Geoscientific Map MAP2005-2

Geology of the southern Wekusko Lake area, Manitoba

H.P. Gilbert and A.H. Bailes

Photo Index

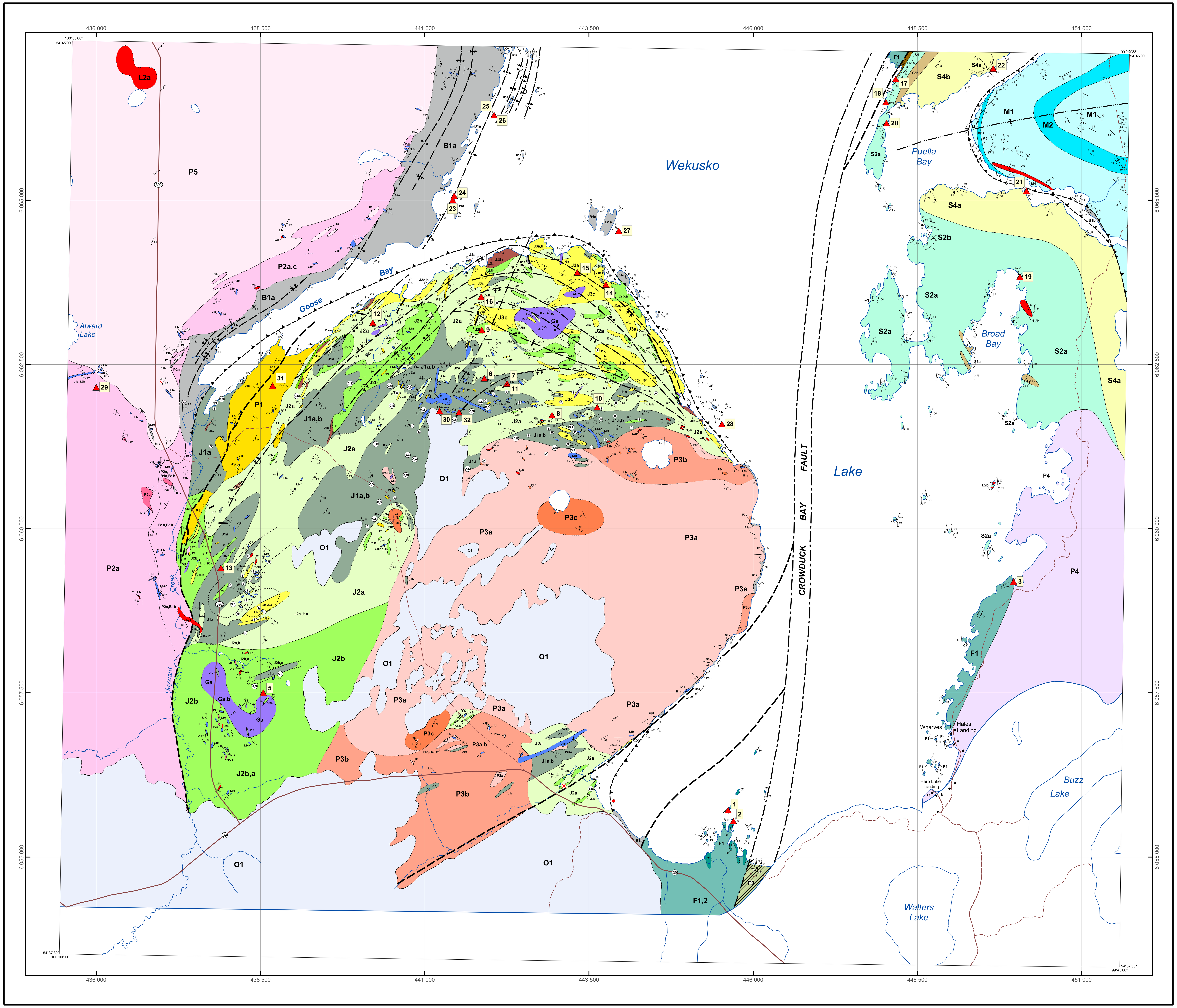
Marginal Notes

Photo locations are indicated on the Photo Index map by red triangles. The photo numbers are displayed next to the triangles and are hyperlinks that can be clicked to jump to the appropriate photograph.

