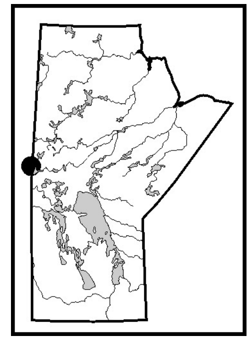
GS-2 Stratigraphic subdivision of the Hidden and Louis formations, Flin Flon, Manitoba (NTS 63K16SW)

by Y.M. DeWolfe[1] and H.L. Gibson[1]



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Summary

The hangingwall to the Flin Flon volcanogenic massive sulphide (VMS) deposits, which consists of basaltic flows, sills and volcaniclastic rocks with subordinate rhyolitic flows and volcaniclastic rocks, can be subdivided into two formations, the Hidden formation and the Louis formation. The contact between the Hidden and Louis formations is marked by mafic tuff that represents a significant and mappable hiatus in volcanism traceable throughout the Flin Flon area.

The Hidden formation defines the onset of hangingwall volcanism and comprises, from oldest to youngest, the 1920 unit, the Reservoir member and the Stockwell member. The 1920 unit comprises massive, pillowed and peperite facies basalt flows and is overlain locally by felsic or undifferentiated volcaniclastic rocks. The Reservoir member, which conformably overlies the 1920 unit, comprises massive, pillow, breccia and peperite facies basalt flows. It is conformably overlain by the Stockwell member, which comprises massive, pillowed and breccia facies basalt flows and is locally overlain by mafic volcaniclastic rocks.

The Louis formation conformably overlies the Hidden formation and consists of the Tower and Icehouse members, as well as undivided basaltic flows. The Tower member occurs at the base of the Louis formation and consists of massive to in situ–brecciated, aphyric rhyolite and associated volcaniclastic rocks. The Icehouse member, which conformably overlies the Tower member, consists of massive, pillowed and volcaniclastic facies basalts that are conformably overlain by undivided basaltic flows.

A number of features suggest a synvolcanic graben located on the west limb of the Hidden syncline and another in the area between Sipple hill and Louis lake. These include rapid thickness and facies variations within the 1920 unit of the Hidden formation, north of the Railway Fault, and in the Icehouse member of the Louis formation, between Sipple hill and Louis lake. The occurrence of volcaniclastic rocks within these formations that correspond to the thickest parts of the 1920 unit and Icehouse member suggests infilling of a depositional basin and is consistent with the interpreted synvolcanic graben. Also consistent with a graben in the Hidden formation north of the Railway Fault is the presence of large (up to 20 m by 10 m) domains of massive facies surrounded by pillows in flows of both the Reservoir and Stockwell members. These domains are interpreted to be large lava tubes emanating from a proximal magma source. This is corroborated by a high abundance of synvolcanic basaltic dikes and sills within the 1920 unit, Reservoir member and Stockwell member in the section where thick flows, abundant volcaniclastic rocks and the tube-fed flows occur.

Economic considerations with respect to the Hidden and Louis formations include the following:

- Faults controlling the locations of the grabens were likely active during the volcanism that formed the Flin Flon, Hidden and Louis formations, and therefore may have controlled massive sulphide mineralization in the underlying Flin Flon formation.
- Thrust faults repeating the Hidden formation may also structurally repeat the underlying Flin Flon mine horizon.
- Volcaniclastic units overlie the 1920 unit, separate the numerous flows within the Stockwell member, mark the contact between the Hidden and Louis formations, and separate flows within the Louis formation. They may be prospective along strike at depth because they represent hiatuses in volcanism, occur within topographic depressions, are in vent-proximal environments, and commonly correspond to areas of hydrothermal activity.

Introduction

The lateral extent and thickness of the Hidden and Louis formations, as determined from mapping (Stockwell, 1960; Bailes and Syme, 1989; Thomas, 1994), suggest that they are part of a voluminous basaltic volcano within the hangingwall of the Flin Flon, Callinan and Triple 7 VMS deposits (Figures GS-2-1, -2). A premise of this study is that these formations represent an integral part of the volcanic and subsidence history that characterizes the ore-forming environment at Flin Flon. Thus, reconstructing the volcanic architecture and the magmatic, subsidence and hydrothermal history of this basaltic volcano are primary objectives of this research.

[1] Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, 933 Ramsey Lake Road, Sudbury, Ontario P3E 6C7

