The mineralisation occurs mainly as semi massive thin (0.2-1cm) bands and lenses, or dissemination along wider deformation bands (10-20cm)

One of these rusty bands found in the middle of the metagreywacke sequence (Fig. 9A) was chosen for detailed investigations of mineralisation. An approximately one meter thick dextral oblique-slip shear zone, characterised as D_3-D_4 by Angvik et al. (included manuscript I), striking NE-SW can be followed for hundreds of meter with several bifurcations of other shear zones along strike. It follows the contacts around a 4 meters wide and 60 meters long metadolerite. The sulphide-bearing metagreywacke is strongly ductily deformed with a pronounced micaceous foliation (Fig 11B and C). It is composed dominantly of quartz forming a very fine-grained matrix (1-20µm) together with subordinate plagioclase, epidote and biotite. The D_3-D_4 shear foliation is defined by epidote stringers and parallel orientated aggregates and crystals (1-60µm) of chlorite, biotite and/or muscovite which locally fill pressure shadows (Fig. 11 C). The sulphides which occur disseminated in the fine-grained matrix comprise arsenopyrite and chalcopyrite, as well as minor pyrrhotite, sphalerite and accessory galena and native gold. The arsenopyrite occurs as cataclastic crystals intergrown with chlorite and epidote. It contains abundant micro-fractures filled with chalcopyrite and/or quartz as well as occasional micrometer-sized grains of galena and native gold (Fig. 11 D and E). Some of the cataclastic arsenopyrite grains appear as rotated sigmaclasts with pressure shadows filled with biotite and chlorite. The orientation of these indicate both sinistral and dextral shear senses on micro-scale with chlorite and biotite aligned along the shear band (Fig. 11C).

Eight samples were collected for chemical analyses across the rusty sulphide-bearing shear zones in the metagreywacke. They were taken from lithologies showing different degrees of strain, i.e. from fine-grained weakly strained medium-grained metagreywackes to fine-grained highly strained greywacke and dark mylonitic grey schists. The normalised metal distribution shows that the high-strain zones contain more sulphides and metals than the zones of lower strain (Fig. 11G). The shear zone is mainly enriched in Au, As, Bi, Sb, Cu and Pb (± Se, Te, Co, Ag, Cd and Zn) compared to a sample of the weakly deformed, layered and unmineralised greywacke.

The metamorphic grade in the shear zones and around the metasomatic deposit is interpreted to be of greenschist facies based on the mineral assemblages associated with the D_3-D_4 metadolerite: chlorite- actinolite (Fig.14G), Metagreywacke: quartz- K-felspar-albite-chlorite, chloritized biotite-muscovite-scapolite (14C) Marble: calcite- tremolite- quartz- muscovite (Fig 14B)

3.2.2 Metasomatic As-Au-Fe deposit

In the early 1900'es, the Gautelis As-Au-Fe deposit was subject to test mining for gold and arsenic (Foslie, 1917; Blomlie, 2011). Since then, a series of companies have explored the area for gold and base metals (e.g. Pedersen, 1984; Flood, 1985; Tollefsrud, 1986). The mine appears today as a several meter deep water-filled inclined adit measuring 1.5m x 2.0m horizontally (Fig 12).

The mined ore zone occurs at the segmented, and strongly sheared and folded contact zone between the upper calcitic marble, a sub-vertical metadolerite and overlying layered metagreywacke. The metasedimentary units are less affected by the shear deformation away from the metadolerite. The mineralisation is mainly hosted by the high-strain zones in the metagreywacke and some in the marble. A mélange at the transition from greywacke to marble consist of the metagreywacke enclosing tectonic lenses of the marble (mix zone in Fig. 12A and 13A). The foliation is parallel to the NE-SW trending shear zone and is sub vertically dipping towards the west. A sub vertical metadolerite dyke has intruded along the mix zone parallel to the marble contact and represents one of several dykes that are parallel to the main NE-SW shear foliation in the Gautelis belt (Larsen et al., 2013). The dyke at the mine is approximately 15m long and 1.5m thick, is more competent and show little deformation. The metadolerite shows a typical magmatic texture and the contact to the surrounding rocks are sharp and strongly sheared. It is composed of plagioclase and actinolite, as well as aggregates of quartz, sericite and epidote related to retrogression (Fig. 14G).

The main ore zone occurs in the metagreywacke close to the metadolerite dyke (Zone 2 and 3; Fig. 12A and 13). It is recognised by its supergene alteration giving rusty to dark bluish surface coatings (Fig. 12A). The rusty colour is very extensive in this area and can be followed for tens of meters northwards and several meters east as a thick lens shaped body parallel to the shear zone, and are bounded by the marble in the south. The sulphide mineralisation is composed of pyrrhotite, sphalerite, arsenopyrite, chalcopyrite, pyrite and locally magnetite which occur as dissemination to massive zones. Eight zones have been identified with different proportions and types of gangue minerals, sulphides and magnetite (Fig. 12, 13, 14 and 15). The main sulphide zones are found in metagreywacke and the mixed zones on each side and close to the metadolerite dyke (Fig. 13A). Zone 1 of the mineralisation comprises scattered grains of pyrrhotite occurring in penetratively foliated metagreywacke in the eastern periphery of the mine area (Fig. 12, 13 and 14A). The metagreywacke is medium- to fine-grained and is composed of quartz, feldspar, muscovite, biotite and variably chloritised biotite. The minerals comprise bands with granoblastic texture (Fig. 14A) separated by foliation planes defined by aggregates of chlorite and mica. The quartz frequently forms micro-veinlets parallel to the foliation. Fine-grained pyrrhotite, chalcopyrite and arsenopyrite occur as disseminated grains and aggregates constituting about 5 volume % of the rock. The sulphide content increases in Zone 2 (up to 40 volume %) (Fig. 14C and 14D). The sulphides appear as semi-massive to massive, irregular segregations of pyrrhotite which occurs intergrown with some irregular grains and segregations of chalcopyrite and disseminated arsenopyrite (Fig. 14D). These sulphides occur intergrown with tremolite, quartz, scapolite, epidote and sericite (Fig 14C). The arsenopyrite is anhedral to euhedral and intergrown with tremolite which shows that the minerals have been deposited synchronous. The epidote and sericite occur as irregular aggregates along the foliation and quartz micro-veins. Zone 3 occurs immediately adjacent to the eastern contact of the metadolerite dyke (Fig. 13A). The zone comprises disseminated to massive sulphides composed of arsenopyrite and minor irregular grains of pyrrhotite, chalcopyrite and sphalerite (Fig. 14E and F). The zone is approximately one meter thick and probably tens of meters long. The sulphides occur as bands parallel to the micaceous foliation which are intersected by quartz veins and tremolite veinlets. The arsenopyrite which occasionally occurs along quartz veins is often found as strongly fractured cataclastic crystals in the fine-grained matrix of the metagreywacke where it occurs intergrown with pyrrhotite, chalcopyrite and tremolite (Fig.14E). The three latter minerals also occur as separate aggregates containing sphalerite. Zone 4 comprises the metadolerite (Fig. 12 and 13), and the sulphide mineralisation is weak and comprises fine-grained dissemination of irregular minor pyrrhotite and accessory grains of arsenopyrite (Fig. 14G,H). Along the boundary of the dyke and the marble, clinopyroxen have been identified together with large aggregates of quartz which may indicate a higher temperature caused by the dyke. The mineralisation in Zone 5 is comparable with semi-massive ores in Zone 3 on the opposite side of the metadolerite. (Fig. 13 and 15A). The sulphides occur as semi-massive to massive irregular aggregates and bands. They consist mainly of cataclastic arsenopyrite with strongly ductily deformed pyrrhotite and chalcopyrite intergrown with tremolite, quartz, calcite, muscovite and feldspar (Fig. 15B). Chalcopyrite and gold can be found along micro-fractures in cataclastic grains of arsenopyrite (Fig. 15B). Sericite and epidote has overgrown the other minerals. Zone 6 is located in folded calcitic marble west of the strongly deformed mix zone (Fig. 12A and 13A) and are composed of disseminated to semi-massive magnetite intergrown with tremolite and calcite, as well as minor epidote (Fig. 15C). Magnetite occurs as irregular aggregates and bands that have been folded. The magnetite mineralisation coexists with scattered grains of chalcopyrite pyrite and quartz. The weak pyrrhotite chalcopyrite and arsenopyrite dissemination in Zone 7 is hosted by a weakly deformed calcite marble carrying parallel orientated stringers of sericite-epidote, tremolite- and/or quartz defining the foliation (Fig. 15E and 15F). Zone 8 represents the non-mineralised marble close to the top of the underlying weakly deformed conglomerate beds (Fig. 12). The marble is part of the lower dolomitic marble member and consists mainly of dolomite/calcite with some quartz veins and aggregates of tremolite, chlorite, muscovite and epidote along the foliation (Fig. 14B).

Similar metasomatic occurrences can be found scattered elsewhere in the Gautelis area and show typical skarn occurrences with magnetite and pyrrhotite together with garnet, diopside and epidote along contacts of marble and greywacke (Fig. 15G). In this setting no intrusion can be found in direct contact to the marble, but metadolerites occurs nearby, within <100m.

4.0 Discussion

4.1 Genesis of the sulphide deposits in RTW

Based on field work mapping and sampling we suggest that the studied mineralisations along the Rombaken-Skjomen Shear Zone (RSSZ) can be divided into 1) pre-orogenic SEDEX deposits along distinct metasedimentary beds, locally remobilised during tectonic events, 2) syn-orogenic metasomatic deposit affected by shear zones and parallel dolerites and 3) late orogenic gold deposits following the deformation zones. The RSSZ is a progressive result of a Svecofennian orogenic transpressive event incorporating Paleoproterozoic volcanic and sedimentary rocks (Larsen et al., 2013), that we strongly connect to the mineralisations with distribution and genesis.

4.1.1 Haugfjellet SEDEX deposits

The stratiform Zn-Pb and pyrite or pyrrhotite mineralisations occurring in undeformed metagreywacke in Sildvika, Jernvann and Haugfjellet areas mineralisation are interpreted to represent low-grade sedimentary exhalative type deposits (SEDEX). These deposits are believed to form by hydrothermal fluids in extensional sedimentary basins, resulting in precipitation of stratiform mineralisation. It is commonly referred to as laminated, bedding-parallel, Pb-Zn rich siltstones appearing as a series of stacked mineralised lenses interbedded with pyritic and carbonaceous siltstones. These sulphides are hosted of fine grained, organic bearing, dolomitic siliciclastic siltstones and shales, and the mineralisation is located close to major basin-scale faults acting as fluid channels (Gustafson & Williams, 1981; Solomon & Groves, 2000; Large et al., 2005). SEDEX deposits are thought to be a Paleoproterozoic worldwide event and to be caused by the global ocean chemistry at the time (Lyons et al., 2006).

SEDEX type of deposits on Haugfjellet have been mentioned by several authors (Flood, 1984; Flood 1985; Korneliussen & Sawyer, 1986; Coller, 2004) although Flood (1984, 1985) considered the Pb-Zn to be associated with the As and Au mineralisation. Coller (2004) suggested a SEDEX type deposit, however, he did not include the Pb-Zn, but the enrichment of pyrite and pyrrhotite. Because of the nature of these sulphides following distinct beds, we suggest that the SEDEX mineralisation consist of Pb-Zn and also the pyrite and pyrrhotite mineralisation which have been deposited syn-sedimentary during the opening of the basin and the transition to the island arc setting, which is in accordance to the tectonic setting of the greywackes (Sawyer et al., 1989). The Fe sulphides could represent a more distal facies to the Pb-Zn mineralisation.

A syngenetic deposition of the Pb-Zn mineralisation is supported by ore lead systematics, with a population of 206Pb/204Pb isotopes that have been found at Sildvika and Haugfjellet to have a Svecofennian signature (Larsen et al., 2013). They found local changes with less and less radiogenic lead from west (Sildvika) to east (Haugfjellet), suggesting that the galena either have deposited in a further distance from the mantle source, caused by the progressive change from mantle derived (mafic) magmatism to more continental derived (felsic) magmatism. Similarly may also different stratigraphic levels explain the change where the more radiogenic values are higher in the stratigraphy when the island arc (mafic and radiogenic) has developed into a more continental system (felsic and less radiogenic). They further showed how the values from RTW was similar to the Proterozoic Pb/Pb signatures values from Tjåmotis-Skuppe area, and that they fit on a line and show the relative distance (either by stratigraphy or tectonic progression). This tectonic model is supported by the study of Korneliussen & Sawyer (1989) and Sawyer & Korneliussen (1989), which suggested a similar development. Similarly did Larsen et al., (2013) present a structural based tectonic model which confirm the structural development of the sedimentary layers and that the sedimentation is of Paleoproterozoic age.

We suggest that these deposits have been overridden by fold-thrust belts and steep ductile shear zones which have caused remobilisation of the Fe and Pb-Zn mineralisations as discussed in section 4.1.3.