Geoscientific Map MAP2005-2

Geology of the southern Wekusko Lake area, Manitoba

(NTS 63J12NW)



1:20 000

1 0 1 2 3 kilometres

Click to jump to geochemical plots Figure 4

Legend

PALEOZOIC

Ordovician

Dolomite (Red River Formation)

O1	Dolomite (Red River Formation)

PALEOPROTEROZOIC

INTRUSIVE ROCKS (<1.84 Ga); INCLUDES ROCKS OF UNKNOWN AGE

Late intrusive rocks

L2	(a) Quartz diorite, diorite (b) Quartz-plagioclase porphyry; minor intrusion breccia
L1	(a) Gabbro (b) Anorthositic gabbro, quartz gabbro (c) Diabase, aphyric to porphyritic, locally amygdaloidal (d) Diabase, trachytic (e) Diabase, megaphyric, cumulophyric

Granitoid and related rocks

Wekusko Lake pluton (1.84 +8/-6 Ga; Gordon et al., 1990)

P5	Granodiorite, granite; minor pegmatite and aplite

Broad Bay pluton

P4	Granodiorite, granite; minor pegmatite and aplite

Southwest Wekusko Lake pluton

P3a	Tonalite, quartz diorite, leucotonalite; minor diorite
P3b	Diorite, minor quartz diorite
P3c	Granodiorite, granite

Alward Lake pluton

P2	(a) Tonalite, quartz diorite, leucotonalite; minor diorite (b) Diorite, minor quartz diorite
P2c	Granodiorite, granite

Goose Bay porphyry

P1	Quartz-plagioclase porphyry

Mafic to ultramafic rocks

G	(a) gabbro, equigranular to porphyritic (b) hornblendite (c) diabase, aphyric to porphyritic

(SUCCESSOR) VOLCANIC, SEDIMENTARY AND HYPABYSSAL INTRUSIVE ROCKS (1.88–1.83 Ga)

Missi Group fluvial-alluvial sedimentary rocks (1.85–1.83 Ga)

M2	Polymictic conglomerate, sandstone
M1	Sandstone, crossbedded sandstone

Burntwood Group turbidite (1.85–1.84 Ga)

B1	(a) Feldspathic greywacke, pebbly wacke, siltstone and mudstone (b) Paragneiss and migmatite

Puella Bay volcanic, volcaniclastic and sedimentary rocks (1.88–1.87 Ga)

Felsic volcanic rocks (1.76 ±2 Ga; Ansdell et al., 1999)

S4	(a) Dacite tuff, lapilli tuff, scoria-rich, minor heterolithic volcanic conglomerate (b) Massive dacite

Andesite

S3	(a) Plagioclase-phyric andesite: massive, amygdaloidal (b) Aphyric andesite: massive, amygdaloidal, possibly intrusive

Volcanic conglomerate and arenite

S2	(a) Heterolithic trachyandesite cobble- to boulder-conglomerate (b) Heterolithic pebble-conglomerate and arenite, minor mafic wacke
S1	Mafic mudstone

OCEANIC VOLCANIC, SEDIMENTARY AND INTRUSIVE ROCKS (1.88 Ga)

Hayward Creek juvenile arc volcanic, intrusive and sedimentary rocks

Greywacke, resedimented mafic tuff

J4	(a) Feldspathic greywacke, siltstone (b) Mafic tuff, resedimented

Felsic volcanic and related fragmental rocks

J3	(a) Rhyolite, autoclastic breccia; minor associated intrusive rocks (b) Rhyolite flow breccia (c) Felsic volcanic breccia, minor felsic tuff (d) Intermediate to felsic tuff, lapilli tuff

Mafic fragmental rocks

J2a	Heterolithic, mafic to felsic volcanic breccia
J2b	Mafic tuff, crystal tuff, lapilli tuff
J2c	Altered mafic tuff (andalusite-bearing)

Basalt

J1	(a) Basalt flows, minor autoclastic breccia and minor associated intrusive rocks (b) Basalt flow breccia (c) Hornblende-plagioclase gneiss, amphibolite

South Wekusko Lake ocean floor volcanic and intrusive rocks

F3	Mafic phyllonite: amphibole-chlorite-carbonate schist
F2	Gabbro
F1	Tholeiitic basalt; pillowed, aphyric

Symbols

- Axial trace of first-generation anticline, (upright, overturned)
- Axial trace of first-generation syncline, (upright, overturned)
- Axial trace of third-generation anticline
- Axial trace of third-generation syncline
- Fault
- Shear zone
- Thrust
- Alteration zone
- Geological contact (approximate, gradational, assumed)
- Diamond-drill hole, kimberlite occurrence
- Copper-Man, VMS deposit
- Bedding: tops unknown, known, overturned
- Pillows: tops unknown, known
- Igneous layering: tops unknown, known
- Flow contact: tops unknown, known
- Foliation: generation unknown, first generation, second generation
- Fault
- Shear zone
- Fold axis: generation unknown, second generation
- Stretch lineation
- Fold axial-plane
- Fold symmetry: symmetrical, s-shaped, second generation
- Spaced cleavage: generation unknown, second generation
- Provincial road
- Gravel road
- Trail

Alteration

- Ⓐ Amphibolitization
- Ⓔ Epidotization
- Ⓒ Carbonatization
- Ⓢ Silicification

Geology by H.P. Gilbert (1992–1994) and A.H. Bailes (parts of 1995, 1997 and 1998)

Cartography by M.E. McFarlane

Suggested reference:
Gilbert, H.P. and Bailes, A.H. 2005: Geology of the southern Wekusko Lake area, Manitoba (NTS 63J12NW); Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, Geoscientific Map MAP2005-2, scale 1:20 000.