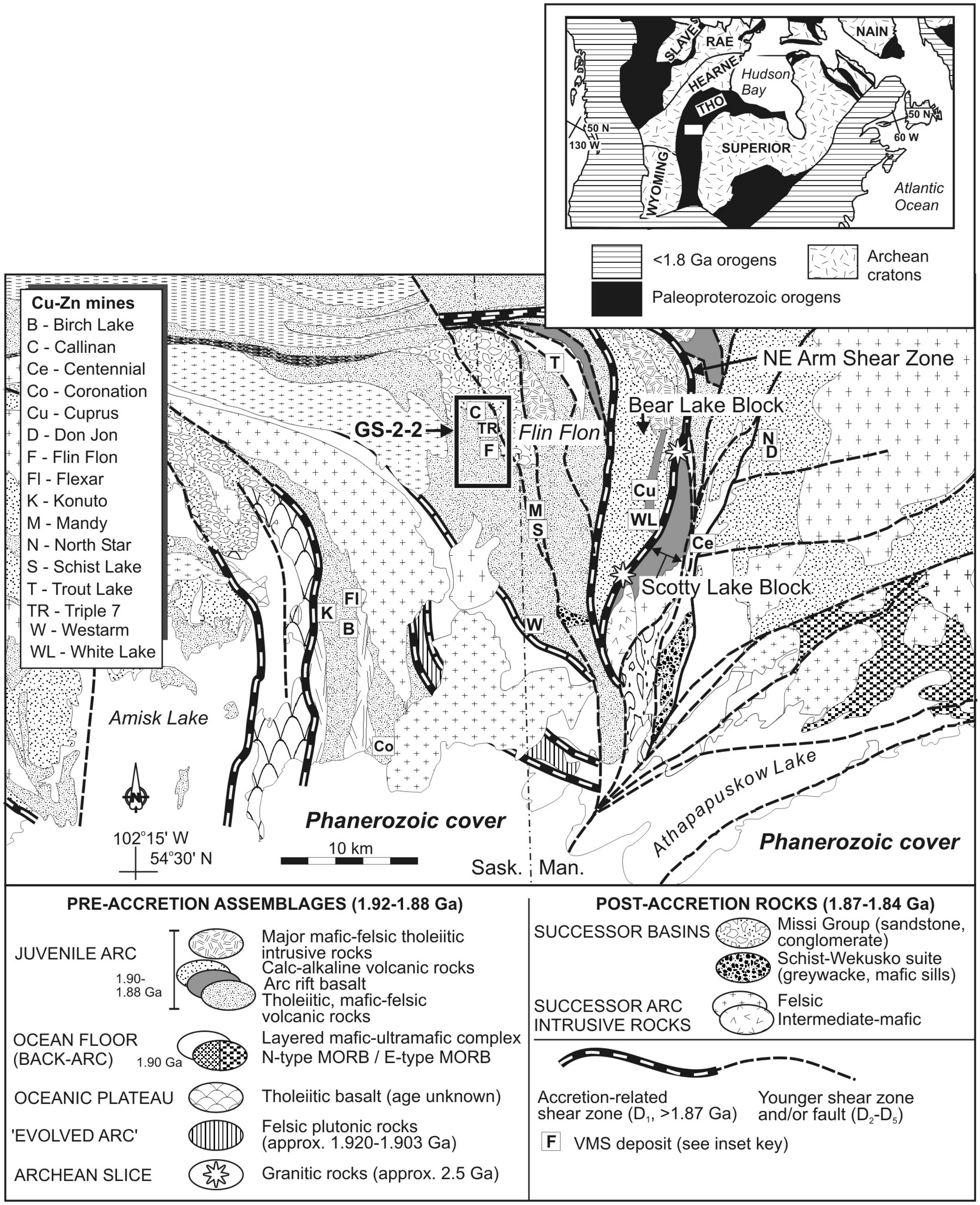

Figure GS-2-1: *Geology of the Flin Flon Belt, showing the locations of known volcanogenic massive sulphide (VMS) deposits (*modified from *Syme et al., 1996); box indicates area covered by Figure GS-2-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

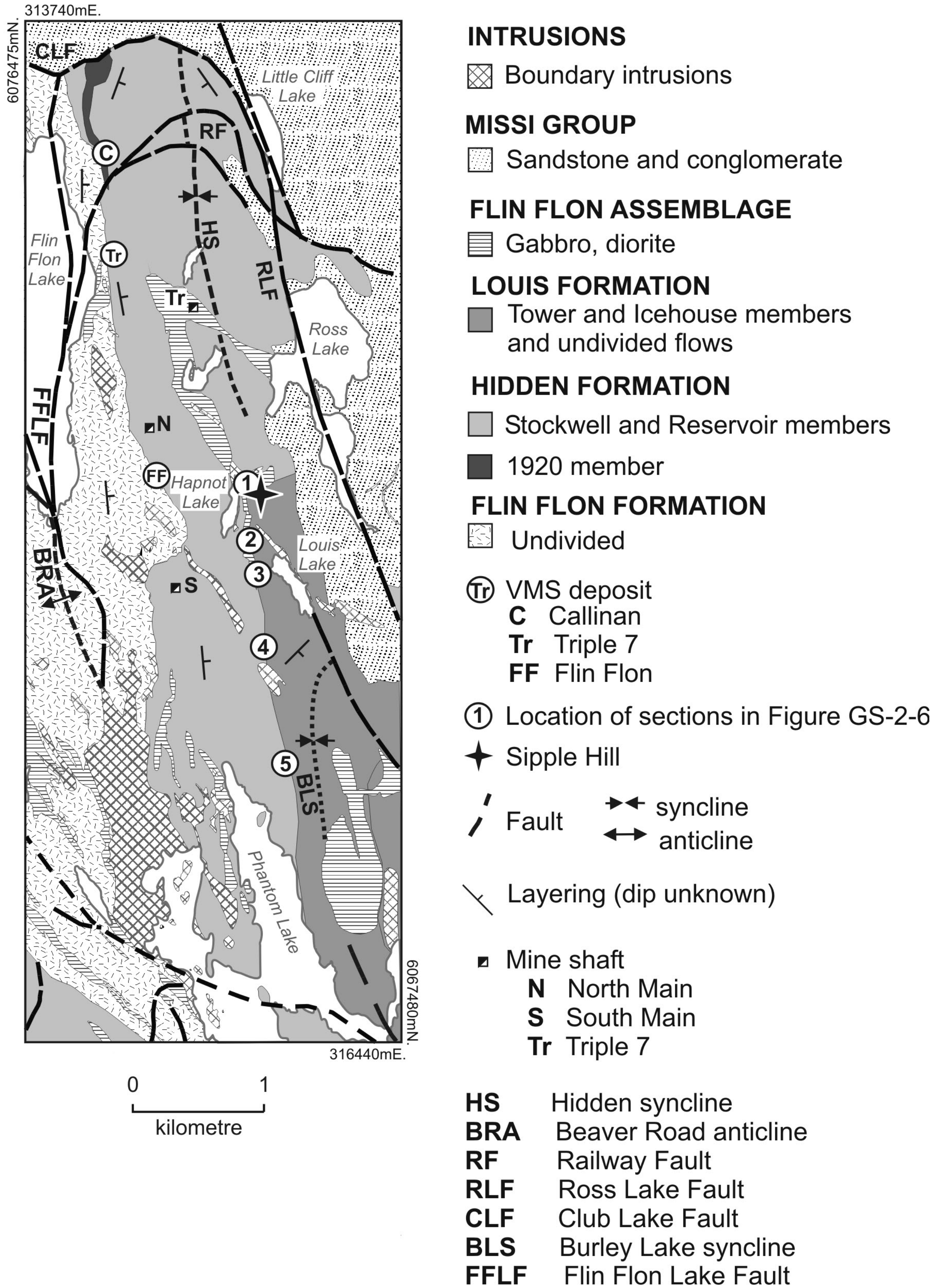

Figure GS-2-2: *Preliminary geology of the Flin Flon area* (modified from *Stockwell, 1960);* see *Figure GS-2-1 for location.*

Identification of synvolcanic structures controlling Hidden and Louis formation volcanism may reveal hydrothermal conduits to buried VMS deposits. This will not only aid exploration in the Flin Flon area, but also add to the understanding of processes forming VMS deposits during evolution of submarine volcanic complexes.

The purpose of this paper is to provide a new stratigraphic subdivision for the Hidden and Louis formations that is mappable, reflects the volcanic history and petrogenesis of these formations, and clearly defines and subdivides the hangingwall sequence to the Flin Flon orebodies. This new proposed stratigraphic subdivision is based on detailed mapping over a three-summer field program, conducted at scales ranging from 1:500 to 1:2000, and focused on these two formations in the Flin Flon area. Lithofacies within the Hidden formation have been described in detail by DeWolfe and Gibson (2004, 2005) and therefore will only be summarized in this report. A preliminary description of lithofacies recognized within the Louis formation is provided herein.

Regional geology

The Paleoproterozoic Flin Flon greenstone belt is part of the southeastern Reindeer Zone of the Trans-Hudson Orogen and contains 27 known VMS deposits (Figure GS-2-1). The greenstone belt consists of a series of assemblages that range in age from 1.9 to 1.84 Ga (Stern et al., 1995) and include arc, back-arc, ocean-floor and successor-arc successions. The Flin Flon and Snow Lake ocean-arc assemblages contain the majority of the VMS deposits.