4.1.2 Gautelis metasomatic deposit

In this study there was recognised several metasomatic deposits in the Gautelis area with a zonation, where one was studied in detail. Metasomatic deposits have been described from numerous authors (e.g. Einaudi et al., 1981; Burt, 1982), and are referred to as either contact or regional metamorphic processes with calc-silicate minerals metasomatic replacing of carbonate rocks (Robb, 2005). In addition, the zonation replacement pattern are typical for skarns (e.g. Einaudi & Bart, 1982).

Eight different zones were identified (Fig. 12, 13) and the ore in the Gautelis mine is interpreted to be an As-Au metasomatic deposit related to the sub-vertical metadolerite crosscutting the folded marble and greywacke. The deposit show complexities because of the syn-genetic relationship between the metadolerite and the late orogen sub-vertical shear zones. The metadolerite has intruded parallel to the weakness zones. It has therefore been interpreted to be syn- or late tectonic with strong relation to these shear zones, with a weakly overprinting by late shear zones that may have caused remobilisation of minerals. This metasomatic deposit probably has formed by fluids transported in the shear zone.

Similar minor skarn occurrences in the Gautelis area have been described by Korneliussen et al. (1986) as irregular, fine grained aggregates or lenses/boudins occurring up to a few meters wide with chalk silicates with sulphides and magnetite. The lenses show a small zoning with a rim of diopside/tremolite and a core of grossular and epidote and the skarn occurrences are strongly deformed and folded which is consistent with the present study (op cit.). Similar observations have also been done by other authors, but interpreted the genesis differently. Bugge & Foslie (1922) characterised the deposit as a vein-type, formed by metasomatic processes. They describe the mineralisation as a metasomathic deposit between hornblende schist (here described as metadolerite) and the marble. Arsenopyrite occurs in quartz veins together with biotite and pyroxene, and pyrrhotite and chalcopyrite are locally/occasionally observed in the marble (op cit.). They also describe the deposit to be thickened and folded, but do not direct link the deposit to the structures. Priesemann (1984b) interpreted the mineralisation to be related to a volcanic explosive hydrothermal vent because of the brecciation of the arsenopyrite and the boudinaged and laminated bands. Boudinage structures are common in ductile deformation (e.g. Davis & Reynolds; 1996) and we have therefore interpreted the deposits to be related to the shear zone development.

Skyseth & Reitan (1995) showed in their study of fluid inclusions that the deposit is derived from high saline fluids and suggested that the fluids got trapped along the barrier between low and high competency rocks. They interpreted the structures to be of Caledonian age, while Larsen et al. (2013) have demonstrated that the structures are Paleoproterozoic. The high saline fluids may have its source from the syn tectonic Rombak granite (Larsen et al., 2013) The role of the metadolerite is not fully understood and may have co-acted as a local heating or fluid source when crosscutting the marble changing the pH and releasing fluids.

Because the syn orogenic metadolerite in the Gautelis deposits are closely related to the sulphides, it is therefore reasonable to believe that the metadolerite may have had an important role in the process. Metasomatic deposits associated with metadolerites are not as well understood as connected to felsic intrusions. However, similar metasomatic deposits to Gautelis have been described. A gold skarn deposit from British Columbia (Dawson, 1981) is associated with metadolerites and show several stages of overprinting deformation and that they acted as fluid conduits. Spooner (1993) showed how metadolerite intrusives in Archean terrain could be a gold-skarn target caused by their high volatile content before sulphide loss.

The formation of the metasomatic Gautelis deposits is assumed to be associated to the intrusion of dolerite along regional shear zones, with contemporaneous granites as probable fluid source. The combination of a dolerite heat source, a regional shear zone structure and a possible change in pH when crosscutting the marble, are contributing to this type of metasomatic deposit.

4.1.3 Rombaken-Skjomen orogen deposits

Several classifications of orogenic gold deposits exist (e.g. Groves et al.,1998; McCuaig and Kerrich 1998). Groves et al.(1998) suggested a classification scheme including late Archean to Phanerozoic rocks on a deformed continental margin with structural highs in late stage of deformation, mafic volcanics, intrusive or greywacke rocks mainly in greenschist facies metamorphism, associated with intrusions of felsic to lamprophyre dykes or continental batholits, variable and late tectonic mineralisation style with structurally complexity, strong overprinting in larger deposits, Au-Ag ± As ± B ± Bi ± Sb ± Te ± W metal association, cryptic lateral and vertical zoning, low salinity with P: 0.5–4.5 kbars and T: 220º–600ºC, metal sources are thought to be from subducted crust, supracrustal rocks or granitoids and heat source from granitoids. Based on these parameters compared to the geological evolution of the RTW, we propose an orogenic gold ore-genesis for deposits occurring within the RSSZ. The Paleoproterozoic age range (Larsen et al., 2013), the Andean type accretion tectonic setting with greywacke and marble as the host rock (Sawyer & Korneliussen, 1989) and the steep anastomosing transpressional structural setting with a syn orogenic granite intrusion as the heat source (Larsen et al., 2010) of the RTW, all correspond to what Groves et al. (1998) suggested.

The metamorphic grade in the host rock has earlier been discussed from the RTW (Korneliussen et al., 1986; Sawyer, 1986; Skyseth & Reitan, 1995). We have shown that the rocks within the shear zone are of greenschist facies. The main metamorphism in the RTW is thought to be amphibolite facies (Sawyer, 1986), but Korneliussen et al. (1986) also found that the N-S going shear zones (D_3) in Norddalen (Fig. 2) show evidence of retrogradation from amphibolite facies to greenschist facies metamorphism. He explained this change to be caused by fluids transported along the Paleoproterozoic shear zones. Similarly, Skyseth & Reitan (1995) documented a retrogradation to greenschist facies metamorphism in the Gautelis area. However, they linked the metamorphism and gold deposition to the Caledonian orogeny. We suggest that this retrogressive of the metamorphic event is linked to the Paleoproterozoic development of the regional shear zone (D_3-D_4) running from Gautelis, through Norddalen and Sjangeli, and covered by the Caledonian nappes to the east (Larsen et al., 2013). The N-S trending shear zone at Haugfjellet shows a similar retrogression where the chlorite is present within the quartz veins occurring as a late event of deformation.

The mineralisation styles for orogenic gold deposits may occur in a large variety (Groves et al., 2003). However, strong overprinting and veining are typical for orogenic gold. In the RTW are the structural overprint of earlier-formed deposits are extensive, where shear zones cut through SEDEX deposits and metasomatic deposits that can be seen with sericite overprinting other mineral assemblages and deposit together with As and Au in particular. In addition, the quartz veins are thought to be a late stage of the orogen (D_3-D_4) as they cut the fold structures and shear zones, but are slightly sheared themselves (Larsen et al., 2013). Similarly, Coller (2004) suggested that the gold values were related to the quartz-veins and silica alteration in the Haugfjellet area and that the shear zone were responsible for transporting the silica. The Au, Cu, Bi, Ag, Pb mineralisations are therefore believed to be the latest stage of sulphide mineralisation in the orogenic deposits.

Orogenic gold deposits are believed to be characterised by low saline fluid (Groves et al.. 1998; 2000; 2003). However, in a fluid inclusion study carried out by Skyseth & Reitan (1995) nearby the metasomatic As-Au deposits at the Gautelis mine, they found that the mineralising fluids where highly saline. High saline fluids have been reported from several gold provinces classified as orogenic gold (e.g. Tyler & Tyler, 1996; Khin et al., 1994; Rowins et al., 1997; Eilu et al, 2007). The high saline fluids can be explained with rocks developing in a basinal setting, the pore water may stay within the original rock until melting occurs (Yardley, 1997). However, the fluid inclusion study does not show if the fluids are connected directly to the metasomatic deposit or to the shear zones (D_3-D_4).

The suggested ore-genesis of orogenic gold, defined by Groves et al. (1998; 2000; 2003). is supported by work of Larsen et al., (2013) that related RTW and the gold line in central Sweden, to the north coast of Norway. The RSSZ is linked to major Paleoproterozoic shear zone systems across the whole of the Fennoscandian shield (Bergh et al., 2013; Larsen et al., 2013). This large system is known for its gold deposits in Northern Norway, Finland and Sweden (e.g. Eilu & Weihed, 2005) which now can be extended underneath the Caledonian nappe complex to include the RTW, (Larsen et al., 2013).

4.2 Timing and spatial relationship of the sulphide deposits along the RSSZ

Several stages of sulphide mineralisation have been found and can be either pre-dated or structurally linked to the RSSZ. In this paper we are able to put the investigated mineralisation into four stages of mineralisation (Fig. 16); 1) pre-orogen SEDEX deposits (D_0), 2) syn-orogenic metasomatic deposit, 3) Syn-orogenic shear zone overprinting metasomatic deposit and with a signatures of orogen- type Au-As deposits (D_3-D_4) and 4) late, syn-orogenic quartz veins (D_3-D_4).

It is well known from the Fennoscandian shield that in the early Paleoproterozoic, the continent was characterised by extension, breakup and basin development (e.g. Gorbatschev & Bogdanova, 1993; Nironen, 1997). In the RTW, the basin gradually changed into an Andean type setting (Korneliussen & Sawyer, 1989) with development of the Sjangeli island arc (Romer et al., 1992). Greywacke sediment infill continued in the RTW (Sawyer & Korneliussen, 1989) before closure, accretion and intrusion of granite plutons.

We have identified SEDEX occurrences in the lower deformation zones and within the same rocks that Sawyer & Korneliussen (1989) suggested to be turbiditic greywacke sequences deposited in an Andean-type setting which again put the SEDEX deposit in a setting developing from an extensional basin regime into an island arc system (Fig. 16). The SEDEX deposits are mainly found along beds with low deformation and are remobilised in areas of high deformation. Cu-Fe sulphides from island arc rocks in Sjangeli are similarly found to be stratabound and syngenetic with the deposition of the tuffs (Romer, 1989).

The metasomatic deposits in Gautelis are interpreted to have developed within a shear zone (D_3-D_4) in association with metadolerites. Metadolerites in an accretionary regime are thought to develop from an early stage of subduction where the magma is derived from the mantle and have not been contaminated by melting of the continental crust (e.g. Hall & Hughes, 1993). This is also according to Korneliussen & Sawyer (1989) which interpreted the igneous rocks in RTW as a continuous change from ultramafic/mafic to felsic magma series through the Paleoproterozoic. Because of the metadolerite dykes that crosscut the already folded strata and stratigraphy, and that they have intruded along steep dipping weakness zones or shear zones. We suggest an early D_3-D_4 syn-orogenic metasomatic development is found where marbles, large ductile oblique-slip shear zones and dolerite s are present (Fig. 16).

Larsen et al. (2013) presented a model of two folding (D_1-D_2) and two oblique-slip syn-orogenic (D_3-D_4) events; one sinistral (D_3) overprinted by a dextral event (D_4). They furthermore suggested that all four events were a result from progressive syn-orogenic transpressive strain partitioning. The interpreted orogenic gold is found in deformation zones either within ductile oblique-slip deformation zones or with brittle-ductile fractures (D_3-D_4), both within the shear zone. The orogenic gold found within the shear zone is only found within the steep ductile oblique-slip shear zones and not in the fold-thrust belt (D_1-D_2). The brittle ductile fractures (D_3-

D_4) cuts these shear zones and represent the last event of gold formation. The D_1-D_4 shear zones in RTW are believed to be part of a large regional scale tectonic event (e.g. Nironen, 1997; Larsen et al., 2013) and are interpreted to be directly linked to Sjangeli, Kopparåsen, Tjåmotis, the Bothnian basin and the southern part Skellefte district in Sweden (Fig. 16) and to the western Precambrian provinces in North Norway (Larsen et al., 2013). For example are Cu-U mineralisations found along large deformation zones at Kopperåsen, dated to 1.780 Ma (Adamek, 1975; Romer, 1988). Orogenic gold is actively mined from the gold line, in similar aged and type of greywacke rocks, in the southern part of the Skellefte district (Bark & Weihed, 2007). Svecofennian shear zones described from Finland and Russia have shown to be carriers of large amounts of orogenic gold (e.g. Sundblad & Ihlen, 1995; Sundblad, 2003; Goldfarb et al., 2001; Ojala, 2007).We hereby suggest that the RTW is part of this large regional juvenile event during the Svecofennian orogeny and orogenic gold is likely to be found along the late stage shear zone structures (D_3-D_4) as found in quartz veins, microstructures and weakness zones.

5.0 Conclusions

- Three genetic types of principally sulphide mineralisations have been identified within the rocks and structures of Rombaken Tectonic Window; 1) Syn-sedimentary Pb-Zn and Fe-sulphide SEDEX deposit (D_0), 2) Syn-orogenic intrusion related metasomatic As-Au-Cu deposit (D_3-D_4) and 3) Orogenic gold deposits with Au-As enrichments along shear zones (D_3-D_4) and 4) late orogenic Cu-Au quartz veins (D_3-D_4).

- The SEDEX deposits vary between pyrite, pyrrhotite and galena-sphalerite dominated layers within the greywacke sequence.