Keywords:
basalts; calc-alkalic composition; Churchill Province; Copper-Man deposit; economic geology; Flin Flon Belt; geochemistry; island arcs; kimberlite; Manitoba; massive sulphide deposits; ocean floors; Paleoproterozoic; Precambrian; rare earths; rhyolites; Snow Lake; supracrustals; tholeiite; Trans-Hudson Orogeny; VMS deposits; volcanism; Wekusko Lake

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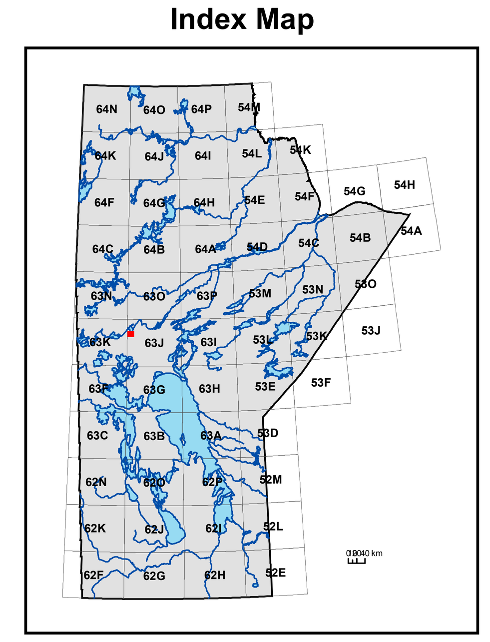

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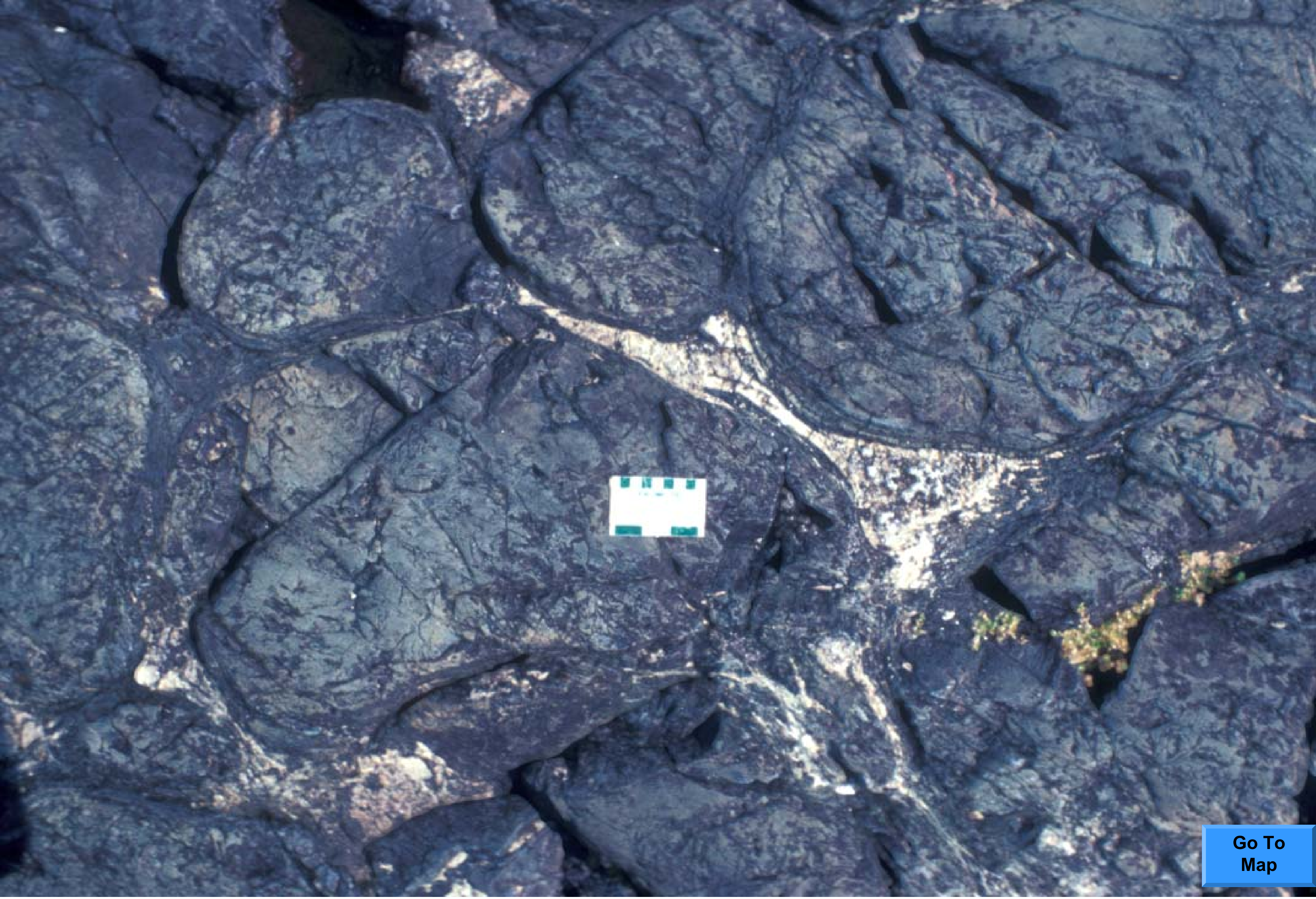