The study area is located around the town of Flin Flon in the Flin Flon arc assemblage. It is composed of juvenile metavolcanic rocks (1.91–1.88 Ga) that are unconformably overlain by successor-arc fluvial sedimentary rocks of the Missi Group (ca. 1.84 Ga). Rocks of the Flin Flon arc assemblage are interpreted to have been erupted and emplaced in an island-arc–back-arc setting (Syme and Bailes, 1993), and consist of basalt, basaltic andesite flows and breccia, with lesser rhyolite flows. The Flin Flon, Callinan and Triple 7 VMS deposits (Figure GS-2-2), which total more than 85.5 million tonnes grading 2.2% Cu, 4.3% Zn, 2.49 g/t Au and 38.16 g/t Ag, are interpreted to have formed during a period of localized rhyolitic volcanism in a synvolcanic subsidence structure, or caldera, within a much larger, dominantly basaltic, central volcanic complex (Bailes and Syme, 1989; Devine et al., 2002; Devine, 2003). The Hidden and Louis formations (Figure GS-2-2) are interpreted to have been erupted during a period of resurgent basalt volcanism and subsidence that immediately followed a hiatus in volcanism marked by VMS ore deposition.

Previous stratigraphic subdivisions and nomenclature proposed for the hangingwall Hidden and Louis formations

Several stratigraphic subdivisions and nomenclature systems have been proposed for the basaltic flows, sills and volcaniclastic rocks, and subordinate rhyolitic flows and volcaniclastic rocks occurring in the hangingwall to the Flin Flon VMS deposits. Stockwell (1960) subdivided the hangingwall succession based on lithological differences into aphyric and plagioclase-porphyritic andesitic and basaltic flows overlain by plagioclase- and pyroxene-porphyritic basaltic flows (Table GS-2-1). Bailes and Syme (1989), in turn, subdivided the hangingwall into

Table GS-2-1: Summary of previous stratigraphic subdivisions and nomenclature proposed for the Hidden and Louis formations, Flin Flon area.

Source	Dominantly aphyric basalt and andesite		Dominantly plagioclase porphyritic basalt	
	Formation names	Members	Formation names	Members
This report	Hidden formation	Stockwell member Reservoir member 1920 unit	Louis formation	Icehouse member Tower member
DeWolfe and Gibson (2004, 2005)	Hidden formation	Tower member Newcor member Bomber member 1920 member	Louis formation	
TGI-1 working group (Ames et al., 2003)	Hidden formation	Tower member Newcor member Bomber member 1920 member	Louis formation	
Ames et al. (2002)	Hidden formation	Tower member Reservoir member unnamed member '1920 member'	Louis formation	
Bailes and Syme (1989)	Hidden Lake basalt		Burley Lake basaltic andesite	

lower and upper units, the Hidden Lake basalt and Burley Lake basaltic andesite, respectively; however, they described the Hidden Lake basalt as dominantly plagioclase-porphyritic with thin aphyric and sparsely plagioclase-porphyritic flows, and the Burley Lake sequence as including basalt, basaltic-andesite and rarely andesite. Ames et al. (2002) retained the Hidden formation name and divided the formation into the '1920 member', an unnamed basaltic unit with peperite, interflow and interpillow sediment, the Reservoir member, and the Tower member (Table GS-2-1). Ames et al. (2002) considered the 'Tower member' to be the top of the Hidden formation. They termed the overlying sequence of feldspar-pyroxene-phyric basaltic flows and sills, and minor aphyric pillowed basalt, scoriaceous amoeboid breccia and scoriaceous lapilli tuff the Louis formation.

DeWolfe and Gibson (2004, 2005) and the Targeted Geoscience Initiative (TGI) I Working Group (unpublished map, 2003) further subdivided the Hidden formation, as defined by Ames et al. (2002), into the 1920, Bomber, Newcor, and Tower members (Table GS-2-1).

New stratigraphic subdivision and nomenclature for the Hidden and Louis formations

The summer of 2006 was the last of three field seasons in the Flin Flon area by M. DeWolfe, Ph.D. candidate at Laurentian University, that were aimed at documenting the hangingwall stratigraphy of the Flin Flon, Callinan and Triple 7 VMS deposits. During this project, detailed volcanic lithofacies mapping ranged in scale from 1:250 to 1:2000, and in stratigraphic position from the base of the Hidden formation, exposed in the western part of the town of Flin Flon, to the highest stratigraphic exposure of the Louis formation, in the core of the Burley Lake syncline east of Phantom Lake (Figure GS-2-2). The detailed lithofacies mapping also covered the entire length of the hangingwall stratigraphy to the VMS deposits. Based on this mapping, the authors propose a new coherent stratigraphic subdivision and nomenclature for the area that is mappable, reflects the volcanic history and petrogenesis of these rocks, and clearly defines and subdivides the hangingwall sequence to the Flin Flon orebodies.

Figure GS-2-3 schematically represents the new hangingwall stratigraphy of the Flin Flon orebodies (*modified from* Devine et al., 2002; Ames et al., 2002; Devine, 2003; DeWolfe and Gibson, 2004, 2005; Simard, GS-1, this volume). The formation names and distribution remain the same as the stratigraphic subdivisions and nomenclature for the basaltic and rhyolitic hangingwall succession, as first proposed by Bailes and Syme (1989) and as modified by Ames et al. (2002). The mafic tuff associated with the Tower member is an extensive unit representing a significant and mappable hiatus in volcanism that is widely distributed and readily recognized (Ames et al., 2003). For this reason, it better defines the top of the Hidden formation than the local Tower member rhyolite. This change, however, requires that the Tower member belong to the base of the Louis formation. The names of the Bomber and Newcor members of the Hidden formation (Thomas, 1994; DeWolfe and Gibson, 2005) are changed to the Reservoir and Stockwell members, respectively. This name change reflects the fact that the old definitions for these units (Thomas, 1989) are not applicable to the Hidden formation in its type section at Flin Flon, as they are derived from localities more than 3.5 km distant. As well, to comply with the North American Stratigraphic Code, the 1920 member is now termed the 1920 unit, as it is dominated (>95% by volume) by sills (cryptoflows).

Hidden formation

The Hidden formation consists, from oldest to youngest, of the 1920 unit (previously referred to as the 1920 member; DeWolfe and Gibson, 2004, 2005), the Reservoir member (previously referred to as the Bomber member; DeWolfe and Gibson, 2005) and the Stockwell member (previously referred to as the Newcor member; DeWolfe and Gibson, 2005).

The formation is dominated by basaltic and andesitic flows and intrusions, with minor interflow tuff and volcaniclastic rocks. Its exposed thickness ranges from 400 to 880 m, but determining this thickness accurately is complicated by D_1 thrust faulting and D_2 folding. The base of the Hidden formation is placed at the last occurrence of tuff and/or rhyolite of the underlying Millrock member of the Flin Flon formation, followed by 1) basaltic aphyric to sparsely (<5%) plagioclase-porphyritic flows and/or sills (Reservoir member), or 2) icelandite flows or sills (1920 unit; Figure GS-2-3).

