The Silidor Deposit, Rouyn-Noranda District, Abitibi Belt: Geology, Structural Evolution, and Paleostress Modeling of an Au Quartz Vein-Type Deposit in an Archean Trondhjemite

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Abstract

Late orogenic gold-bearing quartz vein deposits within the Rouyn-Noranda mining district occur mainly within Archean tonalitic plutons of the Blake River Group (southern Abitibi belt). The Silidor deposit is a representative example of a pluton-hosted lode gold deposit. The Silidor mine contained 2.95 million tons (Mt; mined and estimated reserves), grading 5.1 g/t Au (~15 t Au). The mineralized zone is 900 m in length and has a vertical extent of 900 m, an average thickness of 3.5 m, and trends northwest-southeast with a dip of 50° to 70° NE. Its alteration envelope consists of a red hematite-altered trondhjemite. Measured δ18O values for quartz veins (7.7–10.9‰) and δ34S values for pyrite (–6.1 to –9.4‰) imply oxidizing conditions during gold deposition. The mineralized zone comprises: vein quartz (white, gray, and smoky varieties), beige mineralized trondhjemite, and green carbonate-sericite-fuchsite breccia, which resulted from shearing and metasomatism of an early northwest-southeast dioritic dike.

A quantitative microtectonic study (>400 measurements) was carried out on the Powell tonalitic sill in the Silidor mine area to reconstruct the deformation before, during, and after the mineralizing events. The reduced stress tensors display large variations in σ1 orientation, trending successively northwest-southwest, northeast-southwest, and finally north-south. The Silidor deposit is the result of several vein-filling events, which occurred during evolution from strike-slip faulting to reverse faulting regimes, with σ1 remaining northeast-southwest but with change of orientation of σ2 and σ3. Such variations may reflect an oblique collision and processes of stress permutation.

Paleostress mapping of Archean terranes can be used as a targeting tool for mesothermal lode gold deposits. Reduced stress tensors were used for the computation of paleostress maps, using a distinct element model. The Silidor Au quartz mineralization appears on these paleostress maps in an area characterized by low mean stress throughout the deformation history of the area near the Horne Creek fault. This study emphasizes the role of second-order faulting in the location of low- and high-pressure zones in the Archean crust and the possible role of a tectonic indentor in the location of Au mineralization.

Introduction

The Rouyn-Noranda area is well known for its Cu-Zn massive sulfide deposits, in spite of the fact that the first prospector went into the area in 1922 for gold, one year before the discovery of the Horne deposit. Since then, most of the gold production has come from the Horne massive sulfide deposit (350 t) and from mesothermal vein-type deposits mainly associated with Archean tonalitic plutons (77 t; Carrier, 1994). The Silidor mine was discovered in 1985 by Noranda Exploration, as a result of statistical studies on quartz vein orientations and interpretation of aerial photographs (Fig. 1). The initial diamond drill hole at Silidor hit 6.4 m at 12.7 g/t Au (Picard, 1990). Production began in 1990 and ended in 1997 for a total production of 15 t Au at an average grade of 5.1 g/t Au.

Mesothermal vein-type deposits in the Abitibi greenstone belt have been thoroughly studied over the last two decades. Some of the deposits, such as the Sigma deposit near Val d’Or (Robert and Brown, 1986 a, b), are considered as classic models for this style of mineralization. There are, however, some differences between deposits of this class (e.g., Hodgson, 1990; Groves et al., 1992). Such variations could be related to numerous factors: nature of host rock, conditions of deposition related to different timing (Couture et al., 1994; Robert, 1994), or variations in pressure-temperature conditions (continuum model, Groves et al., 1992). Within plutonic rocks, several mineralization models have been proposed, resulting in differences in mineral assemblage, alteration, and tectonic regime (Jébrak, 1991).

Accurate age dates for these deposits have been provided by Wong et al. (1991), Carignan and Gariépy (1993), Corfu (1993), and Kerrich and Cassidy (1994); however, recent discussions have shown that even detailed and high-quality measurements can be difficult to interpret, because of mineral...
inheritance and thermal resetting (Kerrich and Cassidy, 1994). Structural reconstruction allows us to correlate the emplacement of an ore deposit with a regional deformation event and, therefore, has the potential to tightly constrain the relative age of mineral deposition (Paradis and Faure, 1994; Jébrak and Hernandez, 1995; Faure et al., 1996).

In the Abitibi greenstone belt, the end of the Archean is marked by the Kenoran orogeny, for which previous studies have distinguished two main phases of deformation (Hubert et al., 1984; Robert, 1990; Corfu, 1993). The first phase occurred after deposition of the volcanic pile and before the deposition of Timiskaming-type sediments (ca. 2686 Ma). The absence of associated metamorphism suggests that this phase may be related to thin-skinned tectonic processes. The second phase occurred after the deposition of Timiskaming-type sediments and was marked by intense folding and faulting, especially along regional corridors of deformation. Good examples of such large deformation zones are the Cadillac-Larder Lake and the Destor-Porcupine breaks. Deformation during this phase probably evolved rapidly from ductile to brittle, with rotation of the paleostress field (Robert, 1990; Jébrak and Faure, 1992). There is evidence of thermal resetting after this tectonic event (Kerrich and Cassidy, 1994), but few data are yet available on the structural context of this resetting.

The objectives of this study are twofold: (1) to use detailed structural analysis to correlate the evolution of a mesothermal gold deposit with the regional structural evolution, and (2) to show how structural analysis may help in modeling of the location of such deposits. Ductile deformation leads to very complex patterns in a polyphase environment; however, brittle deformation can be deciphered with less ambiguity, using mineralogical and structural markers. Detailed tectonic analysis of brittle deformation allows precise determination of both the chronology of events and the paleostress regimes (Angelier, 1994). It is, therefore, possible to distinguish the different episodes of deformation during gold mineralization and to reconstruct the stress field during mineral deposition. Furthermore, using the determined different stress tensors, it is also possible to apply a numerical modeling technique for the prediction of fluid movement and the possible location of the zones of enhanced fluid flow. Paleostress studies thus have the potential to provide information on the possible location of a mineral deposit at the property scale.

This paper is organized as follows: after a description of the regional geology and main ore deposits of the Powell pluton, a comprehensive description of the Silidor deposit is given. Structural measurements are used to reconstruct the evolution of the paleostress and hence to explain the geometry of the deposit. Paleostress mapping allows us to reconstruct the possible paleohydrology of Au-mineralized fluids at the end of the Archean, following the approach of Holyland (1990), Oliver et al. (1990), Ridley (1993), Vearncombe and Holyland (1995), and Holyland and Ojala (1997). We emphasize the role of the regional stress pattern in controlling the movement of hydrothermal fluids from high- to low-lithostatic pressure zones. The location of the mesothermal gold mineralization appears to be related to indentations along major faults.