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Figure 1: Pillowed, nonvesicular aphyric basalt (unit F1). Pillows have 1 cm wide dark rims and light-coloured, epidotized interpillow domains. UTM Zone 14U, 445618E, 6055717N.

Figure 2: Pillowed aphyric basalt (unit F1). The large pillow in the centre displays a series of drain-back cavities up to 20 cm long. The flat bottoms to the drain-back cavities were horizontal when formed. The curved tops indicate the pillows young toward the west (left side of the photo). The cavities are filled by epidote. UTM Zone 14U, 445696E, 6055549N.

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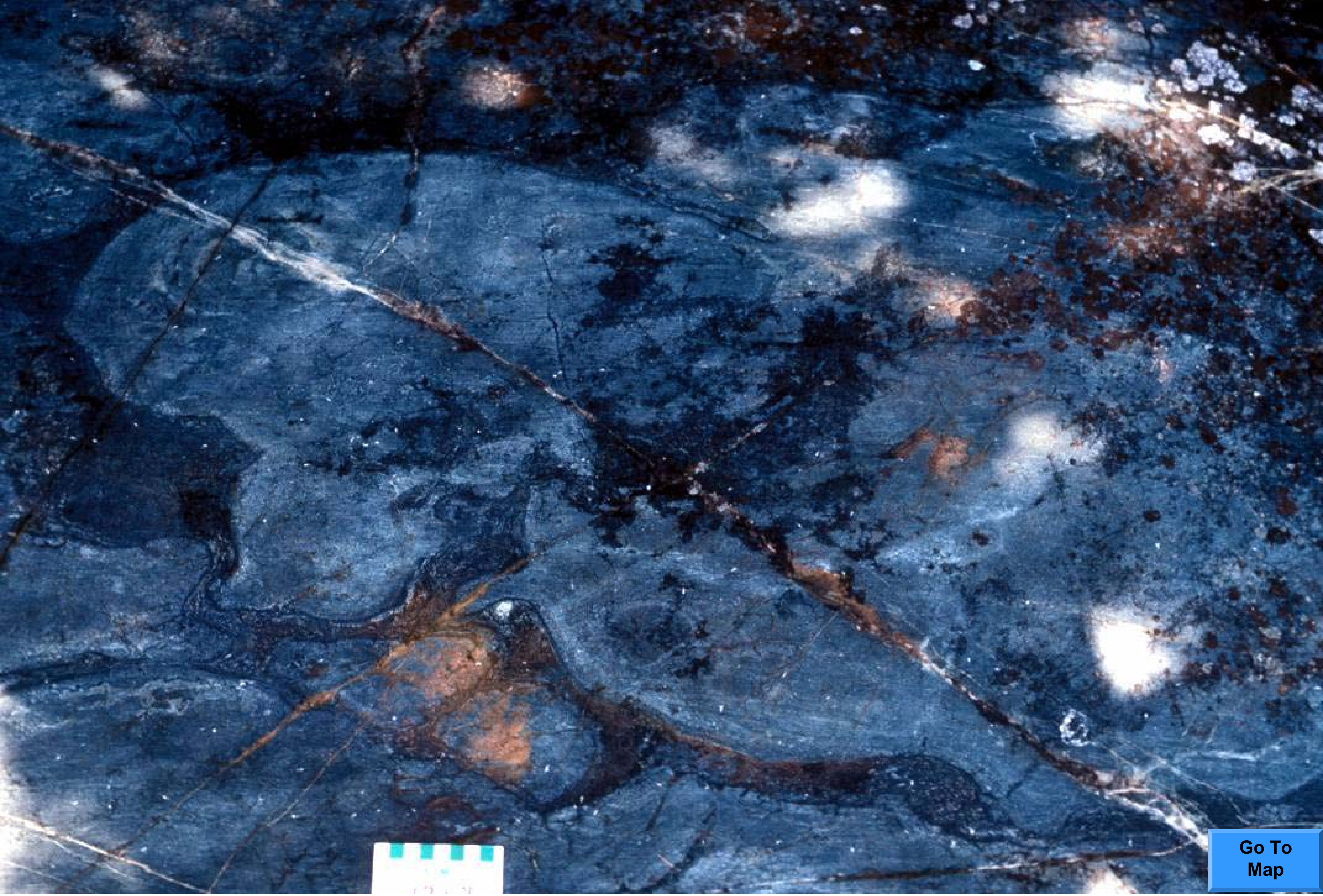

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Figure 3: Pillowed aphyric basalt (unit F1). The bun-shaped pillow in the centre indicates the pillowed flow faces east-northeast (top of the photo). Light-coloured domains are areas of silicification. UTM Zone 14U, 450015E, 6058931N.