The 1920 unit, which is thought to define the onset of Hidden formation volcanism, is restricted to the northwest limb of the Hidden syncline (Figure GS-2-2). It is recognized in the field by prominent acicular amphibole phenocrysts and is geochemically enriched in TiO_2, Fe_2O_3 and P_2O_5 compared with other mafic rocks in the Hidden formation. It has an average SiO_2 content of 55.50 wt. % and has been identified as icelandite by Wyman (1993). Stratigraphically, the 1920 unit occurs at the base of the Hidden formation, where it overlies volcaniclastic rocks of the Millrock member of the Flin Flon formation (Figure GS-2-3). The top of the 1920 unit is marked either by a felsic volcaniclastic unit and mafic sills of the Reservoir member, or by mafic volcaniclastic rocks overlain by plagioclase-porphyritic flows of the Stockwell member. The 1920 unit and these conformably overlying units are recognized in two distinct fault blocks separated by two northeast-striking thrust faults that structurally repeat the 1920 unit and the bounding basalt sills or flows (DeWolfe, 2005).

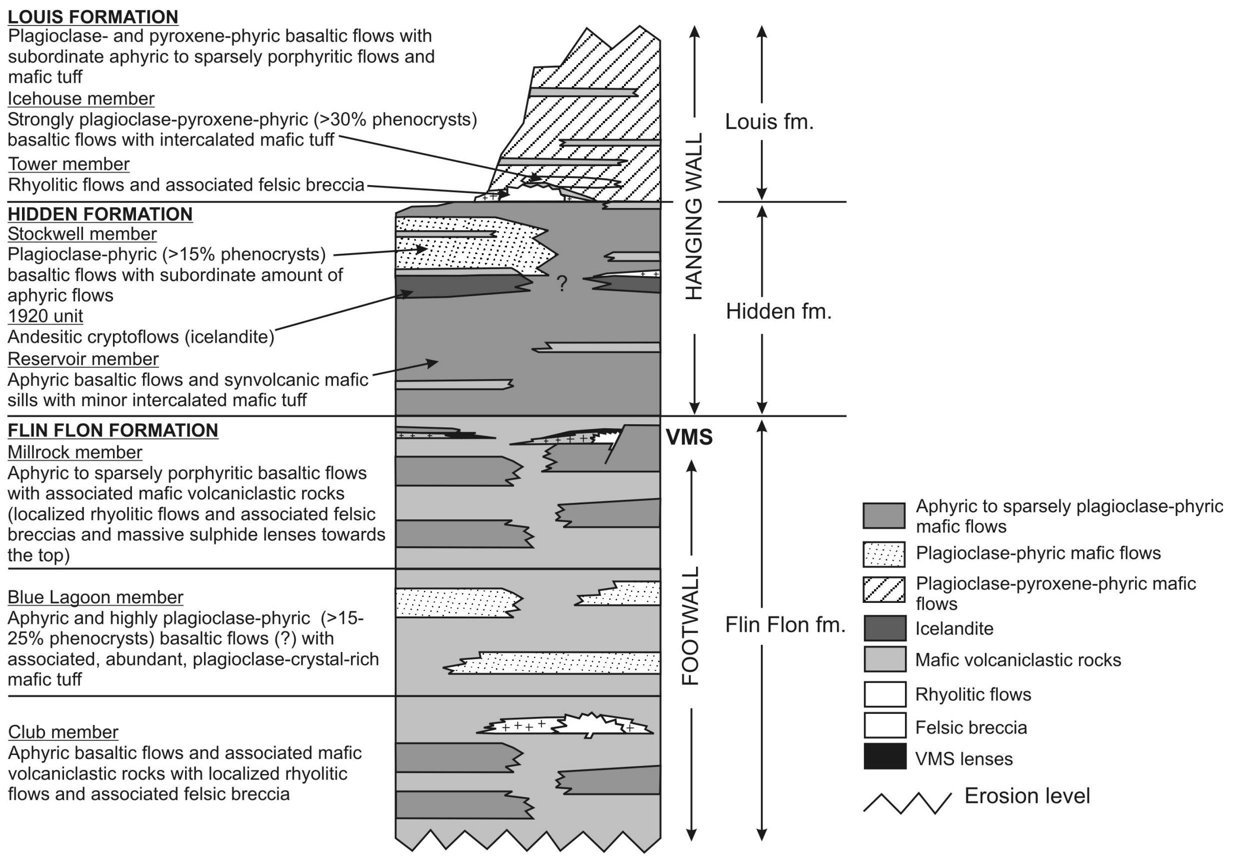

Figure GS-2-3: *Idealized stratigraphic section depicting the footwall and hangingwall to the Flin Flon VMS deposits* (modified from *Devine et al., 2002; Ames et al., 2002; Devine, 2003; DeWolfe and Gibson, 2004, 2005; Simard, GS-1, this volume).*

The Reservoir member is a green, aphyric to weakly plagioclase- and pyroxene-porphyritic (<15%) fine-grained basalt, and occurs as massive, pillowed and peperite facies. It occurs stratigraphically above the 1920 unit as sills and flows, and locally as sills below the 1920 unit (Figure GS-2-3). Where the 1920 unit is absent, the Reservoir member is in direct contact with the overlying plagioclase-porphyritic Stockwell member. The Reservoir member ranges in total thickness from 92 to 148 m, with individual flows ranging from 5 to 80 m thick.

The Stockwell member is a strongly plagioclase-porphyritic (≥15%) basalt and occurs as massive, pillowed and in situ–brecciated pillowed facies. The Stockwell member occurs north of the Railway Fault on both the west and east limbs of the Hidden syncline, forming a continuous unit around its fold nose (Figure GS-2-2; DeWolfe, 2005). It has a thickness of 57 m on the west limb and 79 m on the east limb (approximate true thickness). In one location in the western fault block on the west limb of the Hidden syncline, the Stockwell member occurs immediately above the 1920 unit. It is more commonly located, however, directly above Reservoir member flows and sills (Figure GS-2-3). The top of the Stockwell member is marked by undifferentiated aphyric basaltic flows of the Hidden formation.

In most places, the upper contact of the Hidden formation is defined by a thinly bedded to laminated mafic tuff. This unit ranges from <1 m to several metres in thickness. The true thickness of this tuff unit is frequently difficult to ascertain, as it is commonly intruded by multiple mafic sills. Along the west side of Louis lake and continuing south to the east side of Phantom Lake (south of the golf course), the mafic tuff is locally strongly epidote-quartz altered and contains sporadic sulphide mineralization (marked by strong iron-staining). The upper part of the mafic tuff unit locally contains beds of rhyolitic lapilli tuff (>20% aphyric rhyolite clasts, 0.2–10 cm in size) and, where this is the case, these rhyolite-bearing breccia beds are included in the Tower member of the Louis formation (*see* description below).