- The metasomatic Au-As-Cu deposit is related to metadolerites crosscutting the folded beds of marble and greywacke. The metadolerites are probably an important heat source. They are also syn-orogenic and might be a source for fluids, and together with the shear zones that may have acted as carriers of the fluids.

- The orogenic gold deposits are related to regional structures, continuing into Northern Norway, Finland and Sweden, that indicate mineral potential in large areas. The RSSZ crosscuts several of the pre orogenic localised zones of sulphide deposits which makes the orogen deposits differ slightly from the definition by Groves et al., (1998) with atypical mineralisation caused by remobilisation.

- We propose a regional model developing through time (D_0-D_4) which incorporates several mineralisation events. They are developing from a syngenetic stage of sediment deposition and basin development (D_0), to volcanic rocks and deposits related to an active margin turning into a stage of orogeny (D_1-D_2) and all deposits are accreted into the large regional scale orogeny (D_3-D_4)
- The spatial relationship between the sulphide deposits and the large structures are closely related. The SEDEX are syngenetic (D_0) found along undeformed greywacke beds in low deformation zones, but also redistributed along ductile shear zones D_3-D_4. The metasomatic deposits are found in locations where metadolerites, marbles and steep ductile shear zones exist (D_3-D_4). The orogenic gold and their related sulphides are found in dilatational structures and weakness zones along the large scale shear zones including quartz veins and steep ductile oblique-slip structures (D_3-D_4).

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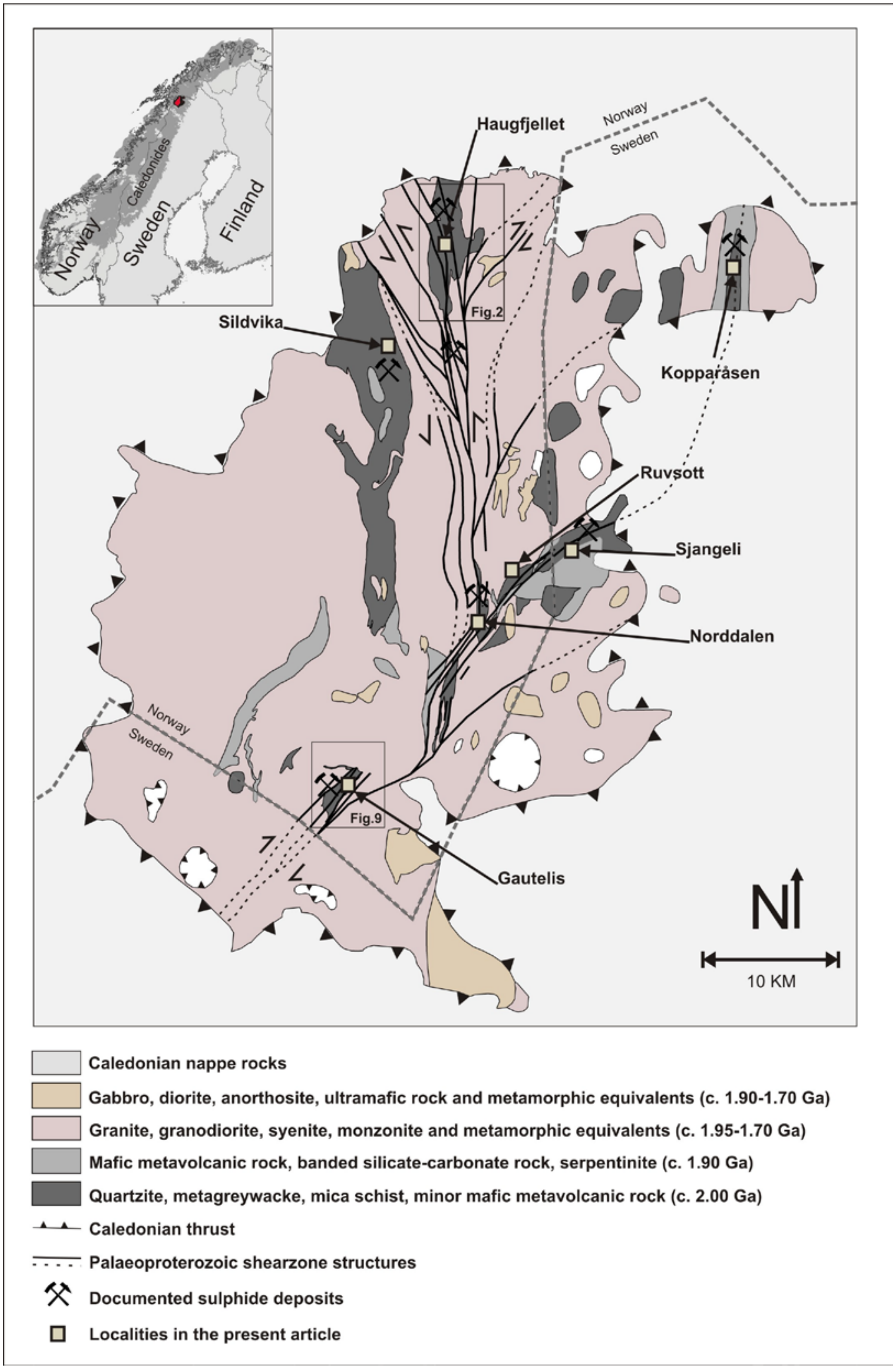


Fig. 1. Geological and structural map over the Rombaken Tectonic Window with sulphide deposits marked along the Rombaken-Skjomen Shear Zone.

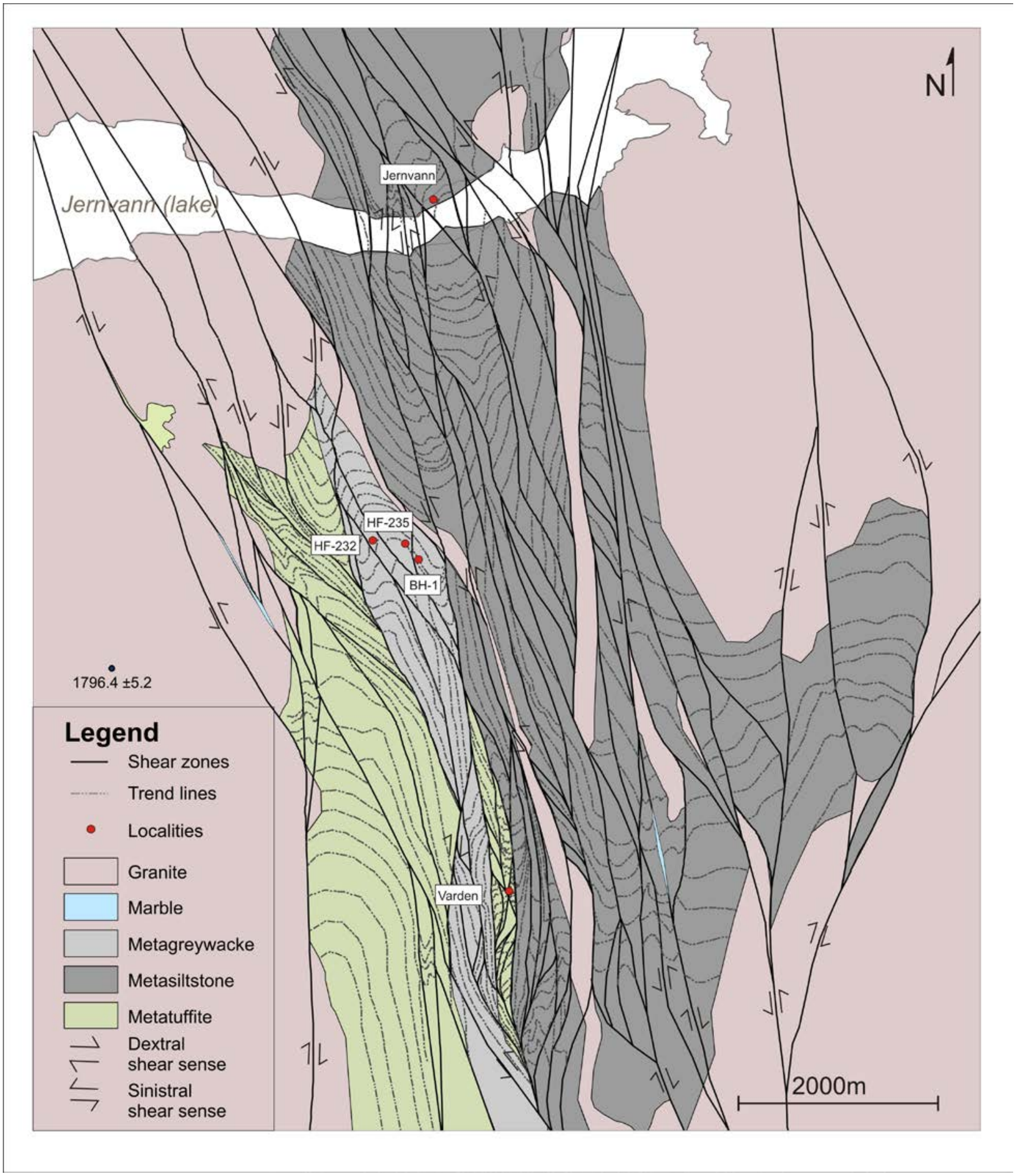


Fig. 2. Geological and structural map of the Haugfjellet area showing the localities of samples and drill hole. The marble is only found as narrow bands or lenses smeared out along the shear zones.

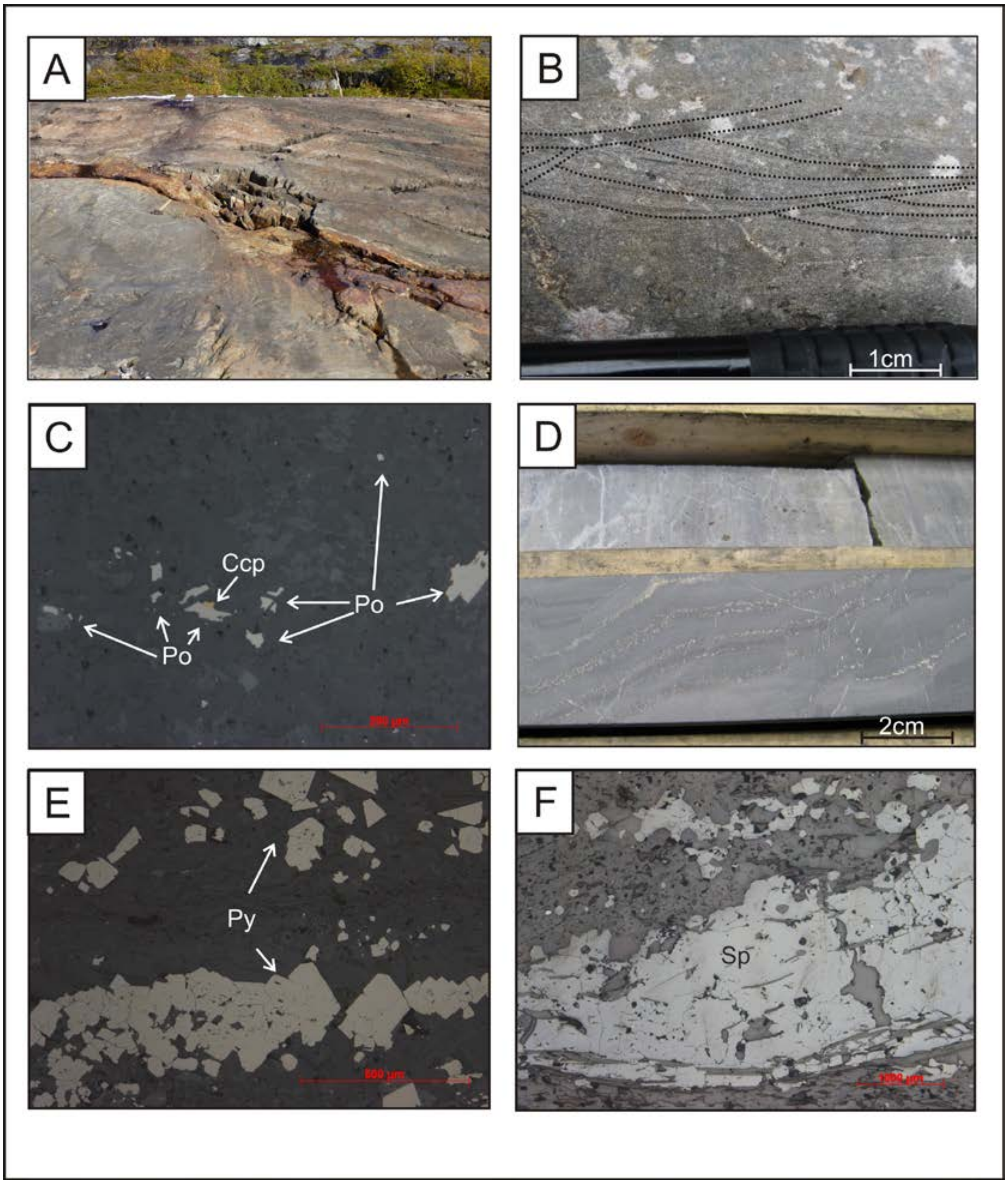


Fig. 3. Undeformed and layerparalell mineralisations at Haugfjellet and Sildvika. A) Layer parallel pyrrhotite along greywacke beds at the Jernvann locality (Fig. 2). B) Primary structures with trough cross-bedding found in the greywacke sequences at Sildvika implying very little deformation. C) Type 1: Photomicrograph of disseminated pyrrhotite accompanied by chalcopyrite (reflected light). D) Typical bedding parallel pyrite within Haugfjellet drill core (Photo: Jan Sverre Sandstad). E) Type 2: Photomicrograph of semi-massive pyrite bands in metatuffite from Haugfjellet (reflected light). F) Type 3: Photomicrograph of semi-massive sphalerite in the undeformed metagreywacke in the Sildvika locality (reflected light). Abbreviations: Po - pyrrhotite, Ccp - chalcopyrite, Sp - sphalerite