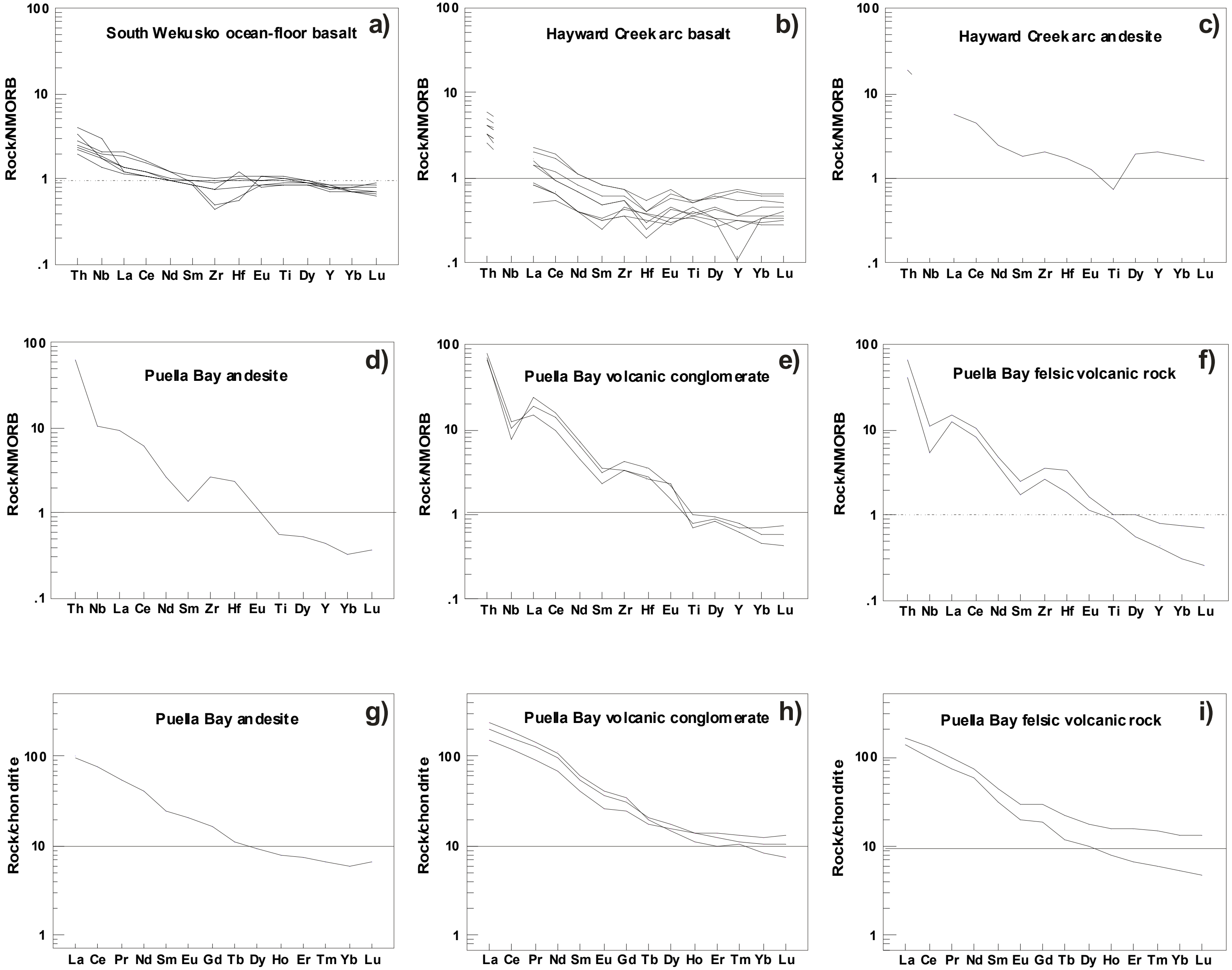

Figure 4: a) to f) N-MORB–normalized extended element plots of arc basaltic rocks in the west part, MORB-like rocks in the south part, and arc-type intermediate to felsic volcanic rocks in the east part of the southern Wekusko Lake area; normalizing values from Sun and McDonough (1989). **g) to i)** Chondrite-normalized extended element plots of arc-type intermediate to felsic volcanic rocks in the east part of the southern Wekusko Lake area; normalizing values from Sun and McDonough (1989).

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Figure 5: Pillowed aphyric basalt (unit J1a) with epidotic and silicic alteration. UTM Zone 14U, 438541E, 6057506N.