Northwest of Carlisle Lake, the contact between the Hidden and Louis formations is marked by a change from aphyric, very strongly epidote-quartz-altered and silicified, pillowed basaltic flows of the Hidden formation to plagioclase- (15%) and pyroxene (5%)-porphyritic basaltic flows of the Louis formation. At this location, the Louis formation flows display only weak, pervasive epidote-quartz alteration, suggesting that the alteration is synvolcanic and predates deposition of the Louis formation.

Louis formation

The Louis formation is dominated (>85%) by plagioclase (>15%)– and pyroxene (>5%)–porphyritic basaltic flows (Figure GS-2-4a). It includes two mappable members near its base: the Tower member, an aphyric rhyolite unit with associated breccia and mafic tuff (Figures GS-2-4b, -4c, -4d, -4e); and the Icehouse member, a strongly plagioclase-pyroxene-porphyritic basaltic flow (Figures GS-2-5b, -5c, -5d, -5f, -6).

Where the Tower member is not present, the base of the Louis formation is defined by 1) the first occurrence of plagioclase-pyroxene-porphyritic basaltic flows, 2) aphyric basaltic flows followed by plagioclase-pyroxene-porphyritic basaltic flows, 3) aphyric or sparsely feldspar- and quartz-porphyritic rhyolitic flows overlain by plagioclase-pyroxene-porphyritic flows or aphyric then plagioclase-pyroxene-porphyritic basaltic flows (Figure GS-2-6). In all cases, rocks above the contact with the underlying Hidden formation are dominated by plagioclase-pyroxene-porphyritic flows. The top of the Louis formation is not exposed and is therefore represented by the present-day erosion surface (Figure GS-2-3).

Tower member

Distribution

The Tower member rhyolite is aerially restricted, occurring only near the water tower on Sipple hill (Figure GS-2-2); however, a time-stratigraphic equivalent rhyolite occurs in the Schist Lake–Mandy Road area to south (*see* Simard, GS-1, this volume). The Tower member ranges from <1 to 20 m thick (not true thickness), but this thickness is only an estimate due to folding and a crosscutting mafic intrusion.

Lithology

The Tower member consists of massive to in situ–brecciated, aphyric or sparsely feldspar- and quartz-porphyritic rhyolite and volcaniclastic rocks dominated by aphyric rhyolite clasts locally overlain by mafic tuff.

Contact Relationships

The lower contact of the rhyolite is conformable, with in situ–brecciated rhyolite in sharp but irregular contact with the underlying amygdaloidal, aphyric, pillowed basalt of the Hidden formation (Figures GS-2-3, -4b). The upper contact of the rhyolite is sharp and conformable with an overlying mafic tuff (Figure GS-2-4c), which contains beds (5%) with 5 to 20% rhyolite clasts (0.2–20 cm). A similar rhyolite at Burley Lake is conformably overlain by basaltic plagioclase-porphyritic flows (Simard, GS-1, this volume). At Sipple hill and along strike, the upper contact of the Tower member is generally missing due to a fine- to medium-grained mafic intrusion that crosscuts the contact.

Massive facies

The massive, coherent facies of the Tower member rhyolite occurs within the middle of the unit. The rhyolite is aphyric, locally flow banded, strongly silicified and locally sericitized.

In situ–brecciated facies

The in situ–brecciated facies of the Tower member rhyolite occurs locally at the bottom of the unit along the contact with the underlying pillowed basalt of the Hidden formation and along the top of the unit. The in situ breccia is characterized by angular to subrounded fragments of rhyolite, 5 to 25 cm in size, closely packed with only hairline fractures between fragments (jig-saw puzzle fit; Figure GS-2-4d).

Volcaniclastic facies

The volcaniclastic facies of the Tower member locally occurs along the lower contact of the rhyolite. The volcaniclastic facies is crudely bedded and clast supported; bedding is defined by changes in clast size. The volcaniclastic facies contains lapilli- to block-sized fragments of aphyric rhyolite, subrounded to rounded, in a fine-grained (mafic?) tuff matrix (Figure GS-2-4e). The volcaniclastic facies also contains rounded, aphyric basalt clasts (5–10%, <8 cm in size).

Icehouse member

Distribution

The Icehouse member occurs between the water tower on Sipple hill and the northernmost extent of Louis lake (Figure GS-2-2). Near the water tower, it includes two massive flows with a combined thickness of 110 m (not true thickness). Farther south, the member is defined by one massive to pillowed flow, which is 43 m thick and thins to 27 m at its southernmost extent, west of the northern tip of Louis lake.

Lithology

The Icehouse member is massive to pillowed, locally overlain by mafic volcaniclastic rocks. It is coarsely porphyritic and contains 20 to 25% plagioclase phenocrysts, ranging in size from 1 to 5 mm, and 15 to 20% pyroxene phenocrysts, ranging in size from 1 to 8 mm.

Contact Relationships

To the north, the Icehouse member has a lower contact with a mafic intrusion. Its upper contact is marked