Regional Geology

The Silidor deposit lies within the Powell pluton of the Blake River Group. The Powell intrusion forms a subhorizontal, 1-km-thick sill, shallowly dipping to the east (Keating, 1992). It is considered to have originally been part of the Flavrian pluton, dated at 2700 ± 2 Ma, from which it was subsequently separated by faulting (Mortensen, 1993). A chronological succession of intrusive phases of the Powell pluton has been proposed by Goldie (1976): (1) the Héré unit granodiorite, (2) tonalitic hybrid rocks, (3) trondhjemite, (4) tonalitic
breccia, and (5) diorite dikes (northwest-southeast and east-northeast–west-southwest) and rhyolitic quartz-feldspar porphyry dikes (east-northeast–west-southwest). During mining at Silidor, host rocks were named tonalite, but Goldie (1976) and Gaulin (1992) considered these rocks as true igneous trondhjemites based on geochemical features and feldspar composition. In this paper, the term “trondhjemite” will be used to described the Silidor host rocks even if this rock may also be an albitized granodiorite. The intrusion phases of the Powell pluton are believed to be related to the upper Blake River Group metavolcanic rocks (Paradis et al., 1988), which have been interpreted as a volcanic cauldron (Kerr and Gibson, 1993).

The Powell pluton is bounded by east-northeast–west-southwest faults: the Beauchastel fault to the north and the Horne Creek fault to the south. There are three sets of major faults in the Silidor area, oriented east-northeast–west-southwest, northwest-southeast, and northeast-southwest (Fig. 2). The major east-northeast–west-southwest-trending faults are subvertical or north dipping and are second-order faults subparallel to the Cadillac break (Robert, 1989). They probably branch from the break at depth (Jackson et al., 1995; Verpaelst et al., 1995). These fault zones were active during the entire structural evolution and display evidence of both ductile and brittle behavior.

The structural history of the area includes: an early synvolcanic extensional event (around 2700 Ma) and two main periods of deformation, D1 and D2 (Dimroth et al., 1983; Hubert et al., 1984). Synvolcanic extension is deduced from the paleogeography of the volcanic series, which displays normal movement and facies changes along east-northeast–west-southwest faults (de Rosen-Spence, 1976; Kerr and Gibson, 1993). The northwest-southeast faults also show evidence of a protracted tectonic evolution; they control the intrusion of feeder dikes and synvolcanic hydrothermal fluid flow (Settlerfield et al., 1995).

The early D1 episode of tectonism produced numerous major northwest-southeast-trending folds. The Silidor area is located on the gently dipping upright limb of one of these folds. Associated D1 shear zones typically consist of bedding-parallel zones of schistosity. Powell et al. (1995a, b) suggested that the development of D1 regional folds predated regional metamorphism.

The main cleavage-forming event was D2, which resulted in the formation of east-west-trending folds and an associated cleavage ($S_2$). This deformation has been recorded in the Rouyn-Noranda and Val d’Or areas (Hubert et al., 1984; Daigneault and Archambault, 1990; Robert, 1990), where it is associated with the emplacement of syntectonic granitic plutons (Feng et al., 1993). The Powell pluton was weakly affected by the $S_2$ subvertical foliation along a large east-west anticline (Goldie, 1976). Early movement on the Héré Creek fault, ductile fabric, and hematitic alteration could be associated with the end of the D2 event (Pelletier, 1992). Locally in the Silidor area, the $S_2$ foliation is folded as a result of dextral strike-slip movement, compatible with a northeast-southwest-trending schistosity. It is still unclear however whether the two schistosities represent a single event (D2) or two

![Regional geologic context, showing the different lithologies and the major ore deposits (volcanogenic massive sulfide deposits, lode gold deposits, east-northeast, northwest, and northeast faults, and occurrences of porphyry-type Mo-Cu-Au mineralization).](image-url)
distinct events (D2 and a possible D3). The S2 foliation is associated with regional metamorphism and occurred after the deposition of Timiskaming-type sediments (Powell et al., 1995b) and, therefore, after 2673 ± 3 Ma (Davis, 1991).

Late events (post-D2) also affected the area; the Silidor vein and shear cut the S2 foliation. The Héré Creek fault is marked by late brittle movement (gouge) which cuts and displaces the Silidor mineralized structure. Late intrusions within faults are also known, an example of this would be the strong positive magnetic anomaly caused by a Proterozoic dolerite dike in the Smokey Creek fault (Figs. 1 and 3). Late movements on some of these faults is also demonstrated by offsets of the Donalda gold-bearing quartz veins and Proterozoic dolerite dikes. Both the Beauchastel and the Horne Creek faults show a late sinistral movement, which is considered Proterozoic in age (Kerr and Mason, 1990; Riverin et al., 1990).

Mineralization

The Powell pluton contains two types of deposits (Fig. 3): a gold-copper-molybdenum porphyry deposit in the Don Rouyn area (Kotila, 1975; Goldie et al., 1979; Jébrak et al., 1995; Carrier and Jébrak, 1996) and shear zone-related mesothermal gold-bearing quartz vein deposits such as Silidor (McMurchy, 1948; Wilson, 1962; Carrier, 1994). The gold-bearing quartz vein deposits are related to brittle-ductile faults and shear zones which are spatially associated with northwest-southeast dioritic dikes in the Powell pluton. These mesothermal gold deposits follow structures with a northwest-southeast to approximately north-south orientation, dipping to the northeast and east (Table 1; Fig. 3). Mineral phases identified in these mesothermal deposits include quartz, fuchsite-sericite, and carbonate (dolomite, calcite), with pyrite, hematite, gold with some silver, tellurobismuthinite, galena, chalcocpyrite, and AuTe.

At Silidor, the auriferous ore zone included (Fig. 4): (1) a continuous brittle-ductile quartz lode, which is a shear vein with multiple infilling events (e.g., Silidor vein); (2) less continuous pyritized and albited wall rocks (e.g., mineralized trondhjemite); and 3) a discontinuous sheared and metasomatized dioritic dike (e.g., carbonate-sericite-fuchsite breccia).

Geometry and deformation

The extent of the Silidor gold-bearing ore zone (e.g., Silidor vein + mineralized trondhjemite + carbonate-sericite-fuchsite breccia) is similar to the extent of the Silidor brittle-ductile vein. The Silidor vein extends along a strike length of 900 m and over a depth of 900 m and has an average thickness of 3.5 m. The Silidor vein is oriented N 340° with an average dip of 60° toward the northeast. It has numerous variations in strike, dip, and thickness. At the northern end of the deposit, the vein splits into a horsetail-like structure, with a shallow dip. The dip of the Silidor auriferous ore zone changes gradually from 54° in the northern part of the deposit to 65° in the south. The Silidor vein itself shows larger variations in dip, in the range of 45° E to 70° E. Pinch and swell structures occur both on vertical and horizontal axes, but the general elongation of the lenses defines a pitch of 60° toward the northeast. The vein shows a sharp change in strike, with usually barren east-west-oriented segments. A less extensive vein, call the Bonus vein, is parallel in strike and has a shallower dip; it joins the main vein at the 220-m level. In the southern part of the deposit, the Silidor vein is sinistrally offset along the Héré Creek fault by 50 m. This zone is marked by increased thicknesses of ore and alteration zones.
The Silidor mineralized zone has a complex structural history. Although most of the deformation is brittle in style, an early ductile deformation event is recorded in the northwest-southeast dioritic dike. This northwest-southeast dioritic dike is the locus of the Silidor structure. The dike is locally altered to a carbonate-sericite-fuchsite ore assemblage (described below with the alteration). The dioritic dike is commonly transformed to a zone of mylonite, with S-C structures marked by sericite, which indicates a reverse-dextral movement. This deformation clearly crosscuts the S2 regional east-west schistosity and is crosscut by quartz and carbonate veinlets. These veinlets are themselves folded and boudinaged.