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Figure 6: Rhyolite fragment within monolithic volcanic breccia (unit J3b). Internal conchoidal fractures in the clast are attributed to cooling stress and indicate the detritus is derived by fragmentation of massive felsic volcanic rock; the deposit possibly represents the marginal breccia facies of a rhyolite flow. UTM Zone 14U, 441905E, 6062292N.

Figure 7: Monolithic, clast-supported rhyolite breccia of inferred autoclastic origin (unit J3b). UTM Zone 14U, 442252E, 6062213N.

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Figure 8: Massive rhyolite lobe within plagioclase-phyric, rhyolitic fragmental rock (unit J3c). UTM Zone 14U, 442936E, 6061731N.

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Figure 9: Heterolithic volcanic breccia containing a block of redeposited lapilli tuff (unit J2a). UTM Zone 14U, 441866E, 6063029N.

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Figure 10: Heterolithic volcanic breccia with subrounded to angular, locally irregularly shaped fragments (unit J2a). UTM Zone 14U, 443624E, 6061851N.

Figure 11: Heterolithic volcanic breccia with porphyritic mafic and felsic clasts and quartz-plagioclase porphyry fragments (unit J2a). UTM Zone 14U, 442252E, 6062213N.

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Figure 12: Heterolithic volcanic breccia with angular to irregularly shaped, mafic to felsic clasts (unit J2a). UTM Zone 14U, 440208E, 6063139N.

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Figure 13: Layered tuff (unit J2a) showing crossbedding that is truncated by overlying volcanic breccia, interpreted as a mass-flow deposit. UTM Zone 14U, 437895E, 6059404N.