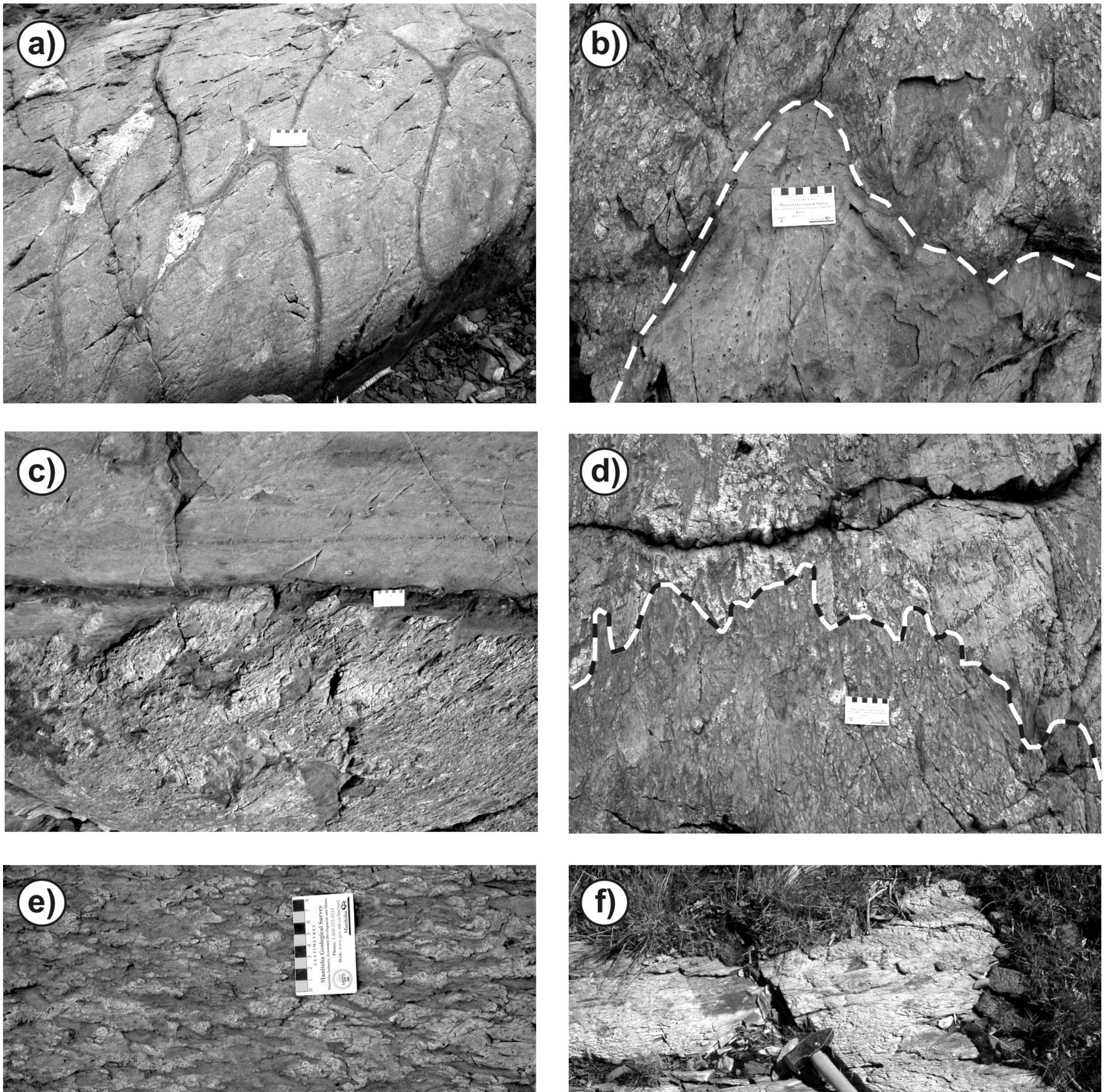

Figure GS-2-4: *Photographs of the Louis formation, Flin Flon area:* ***a)*** *plagioclase-pyroxene-porphyritic pillowed basalt with quartz-epidote-altered mafic tuff between pillows;* ***b)*** *contact (dashed white line) between aphyric pillowed basalt of the Hidden formation (bottom) and in situ–brecciated rhyolite of the Tower member, Louis formation (top);* ***c)*** *in situ–brecciated rhyolite of the Tower member in contact with overlying, finely laminated mafic tuff;* ***d)*** *internal contact (dashed white line) within the Tower rhyolite between heterolithic (rhyolite-dominated) volcaniclastic bed (bottom) and in situ–brecciated coherent rhyolite (top);* ***e)*** *heterolithic (rhyolite-dominated) volcaniclastic bed within the Tower member;* ***f)*** *strongly quartz-epidote-altered and iron-stained mafic (?) tuff, which locally marks the contact between the Hidden and Louis formations.*

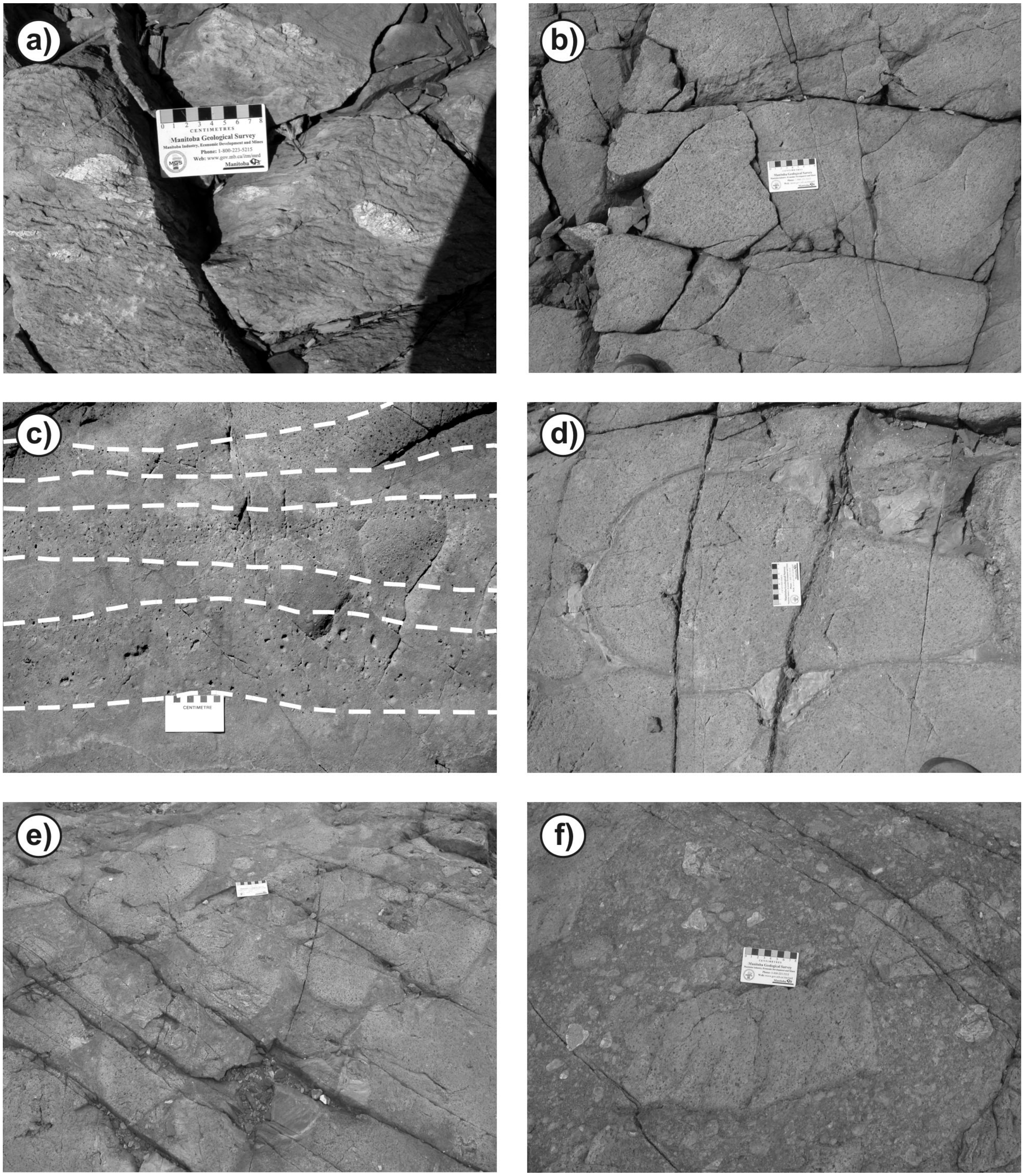

Figure GS-2-5: *Photographs of the Louis formation, Flin Flon area:* ***a)*** *aphyric rhyolite clasts within a mafic tuff of the Tower member, denoting the contact between the Hidden and Louis formations;* ***b)*** *columnar-jointed, coarsely plagioclase-pyroxene-porphyritic basalt of the Icehouse member;* ***c)*** *fine-grained flow top with bands of amygdules (dashed white lines) parallel to the flow top;* ***d)*** *pillowed, coarsely plagioclase-pyroxene-porphyritic basalt with quartz-epidote-altered mafic tuff between pillows, Icehouse member;* ***e)*** *pillow breccia overlying pillowed flow shown in part (d);* ***f)*** *heterolithic volcaniclastic unit overlying pillow breccia shown in (e).*