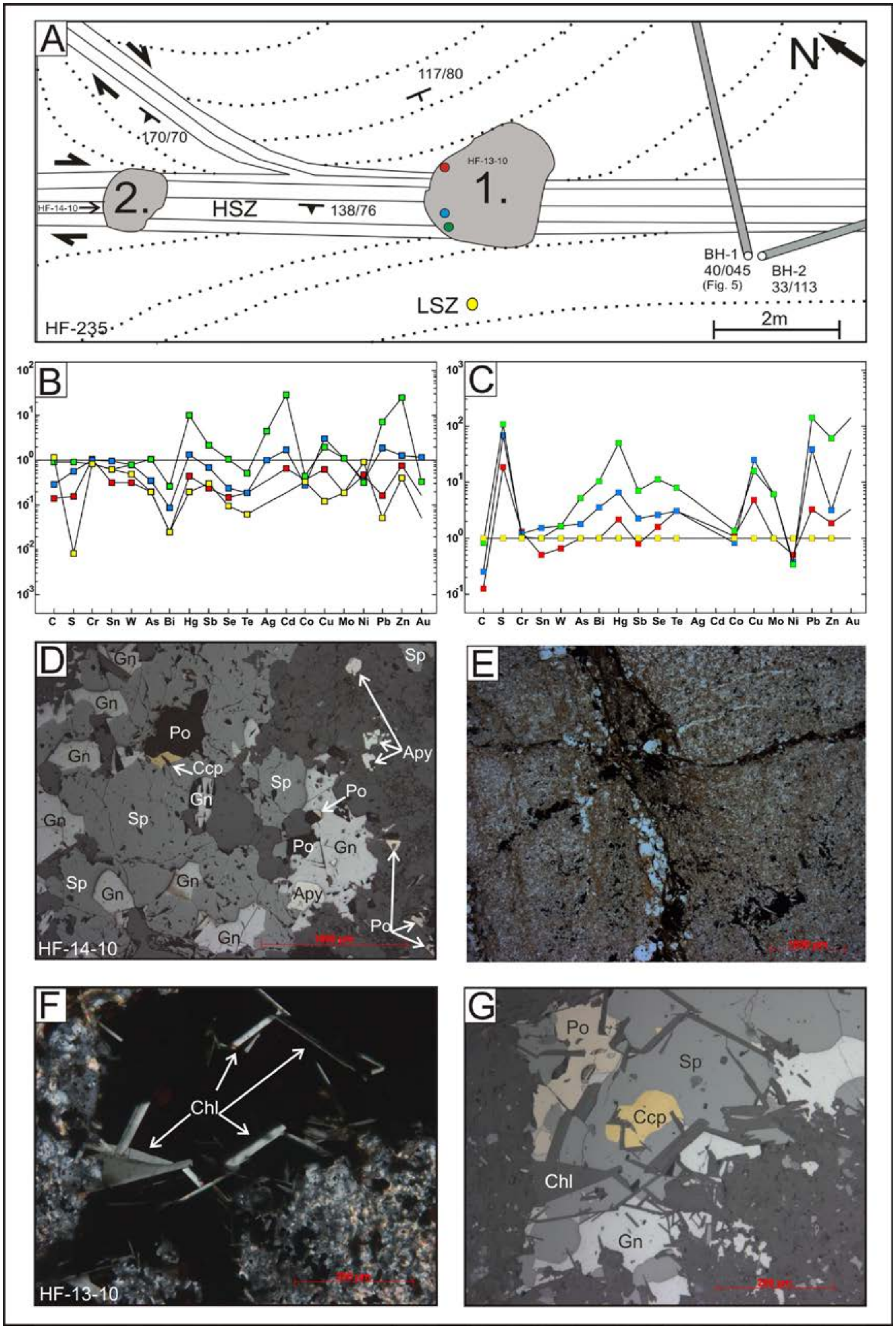
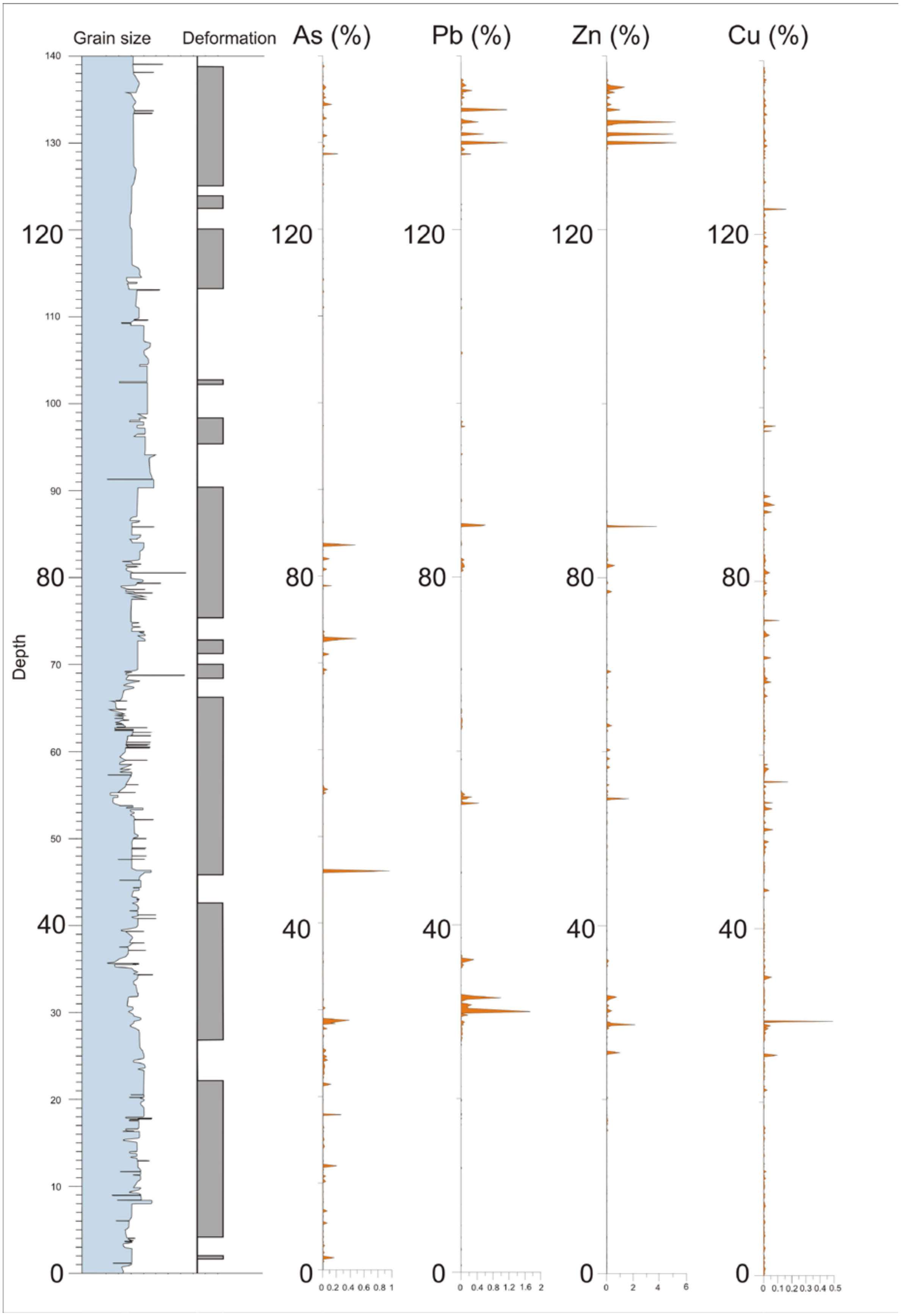

A
N
117/80
170/70
HF-13-10
1.
2.
HF-14-10
HSZ
138/76
BH-1
40/045
(Fig. 5)
BH-2
33/113
LSZ
HF-235
2m
B
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
C S Cr Sn W As Bi Hg Sb Se Te Ag Cd Co Cu Mo Ni Pb Zn Au
C
10^3
10^2
10^1
10^0
10^{-1}
C S Cr Sn W As Bi Hg Sb Se Te Ag Cd Co Cu Mo Ni Pb Zn Au
D
Gn
Po
Ccp
Sp
Apy
HF-14-10
E
F
Chl
HF-13-10
G
Po
Sp
Ccp
Chl
Gn

Fig. 4. A) Sketch of locality HF-235 found as an old working at Haugfjellet (Fig. 2). The old working is located along a dextral shear zone in metagreywacke and consist of two blasted holes (1 and 2) and two drill holes (Fig. 6) B) Spider plot of geochemical data of samples from locality HF-235 (colouring of samples as in Figure A). The analytical data are normalised to the average composition of unmineralised and undeformed metagreywacke sampled in different localities at Haugfjellet. C) Geochemical data of samples from locality HF-235 in a spider plot seen in Figure A with the same colours. The data are normalised to the host rock in the undeformed and unmineralised area seen as the yellow plots. D) Photomicrograph of a massive sulphide with unusual mineral assemblages, mainly sphalerite and galena together with minor amount of chalcopyrite, pyrrhotite and arsenopyrite (HF-14-10) from locality HF-235 (reflected light). E) Photomicrograph of sulphide accumulation along veins and fractures (HF-13-10) (cross-polarised, transmitted light). Abbreviations: LSZ - Low strain zone, HSZ - High strain zone. F) Photomicrograph of section HF-13-10 (cross-polarised, transmitted light) that shows intergrown chlorite and sulphide minerals G) As F, showing sphalerite, galena, chalcopyrite and pyrrhotite together, intergrown with chlorite (reflected light). Abbreviations: Gn - galena, Sp - sphalerite, Po - pyrrhotite, Apy - arsenopyrite, Ccp - chalcopyrite, Chl - chlorite.



Grain size
Deformation
As (%)
Pb (%)
Zn (%)
Cu (%)
Depth
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
120
80
40
0
0 0.2 0.4 0.6 0.8 1
0 0.4 0.8 1.2 1.6 2
0 2 4 6
0 0.1 0.2 0.3 0.4 0.5

Fig. 5. BH-1 is an old drill core from an earlier prospect (Laundrum, 1995) in the Haugfjellet area. The result of the blue bar demonstrates the optical grain size through the core. The finer grained beds are more frequent deformed. The grey bar indicates where the rocks are deformed. However, the small details of the deformation cutting through the finer grained beds within coarser grained domains cannot be seen in the figure as the scale is too large. The orange graph represents the contents of As, Pb, Zn and Cu in % measured by portable XRF (Niton XL3t 900 Gold). The results are calculated average of three measurements for every second centimeter.

