

## WERNECKE BRECCIA: PROTEROZOIC IOCG MINERALISED BRECCIA SYSTEM, YUKON, CANADA

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**Abstract** - At least 65 iron oxide-copper-gold  $\pm$  uranium  $\pm$  cobalt (IOCG) prospects are associated with a large-scale Proterozoic breccia system in north-central Yukon Territory, Canada. The breccia system, known as Wernecke Breccia, consists of numerous individual breccia bodies that occur in areas underlain by the Early Proterozoic Wernecke Supergroup, an approximately 13 km-thick deformed and weakly metamorphosed sequence of sedimentary rocks. The IOCG mineralisation occurs as multiple episodes of veining and disseminations within and peripheral to the breccia bodies. Brecciation and mineralisation are associated with extensive sodic and potassic metasomatic alteration overprinted by pervasive carbonate alteration and are spatially associated with regional- and local-scale faults. The scale of brecciation in this area is similar to that in other large-scale breccia provinces that contain significant mineralisation, e.g., Cloncurry and Gawler districts of Australia that host the Ernest Henry and Olympic Dam deposits. Implied similarities between the two areas and the possibilities for significant discoveries have led to the renewed exploration interest in the Wernecke Breccias.

### Introduction

Iron oxide-copper  $\pm$  gold  $\pm$  uranium  $\pm$  cobalt (IOCG) mineralisation, and extensive metasomatic alteration, are associated with a large-scale Proterozoic breccia system known as Wernecke Breccia, that extends for several hundred kilometres from the Wernecke to the Ogilvie Mountains in the north-central Yukon Territory, (Fig. 1; e.g., Bell, 1986a,b; Thorkelson, 2000; Laznicka, 2002; Yukon MINFILE, 2008). Multiple phases of vein and disseminated IOCG mineralisation occur within the numerous individual breccia bodies that make up the breccia system, and in rocks peripheral to the breccia.

The age of the Wernecke Breccias, along with the scale of brecciation and alteration, are similar to other large Proterozoic breccia provinces, including those in Australia that host the Ernest Henry and Olympic Dam deposits. These similarities, along with the possible proximity of ancestral North America and Australia in Proterozoic time, have led some authors to speculate that there may be a genetic connection between the two areas (e.g., Thorkelson *et al.*, 2001a). These similarities and the implied possibilities for significant discoveries in the Wernecke area have fuelled exploration interest for the last several years.

### Regional Geologic Setting

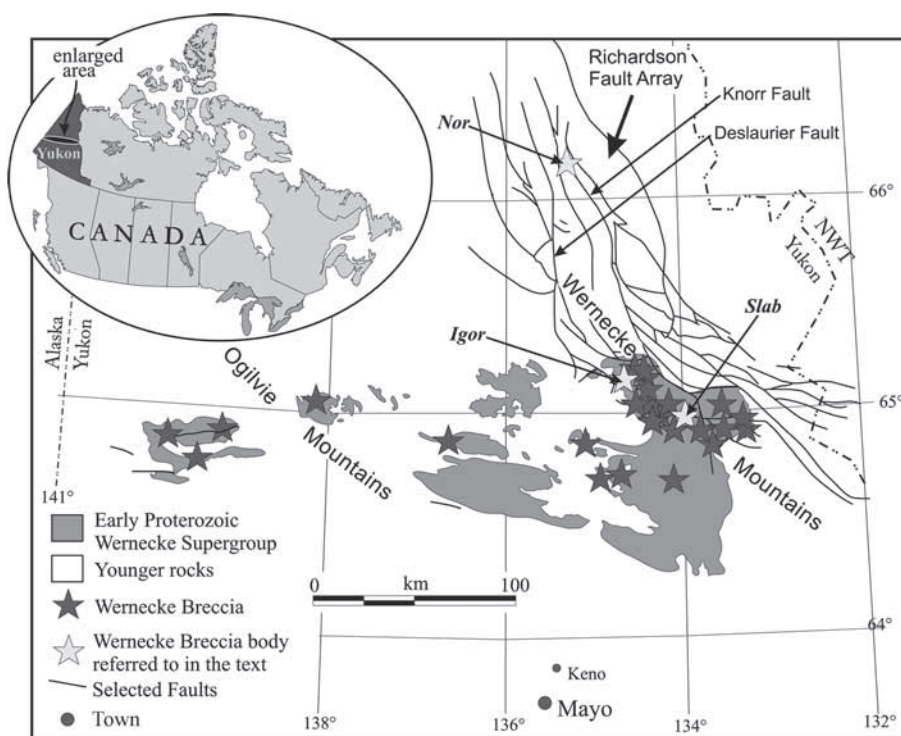
Wernecke Breccia bodies and associated IOCG mineralisation, occur in Early Proterozoic strata made up of Wernecke Supergroup (WSG), Bonnet Plume River Intrusions (BPRI), and Slab volcanics (e.g., Gabrielse, 1967; Delaney, 1981, Thorkelson, 2000). The Early Proterozoic rocks are unconformably overlain by Middle Proterozoic Pinguicula Group carbonate and siliciclastic

rocks. The base of WSG is not exposed but is interpreted to sit on  $\geq 1.84$  Ga crystalline basement that is the westward continuation of the Canadian shield (e.g., Norris, 1997; Thorkelson, 2000).

The Fairchild Lake, Quartet and Gillespie Lake groups make up the WSG and together form an approximately 13 km-thick package of fine-grained marine sedimentary rocks and carbonates (Delaney, 1981) that were deposited as two clastic to carbonate grand cycles (e.g., Thorkelson, 2000). The Fairchild Lake Group represents initial subsidence followed by infilling, and the Quartet and Gillespie Lake groups represent subsequent subsidence followed by infilling. The grand cycles may reflect continental rifting and equate to two stages of lithospheric stretching, subsidence and thermal deepening of the basin (Thorkelson, 2000).