Infilling

The Silidor vein is composed of three different facies: highly mineralized smoky quartz, gray quartz, and poorly mineralized white quartz (Figs. 4 and 5). In all facies, gold occurs principally in association with pyrite both coating grains or as inclusions. The gold grade shows a correlation with pyrite concentration and this relationship was used during mining as an estimate of gold grade, with 1 percent pyrite representing about 1 g/t Au (G. Laperle, oral commun.). The average silver content of the gold is between 7 and 8 percent Ag and locally up to 16 percent Ag (Carson, 1986). Pyrite, chalcopyrite, rutile, and specular hematite are associated with gold.
The gray quartz and the smoky quartz form thin veins (≤40 cm), with high gold grade (20 g/t Au). They are usually located along the footwall of the vein. Strike and dip of these veins varies from east-west to northwest-southeast and from 30° to 40° to the northeast. The smoky quartz (Fig. 5a) has been intensely recrystallized, with large crystals and bands of polygonal quartz neograins containing disseminated sulfides (chalcopyrite, pyrite with octahedral faces). Gold and chalcopyrite fill fractures in pyrite. The pyrite in the smoky quartz vein has commonly been broken, with the crystals showing a large number of mainly octahedral faces. This smoky quartz locally crosscuts a minor phase of dark quartz which is rich in disseminated tabular hematite.

The white quartz forms thick zones, up to 5 m in thickness. It occurs as lenses along the fault with a horizontal elongation and a high aspect ratio. The strike and dip of the white quartz veins are more consistent than for the smoky quartz veins, varying from north-northwest–south-southeast to west-northwest–east-southeast. They have a brecciated texture, locally with fragments of deformed host rock, fresh or altered, and fragments of smoky quartz (Fig. 5c and d). The angular nature of the fragments and the structure of the breccia indicate mainly hydraulic brecciation, with a jigsaw pattern, evolving toward collapse brecciation, with shingle-shaped fragments located at the bottom of rhombic cavities (Jébrak, 1997). This quartz is low grade (0.3 g/t Au) but may reach 4 g/t Au because of the abundance of mineralized fragments. The quartz consists of large recrystallized grains, with both undulatory extinction and small sericite crystals being located on the borders of neograins. Sulfides consist mainly of chalcopyrite, cubes of pyrite, and minor molybdenite. The white quartz is locally cut by late transverse veinlets, composed of quartz, carbonates, pyrite, chalcopyrite, gold, electrum, hessite, freibergite, and petzite. Gold, electrum, and hessite are enclosed in pyrite. The similar sulfide association of these veinlets and the smoky quartz veins suggests a protracted mineralizing event rather than a late remobilization in different pressure-temperature conditions. The presence of such late veinlets reflects the continuity and the dynamics of the mineralized tectonic system.

The Silidor vein is associated with rare centimeter-scale horizontal tension cracks which have been filled with quartz-hematite, quartz-calcite-chalcopyrite, quartz-chlorite, and late pink calcite. Although these structures are poorly developed, they indicate that σ3 was at one stage subvertical.

Postore mineral infilling includes: thin barite veinlets (Gaulin, 1992), small gypsum steep north-south veinlets, and clay-filled fault. Gypsum veinlets have been associated either with recent circulation of brines in the Superior province or with the last stage of hydrothermal activity in gold deposits (Frape and Fritz, 1987; Couture and Pilote, 1993).

A clay-filled fault which follows the whole Silidor structure was used as a key marker during mining. The same type of filling is known to follow the Héré Creek fault. The mineralogical
assemblage is quartz, calcite, chloride, smectite, kaolinite, and low-crystallinity illite, indicating a relatively low temperature of the fluid, probably below 200°C (Velde and Vasseur, 1992).

**Alteration**

Four mappable alteration facies were distinguished systematically during mining. From the distal to the proximal zone (Fig. 4) they consist of: chloritized trondhjemite, hematized trondhjemite, mineralized trondhjemite, and carbonate-sericite-fuchsite breccia (Carson, 1986; Picard, 1990; Gaulin, 1992; Carrier, 1994).

The chloritized trondhjemite is the least altered unit. It has, however, been affected by regional chloritization. It consists of quartz (35%), oligoclase (36%), muscovite-sericite (10%), chlorite (9%), carbonates (7%), hematite (<2%), rutile, and leucoxene (1%), and sulfide (<1%). This unit is locally crosscut by quartz-sericite-chlorite veinlets.

The hematized trondhjemite forms a unit with an average thickness of 30 m. This thickness increases to 50 m in the area where the Héré fault crosscuts the Silidor vein and attains 140 m in the northern horsetail structure. The thickness of hematization increases at depth and can be followed down to 600 m below the surface. This alteration affected not only the trondhjemite but also quartz porphyry and diorite. Rocks become red in color due to the presence of finely dispersed hematite. Albite forms up to 75 percent of the rock. Remnants of green chlorite are abundant and small crystals of apatite, carbonates, and rutile bordered by ilmenite are also present. They are relatively rich in gold (400–575 ppb), locally with some nickel (53 ppm) and molybdenum. This hematization could be the product of oxidation accompanied by substantial alkali metasomatism.

The mineralized trondhjemite is beige in color. It forms units of limited extent, 10 m long and up to 2 to 3 m thick on each side of the quartz vein. There is a weak correlation between the thickness of the quartz vein and the thickness of the mineralized trondhjemite, caused by the polyphase nature of the quartz infilling (Fig. 4). Hematite is not present in this zone. Albite and Mg carbonate are abundant, with acicular crystals of magnetite. Pyrite is locally abundant and contains ovoid inclusions of chalcopyrite and sphalerite. Gold values are usually economic, with an average grade of 4.2 g/t Au, with some tungsten and copper enrichment. No arsenic or antimony has been encountered. Using the isocon approach of Grant (1986) relative to unaltered rocks, a strong leaching has been inferred for LREE, K2O, Ba, Th, Cr, and U, and slight enrichments in Au, W, CO2-H2O, CaO, and Na2O. Other elements do not vary significantly (Gaulin, 1992; Carrier, 1994).

The carbonate-sericite-fuchsite breccia alteration facies is in the Silidor structure. This alteration facies is the result of the metasomatism of the northwest-southeast dioritic dike. The carbonate-sericite-fuchsite breccia is an auraniferous ore assemblage which has a characteristic apple green color. The original texture of the dioritic dike has been sheared and overprinted. The dike has been transformed into an assemblage of chlorite, Cr2O3-rich sericite, quartz, and fuchsite (Carson, 1986). Sulfides are abundant in this alteration facies and include chalcopyrite, pyrite, proustite-pyrrargirite, gold, electrum, hessite, and freibergite, with disseminated hematite and rutile.

The formation of the Silidor vein: A summary

Reconstruction of the deposition history of the Silidor vein has been accomplished through detailed study of the mineralization. Alteration at Silidor overprints early ductile fabrics such as S2 foliation. Following the metamorphic event and the associated deformation, three main episodes have been distinguished, based exclusively on crosscutting relationships: (1) hematization, (2) mineralization, and (3) white quartz deposition.

Hematization was the first metasomatic phase; it is a distal and pervasive alteration which is known to follow the Silidor and Héré structures. Hematization is also widespread in the Powell pluton and could be related to the emplacement of the Don Rouyn porphyry system. The Silidor vein is located in the outer aureole of the Don Rouyn porphyry system, as identified by Goldie et al. (1979). The abundance of hematite suggests a high oxygen fugacity during this episode of alteration.