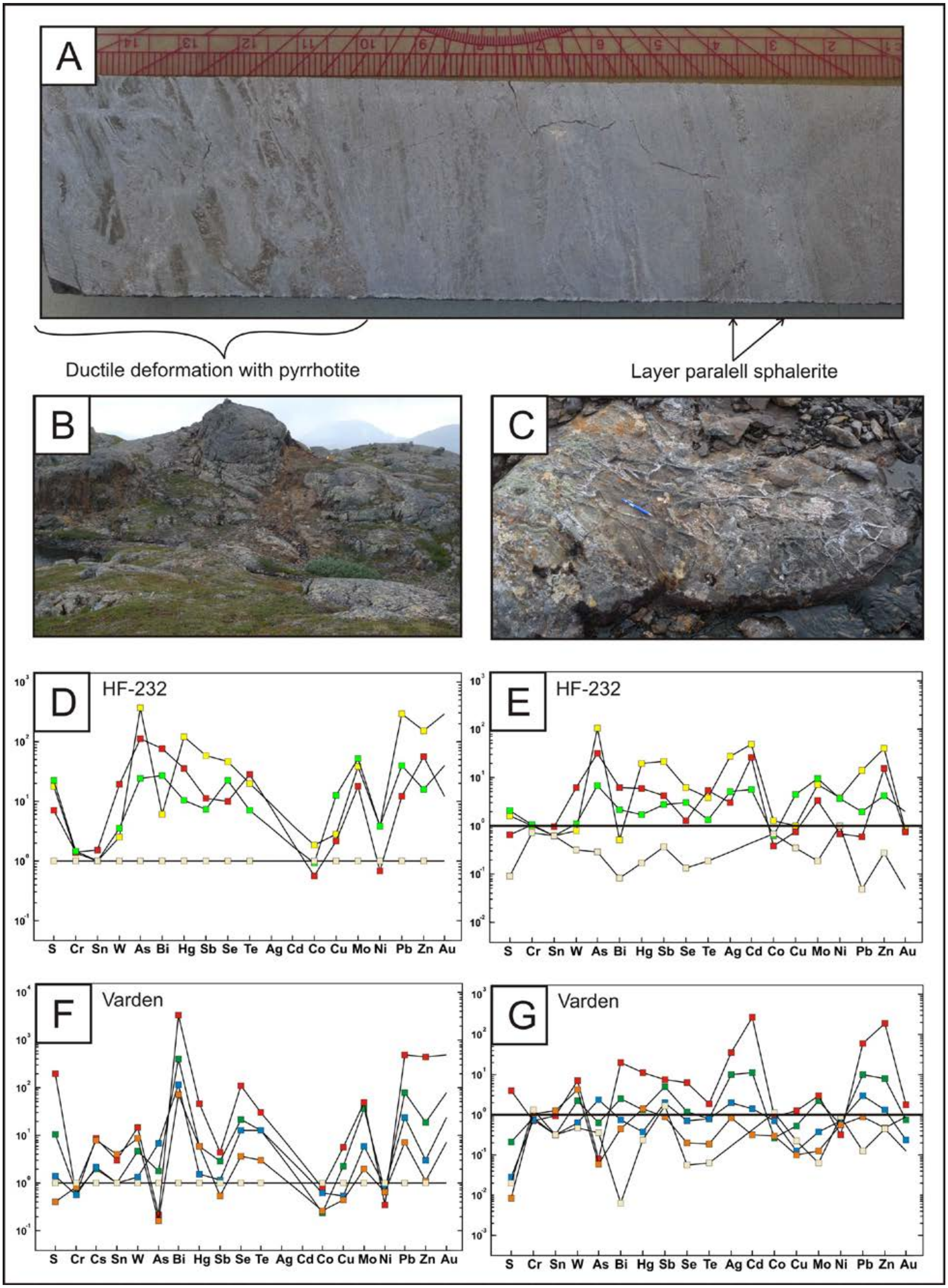

A
Ductile deformation with pyrrhotite
Layer paralell sphalerite
B
C
D
HF-232
S Cr Sn W As Bi Hg Sb Se Te Ag Cd Co Cu Mo Ni Pb Zn Au
E
HF-232
S Cr Sn W As Bi Hg Sb Se Te Ag Cd Co Cu Mo Ni Pb Zn Au
F
Varden
S Cr Cs Sn W As Bi Hg Sb Se Te Ag Cd Co Cu Mo Ni Pb Zn Au
G
Varden
S Cr Sn W As Bi Hg Sb Se Te Ag Cd Co Cu Mo Ni Pb Zn Au

Fig. 6. Shear-zone-hosted/related Cu-As-Au and remobilised Pb-Zn mineralisation from Haugfjellet area. A) A photo of a drill core (BH-1) with both ductily deformation metagreywacke with pyrrhotite and non deformed layer parallel sphalerite. B) Rusty coloured shear zone (locality HF-235) that can be followed for hundreds of meters to the right of the knob. C) Quartz vein brecciation at Varden locality often found together with Pb-Zn mineralisation. D) Geochemical data of samples from locality HF-232 in a spider plot. The data are normalised to the host rock in the undeformed and unmineralised area next to the shear zone. E) Geochemical data of samples from locality HF-232 in a spider plot. The data are normalised to the average of undeformed metagreywacke rocks found in Haugfjellet. The beige colour is the undeformed sample at the locality F) Geochemical data of samples from the Varden locality in a spider plot. The data are normalised to the host rock in the undeformed and unmineralised area next to the shear zone. G) Geochemical data of samples from the Varden locality in a spider plot. The data are normalised to the average of undeformed greywacke sediments found at different areas in Haugfjellet. The beige colour is the undeformed sample.

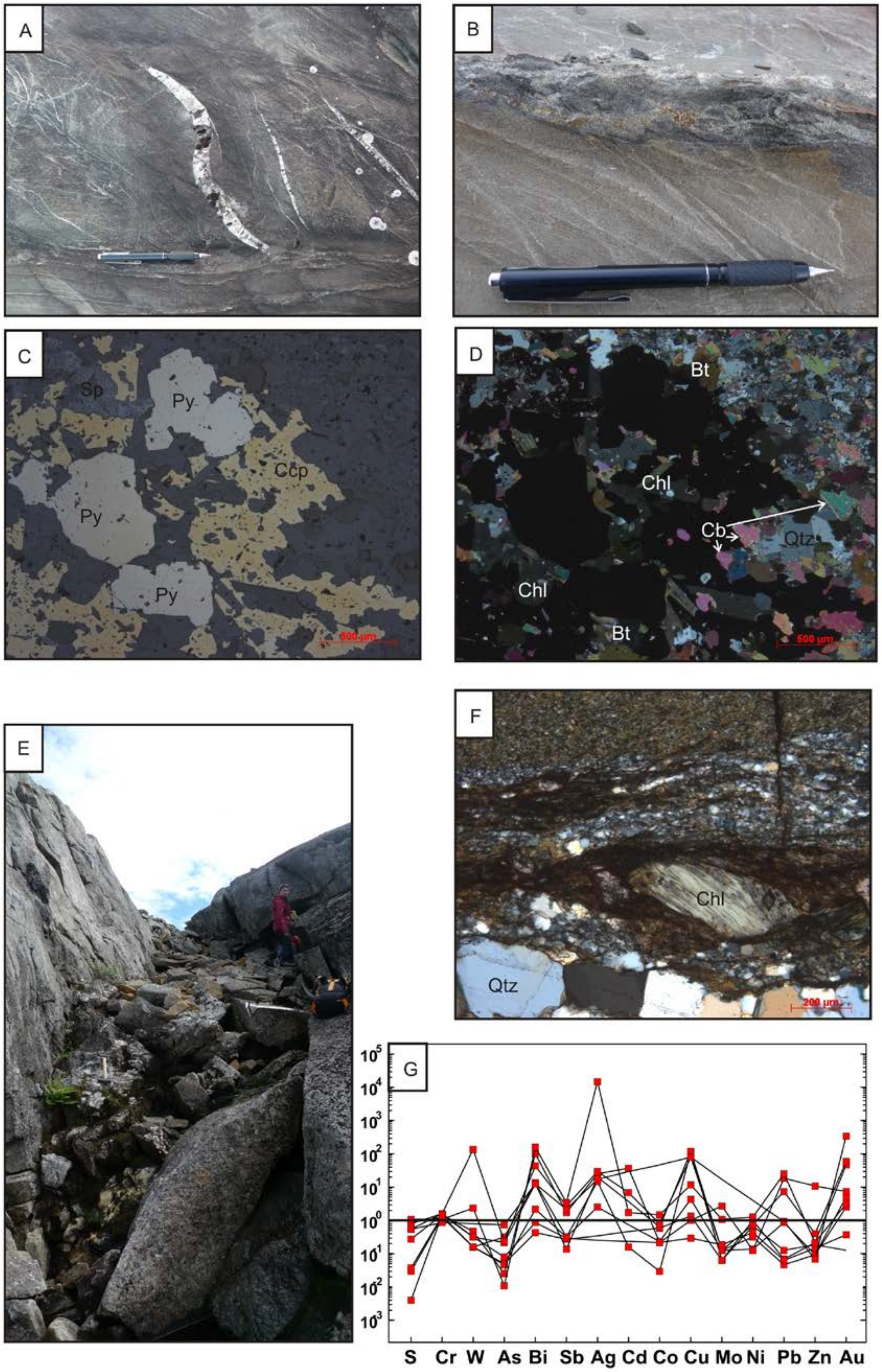

A
B
C
Sp
Py
Ccp
Py
Py
500 µm
D
Bt
Chl
Cb
Qtz
Chl
Bt
500 µm
E
F
Chl
Qtz
200 µm
G
10^5
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
S Cr W As Bi Sb Ag Cd Co Cu Mo Ni Pb Zn Au

Fig. 7. Brittle-ductile quartz veins in the Haugfjellet area. A) En echelon quartz vein ductily deformed into sigmoidal quartz veins defining a dextral shear sense. There are also thin non-directional veins occurring close to those veins B) Chalcopyrite and pyrite rich quartz vein with minor chlorite and biotite. C) Photomicrograph with reflected light of chalcopyrite and pyrite in quartz vein shown in Fig. 7B D) Photomicrograph with (cross-polarised, transmitted light) of quartz, chlorite, biotite and a minor calcite in quartz vein as Fig. C. E) A major quartz vein found in the middle of a 2 meter wide mylonite zone. The quartz vein is filling most of the gully, ca two meters wide. F) Photomicrograph with the sheared contact along a quartz vein seen at the bottom of the photo. The shear zones are also parallel to and together with minor micro quartz veins. A large chlorite grain is seen as a sinistral sigmaclasts. (cross-polarised, transmitted light). G) Geochemical data of quartz vein samples in a spider diagram which are normalised to the average greywacke values. Note the high Bi, Cu and Au content. Abbreviations: Sp - sphalerite, Py - pyrite, Ccp - chalcopyrite, Chl - chlorite, Bt - biotite, Qtz - quartz, Cb - carbonate.

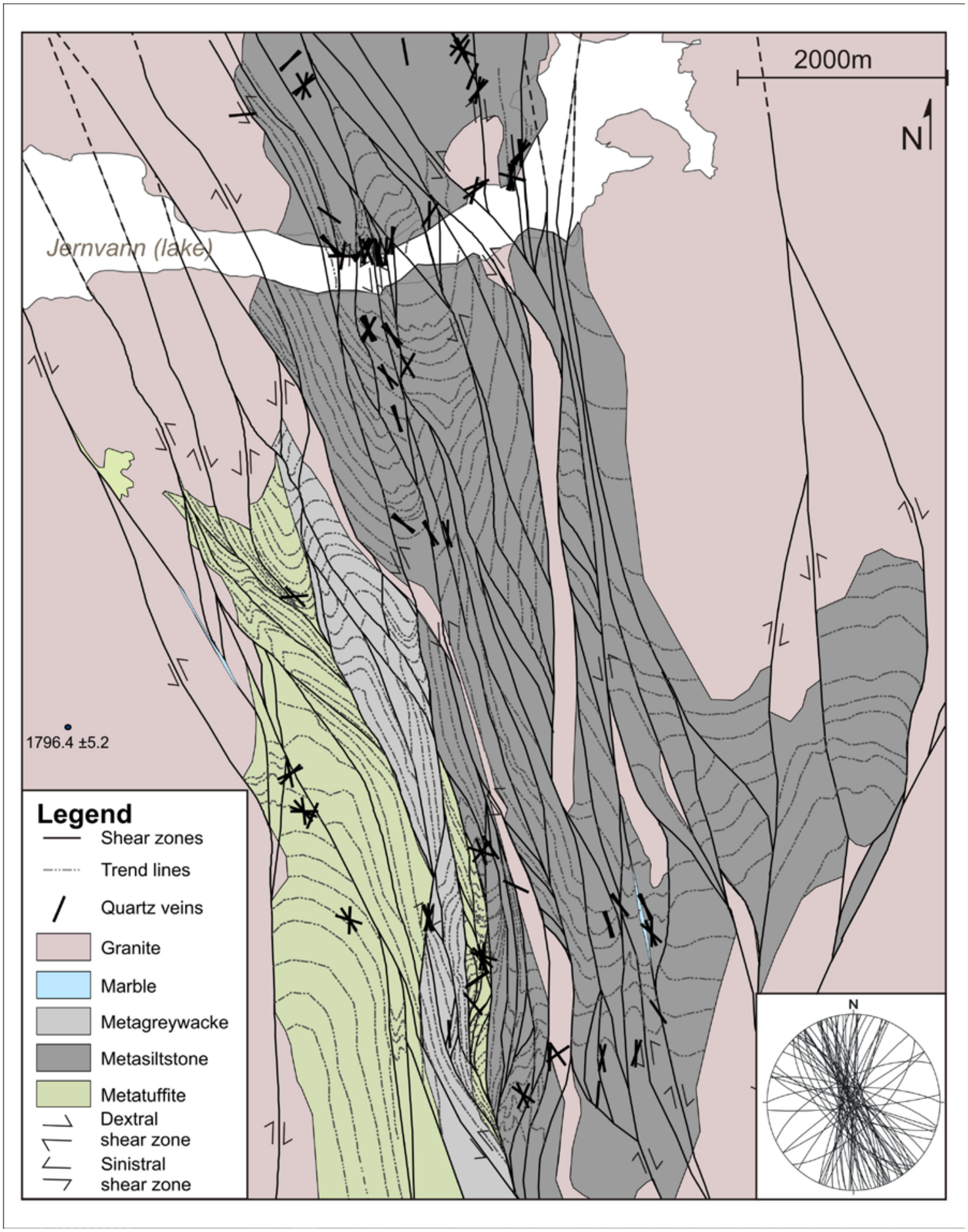


Fig. 8. Geologic and structural map of the Haugfjellet as Fig. 2 showing the orientation of the studied brittle-ductile quartz veins that are commonly found with Cu-Au sulphides. The map is the same as in Figure 2 but shows the measured brittle ductile quartz veins. The stereo plot shows the orientation of the veins.