The Fairchild Lake Group forms the basal part of the WSG and consists of at least 4 km of shallow marine sedimentary rocks, made up largely of siltstone, mudstone, claystone and fine grained sandstone (Fig. 2; e.g., Delaney, 1981; Thorkelson, 2000). Minor intercalated carbonate rocks are present locally and halite-facies meta-evaporites occur in the upper part of the Fairchild Lake Group strata (Hunt, 2005; Hunt *et al.*, 2005). The Quartet Group overlies the Fairchild Lake Group and is at least 5 km thick (Fig. 2; e.g., Delaney, 1978, 1981). The basal part of the Quartet Group consists of black carbonaceous shale. This is overlain by interlayered shale, siltstone and sandstone. The Gillespie Lake Group gradationally overlies the Quartet Group and forms the upper part of the WSG. It consists of at least 4 km of shallow marine, buff-, orange- and locally grey-weathering dolostone, limestone, claystone, mudstone and sandstone (Fig. 2; e.g., Delaney, 1978, 1981).

The Bonnet Plume River Intrusions (BPRI) are generally fine- to medium-grained and composed of tholeiitic diorite



**Figure 1:** Location of the Wernecke and Ogilvie Mountains, and areas underlain by Early Proterozoic Wernecke Supergroup and Wernecke Breccia (modified from Hunt *et al.*, 2005).

or gabbro, with lesser syenite and anorthosite (Fig. 2; Thorkelson *et al.*, 2001b). They are small igneous bodies of Early Proterozoic age (*ca.* 1710 Ma) that generally occur as clasts in the Wernecke Breccia. Earlier work (e.g., Thorkelson, 2000; Thorkelson *et al.*, 2001a,b) suggested that the BPRI crosscut the WSG, although new evidence from detrital zircon geochronology indicates that the WSG is not as old as previously thought and is actually younger than the BPRI (Furlanetto *et al.*, 2009).

The Slab volcanics (informal name) are made up of mafic to intermediate, subaerial flows with minor intercalated volcanoclastic and epiclastic units (Fig. 2; e.g., Laughton *et al.*, 2002; Laughton, 2004). The main exposure is a 160 x 380 m block that consists of about 30 flows with minor sandstone and conglomerate. The age of the volcanic rocks is not known. They have only been observed as clasts in Wernecke Breccia emplaced into upper Fairchild Lake Group strata in several localities along the Bonnet Plume River valley (Thorkelson, 2000; Laughton *et al.*, 2002; Laughton, 2004; Hunt, 2005; Hunt *et al.*, 2005). Since they occur as clasts within the breccia they must be older than the breccia but it is not clear if they are younger or older than WSG or if they were formed during WSG deposition (Hunt *et al.*, 2005; Thorkelson *et al.*, 2005).

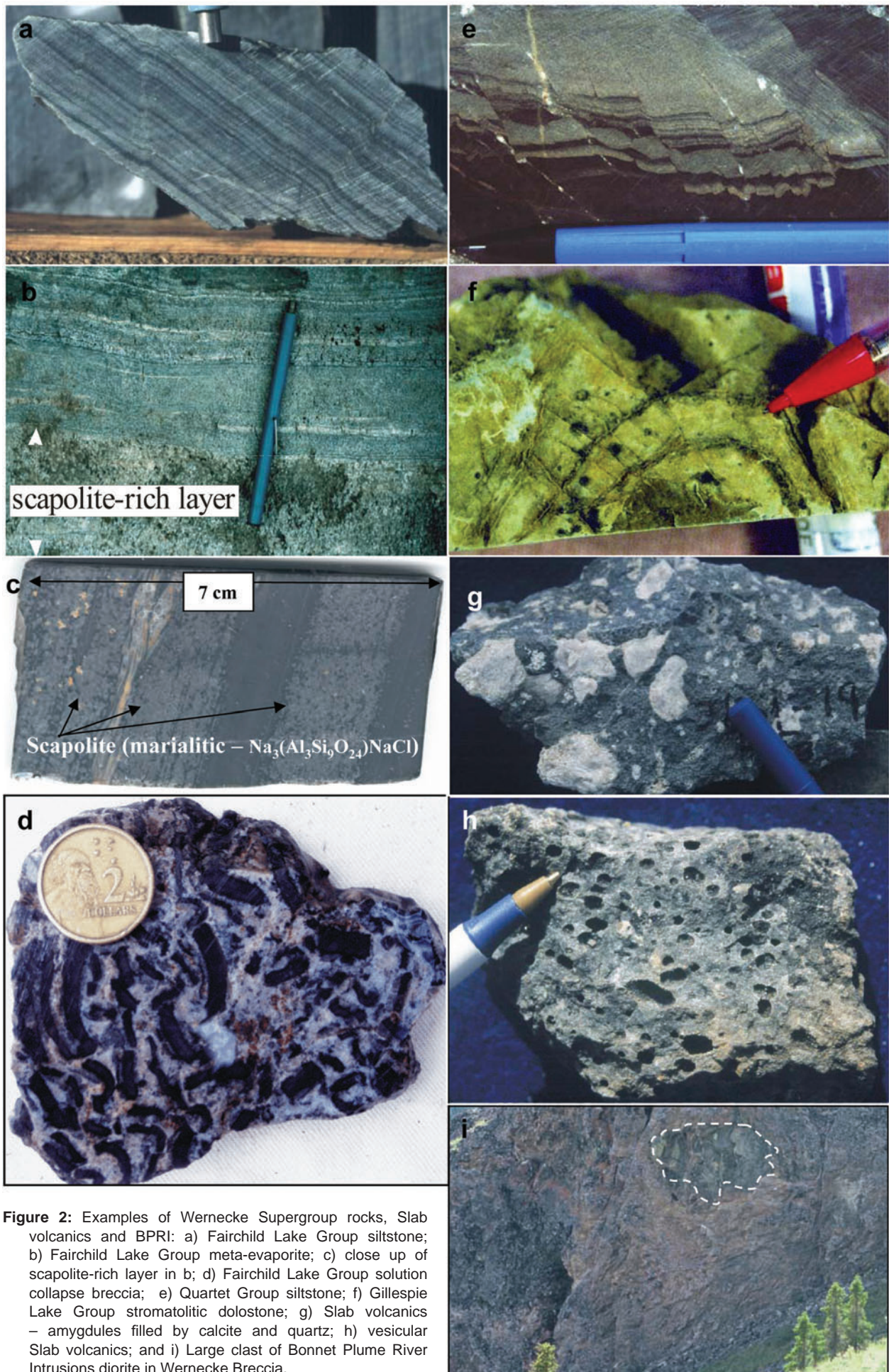
### Metamorphism and Deformation

Strata of the WSG were deformed and metamorphosed during contractional deformation assigned to the Racklan orogeny (e.g., Thorkelson, 2000; Thorkelson *et al.*, 2001b; Brideau *et al.*, 2002; Thorkelson *et al.*, 2005). The Racklan orogenesis produced greenschist facies metamorphic assemblages, e.g., chlorite-muscovite-chloritoid-quartz  $\pm$  garnet (peak metamorphic conditions of 450 to 550°C and approximate pressures of 3 to 6 kbars; Thorkelson, 2000; Brideau *et al.*, 2002) and three phases of deformation in WSG rocks. The distribution of strain throughout the WSG was heterogeneous and resulted in schist belts flanked by relatively undeformed rocks, many of which retain original sedimentary structures.