The mineralization of the trondhjemite is temporarily associated with smoky quartz deposition. The association of albite-carbonate metasomatic zones with quartz deposition is well known in mesothermal gold deposits, indicating that sodium was the dominant cation in solution (Robert and Brown, 1984; Mikucki and Ridley, 1993). Such associations have been observed frequently in lode gold deposits laid down at low temperature (225°–400°C) and low pressures (<1 kbar; McCuaig and Kerrich, 1994). Although such alteration may occur in porphyry systems (Morasse et al., 1995), in the Silidor vein-type deposit it appears clearly associated with shearing and deformation.

Few data are available on the composition of the fluid responsible for the Silidor mineralization. Six measurements on the Silidor quartz gave a δ18O value of 10.1 ± 1.2 per mil, similar to that measured in adjacent quartz veins at Elder and Pierre-Beauchemin (9.2–10.3‰; Kennedy and Kerrich, 1982). In addition, δ34S has been measured on four pyrites from Silidor with values between –6.1 and –9.4 per mil, similar to that measured in lode gold deposits such as Francoeur (–9.4 to –11.4‰; Couture and Pilote, 1993), Hemlo, Ontario (0 to –17.5‰), Golden Mile, Western Australia (–3.1 to –9.6‰; McCuaig and Kerrich, 1994). Lange et al. (1995) have shown that such negative values could be the result of δ34S values close to the ΣSO4–H2S buffer (Ohmoto and Rye, 1979) and could be related to several processes, including extensive interaction of hydrothermal fluids with Fe3+-bearing silicates in wall rocks or intrinsically oxidizing magmatic fluids (Lambert et al., 1984; Cameron and Hattori, 1987). The nature of the mineralized trondhjemite alteration, preliminary observations on fluid inclusions, and comparisons to similar deposits in the Powell gold district suggest that fluids were of CO2-H2O composition. The association of gold with sulfide suggests that gold was transported as a reduced sulfur complex and that sulfidation of wall rocks could have been a very efficient gold-depositing mechanism.

Late white quartz belongs to the same metallogenic event as smoky quartz; however, observations indicate that modification of the hydrothermal system to a lower sulfur fugacity had occurred, either due to lower capacity of metal transportation of the fluid or to less interaction with wall rocks (= iron), because they were already altered.
Paleostress Evolution

The analysis of brittle faults and tension gashes reveals that the Powell pluton underwent several phases of deformation. Most of the faults are brittle, so it is possible to reconstruct the different paleostress regimes using quantitative methods based on shear-stress relationships.

Methodology

Orientation data were collected for dilatant veins, dikes, and striated faults. The fault slip data were collected from the underground workings at Silidor. They were compared to data independently collected from the Don Rouyn quarry, located 1 km east of Silidor. Data from more than 350 striated fault planes and 50 veins or dikes were used to reconstruct the paleostress history of the Silidor deposit area. Faults and veins were easily identifiable because of the presence of slickenside lineations and mineral infill (especially quartz, chlorite, hematite, and carbonates).

Our analysis is based on the concepts of mechanical relationships between brittle features (especially striated faults) and paleostress first developed by Carey and Brunier (1974), using the stress-shear relationship described by Wallace (1951) and Bott (1959). Over the last few decades, such analyses have proved to be successful for identification and characterization of tectonic events. It is, therefore, extensively used in order to interpret fault slip patterns. In this study, the inverse method is used to determine the local stress tensors from directions and senses of slip on numerous faults of various orientations. This approach is based on the principles and methods described by Angelier (1975, 1984, 1989, and 1991).

In practice, one searches for the best fit between all slip data collected in a rock mass which experienced faulting during a given tectonic event and a common unknown stress tensor. Consideration of tension data, such as for tension gashes, veins or dikes, provides useful additional information. The assumption that all faults which moved during the same tectonic event in a rock mass were moving independently but consistently under a single homogeneous stress regime expressed by a single stress tensor is an obvious approximation, but theoretical and practical evaluations show that results are consistent if fault slip data sets are large and include a variety of orientations (Dupin et al., 1993; Angelier, 1994, and references therein).

A major difficulty, however, arises in the Silidor area because several brittle tectonic events have obviously affected the rock mass. This situation may also occur during a single deformational event, where changes in the stress regime occurred, resulting in rotation or permutation of principal axes during brittle deformation. Block rotations during a tectonic event produce similar effects. In all these cases, brittle tectonic features observed in a single outcrop correspond to a certain number of distinct stress regimes, which themselves correspond to one or more tectonic events. In such situations of apparent or actual polyphase tectonism, reliable determination of paleostress regimes requires separation of fault slip data. From the tectonic point of view, it is important to distinguish brittle structures related to distinct tectonic regimes, and it is still more important to separate structures resulting from different tectonic events. The analysis of syntectonic mineral infilling provides valuable information because mineral development corresponds to pressure-temperature and fluid-chemical conditions which may differ from one event to another. Particular attention was thus paid, in our study, to the relationships between mineral development and shear or tension brittle deformation. The mineralogical nature of vein infill and of mineral steps on striated faults was consequently examined in detail, in close connection with the collection of structural data.

The relative chronology of structures was also considered. In particular, numerous data on crosscutting relationships between different generations of brittle structures (faults, veins, and dikes), as well as superimposed slickenside lineations, were collected. These data allowed distinction of tectonic events based on a matrix method described previously by Angelier (1994), taking into account the mechanical consistency expected for each stress regime. In most cases, a given striated fault surface (or a vein) could be assigned to a specific tectonic regime. Detailed observations and the list of the observed crosscutting relationships are given in Carrier (1994).

An automatic separation of stress tensors and subsets of fault slip data was also performed on the Silidor data, following a procedure proposed by Angelier and Manoussis (1980) and discussed by Angelier (1983). This procedure is based on cluster analysis applied to stress-slip relationships combined with stress tensor determinations. Such an automatic separation does not indicate chronology but allows rigorous separation of mechanically consistent fault slip subsets. Finally, a compilation of these different sources of information (syntectonic mineral development, relative chronology, mechanical consistency, and identification of newly formed fractures patterns) enabled us to establish the general chronology of brittle events at Silidor.

Methodological and technical aspects of stress tensor determination were described and discussed in detail by Angelier (1983, 1991, and 1994). The actual stress tensor has six degrees of freedom, but consideration of shear directions and senses alone allows determination of four of these variables, namely the three principal stress axes σ1, σ2, and σ3 (maximum, intermediate, and minimum principal stresses, respectively, with pressure considered to have a positive sign), and a ratio between principal stress differences, which is conveniently expressed by the φ ratio defined as (Angelier, 1975) φ = (σ2-σ3)/(σ1-σ3).

The two remaining stress tensor variables cannot be determined unless rock mechanic properties (rupture and friction) and/or depth of overburden and fluid pressure condition (at the time of brittle deformation) can be evaluated (see Angelier, 1989, for details). These two variables, which together with the ratio φ control the magnitudes of all principal stresses, could not be determined with the data available in the present case study.