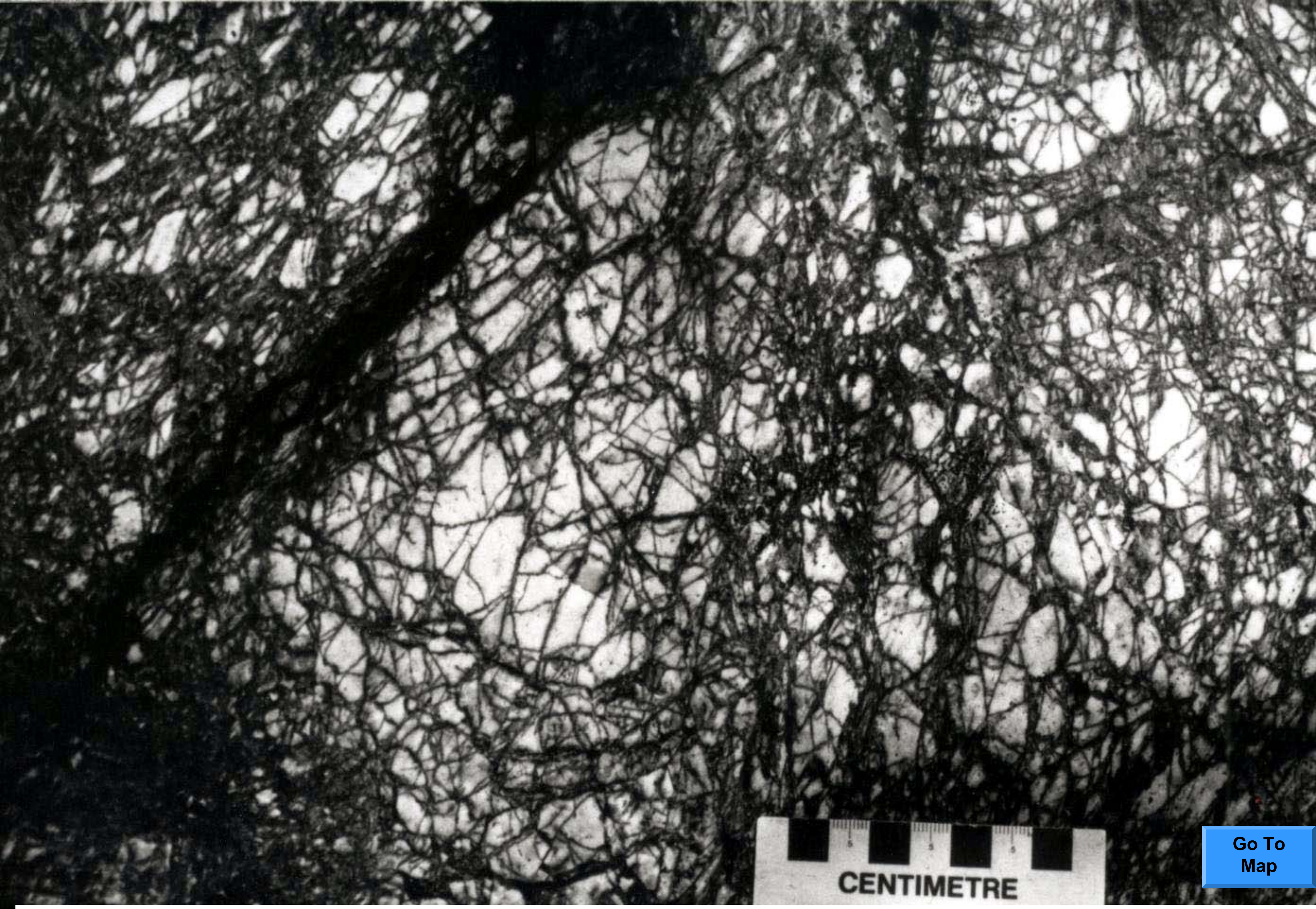

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Figure 14: Brecciated plagioclase-phyric rhyolite in the marginal part of a massive volcanic flow (unit J3a); the chlorite-filled fracture network is attributed to in situ brecciation during cooling of the extrusive unit. UTM Zone 14U, 443756E, 6063720N.

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Figure 15: Flow-banded rhyolite block in monolithic, felsic volcanic breccia (unit J3b). UTM Zone 14U, 443322E, 6063903N.

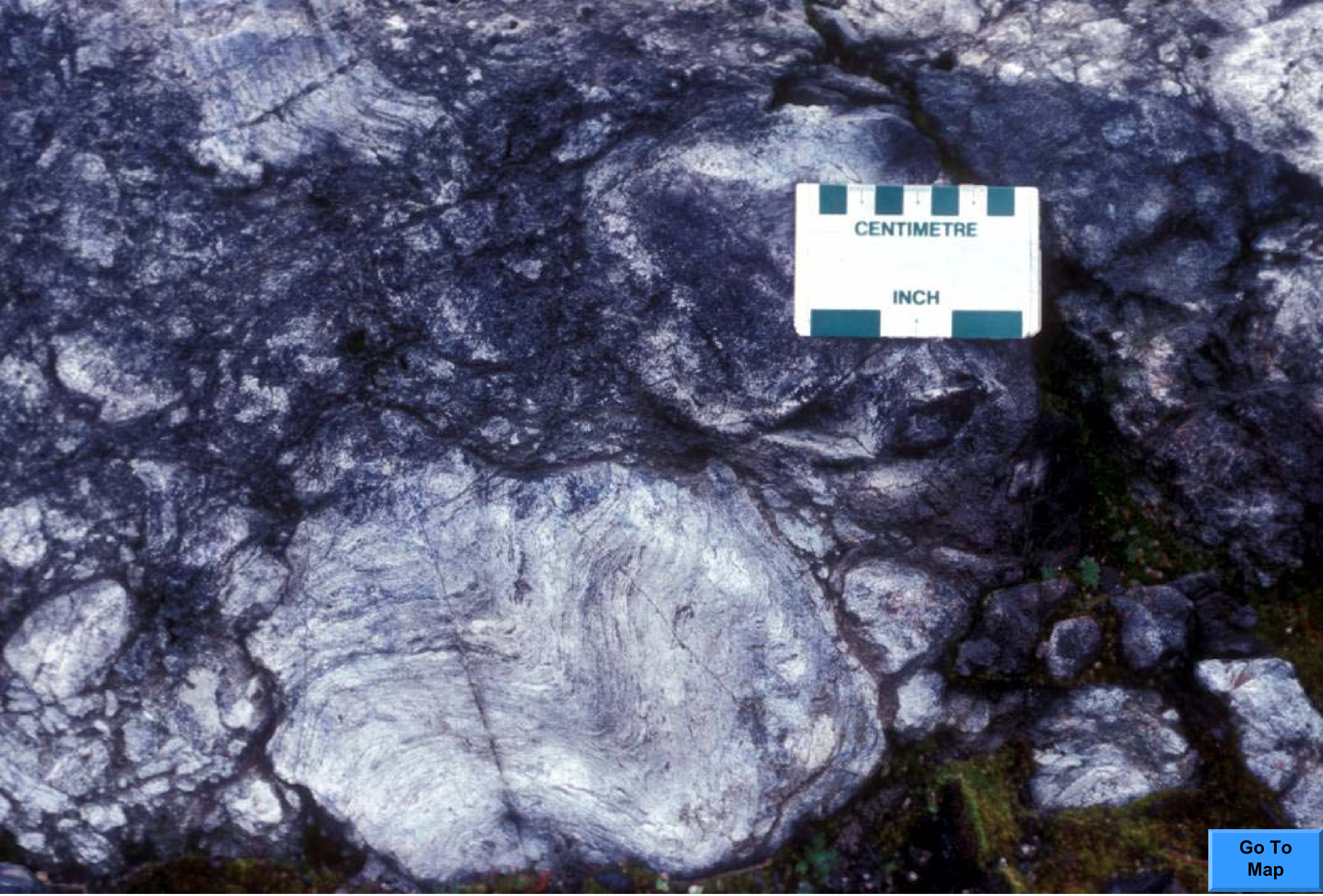

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Figure 16: Flow-banded rhyolite block in monolithic, felsic volcanic breccia (unit J3b). UTM Zone 14U, 441858E, 6063536N.