The age of the Racklan orogeny is constrained by the age of hydrothermal titanite (*ca.* 1600 Ma) from the matrix of a Wernecke Breccia body that contains clasts of foliated, kinked meta-siltstone (Thorkelson *et al.*, 2001a), and thus, the Racklan orogeny must be older than *ca.* 1600 Ma. The timing of magmatism relative to Racklan deformation is uncertain as there are no documented outcrops of BPRI or Slab volcanics that contain Racklan deformation fabrics. Minerals within the BPRI and the Slab volcanics have been affected by alteration, although some (or all) of this alteration may be due to metasomatism associated with Wernecke Breccia emplacement, and not regional metamorphism (Thorkelson, 2000; Thorkelson *et al.*, 2001b; Laughton *et al.*, 2002; Laughton, 2004). Wernecke Breccia and host strata have also been affected by several post-Racklan orogenic events as described by Norris (1997), Abbott (1997) and Thorkelson, (2000).

### Wernecke Breccia - Geology

Wernecke Breccias occur in areas underlain by WSG in a generally east-west-trending belt that extends from the Ogilvie to the Wernecke Mountains, with the exception of the Nor prospect that occurs in the Richardson Mountains approximately 120 km to the north (Fig. 1). The breccia bodies occur throughout the WSG stratigraphy but are most widespread in the upper Fairchild Lake Group (Delaney, 1981; Lane, 1990). Contacts between country rock and breccia vary from sharp to gradational (Fig. 3). Gradational boundaries with the WSG extend for a few centimetres to several tens of metres and the degree of brecciation gradually decreases outwards, from strongly disrupted sedimentary rocks to fractured country rock. The breccia complexes vary greatly in size from a few centimetres to several hundred metres to several kilometres across. Their shape is also variable. In plan view they are elliptical, elongate, or irregular in shape, and in vertical section they can be discordant or parallel to layering with no or numerous offshoots. Many breccia zones are polygenetic and probably grew over an interval of time during which crack-and-seal hydrothermal activity was prevalent.



**Figure 2:** Examples of Wernecke Supergroup rocks, Slab volcanics and BPRI: a) Fairchild Lake Group siltstone; b) Fairchild Lake Group meta-evaporite; c) close up of scapolite-rich layer in b; d) Fairchild Lake Group solution collapse breccia; e) Quartet Group siltstone; f) Gillespie Lake Group stromatolitic dolostone; g) Slab volcanics – amygdules filled by calcite and quartz; h) vesicular Slab volcanics; and i) Large clast of Bonnet Plume River Intrusions diorite in Wernecke Breccia.

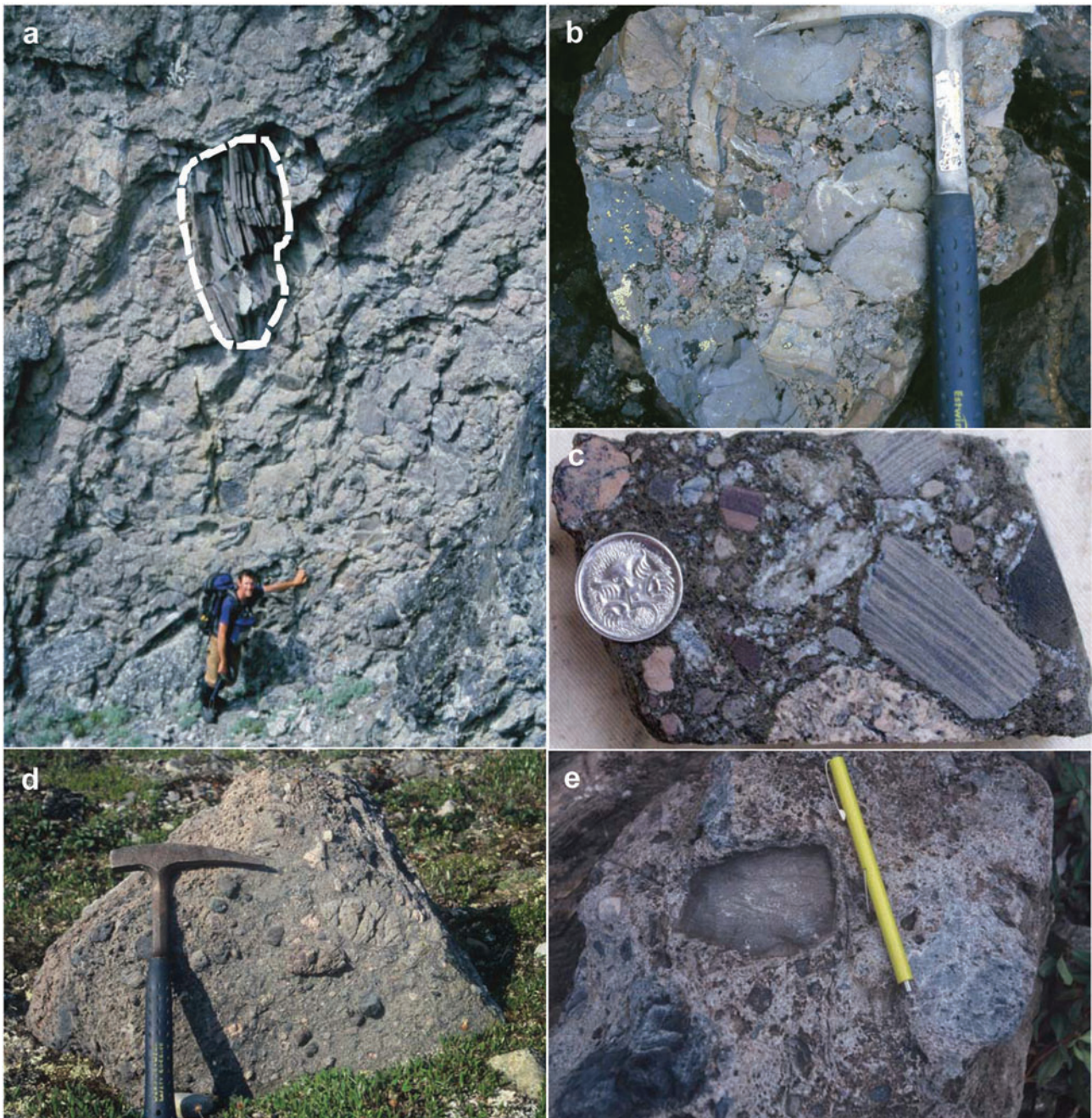
The breccia bodies vary from clast to matrix supported with generally sub-angular to sub-rounded clasts that range from <1 cm to metres to several hundred metres across (Fig. 3; *e.g.*, Bell, 1986a,b; Thorkelson, 2000; Hunt *et al.*, 2002, 2005). The clasts appear to be locally derived and are dominated by WSG lithologies except locally where BPRI and Slab volcanic clasts are abundant. The breccia matrix is made up of rock fragments and hydrothermal precipitates consisting mainly of feldspar (albite and/or potassium feldspar), carbonate (calcite, or dolomite/ankerite, locally siderite) and quartz (Fig. 3). Locally, the breccia matrix contains abundant hematite, magnetite, chalcopryrite, biotite, muscovite barite and fluorite, with lesser tourmaline and actinolite, and rare titanite and monazite. In some places the matrix is coarsely crystalline and is made up of quartz, calcite and fluorite, while in others, coarse biotite, muscovite and magnetite crystals occur within a finer grained matrix.