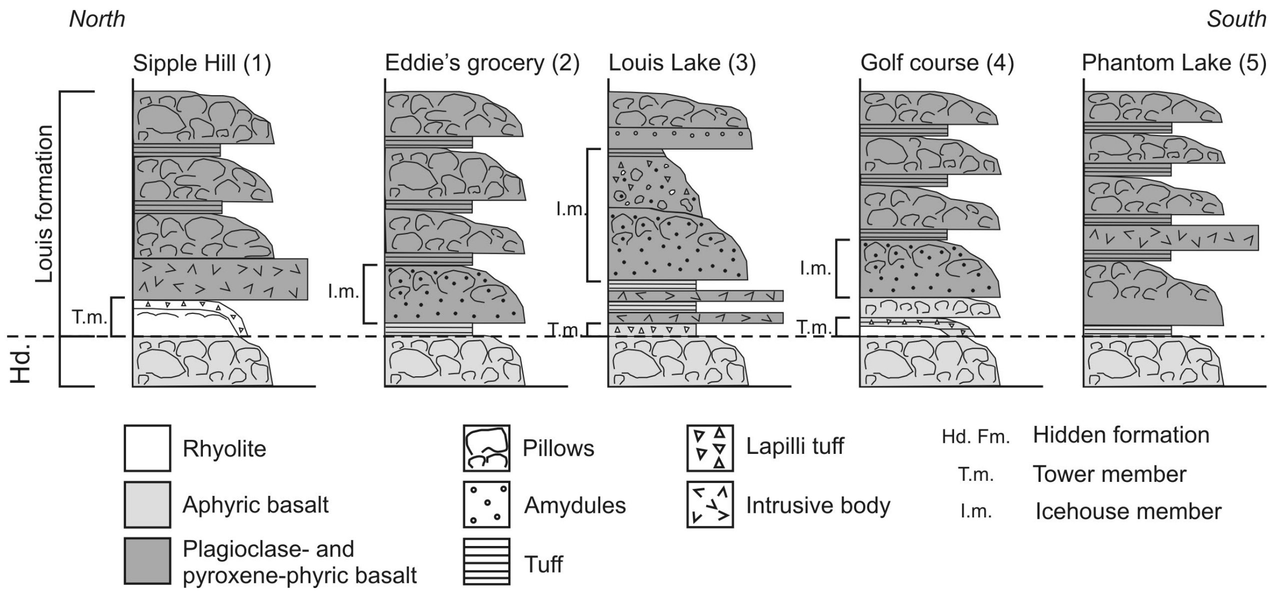

Figure GS-2-6: *Idealized stratigraphic sections showing the contact between the Hidden and Louis formations in five different locations (*see *Figure GS-2-2), moving from north to south through map area.*

by a finely laminated mafic tuff, or a massive-bedded mafic lapilli tuff that is 1 to 4 m thick, or both. To the south, the Icehouse member has a sharp and conformable contact with an underlying, finely laminated, strongly silicified and iron-stained, mafic tuff to lapilli tuff containing clasts of rhyolite (>20% aphyric rhyolite clasts, 0.2–10 cm in size). The rhyolite-clast-bearing mafic volcaniclastic rock marks the bottom of the Tower member of the Louis formation (Figures GS-2-4f, -5a, -6). A 20 m thick heterolithic volcaniclastic unit marks the upper contact of the Icehouse member to the south (Figures GS-2-5e, -5f).

Massive facies

The massive facies of the basaltic flows of the Icehouse member is coarsely plagioclase (25–30%, 1–3 mm) and pyroxene (20%, 1–7 mm) porphyritic and commonly columnar jointed (Figure GS-2-5b). Where in contact with pillows, the massive facies grades into the pillowed facies over a distance of 1 to 2 m. Near the flow-top, the massive facies increases in quartz amygdule content from 5 to 30% (<1–5 cm). At one locality, the massive flow is finer grained over the upper 5 m and, in the uppermost metre, the flow contains bands of amygdules (20–30%, <2 cm) that are 5 to 10 cm wide and oriented parallel to the flow top (Figure GS-2-5c).

Pillowed facies

Pillows are 0.2 to 1 m wide with thin (≤2 cm) selvages, and contain 5 to 10% quartz amygdules (<1 cm). Finely laminated epidote-quartz-altered mafic tuff commonly occurs between the pillows (Figure GS-2-5d). The upper margin of the pillowed flow of the Icehouse member is irregular and broken, with a gradation over a distance of 1 m from intact pillowed flow to pillow breccia to an overlying volcaniclastic facies (Figure GS-2-5e; *see* description below).

Volcaniclastic facies

Overlying the pillowed facies is a 20 m thick, normally graded, heterolithic volcaniclastic unit. The lower 5 m is clast supported, with 20% large blocks (6.4–50 cm) of plagioclase- and pyroxene-porphyritic, quartz amygdaloidal basalt and 5 to 10% aphyric rhyolite blocks (angular to subrounded; Figure GS-2-5f). Overall, the unit contains 50% lapilli-sized, rounded, aphyric to plagioclase- and pyroxene-porphyritic basalt clasts. The matrix is a reddish brown colour and rich in plagioclase (20–25%) and pyroxene (15%) crystals. The next 3 to 5 m marks a transition from clast supported to matrix supported. In this interval, there are only 5% large plagioclase- and pyroxene-porphyritic pillow fragments (>10 cm), 3 to 5% aphyric rhyolite clasts (rounded and ≤15 cm), and 10 to 20% lapilli-sized, aphyric to plagioclase- and pyroxene-porphyritic basalt fragments. The upper 10 m of the unit is matrix supported, consisting mainly of tuff with 30% rounded, lapilli-sized basalt clasts and 5 to 10% subrounded, aphyric rhyolite clasts.

Undivided basalt flows

Distribution

Overlying the Icehouse member of the Louis formation are undivided basaltic flows that account for

>90% of the observed flows of the Louis formation. The undivided flows have a minimum total thickness of 200 m and a maximum of 800 m, but estimating thickness is complicated by thrusting and folding. Individual flows range in thickness from approximately 10 to 50 m.

Lithology

The undivided flows are massive to pillowed and commonly separated by mafic volcaniclastic units. These flows are porphyritic, containing >15% plagioclase phenocrysts that range in size from 1 to 3 mm and >5% pyroxene phenocrysts that range in size from 1 to 4 mm.