Finally, an attempt was made to determine the geologic significance of the paleostress regimes in terms of both the type (reverse, strike slip, or normal), the trend of extension or compression, and the φ ratio. Note, however, that the values of φ should be considered with care because reliable determination is highly dependent on the presence of oblique-slip faults, and large variations of φ are caused by stress variations in rock masses. The computed orientations of axes (trends and plunges) are much more stable, despite local effects.
Results

Eight brittle tectonic episodes have been reconstructed in the Silidor mine. The numerical results of paleostress determinations are summarized in Table 2 and Figure 6.

The early event A is marked by dextral east-west to east-northeast–west-southwest and sinistral northeast-southwest faults. Faults are filled with chlorite-ankerite. Tension cracks displaying the same association are northeast-southwest oriented and subvertical. All these elements mark northwest-southeast compression, with a pure compressive ellipsoid (Guiraud et al., 1989). Event B is the most important event in terms of measured faults and slickensides. Most of the faults strike north-south to northeast-southwest and dip moderately to the west. Horizontal tension cracks are associated with these faults and mark the first movement on the Silidor structure. They also contain chlorite and carbonates, with locally some hematite. These faults formed as a result of a clear northwest-southwest compression, with similar \( \sigma_1 \) axes to the A episode. Note that A and B episodes simply differ by a permutation of \( \sigma_2 \) and \( \sigma_3 \), which suggests that they belong to the same tectonic event.

Scarc e dextral northeast-southwest-oriented and sinistral east-west structures possibly reveal a third, C episode. Associated tension cracks are subvertical and strike northeast-southwest. Chlorite and ankerite are associated in these faults and veins, notably in the Silidor deposit. These elements indicate a possible east-northeast–west-southwest compression. The reconstruction of this episode, however, requires more documentation.

In contrast, the D episode is very well marked at the Silidor deposit, with numerous northwest-southwest reverse faults dipping to the northeast. It corresponds to the faults occurring in the Silidor vein. Subhorizontal tension cracks are also relatively abundant and are filled with quartz, pyrite, chloropyrite, and carbonates. Scarce faults showing the same style of infilling strike north-south and east-west. Inverse modeling shows that they formed as a result of northeast-southwest compression.

The E event is the first observed extensional event. It is marked by conjugate sets of normal faults characterized by east-northeast–west-southwest and west-northwest–east-southeast directions. The Silidor vein shows evidence of such extensional deformation, with normal offsets of moderate throw. Associated tension cracks are subvertical and contain chlorite, sericite, and some sulfides.

Numerous, well-developed northwest-southeast strike-slip dextral faults and some northeast-southwest sinistral faults characterize event F. A sinistral displacement along the Héré fault, offsetting the Silidor vein, is related to this episode (Fig. 7). Chlorite and ankerite crystallized on the slickensides. A well-defined north-south compression is calculated with horizontal east-west-oriented extension.

The G event is also marked by numerous faults, trending northeast-southwest to east-west, with slickensides indicating reverse movement. It is especially developed on the clay-filled Silidor and Héré faults. A north-south compression is well defined, with \( \sigma_1 \) axes identical to the F event. The F and G events are linked through a transition from strike-slip regime to reverse fault regime (permutation of \( \sigma_2 \) and \( \sigma_3 \)). They may thus correspond to a single major tectonic event.

The latest episode reconstructed in Silidor, event H, is marked by northeast-southwest normal faults (Héré fault). Down-dip slickensides indicate normal movement and overprint slickensides from the A event. This last tectonic regime corresponds to an extension with \( \sigma_1 \) vertical, \( \sigma_2 \) northeast-southwest, and \( \sigma_3 \) (main extension) northwest-southwest.

Summary of the tectonic evolution

The tectonic evolution of the Silidor area, as for the whole Powell pluton, is clearly polyphased. Preore deformational features include the regional \( S_2 \) foliation. Early movements related to \( D_2 \) are ductile and have not been quantitatively analyzed in this study. The presence of the east-west-trending schistosity (\( S_2 \)), however, suggests an approximately north-south-trending compression. The precise age of the \( D_2 \) compression is unknown but it certainly occurred after 2673 Ma (see “Regional Geology”).

At Silidor, the east-west schistosity (\( S_e \)) is locally crosscut by another schistosity (\( S_p \)), showing an oblique northeast-southwest orientation. This \( S_e \) foliation suggests a dextral movement on east-west faults which would be related to a northeast-southwest shortening. Such dextral displacements have been documented along the Cadillac-Larder Lake Fault (Daigneault and Archambault, 1990; Robert, 1990; Bardoux et al., 1993) and are known to affect the Timiskaming sediments. This \( S_3 \) transpressive schistosity presents the same

### Table 2. Paleostress Results Determined at the Silidor Deposit

<table>
<thead>
<tr>
<th>Phase</th>
<th>Number of faults</th>
<th>Mean variation</th>
<th>( \sigma_1 )</th>
<th>( \sigma_2 )</th>
<th>( \sigma_3 )</th>
<th>( \phi )</th>
<th>Chronology</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>28°</td>
<td>290°/19°</td>
<td>124°/71°</td>
<td>030°/01°</td>
<td>0.43</td>
<td>Preore</td>
</tr>
<tr>
<td>B</td>
<td>135</td>
<td>10°</td>
<td>307°/02°</td>
<td>217°/09°</td>
<td>048°/81°</td>
<td>0.56</td>
<td>Preore</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>14°</td>
<td>077°/12°</td>
<td>253°/78°</td>
<td>346°/01°</td>
<td>0.18</td>
<td>Synore</td>
</tr>
<tr>
<td>D</td>
<td>49</td>
<td>11°</td>
<td>229°/06°</td>
<td>139°/02°</td>
<td>033°/84°</td>
<td>0.68</td>
<td>Synore</td>
</tr>
<tr>
<td>E</td>
<td>15</td>
<td>14°</td>
<td>246°/79°</td>
<td>108°/08°</td>
<td>017°/07°</td>
<td>0.26</td>
<td>Postore</td>
</tr>
<tr>
<td>F</td>
<td>38</td>
<td>16°</td>
<td>356°/03°</td>
<td>250°/71°</td>
<td>085°/18°</td>
<td>0.26</td>
<td>Postore</td>
</tr>
<tr>
<td>G</td>
<td>58</td>
<td>9°</td>
<td>349°/06°</td>
<td>259°/01°</td>
<td>153°/84°</td>
<td>0.68</td>
<td>Postore</td>
</tr>
<tr>
<td>H</td>
<td>19</td>
<td>13°</td>
<td>023°/80°</td>
<td>223°/10°</td>
<td>132°/03°</td>
<td>0.34</td>
<td>Postore</td>
</tr>
</tbody>
</table>

For each stress tensor the following parameters are presented: the number of fault slip data used; a quality estimator corresponding to the mean deviation between theoretical and measured striation directions; the orientation of the maximum and minimum stress axes (\( \sigma_1 \) = maximum stress axes, \( \sigma_2 \) = intermediate stress axes, \( \sigma_3 \) = minimum stress axes); the calculated value of the ratio between stress differences, \( \phi = (\sigma_2-\sigma_3)/(\sigma_1-\sigma_3) \); these eight episodes are assigned pre-, syn-, and postore using mineralogical markers.
main compressive axes as the A and B tectonic period. The two early northwest-southeast compressive events (A and B) were clearly developed before the mineralizing event of the Silidor deposit. This deformation may also be synchronous with the deposition of the copper-gold-molybdenum (early) association in the Don Rouyn deposit and with chlorite-sericite alteration (Goldie et al., 1979). Deformation of this age seems to control the development of hematitic alteration, both regionally and along the preore Silidor structure.