## Wernecke Breccia – Alteration

Extensive metasomatic alteration occurs within Wernecke Breccia and extends into host rocks for a few metres to tens of metres (*e.g.*, Thorkelson, 2000; Hunt *et al.*, 2002, 2003 a,b, 2005). The composition of the alteration appears to be largely controlled by host rock lithology and consists of dominantly sodium- or potassium-rich minerals overprinted by carbonate.

Sodically-altered rocks occur largely in Fairchild Lake Group strata that include halite-facies meta-evaporites. They are dominantly grey in colour and contain abundant albite and lesser scapolite (Fig. 4; *e.g.*, Hunt *et al.*, 2005). Potassic alteration is dominant in breccia hosted by fine-grained clastic rocks. These rocks are generally pink to red in colour and contain abundant orthoclase  $\pm$  sericite (Fig. 4).

Carbonate overprints the sodic and potassic alteration and forms veins up to 2 m wide that cross-cut Wernecke Breccia (Fig. 4; Hunt *et al.*, 2005). Sodic alteration is



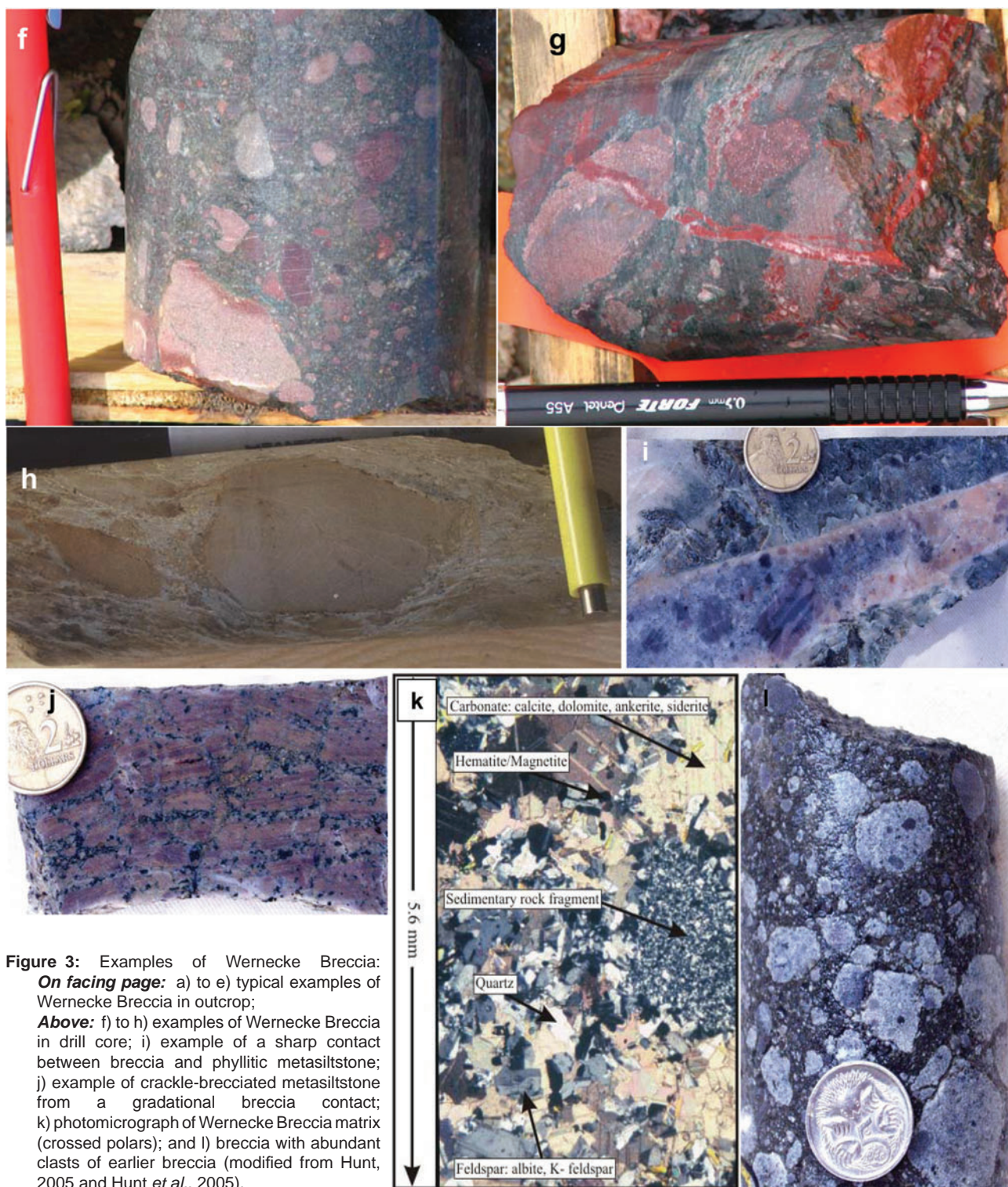
overprinted by carbonate dominantly composed of calcite, whereas potassic alteration is largely overprinted by dolomite and ankerite. Siderite, in addition to dolomite and ankerite (and barite), is locally abundant, e.g., Igor prospect (Fig. 4).