Contact Relationships

The undivided flows of the Louis formation have a conformable lower contact, marked by a mafic volcaniclastic unit (1–20 m thick) with underlying flows of the Icehouse member. The top of the undivided flows is not exposed and is therefore represented by the present-day erosion surface (Figure GS-2-3).

Massive facies

The massive facies of the undivided flows is plagioclase (>15%) and pyroxene (>5%) porphyritic, brown (weathered) or dark grey (fresh) in colour, and accounts for less than half (~30%) of the flows, most of which are pillowed. The massive facies, which typically occurs as the massive portion of multifacies flows, normally displays gradational contacts over 1 to 2 m with the pillowed facies.

Pillowed facies

The pillowed facies of the undivided flows is plagioclase (>15%) and pyroxene (>5%) porphyritic, brown (weathered) or dark grey (fresh) in colour, and contains amygdaloidal pillows that range in size from 0.5 to 2.5 m. The amygdules are quartz filled, range in size from 0.1 to 2.0 cm, are rarely concentrated towards the top margin of the pillow, and are commonly distributed throughout the pillow. Pillow selvages have an average width of 1 cm and are a dark brown to red. Undivided pillowed flows of the Louis formation commonly contain epidote-quartz-altered mafic tuff between the pillows (Figure GS-2-4a).

Volcaniclastic facies

Within the Louis formation, pillowed basalt flows are often separated by mafic volcaniclastic units ranging from <1 to 5 m in thickness. The volcaniclastic units range from clast-supported, massive lapilli tuff beds to finely laminated mafic tuff beds. Lapilli tuff beds consist of 70% plagioclase-pyroxene-porphyritic, amygdaloidal basalt clasts that are rounded to subangular in form and range in size from 0.2 to 6 cm, with an average clast size of 2 cm. They also contain 10% aphanitic basalt clasts (0.2 to 3 cm and subrounded to subangular) and have a grey to brown tuff matrix.

Interpretation

The basaltic to andesitic flows and sills of the Hidden formation are interpreted to represent products of a large shield volcano with a synvolcanic graben and volcanic vent located on the northwest limb of the Hidden syncline. The graben and volcanic vent structure correspond spatially to the location of the 1920 unit (DeWolfe and Gibson, 2005).

Supporting evidence for a graben and a vent-proximal environment on the west limb of the Hidden syncline, where the 1920 unit occurs, includes 1) the presence of volcaniclastic units overlying the 1920 unit and separating multiple flows within the Stockwell member that do not extend to the Stockwell member on the west limb, indicating deposition within a topographic depression; 2) large (up to 20 m by 10 m) domains of massive facies, surrounded by pillows in flows of the Reservoir and Stockwell members, that are interpreted to be large lava tubes emanating from a proximal magma source; and 3) an abundance of synvolcanic basaltic dikes and sills within the 1920 unit and Reservoir and Stockwell members in this area. On the east limb of the fold, flows of the Reservoir and Stockwell members are thinner and characterized by abundant sills, not dikes, indicating emplacement farther from a volcanic vent. The top of the Hidden formation is commonly marked by an extensive mafic tuff unit, indicating a significant hiatus in volcanism between emplacement of the Hidden and Louis formations (Ames et al., 2002, 2003).

Locally, the base of the Louis formation is marked by rhyolite of the Tower member, which, along with aphyric and or plagioclase-pyroxene-porphyritic flows, marks the onset of a second episode of mafic-dominated volcanism following the hiatus at the top of the Hidden formation. The rhyolite is interpreted to have been emplaced as a flow or dome (containing autoclastic breccia) on the seafloor. Rhyolite fragments within the upper part of the mafic tuff are interpreted to have been derived, possibly through mass wasting, from the Tower member rhyolite. Overlying the rhyolite are two very thick, massive, strongly plagioclase-pyroxene-porphyritic flows of the Icehouse member (Figure GS-2-6). These flows do not contain flow-top breccia, but instead fine upwards and, over their upper 1 to 5 m, become more intensely quartz amygdaloidal where they are conformably overlain by a finely laminated, strongly epidote-quartz-altered mafic tuff to lapilli tuff. The absence of peperite along the upper contact of the flows suggests that the tuff was deposited on top of the flows, which were emplaced on the seafloor.

The thick Icehouse flows are interpreted to be ponded or represent lava lakes on the seafloor. Farther south, where the Icehouse member thins and is represented by one flow, it grades into a pillowed facies (Louis lake section, Figure GS-2-6). Where the heterolithic volcaniclastic facies overlies the thick Icehouse member flow, the former is interpreted to have been emplaced within a small (<50 m) synvolcanic graben that also constrained the underlying ponded flows. Reactivation of faults bounding the massive Icehouse flows is interpreted to have exposed the underlying rhyolite (Tower member) and triggered mass flows, which resulted in a localized volcaniclastic deposit (facies), comprising basaltic and rhyolitic detritus, that was deposited in a fault-controlled basin.

The combination of the thick rhyolitic (Tower member) and basaltic (Icehouse member) flows, a localized basin defined by the volcaniclastic facies, and the high proportion of intrusions implies proximity to a volcanic vent and one or more synvolcanic subsidence structures that were active during the onset of Louis formation volcanism. Moving laterally away from the Tower and Icehouse members, which correspond to a vent-proximal environment, the undivided plagioclase-pyroxene-porphyritic flows of the Louis formation begin to dominate. These basaltic flows, which are thinner than those of the Icehouse member, represent a more distal volcanic environment. The flows of the Louis formation are interpreted to represent resurgence in basaltic volcanism and associated subsidence, which continued the growth of a shield volcano. The location of the volcanic vent within the Louis formation differs from that in the underlying Hidden formation, and is in the area between Sipple hill and Louis lake.

Economic considerations

The contact between the Hidden and Louis formations marks an important hiatus in volcanism, and the intense epidote-quartz alteration found along this contact, whether in pillowed, aphyric basaltic flows at the top of the Hidden formation or mafic tuff that locally marks the top of the Hidden formation, indicates the existence of hydrothermal alteration during their emplacement (Ames et al., 2002, 2003). Consequently, this contact may be prospective along strike at depth.

The localized volcaniclastic rocks that overlie the Icehouse member of the Louis formation between Sipple hill and the northern extent of Louis lake (Figures GS-2-2, -6) represent an area of synvolcanic subsidence and a hiatus in volcanism with active hydrothermal activity. Similarly, the volcaniclastic units that overlie the 1920 unit and separate numerous flows within the Stockwell member represent hiatuses in volcanism, occur within a topographic depression in a vent-proximal environment and correspond to rocks that have experienced hydrothermal activity. Similar structures are interpreted to host the Flin Flon VMS orebodies in the underlying Flin Flon formation and, as such, these features in the Hidden and Louis formations may represent domains within the hangingwall that have prospectivity for VMS mineralization along strike at depth.

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