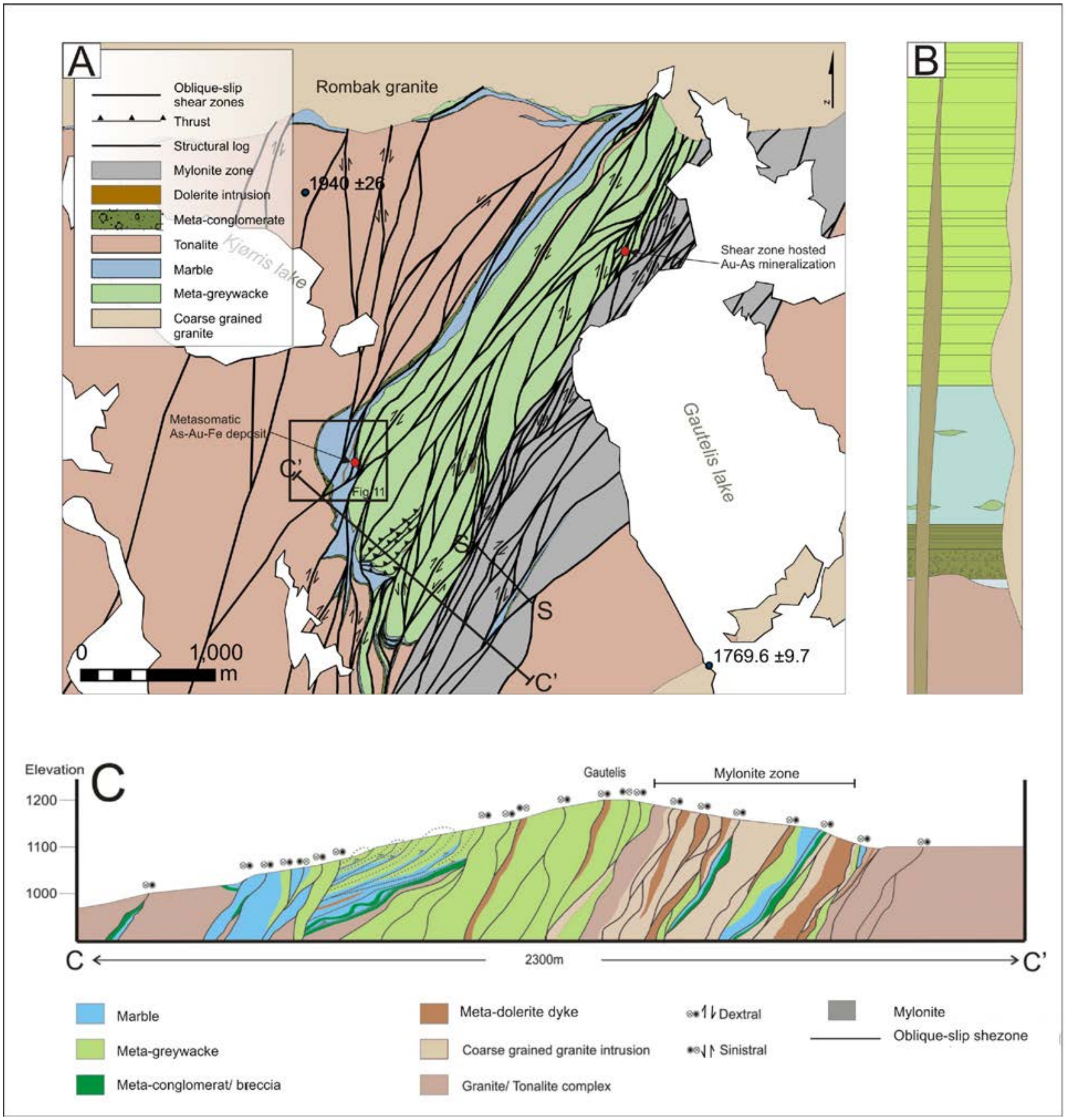


Fig. 9. Geologic and structural map of the oblique-slip dominated Gautelisvann area. A) Geological overview map of the Gautelis area. Location of cross-section profile (Fig. 9C; line C-C'), structural log (Fig. 10; line S'-S) and frame of Figure 11B are marked. Radiometric ages are from Romer et al. (1992). B) Schematic stratigraphic column of the Gautelis area. C) Interpreted cross section of the main ductile shear zone of the Gautelis domain.

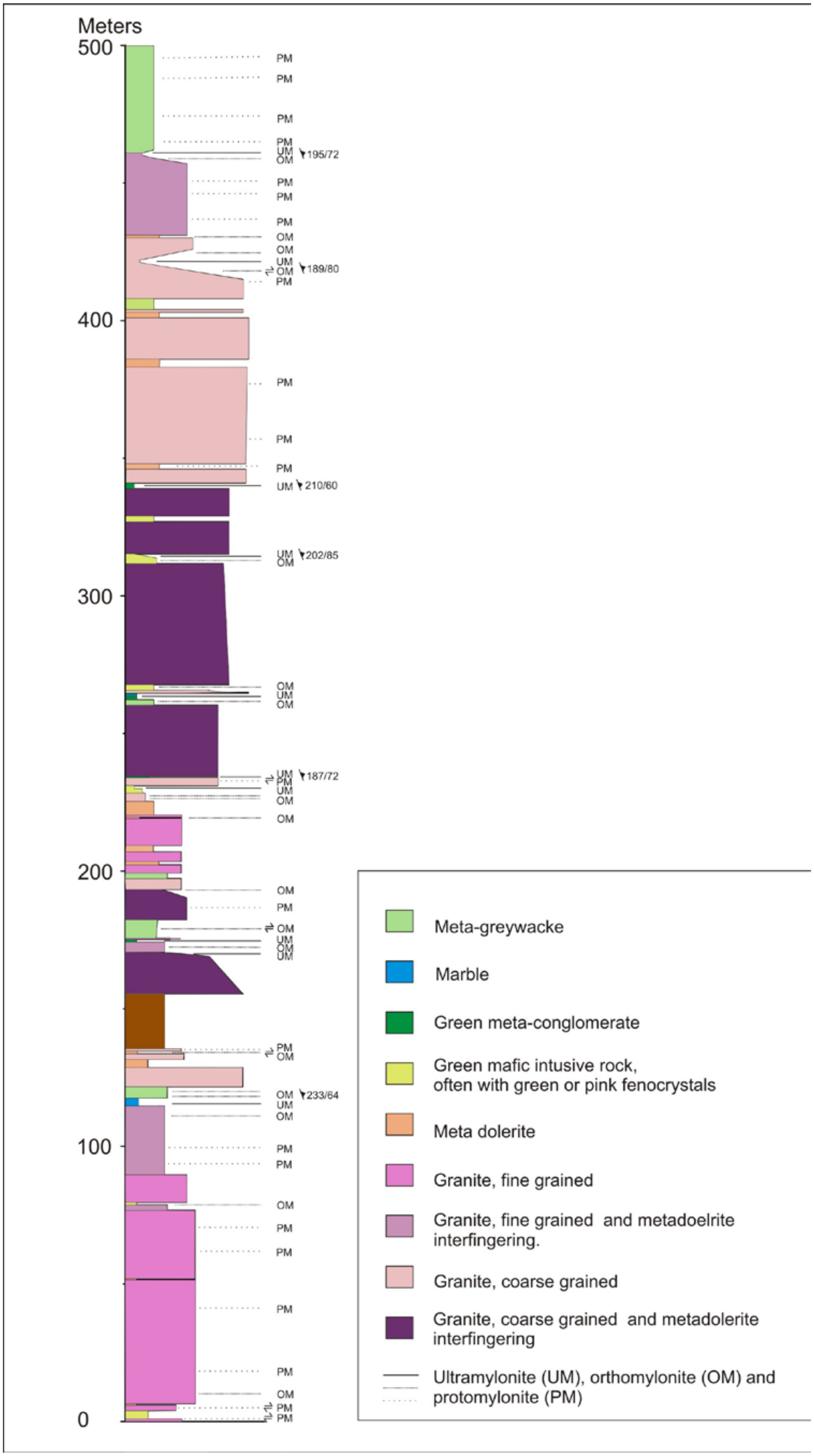

Meters
500
PM
PM
PM
PM
UM
OM
195/72
PM
PM
PM
OM
OM
UM
OM
189/80
PM
400
PM
PM
PM
UM
210/60
UM
OM
202/85
300
OM
UM
OM
UM
PM
187/72
UM
OM
OM
200
OM
PM
OM
UM
OM
UM
PM
OM
OM
233/64
UM
OM
100
PM
PM
OM
PM
PM
PM
PM
OM
PM
0
PM
Meta-greywacke
Marble
Green meta-conglomerate
Green mafic intusive rock, often with green or pink fenocrystals
Meta dolerite
Granite, fine grained
Granite, fine grained and metadoelrite interfingering.
Granite, coarse grained
Granite, coarse grained and metadolerite interfingering
Ultramylonite (UM), orthomylonite (OM) and protomylonite (PM)

Fig. 10. Detailed structural log across the ca. 600 m thick D_4 mylonite shear zone in Gautelis (location line is shown in fig. 9A). Note the rapid variation in rock types across this anastomosing shear zone pattern suggesting high strain segmentation and formation of lens shaped units of the host rocks (modified from Larsen et al., structural manuscript).

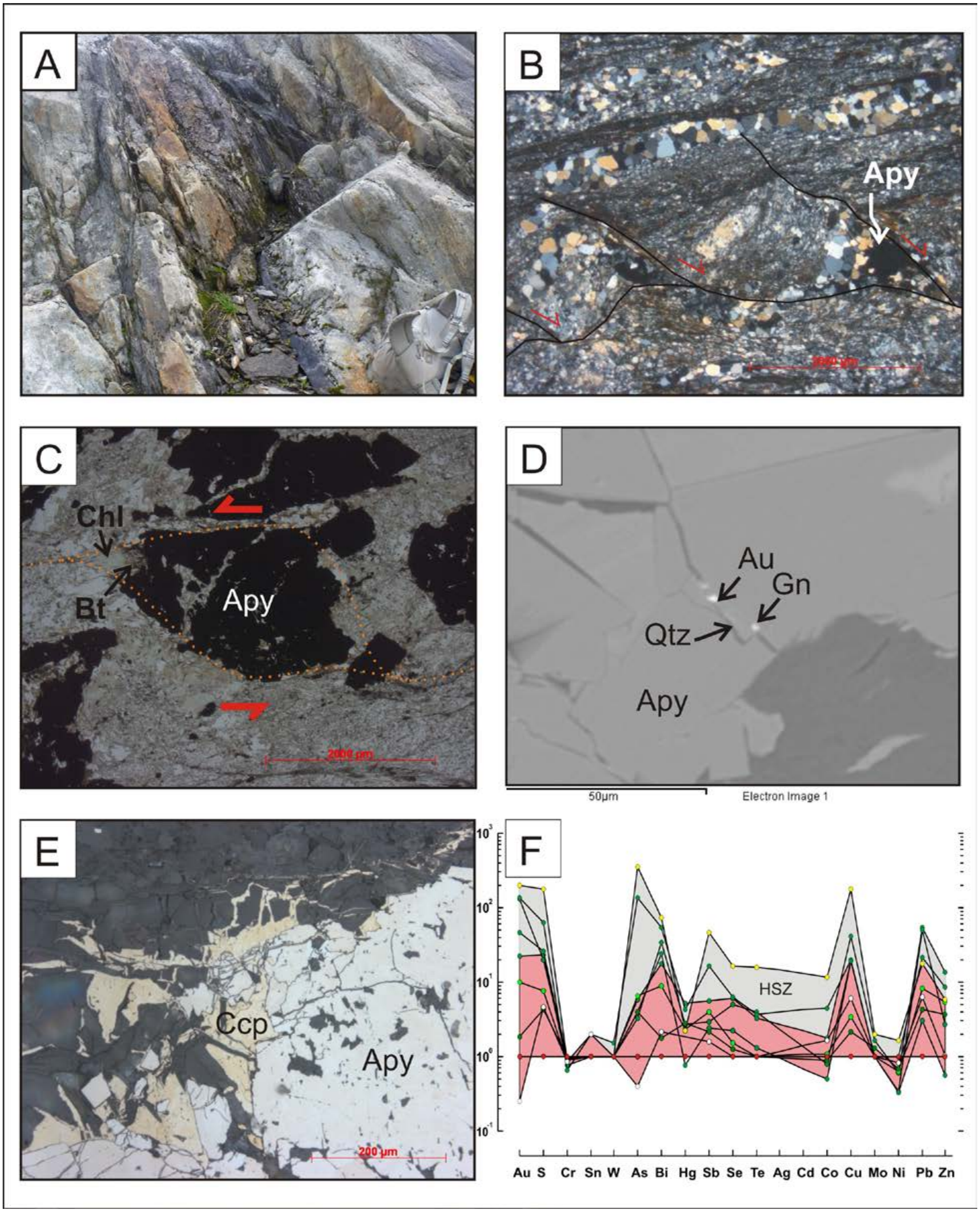


Fig. 11. Photos and diagram illustrating shear zone hosted sulfide and gold occurrences in the Gautelis area. A) Typical sulphides parallel to the mylonite in the Gautelis shear zone. Photo is taken on the eastern side of Gautelisfjell towards the south. B) Photomicrograph of a thin section from the shear zone hosted As-Au

mineralisation near the Gautelisvann showing the clear relationship between the mineralisation and deformation zones on micro scale. The sulphides have deposited in areas of dilation. C) Photomicrograph of a thin section from a ductile shear zone close to the Gautelis mine area that demonstrate that the arsenopyrite act cataclastic as a sigmaclast rotating creating pressure shadows filled with chlorite and biotite. D) Free gold found in fractures of the arsenopyrite together with quartz and galena. The section is from same area is in B. E) Photomicrograph of chalcopyrite are commonly found as fracture fill in the cataclastic deformed arsenopyrite. The sample is from same area as B. F), same location as B. Geochemical data of eight samples collected are across a shear zone hosted As-Au mineralisation plotted in a spider diagram normalised to the host rock samples which has no deformation and visible bedding. The LSZ (Low strain zone) and HSZ (High strain zone) fields have been subdivided based on their deformation observed in field.