## Wernecke Breccia – Mineralisation

Multiple episodes of vein and disseminated iron oxide-copper  $\pm$  Au  $\pm$  U mineralisation occur in Wernecke Breccia and surrounding WSG sedimentary rocks (e.g., Archer and Schmidt, 1978; Thorkelson, 2000; Brooks *et al.*, 2002; Yukon MINFILE, 2008; Hunt *et al.*, 2002, 2003a, 2005).

Sixty-five breccia occurrences are known and all have associated copper, iron oxide and/or uranium minerals including chalcopyrite, magnetite, hematite, pitchblende and brannerite. Although no IOCG mining activity has occurred in the Wernecke area, the region is undergoing active exploration for uranium and copper (e.g., Burke *et al.*, 2008). Descriptions of several of the better known prospects, Slab, Igor and Nor (Fig. 1), are summarised below along with recent results.

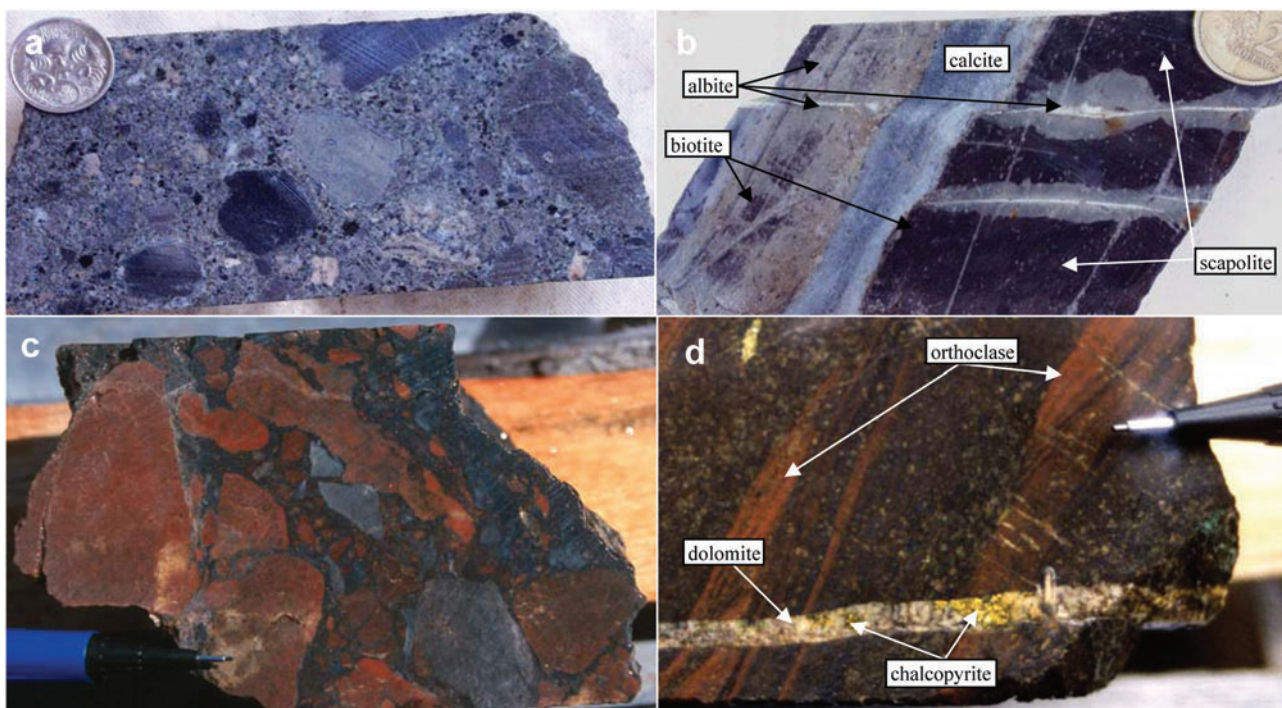
The **Slab prospect** is in upper Fairchild Lake Group rocks on the eastern limb of a large northwest-trending anticlinal structure proximal to a flexure in the trend of the fold (Thorkelson, 2000; Brideau *et al.*, 2002). Wernecke



**Figure 3:** Examples of Wernecke Breccia:

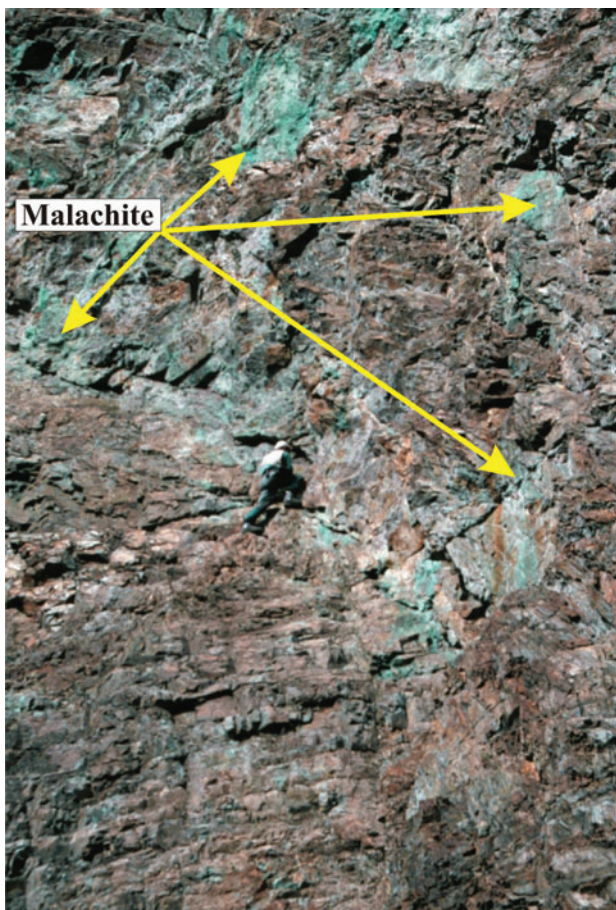
**On facing page:** a) to e) typical examples of Wernecke Breccia in outcrop;