The synore tectonic period is marked by a northeast-southwest compression. This period includes the C and D compression episodes, with northeast-oriented $\sigma_1$ axes. During this period, the Silidor structure acted as a reverse fault, in response to a northeast-southwest regional compressive event. Ductile deformation was localized in the northwest-southeast dioritic dike, and large variations in deformation intensity are probably related to strain partitioning. Strain softening led to localization of the slip into and near the core of the fault and was probably assisted by suprahydrostatic pore-fluid pressure (Littie, 1995). Reverse movement continued after the first mineral deposition, as shown by the distribution of white barren breccia along horizontal opening zones. Variations in fluid pressure explain the existence of both tensional and compressive local features. The mineralizing episodes (C and D) have been dated at 2562 ± 12 Ma, using Pb-Pb in pyrite, quartz, and chlorite (Carignan and Gariépy, 1993). Such an age is

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**Fig. 6.** Chronological succession and illustration of the stress tensors obtained by the Angelier method. a. Phase A. b. Phase B. c. Phase C. d. Phase D. e. Phase E. f. Phase F. g. Phase G. h. Phase H. By using mineralogical markers, phases A and B were assigned preore, phases C, D, and E were assigned synore, and phases F, G, and H were assigned postore. The five, four, and three branch stars, respectively, correspond to $\sigma_1$, $\sigma_2$, and $\sigma_3$. Arrows indicate extensional or compressional axes. Lower hemisphere projections.

**Fig. 7.** Plan view of the Héré fault on the 220-m south level of the Silidor mine, showing a late postmineralization strike-slip movement along this fault.
similar to resetting ages of numerous other gold deposits in the southern Abitibi province (Kerrich and Cassidy, 1994). Late barren infilling in the Silidor vein indicates a late brittle north-northeast-oriented extension (episode E).

The postore period was a time of north-south compression (episodes F and G) and of a late northwest-southeast (episode H) extension. Clay lining of faults suggests low temperatures during movement and no obvious connection with the earlier mineralizing fluids. Weak alteration of host rocks suggests that fluid flow was preferentially within the fault. The ages of these postore episodes are unknown but may be correlated regionally through Ontario and Quebec. Cobalt group sediments are crosscut by numerous faults which indicate north-south Proterozoic compression (Faure et al., 1991; Powell and Hodgson, 1992). East of the Rouyn-Noranda area, sinistral movements along the Bousquet or Kinojevis northeast-southwest faults offset the Cadillac-Larder Lake break (Bardoux et al., 1993). Within the Flavrian pluton, the Hunter Creek fault is parallel to the Horne fault and shows a late reverse movement (Camiré and Watkinson, 1990). All these observations suggest a Proterozoic age for these episodes (F and G, and event H), possibly during the Grenvillian orogeny, around 1250 Ma, as shown by the thermal resetting of isotopic systems (Corfu, 1993).

Paleostress Mapping

The Silidor-Don Rouyn area constitutes a homogeneous district, considering both the tectonic style and the nature of the infilling. Lode gold deposits feature similar mineralogy, isotopic signature, and style of deposition (cf. Kerrich, 1983; Robert, 1991). This provinciality probably reflects the presence of large volumes of hydrothermal solutions of similar composition (i.e., reservoirs).

The distribution and movement of hydrothermal fluids within a district are related to several parameters. The main factors are the geometry of the fissured media and the distribution of pressure gradients within the crust at that moment. Pressure gradients can be set up by deformation, thermal processes, or fluid buoyancy (Oliver et al., 1990). As has been noted in several other areas of the Abitibi greenstone belt (Hodgson, 1990; Robert, 1991), the distinct association between deformation and ore deposition in the Silidor area is indicative that pressure gradients are mainly induced by deformation.

Methodology

Deposition of gold in shear zones is controlled by the movement of hydrothermal solutions within the midcrust. The hydrology of such circulation is not accessible to direct observation, but theoretical calculations and analogy with the migration of hydrocarbons in sedimentary basins can be made based on the distribution of pressure in the crust and fluid buoyancy (Oliver et al., 1990). At a few kilometers depth in the crust, fluid pressures are most likely to be greater than hydrostatic and are controlled in part by rock pressure. Fluid flow is generally upward directed (Holyland et al., 1993), but petrologic investigations and analogies with petroleum reservoirs indicate that it could also be lateral, over large distances, following the lithologic units with the highest permeability (Ferry, 1994). Hydrothermal fluids will accumulate either near zones of low permeability (which act as barriers) or in zones of low pressure (= low mean stress). Such areas may appear due to the stress pattern in relationship to rheological variations, particularly competency contrasts (Oliver et al., 1990; Ridley, 1993; Holyland and Ojala, 1997).

Our tectonic model allows us to develop a technique whereby variations of the mean stress can be reconstructed, using the orientation of the main stress axes and geologic mapping. Stress mapping technology (STM™) based on finite-difference techniques which is well suited for discontinuum modeling (Lemos et al., 1985; Holyland, 1990) was developed by Terra Sancta Inc. It examines the variation in strain and stress through an inhomogeneous terrain upon imposition of a regional stress field. The geology of the area is treated as a mosaic of polygonal blocks composed of homogeneous rock units (modeled as Coulomb materials) and joints (faults and shear zones). It is, however, necessary to reconstruct the geology as it was during the mineralizing event, therefore, around 2.56 Ga.

Production of the stress map requires estimates of the magnitudes and orientations of the far-field horizontal stresses. The latter are given by the previous quantitative analysis of the brittle structures, but the former are difficult to obtain with the present state of knowledge. Empirical values previously used in similar terranes of Western Australia and Africa were adopted (Holyland, 1990; Vearncombe and Holyland, 1995; Holyland and Ojala, 1997). For a depth of about 4 to 8 km, assuming pressure increases with depth at about 25 MPa/km, the chosen values for the stress field for σ1 and σ3 are 100 and 70 MPa, respectively. Rock and fault deformation properties during the Archean are also required to model the interaction of an assemblage of blocks. The required variables include tensile and compressive strength, bulk and shear moduli, and density for each lithology, as well as the friction angle and stiffness for each contact and fault.

Modeling was carried out using a two-dimensional distinct element code (UDEC) on a PC-compatible computer. The method utilizes an explicit time-stepping dynamic algorithm which allows displacements and rotations and general nonlinear constitutive behavior for both the matrix and discontinuities. When an external stress is applied to this system, the blocks are joggled and internally deformed until equilibrium is attained (Lemos et al., 1985). The product of these computations is a stress contour map. Mean or minimum stress maps contour the value of the mean or minimum compressive stress and show typically the same anomalies.