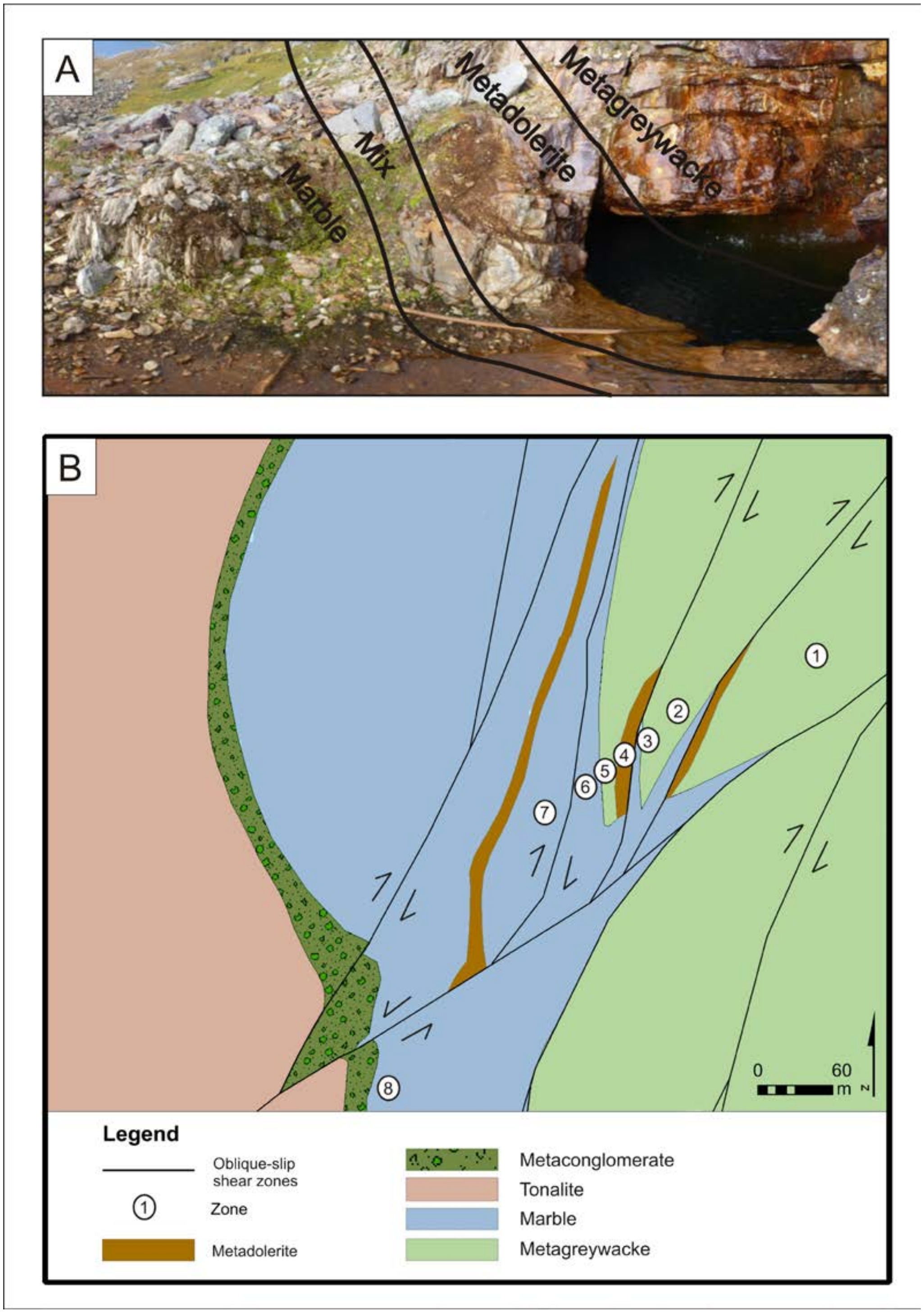
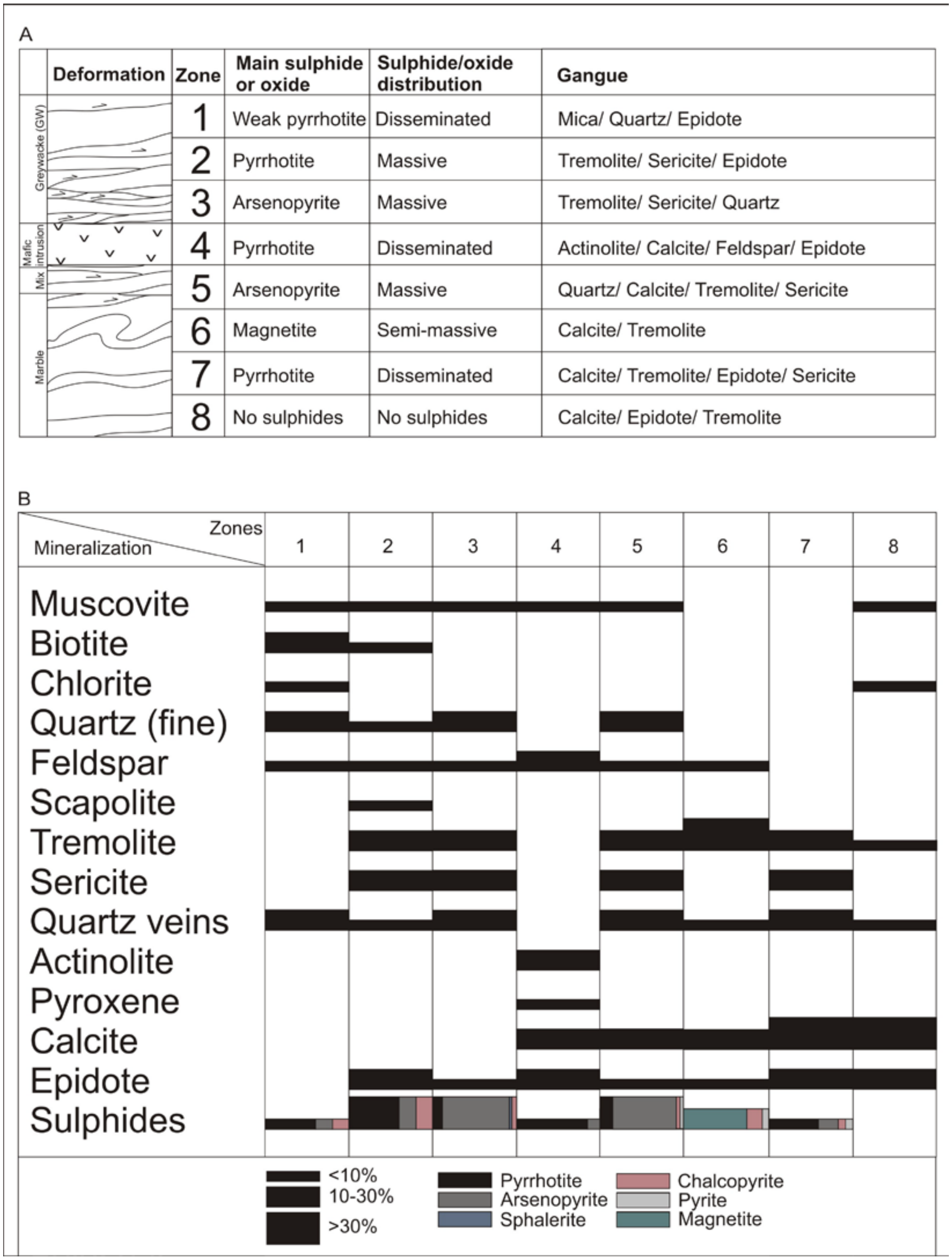


Fig. 12. The Gautelis metasomatic As-Au deposit. A) A photo of the mine area with the contacts between the different units/zones marked. B) A geological map of the mine area showing where the samples and the different zones are located. The scale of the metadolerite is exaggerated to make the dykes more visible in the figure. The real thickness of the dykes is approximately one meter.


A

	Deformation	Zone	Main sulphide or oxide	Sulphide/oxide distribution	Gangue
Greywacke (GW)		1	Weak pyrrhotite	Disseminated	Mica/ Quartz/ Epidote
		2	Pyrrhotite	Massive	Tremolite/ Sericite/ Epidote
		3	Arsenopyrite	Massive	Tremolite/ Sericite/ Quartz
Mafic intrusion		4	Pyrrhotite	Disseminated	Actinolite/ Calcite/ Feldspar/ Epidote
Mix		5	Arsenopyrite	Massive	Quartz/ Calcite/ Tremolite/ Sericite
Marble		6	Magnetite	Semi-massive	Calcite/ Tremolite
		7	Pyrrhotite	Disseminated	Calcite/ Tremolite/ Epidote/ Sericite
		8	No sulphides	No sulphides	Calcite/ Epidote/ Tremolite

Fig. 13 Sulphide mineralisation zones at the Gautelis metasomatic deposit and their relation to deformation and their mineral assemblages. A) Shows the eight differentiated zones of mineralisation with the rock types, deformation style and intensity, sulphides and their gangue minerals. B) A diagram that shows the mineralisation of each zones. The thickness indicate the amount (three levels) and the colour indicates the type of sulphide or oxide minerals and the approximately percentage amount of the total sulphide bar.

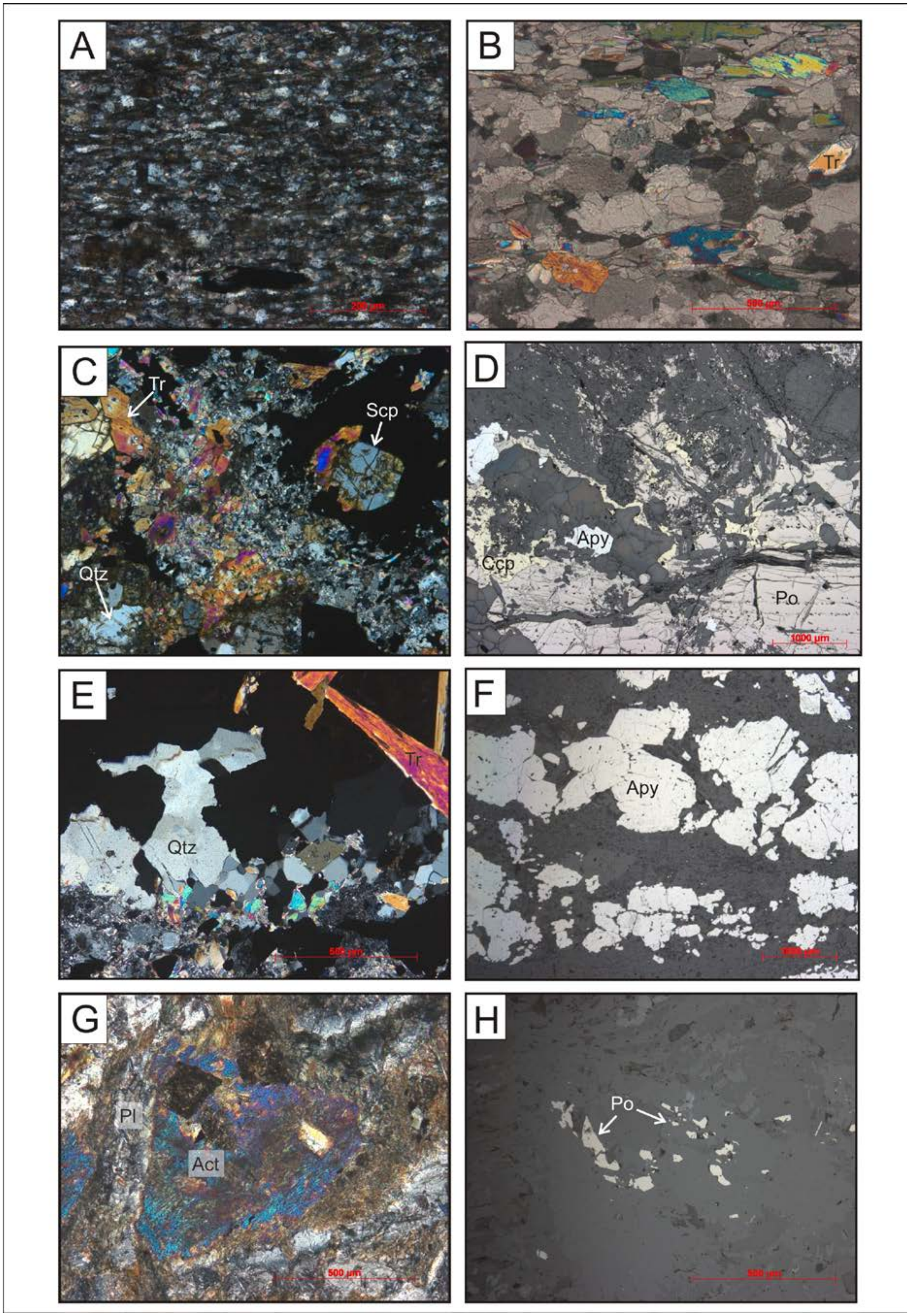

A
200 µm
B
Tr
500 µm
C
Tr
Scp
Qtz
D
Apy
Ccp
Po
1000 µm
E
Tr
Qtz
500 µm
F
Apy
G
Pl
Act
500 µm
H
Po
500 µm