**Above:** f) to h) examples of Wernecke Breccia in drill core; i) example of a sharp contact between breccia and phyllitic metasiltstone; j) example of crackle-brecciated metasiltstone from a gradational breccia contact; k) photomicrograph of Wernecke Breccia matrix (crossed polars); and l) breccia with abundant clasts of earlier breccia (modified from Hunt, 2005 and Hunt *et al.*, 2005).



**Figure 4:** Wernecke Breccia metasomatic alteration: a) grey sodic-altered breccia; b) biotite-scapolite (white spots) alteration in Fairchild Lake Group metasiltstone cut by albite veins, cross-cut by calcite vein; c) red potassic-altered breccia; and d) potassic altered Quartet Group metasiltstone cut by dolomite-chalcopyrite vein (modified from Hunt *et al.*, 2005).

**Figure 5:** Malachite-stained Fairchild Lake Group rocks at the Slab prospect (Yukon MINFILE 106D 071), peripheral to Wernecke Breccia.



Breccia occurs as large, elongate, irregular-shaped masses, as elliptical pipe-like occurrences a few metres in diameter and as narrow bodies parallel to layering in the Fairchild Lake Group (Brooks *et al.*, 2002; Hunt *et al.*, 2002, 2005). Here, cross-cutting relationships demonstrate there are at least three phases of breccia development (Hunt *et al.*, 2002, 2005). These breccias contain the largest clasts observed (up to several hundred metres across) and Slab is one of the few locations where Slab volcanics are preserved as clasts (Thorkelson, 2000; Laughton *et al.*, 2002).

Spectacular malachite staining occurs on the face of Slab Mountain (Fig. 5) where multiple phases of oxide and sulphide mineralisation are found within and peripheral to Wernecke Breccia (e.g., Hunt *et al.*, 2002, 2005). Magnetite is dominant in the early phase of brecciation as disseminations and blebs and locally occurs as massive ankerite-magnetite veins up to 1 m across (Fig. 6). These veins are locally cross-cut by, and included as clasts within, younger phases of the breccia. Lesser amounts of magnetite occur in later paragenetic stages as disseminated fine-grained blebs and euhedral crystals. Hematite, pyrite and chalcopyrite occur throughout the paragenesis but are most abundant as syn-breccia veins in breccia that is post ankerite-magnetite alteration (Fig. 6). Breccia locally contains clasts of massive pyrite-chalcopyrite up to 20 cm across indicating multiple phases of sulphide mineralisation (Fig. 6). Lesser chalcopyrite and pyrite with minor molybdenite is found in calcite  $\pm$  quartz-albite-hematite-magnetite-muscovite-biotite-fluorite veins that cross-cut all earlier phases of breccia (Fig 6). A resource of 20 Mt of 0.35% Cu and 0.17 g/t Au has been defined for Slab (Thorkelson *et al.*, 2003).

The **Igor prospect** is located about 28 km west of Slab in an area underlain by folded WSG metasedimentary rocks (Fig. 1; Norris, 1997) that are interpreted to be part of the Quartet Group. Abundant Wernecke Breccia occurs in the core of an anticline, and cross-cutting relationships demonstrate several phases of breccia are present. Mineralisation occurs largely as massive hematite-magnetite-pyrite-chalcopyrite and lesser pitchblende, with

dolomite, ankerite, siderite, barite, quartz and chlorite in pods up to 4 x 15 m across within the breccia (Eaton and Archer, 1981; Eaton, 1982; Hunt *et al.*, 2005). Exploration is ongoing at Igor and published results for 2007 include 140 m of 0.76% Cu, 0.042%  $U_3O_8$  and 0.05 g/t Au, including 7 m of 7.37% Cu, 0.417%  $U_3O_8$  and 0.33 g/t Au (Cash Minerals, 2008).

The *Nor prospect* is unusual in that it occurs in the Richardson Mountains about 120 km north of other known breccias (Fig. 1). It is located in an area underlain by a folded, fault-bounded block of calcareous meta-siltstone and phyllite that are correlated with the Fairchild Lake Group of the WSG (Hunt and Thorkelson, 2007). Wernecke Breccia occurs as an irregularly-shaped body approximately 1.5 km across in plan view (International KRL Resources Corp, 2008). Locally, the breccia matrix contains up to 90% hematite or up to 50% magnetite and hematite (Sanguinetti, 1978, 1979; Caulfield, 1994). Disseminated chalcopyrite occurs within the breccia and peripheral WSG rocks. Crystalline brannerite is found in potassium feldspar-rich zones that may be crosscutting veins (Tempelman-Kluit, 1981; Burke *et al.*, 2008). Grab samples from 2007 fieldwork returned values from 0.11% to 5.54%  $U_3O_8$  over 1.1 km (Burke *et al.*, 2008).

## Formation of Wernecke Breccia and IOCG Mineralisation

### Paragenesis

Cross-cutting relationships suggest at least some Wernecke Breccia was formed syn-deformation and some occurred post-deformation, after peak metamorphism (*e.g.*, Thorkelson *et al.*, 2005; Laughton *et al.*, 2005; Hunt *et al.*, 2005). Evidence includes: greenschist facies WSG rocks that are overprinted by sodic and potassic metasomatic alteration related to Wernecke Breccia; kinked breccia-related ankerite-magnetite and magnetite veins; clasts of foliated breccia within breccia that does not otherwise contain a fabric; and breccia that contains clasts of foliated, crenulated, kinked WSG phyllite. Together, these observations suggest that Wernecke Breccia was formed syn- to post-deformation, although it is not clear if some (or all) of this deformation is local or is related to the Racklan Orogeny.