Computing was done by one of the authors (P.H.) without knowledge of the location of the ore deposit; this approach could be compared to the blind method used in biological sciences. A highly simplified map of the Powell pluton was used, showing only the three main units (trondhjemite, diorite, and volcanic rocks) and some of the known veins. The relative strengths of the rock are, in decreasing order, diorite > volcanic rocks > trondhjemite > shear zone. Volcanic rocks are composed of thick horizons of andesite and thin layers of rhyolite. Rheologic properties are that of andesite. Fault zones were divided into first- and second-order faults. Three cases were studied, using northwest-, north-, and northeast-directed compression, corresponding to the result of the field observations and paleostress tensor reconstruction.
Results

The results of district modeling experiments show an inhomogeneous paleostress distribution, with alternating zones of high and low pressures along the Horne Creek fault (Fig. 8). The direction of the main compression axes does not drastically modify the distribution of paleopressure zones. The main features of the north-south compression modeling experiment are the following (Fig. 8d): (1) a distinctive zone with alternating low- and high-pressure areas along the Horne Creek fault. Low-pressure zones are associated with the intersection of the east-northeast–west-southwest Horne Creek fault and northwest-southeast-striking faults, either known (Silidor, Smokey Creek faults) or inferred; and (2) the contrasting behavior of the Beauchastel fault, which, despite having a similar orientation and mechanical character to the Horne Creek fault, did not develop areas of high and low pressure along its length. This result is related to the homogeneity of the block to the north. The only zone of low pressure is located at the end of the Silidor-Smokey Creek northwest-southeast-striking faults.

Modeling of a northwest-southeast compression (Fig. 8b) shows a similar distribution. Two more zones of contrasting high pressure occur along the Horne Creek fault between Silidor and the eastern end of the Powell pluton and at the contact between diorite and volcanic rocks. These zones could be related to the embayment of volcanic rocks between two resistant dioritic masses. The high-pressure zone of Silidor moves toward the southwest. A new zone of low pressure appears at the eastern border of the map. The northeast-southwest compression paleostress modeling features the same characteristics with high pressure oriented perpendicular to $\sigma_1$ and a particularly well-developed low-pressure area located at the Silidor deposit (Fig. 8c).

The location of the Silidor gold-bearing quartz vein is predicted by the paleostress modeling. The best fit is observed with the northeast-southwest compression, which is the direction of compression deduced from the microtectonic analysis. The presence of zones of relatively high pressure along some of the preexisting joints helps to explain the nonpercolation of the hydrothermal solutions and the uneven distribution of mineralization. New potential gold-bearing zones are also suggested from these maps.

Fig. 8. Results of stress mapping modeling of the Silidor area (low-mean stress plot). a. Simplified geologic map of the eastern part of the Powell pluton. Results of the paleostress modeling, using b. Northwest-southeast, c. Northeast-southwest, and d. North-south compression. The Silidor lode is illustrated in black on the four maps. Legend: Crosses = Powell pluton, Hachures = diorite, White = Blake River Group volcanic rocks, full line = major faults, dashed line = minor faults, dotted line = inferred faults, H = high-pressure zone, L = low-pressure zone.
Discussion

The evolution of the Silidor deposit constitutes a model for lode gold deposits. It shows some similarities with the classic lode gold deposits, such as Sigma (Robert and Brown, 1986a), but also significant differences (Table 3).

Despite their similar ages, the Sigma and Silidor deposits formed in different tectonic settings. The Sigma deposit was emplaced under a compressive north-south deformation regime, with the hydrothermal conduit being a high-angle reverse fault zone during fault-vaulting episodes (Sibson et al., 1988). The crosscutting relationships at Sigma imply that the stress pattern remained constant during the whole mineralization process. On the other hand, the Silidor deposit displays an evolving stress field during vein infilling, with σ1 remaining northeast-southwest, and an exchange between σ2 and σ3 stress axes, resulting in an evolution from strike-slip faulting to reverse faulting. The Silidor deposit shows less cyclicity during the hydrothermal events. This could be because the hydrothermal fluid flow operated under a near-constant hydraulic gradient (as at the Francoeur deposit in Abitibi; Couture and Pilote, 1993) or because of the greater time variability of the local stress. These local stress variations could be related to an oblique collision mechanism. A similar transpressional environment has been described in the Norseman-Wiluna belt of Western Australia (Hagemann et al., 1992). Silidor shares numerous features with this Australian district, especially the strike-slip movement of the faults, the scarcity of extension veins, and the abundance of implosion breccias. Such features are typical of a brittle environment, with few pressure seals. Fluid movement could have been related to suction pump mechanisms (Sibson et al., 1988).

The grade of metamorphism and vein morphologies of the Sigma and Silidor deposits also differ (Table 3). The Silidor veins show some similarities with the high-level brittle-style mineralization at Wiluna in Australia (Vearncombe et al., 1989; Hagemann et al., 1992). In the Rouyn-Noranda district, the Francoeur deposit, located 15 km southwest of Silidor, shows the same chronological order for alteration assemblages as at Silidor, with hematite preceding the albite-pyrite alteration. The Francoeur deposit is a ductile-shear disseminated replacement type mesothermal deposit (quartz-carbonate veins absent; Couture and Pilote, 1993), hosted in higher metamorphic grade rocks (greenschist-amphibolite facies: actinolite-oligoclase zone; Fowell et al., 1995b). In light of the depth continuum model of Groves et al. (1992), Francoeur could be a deeper expression and Silidor a high-crustal level expression of a regional mesothermal system.

The geologic and rheologic settings at Sigma and Silidor are different. The Silidor lode gold deposit is a rather simple mineralized structure hosted in a relatively homogeneous geologic context (trondhjemite sill). In this case, anisotropic zones such as mafic dikes played a major role in the localization of shear zones. Vein styles at Silidor are characteristic of other lode gold deposits which are hosted in similarly homogeneous and competent environments. The Elder and Pierre-Beauchemin veins in the Flavrian pluton, Rouyn-Noranda

### Table 3. Comparison between the Gold-Bearing Quartz Deposits of the Rouyn-Noranda and the Sigma-Val d’Or Districts

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Sigma deposit1</th>
<th>Silidor deposit2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural context</td>
<td>Reverse faulting (high-angle fault)</td>
<td>Strike-slip, then reverse faulting (moderate-angle fault)</td>
</tr>
<tr>
<td>Shear veins</td>
<td>Abundant (0.2–3 m width)</td>
<td>Few (0.05–0.3 m width)</td>
</tr>
<tr>
<td>Extension veins</td>
<td>Numerous and gold rich (1–100 cm width)</td>
<td>Few and noneconomic (1–20 cm width)</td>
</tr>
<tr>
<td>Tension crack</td>
<td>Abundant</td>
<td>Limited</td>
</tr>
<tr>
<td>Breccia</td>
<td>Hydraulic breccia</td>
<td>Hydraulic breccia and collapse breccia with buck quartz infilling</td>
</tr>
<tr>
<td>Open-space filling and cavities</td>
<td>Comb quartz grown in flat extension veins</td>
<td>Abundant small drusy veinlets and vugs (both flat and fault-parallel)</td>
</tr>
<tr>
<td>Mineral assemblage</td>
<td>Qz, Tm, Ch, Py, Sh, Po, Cp, Bt, Au-Ag, Pz, Tb, Mo, FrO, Il, Sp</td>
<td>Qz, Ch, Py, Cp, Cu-Ag, Au, Ser, Ms, Hm, Gn, Mo, Fr, Tb, As, Ce, Pz, El, Hs, Fre, Il, Pr, Ba</td>
</tr>
<tr>
<td>Alteration</td>
<td>Chlorite-carbonates-white micas, carbonates-white micas, carbonates-albite</td>
<td>Quartz-carbonates-hematite, carbonate-sericite-fuchsite, carbonates-albite</td>
</tr>
<tr>
<td>$f_{O_2}$</td>
<td>Below the $\Sigma$SO$_2$-$H_2$S buffer</td>
<td>On the $\Sigma$SO$_2$-$H_2$S buffer</td>
</tr>
<tr>
<td>Regional level of metamorphism</td>
<td>Greenschist-amphibolite facies transition (actinolite-albite, near surface, to actinolite-oligoclase and hornblende at depth)$^3$</td>
<td>Greenschist facies (actinolite-albite)$^3$</td>
</tr>
</tbody>
</table>