Fig. 14 Photomicrographs of zone 1-4 and 8 from the metasomatic sulphide deposit at Gautelis. A) Zone 1, weakly deformed metagreywacke with mica defining the foliation together with quartz, plagioclase and with scattered grains of pyrrhotite (cross-polarised, transmitted light). B) Zone 8, Weakly deformed and non-mineralised marble consist mainly of dolomite/calcite with some quartz veins and aggregates of tremolite, chlorite, muscovite and epidote along the foliation. (cross-polarised, transmitted light). C) Zone 2: Metagreywacke with semi-massive to massive pyrrhotite, intergrown with non-directional tremolite, quartz, scapolite, epidote and sericite. (cross-polarised, transmitted light). D) Zone 2: Strongly deformed, irregular segregations of pyrrhotite which occurs intergrown with some irregular grains and segregations of chalcopyrite and disseminated euhedral arsenopyrite. (reflected light) E) Zone 3: Metagreywacke found next to the eastern contact of the meta-dolerite dyke. The sulphides are intersected by recrystallised quartz veins and tremolite veinlets. (cross-polarised, transmitted light). F) Zone 3, disseminated to semi-massive arsenopyrite. (reflected light) G) Zone 4: the meta-dolerite dyke have a magmatic texture and weak deformation. The photomicrograph show plagioclase, actinolite and epidote minerals. (cross-polarised, transmitted light) H) Zone 4: The sulphide mineralisation comprises fine-grained dissemination of irregular minor pyrrhotite and accessory grains of arsenopyrite. (reflected light). Abbreviations: Scp - scapolite, Tr - Tremolite, Pl - plagioclase, Act - actinolite, Apy - arsenopyrite, Ccp - chalcopyrite, Po - pyrrhotite.

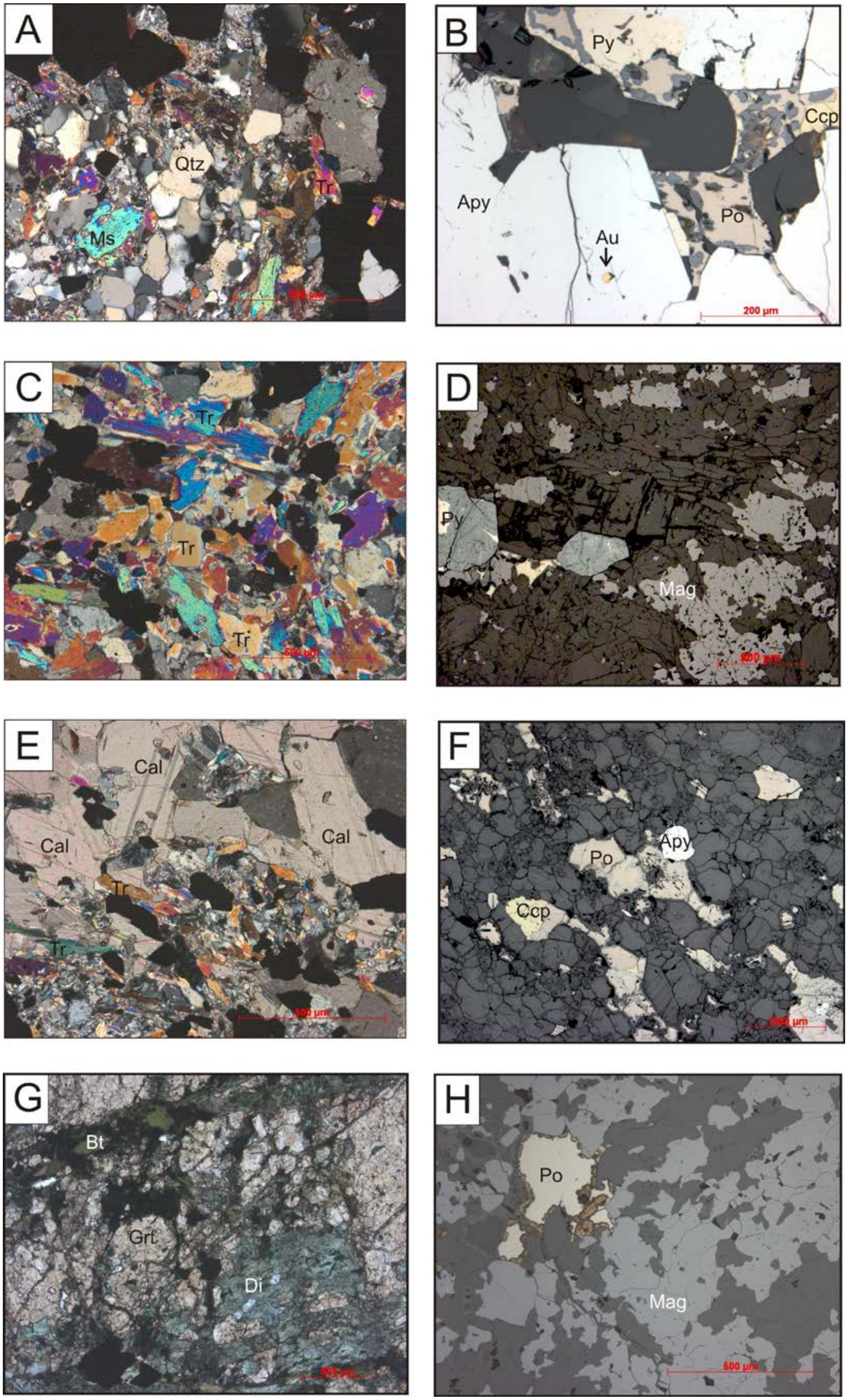

A
Qtz
Tr
Ms
500 µm
B
Py
Ccp
Apy
Po
Au
200 µm
C
Tr
Tr
Tr
500 µm
D
Py
Mag
500 µm
E
Cal
Cal
Cal
Tr
Tr
500 µm
F
Apy
Po
Ccp
1000 µm
G
Bt
Grt
Di
500 µm
H
Po
Mag
500 µm

Fig. 15. Photomicrographs of zone 5-7from the metasomatic sulphide deposit at Gautelis and from a similar metasomatic occurrence nearby A) Zone 5, Sulphide minerals are intergrown with tremolite, quartz, calcite, muscovite and feldspar (cross-polarised, transmitted light). B) Zone 5, The sulphides occur as semi-massive to massive irregular aggregates and bands. They consist mainly of cataclastic arsenopyrite with strongly deformed pyrrhotite and chalcopyrite intergrown. Chalcopyrite and gold can be found along micro-fractures in cataclastic grains of arsenopyrite. (reflected light) C) Zone 6, calcitic marble with high content of tremolite and minor epidote intergrown with magnetite and pyrite. (cross-polarised, transmitted light). D) Zone 6, disseminated to semi massive magnetite and pyrite found in the strong deformed marble. E) Zone 7, calcite marble carrying stringers of sericite-epidote, tremolite, quartz and weak pyrrhotite dissemination. (cross-polarised, transmitted light). F) Zone 7, disseminated pyrrhotite with minor chalcopyrite and arsenopyrite. (reflected light). G) Diopside and garnet from a metasomatic deposit to the north in Gautelis. (cross-polarised, transmitted light). H) Magnetite and pyrrhotite from same location as G. (reflected light). Abbreviations: Tr - Tremolite, Qtz - Quartz, Ms - muscovite, Apy - arsenopyrite, Ccp - chalcopyrite, Bi - biotite, Di - diopside, Grt - garnet, Po - pyrrhotite, Au - Gold, Mag - magnetite.

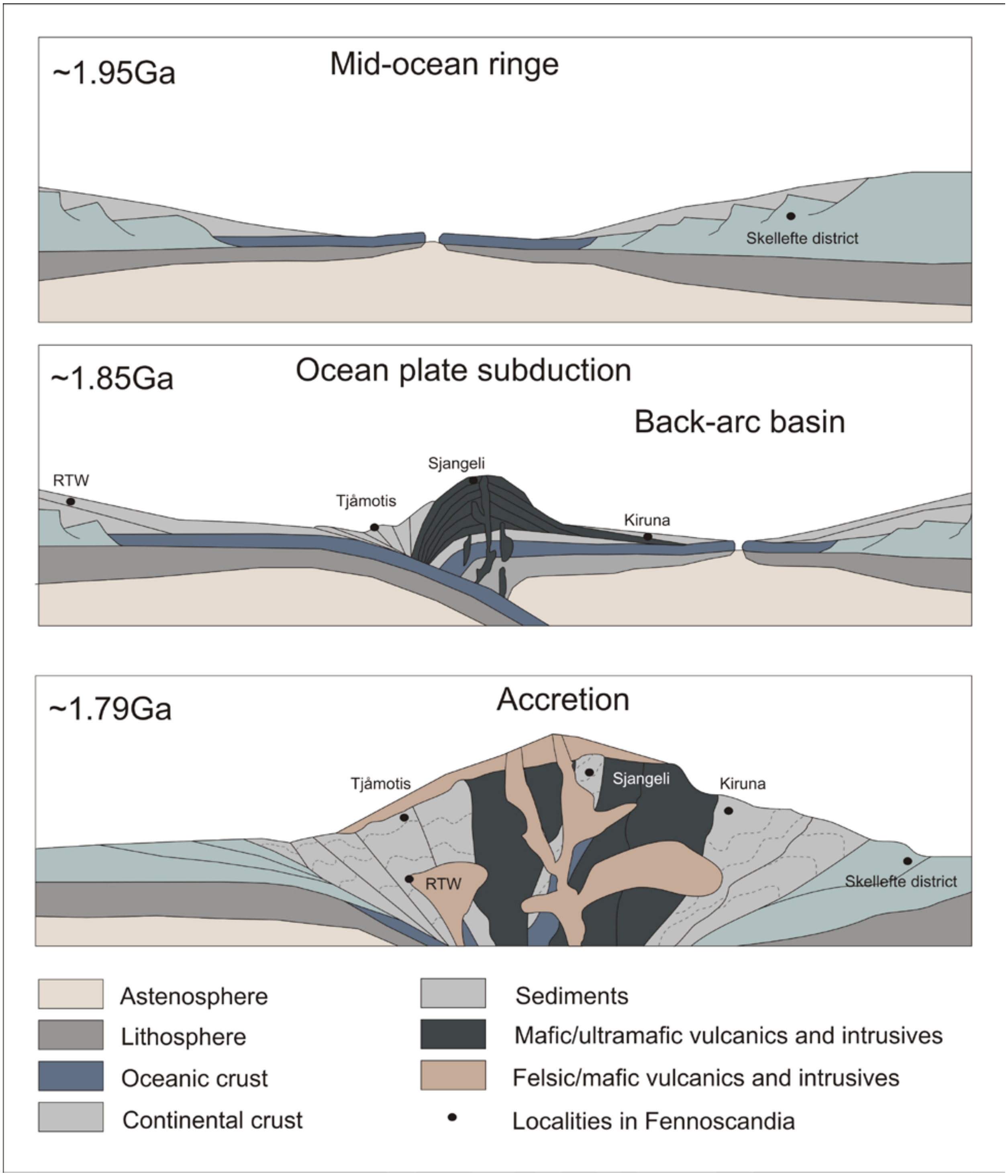


Fig. 16. Tectonic model of the Svecofennian orogeny with timing and spatial relationship to the sulphide and gold deposits in RTW and nearby in Sweden. The model demonstrates the different stages of a progressive development from basin on an active margin to the accretion and orogeny.