Multiple phases of brecciation are also evident from cross-cutting relationships, and early phases of Wernecke Breccia are preserved in some locations as clasts within later breccia (Fig. 3). In general, there is an overall trend of: (1) metasomatic alteration (sodic or potassic) that overprints greenschist facies metamorphic mineral assemblages; (2) early stage brecciation accompanied by abundant magnetite  $\pm$  hematite alteration; (3) main phase of brecciation accompanied by hematite and chalcopyrite-pyrite  $\pm$  magnetite mineralisation; and (4) syn- to post-breccia carbonatisation (calcite, ankerite/dolomite, siderite)  $\pm$  pyrite, chalcopyrite, hematite, magnetite; barite veins are abundant during this stage in at least one location, *i.e.*, Igor.

### Wernecke Breccia/Mineralising Fluids

Breccia forming and mineralising fluids were moderate temperature ( $\sim 80$  to  $350^\circ\text{C}$ ), moderate to high salinity ( $\sim 5$  to  $40$  NaCl<sub>equiv.</sub> wt. %), NaCl-CaCl<sub>2</sub>-H<sub>2</sub>O brines whose composition appears to reflect significant interaction with the host strata (Hitzman *et al.*, 1992; Gillen *et al.*, 2004;

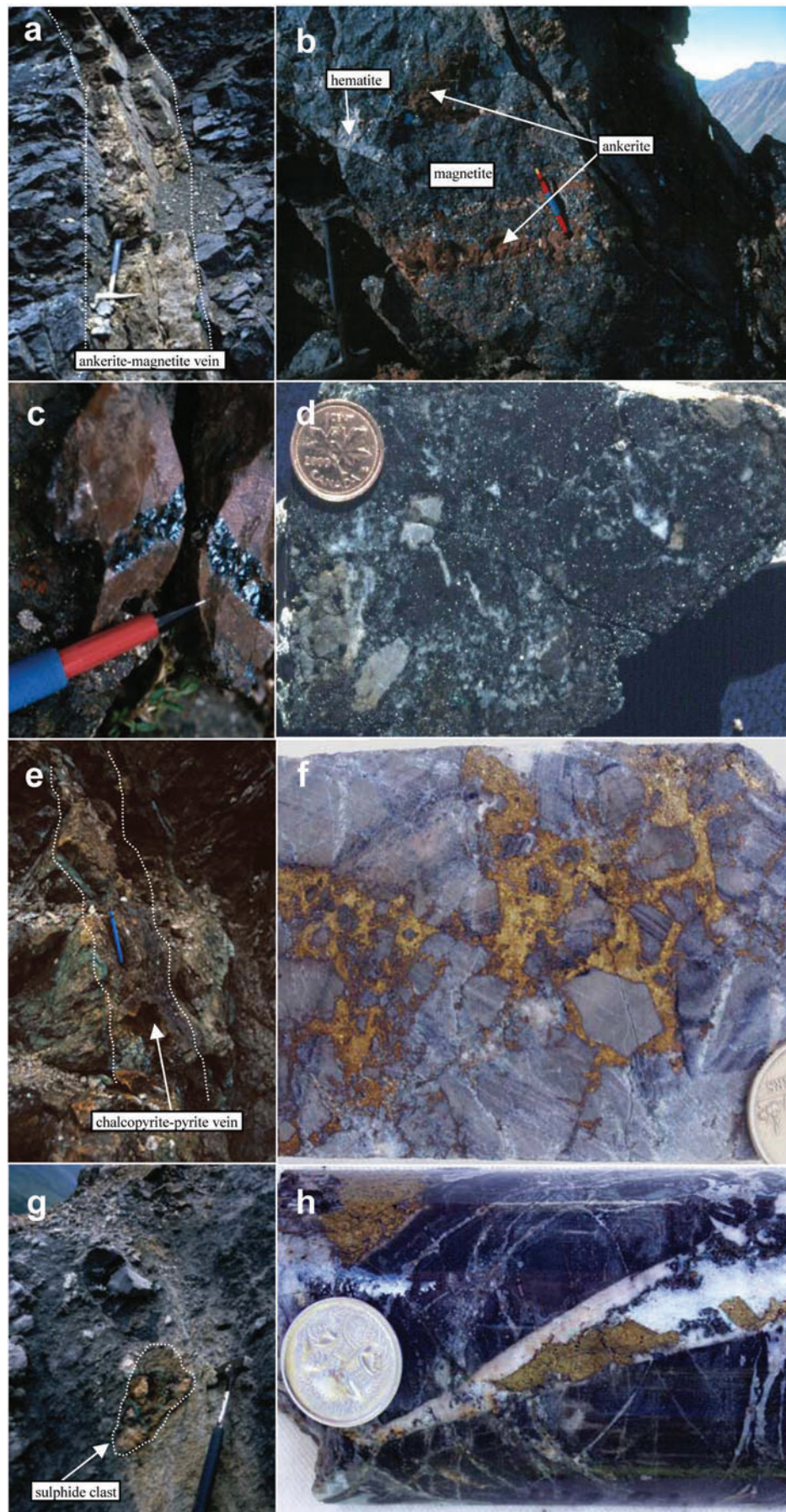
Hunt, 2005; Kendrick *et al.*, 2008; Hunt *et al.*, 2007, 2009). Carbon isotopic data for hydrothermal carbonates indicate carbon was derived in large part from the host WSG (Hunt, 2005; Hunt *et al.*, 2009). Sulphur isotopic values for hydrothermal sulphides and sulphates point to seawater (or sediments/evaporates deposited from seawater) as a likely source for much of the sulphur with possible additional sources from the leaching of biogenic pyrite and/or sulphides in local igneous rocks.

Evolved formational/metamorphic water(s) mixed with variable amounts of low  $\delta\text{D}$  water  $\pm$  evolved meteoric and or evolved sea water as the source of fluids is suggested by hydrogen isotope data (Hunt, 2005; Hunt *et al.*, 2009). Noble gas data also indicate the significant involvement of sedimentary formation water (Kendrick *et al.*, 2008), and preclude a direct link to mantle-derived magmatism. However, the noble gas data do suggest the involvement of a basement-derived fluid that Kendrick *et al.* (2008) suggest could have been generated by metamorphic devolatilisation or by exsolving a magmatic fluid from melts formed during crustal anatexis, or both processes concurrently.