3 Source: Powell et al. (1995b)

Mineral abbreviations: Ag = silver, Au = gold, AuTe = gold tellurides, Ba = barite, Bt = biotite, Ch = carbonates, Cp = chalcopyrite, El = electrum, Fre = freibergite, Fro = frohbergite, Fu = fuchsite, Gn = galena, Hm = hematite, Hs = hessite, Il-ilmenite, Mo = molybdenite, Ms = muscovite, Po = pyrrhotite, Pr = proustite-pyrargyrite, Py = pyrite, Pz = petzite, Qz = quartz, Ser = sericite, Sh = scheelite, Sp = sphalerite, Tb = tellurobismuthinite, Tm = tourmaline
area (Gaulin and Trudel, 1990; Richard et al., 1990), show similar veins styles to Silidor. The numerous veins hosted in the Bourlamaque pluton, Val d’Or area (Vu, 1990; Belkabir et al., 1993), show similarities with Silidor but without the strike-slip movement along the fault. 

At Silidor, the combination of homogeneous and competent units and east-northeast–west-southwest-bounding faults (Horne and Beauchastel) in a strike-slip regime can also explain differences with Sigma. The distribution on a set of northwest-trending faults of the lode deposits of the Powell pluton resembles the results of simple shear experiments in a sandbox (cf. Naylor et al., 1986). The distribution of the lode deposits may also reflect the periodicity of northwest-trending diorite dikes. The early northwest-southwest compressive event (A and B stress states) produced dextral movement on east-northeast–west-southwest faults (Horne and Beauchastel). This also led to the development of northwest-southeast veins, which could be tension cracks or rotated Riedel shears (preore hematized shear zones) of a helicoidal form (Naylor et al., 1986; Sylvester, 1988). This event is followed by the northeast-southwest synore compression event (C and D stress states), which would have caused sinistral movement on the Horne and Beauchastel faults and the development of reverse faulting in the lode deposits.

The rheological contrast between units and the existence of significant permeability allows a vertical transfer of solutions. The presence of a low-pressure zone which remains stable in the southern part of the Silidor deposit, where it crosses the Horne Creek fault, suggests that this area could have acted as a sink for hydrothermal fluid throughout the tectonic history. The horsetail located at the northern part of the deposit suggests that fracture propagation occurred from south to north, activated by the concentration of fluid in the south. Variations in the direction of the main compression slightly modified the distribution of the paleobarometric zones. The paleostress map suggests that circulating fluid mainly followed major ductile structures such as the Horne Creek and Cadillac breaks or the areas of low stress that these large structures created, with possible oblique fluid flow. Few very few changes appear, with even a drastic rotation of the stress field, which indicates that different structural contexts, marking different times of ore deposition, could result in repeated fluid flow at a deposit.

On a regional scale, the Silidor area is located near a zone of relative indentation, south of the Horne fault, corresponding to an area of dioritic rocks within volcanic rocks. There is also abundant evidence of simultaneous high-fluid pressure zones, as demonstrated by hydraulic breccias and fluid flow during reverse faulting. Ridley (1993) has concluded that low-mean stress zones would be zones in which hydrostatic pressures of fractures would be relatively high relative to rock pressure. 

The hydrothermal system at Silidor has a lower content of B and As and a higher content of Mo, compared to Sigma, but both carried Au and W. Conditions of gold deposition were clearly much more oxidizing at Silidor than at Sigma, as demonstrated by the early abundance of hematite and the δ18O values of quartz. Oxidizing conditions of gold deposition have also been documented in other deposits of the Rouyn-Noranda district, by δ34S values in adjacent veins at Elder and Pierre-Beauchemin (Kennedy and Kerch, 1982), and by δ34S values at Francoeur (Couture and Pilote, 1993). Oxidizing conditions of gold deposition seem to be a characteristic of the lode gold deposits of the Rouyn-Noranda district and can explain the lack of boron and arsenic in these deposits.

Conclusions

The Silidor deposit is the result of several events of vein filling (white, gray, and smoky quartz) and associated metamorphism of its host rocks (mineralized trondhjemite and carbonate-fuchsite breccia). The early hematized alteration envelope and δ18O values for pyrite imply oxidizing conditions during gold deposition at Silidor, and this seems to be a general characteristic for most of the late-orogenic lode gold deposits of the Rouyn-Noranda area.

The structural evolution at Silidor was polyphase, characterized by large variations in orientations of the reduced stress tensors. Two major phases occurred before the mineralizing events: a ductile north-south and a brittle-ductile northwest-southeast compressive episode. The tectonic and metallogenic significance of the northwest-southeast compressive episode is illustrated by the deposition of the copper-gold-molybdenum porphyry-type mineralization at Don Rouyn, and it also played a role in the development of the hematite alteration. The Silidor deposit is related to a northwest-southwest compressive episode, during which σ1 remained northeast-southwest but σ2 and σ3 inverted at some stage during the event. The stress axes inversion during the mineralizing event implies a change from strike-slip faulting to reverse faulting and could be related to an oblique collision mechanism (Fig. 9).

![Fig. 9. Block diagram showing relationship between a first-order fault (Cadillac break), second-order faults (Horne Creek, Beauchastel, Smokey Creek faults), and the third-order faults (the mineralized faults). Arrows illustrates upward-ascending hydrothermal fluids. Legend: A = Astoria, AR = Anglo-Rouyn, AT = Atmfield, AU = Augnito, BF = Buffam, BH = Boulder Hill, BZ = Bazooka, C = Cinderella, E = Peel-Elder, GR = Graham, H = Halilwell, L = Lac Pelletier, MC = MacDonald, NM = New Marlon, PB = Pierre-Beauchemin (Eldrich), PR = Powell-Rouyn, Q = Quezabé, SD = Stadacona, SL = Silidor, SY = Sylvie, SR = Senator-Rouyn, W = Wingate, WA = Wasamac.](image-url)
On a regional scale, the paleostress model maps show the position of the Silidor deposit as an area of permanent low mean stress near the Horne Creek fault during the Late Archean tectonic history. The timing of the Silidor mineralization, related to the northeast-southwest compressive episode, coincides with the best fit for the Silidor location under a northeast-southwest compression. In the Rouyn-Noranda area, gold deposits are associated with east-northeast–west-southwest and northwest-southeast second-order faults. However, our paleostress modeling suggests that some of these faults, like the Beauchastel fault, did not act as an area of high and low pressure because of the homogeneity of the blocks on either side. Modeling suggests that inhomogeneity or indentation along these faults was needed to create distinctive zones of low and high pressure, which seem to be characteristic for the mineralized second-order faults.

The combination of paleostress studies and inverse modeling of the distribution of paleopressure offers a new way to explain the distribution of mesothermal ore deposits and to predict the location of new gold targets.

Acknowledgments

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Exploration found the Silidor deposit 63 years after Powell’s discovery in this area in 1922 and a team of geologists from Noranda Exploration visited the Silidor deposit 63 years after Powell’s discovery, only 3 miles away.

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