### Deposit Models

Wernecke Breccias and their associated IOCG mineralisation are spatially associated with regional-scale faults, and breccia emplacement appears to have exploited pre-existing crustal weaknesses at all scales, including the faulted cores of folds, high strain zones, jointing/fractures and permeable sedimentary layers (*e.g.*, Bell, 1986a,b, Thorkelson, 2000, Hunt *et al.*, 2005). However, the mechanisms that formed the breccias are still under investigation. Past hypotheses include formation via: mud diapirs (Lane, 1990), phreatomagmatic explosions (Laznicka and Edwards, 1979), diatremes (Tempelman-Kluit, 1981; Bell and Delaney, 1977), modified evaporite diapirs (Bell, 1989) and explosive expansion of volatile-rich fluids associated with deeply buried intrusions (Thorkelson, 2000; Thorkelson *et al.*, 2001a). Recent studies place constraints on these possible mechanisms (see Thorkelson, 2000 for a review). For example: (1) mud diapirism is ruled out because WSG sediments were metamorphosed and deformed prior to brecciation, as shown by the presence of clasts of deformed WSG showing peak temperatures near  $500^\circ\text{C}$  (Brideau *et al.*, 2002) in Wernecke Breccia; (2) a diatreme origin seems unlikely because breccia clasts are dominantly locally derived and no clasts of crystalline basement or mantle origin have been identified; and (3) BPRI magmatism is unlikely to be related to brecciation because of the considerable age difference between magmatism (*ca.* 1710 Ma - Thorkelson *et al.*, 2001b) and brecciation (*ca.* 1600 Ma - Thorkelson *et al.*, 2001a; Hunt, 2005).

Deposit models need to take into account: (1) the large scale of brecciation and metasomatic alteration; (2) the presence of multiple phases of cross-cutting breccia and mineralisation; (3) the spatial association of breccia with regional-scale faults and the occurrence of breccia bodies in weak, permeable zones; (4) the timing of breccia emplacement, *i.e.* (syn- ) to post-deformation and post-peak metamorphic; (5) the spatial association of breccia (*ca.* 1600 Ma) with BPRI (*ca.* 1710 Ma - Thorkelson *et al.*, 2001a,b) and the age difference between them; (6) the widespread occurrence of breccia in the upper Fairchild Lake Group; (7) the preservation of Slab volcanics only as clasts in breccia emplaced into the upper Fairchild Lake Group; (8) the derivation of breccia clasts



**Figure 6:** Examples of oxide and sulphide mineralisation: a) ankerite-magnetite vein cutting Fairchild Lake Group; b) massive magnetite with lesser ankerite and minor hematite; c) hematite veins cutting Quartet Group metasedimentary rocks; d) abundant hematite in the matrix of Wernecke Breccia; e) massive chalcovrite-pyrite vein cutting Fairchild Lake Group; f) chalcovrite forming matrix to Wernecke Breccia; g) clast of massive pyrite-chalcovrite in Wernecke Breccia; and h) calcite-chalcovrite vein cutting Fairchild Lake Group (from Hunt *et al.*, 2005).

from proximal host rocks; (9) the distribution of sodic and potassic metasomatic alteration; (10) fluid inclusion and stable isotope data that indicate breccia forming/mineralising fluids were dominantly metamorphic/evolved formation waters; (11) fluid pressures calculated from fluid inclusion data that indicate the breccias formed at moderate depths (Hunt, 2005; Hunt *et al.*, 2007, 2009); (12) Nd isotope data that show that the Nd signature of the breccias is largely consistent with fluid derivation from the WSG (Thorkelson *et al.*, 2005); and (13) halogen and noble gas data that indicate a dominantly sedimentary source for breccia forming/mineralising fluids with possible minor input from a basement-derived fluid (Kendrick *et al.*, 2008).

Recent hypotheses for the formation of Wernecke Breccias were presented in Hunt *et al.* (2005, 2007, 2009) and Laughton *et al.* (2005). Hunt *et al.* (2005, 2007, 2009) suggest that periodic over-pressuring of dominantly evolved formational/metamorphic fluids led to repeated brecciation of host strata and coincident mineral precipitation (most likely due to changes in fluid pH, temperature and/or pressure during expansion). The fluids were focussed along permeable pathways such as faults or shear zones, thus leading to multiple brecciation events in the same location as pressure repeatedly built up and was released. Periodic release of pressure, for example by breaking seals on permeable pathways during continued deformation, would lead to rapid expansion of fluid and the formation of breccia particularly in weak, fractured zones such as the cores of folds. In order to maintain repeated brecciation events fluid would have to be added to the system. The addition of fluid could have been accomplished via regional fault systems and may explain why Wernecke Breccia is spatially related to large-scale faults.

The occurrence of widespread Wernecke Breccia in upper Fairchild Lake Group strata compared to the rest of the WSG (Delaney, 1981; Lane, 1990) may be due to the presence of evaporites in this part of the stratigraphy. The dissolution of evaporites during diagenesis, compaction and metamorphism and the accompanying disruption of intercalated and overlying sediments (Warren, 1999) may have produced widespread weak and/or permeable zones that could be utilised by over-pressured fluids, thus leading to the formation of abundant breccia at this stratigraphic level.

## Summary

Iron oxide-copper ( $\pm$  gold, uranium) mineralisation is associated with zones of Wernecke Breccia that occur in a several hundred kilometre long belt underlain by Proterozoic strata of the WSG. The breccia bodies are associated with extensive sodic and/or potassic metasomatic alteration overprinted by carbonate alteration. Cross-cutting relationships demonstrate multiple phases of breccia plus vein and disseminated IOCG mineralisation are present. The mineralisation includes magnetite, hematite and chalcopyrite  $\pm$  gold and uranium minerals. The breccias are spatially related to regional-scale faults and occur in zones of crustal weakness. Fluid inclusion and isotopic data indicate that the breccias were formed by saline NaCl-CaCl<sub>2</sub>-H<sub>2</sub>O brines at moderate depths. The mechanism of formation is still under investigation, although evidence to date suggests that they may have been formed by the expansion of overpressured fluids that were isotopically equilibrated with the metasedimentary host rocks of the WSG.

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