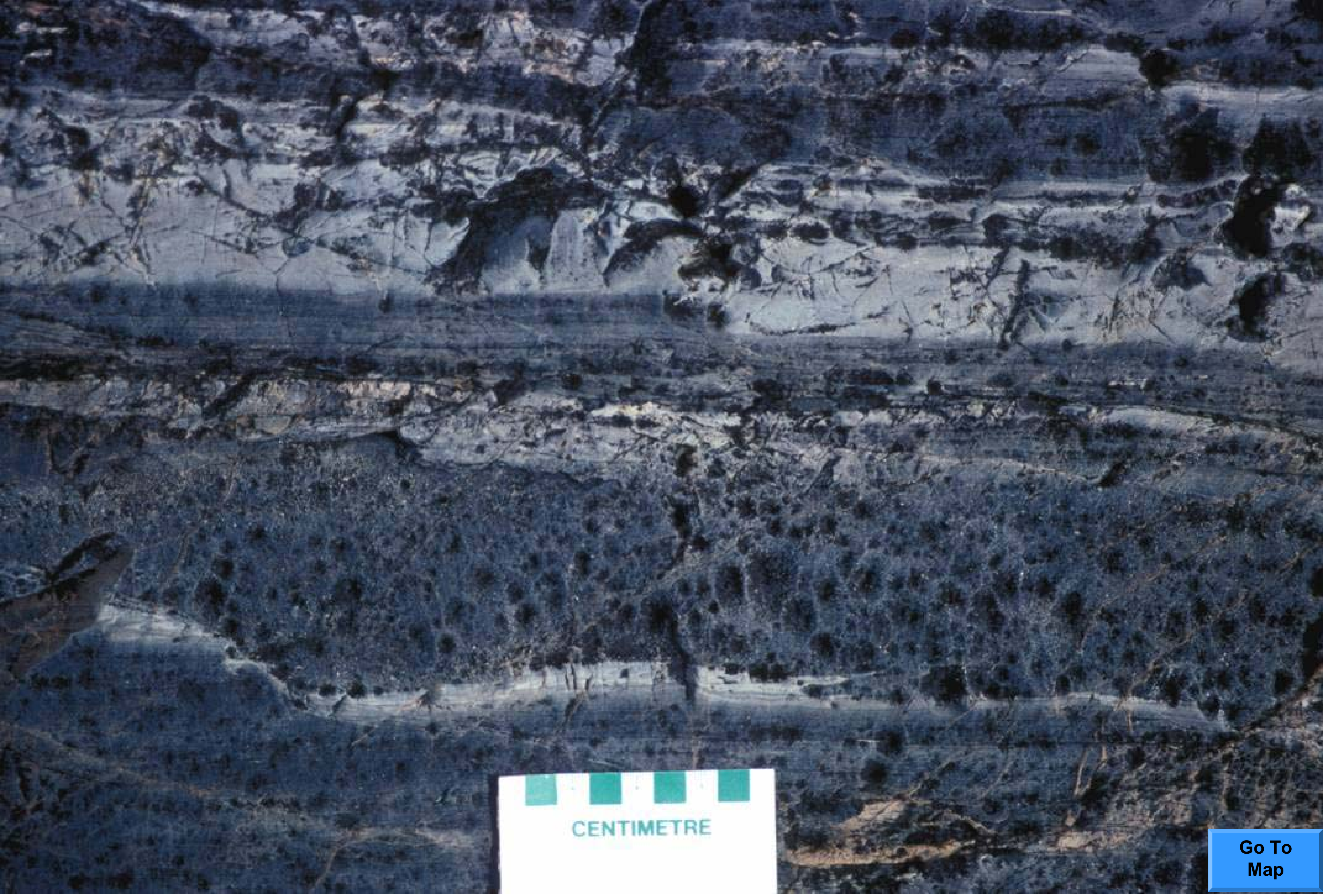

Figure 17: Mafic mudstone and siltstone (unit S1). Note the white mud tops of the siltstone beds and the flame structure at the top of one of the white bed tops, just above the scale card. The mudstone is likely a fine-grained turbidite deposit, genetically related to the directly overlying mafic volcaniclastic rocks of unit S4a. UTM Zone 14U, 448169E, 6066851N.

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Figure 18: Bedded, plagioclase crystal–rich, mafic volcaniclastic rock (unit S2a). Beds are internally zoned and display the A, B, D and E Bouma bed forms of turbidity-current deposited detritus. Coarser varieties of this unit on this outcrop contain trachyandesite pebbles and cobbles, some with scoriaceous texture. UTM Zone 14U, 448018E, 6066496N.

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Figure 19: Heterolithic mafic volcanic conglomerate (unit S2a). Dashed line outlines a subrounded boulder of trachyandesite containing a quartz-vein system, terminated at the boulder margin. UTM Zone 14U, 450060E, 6063837N.

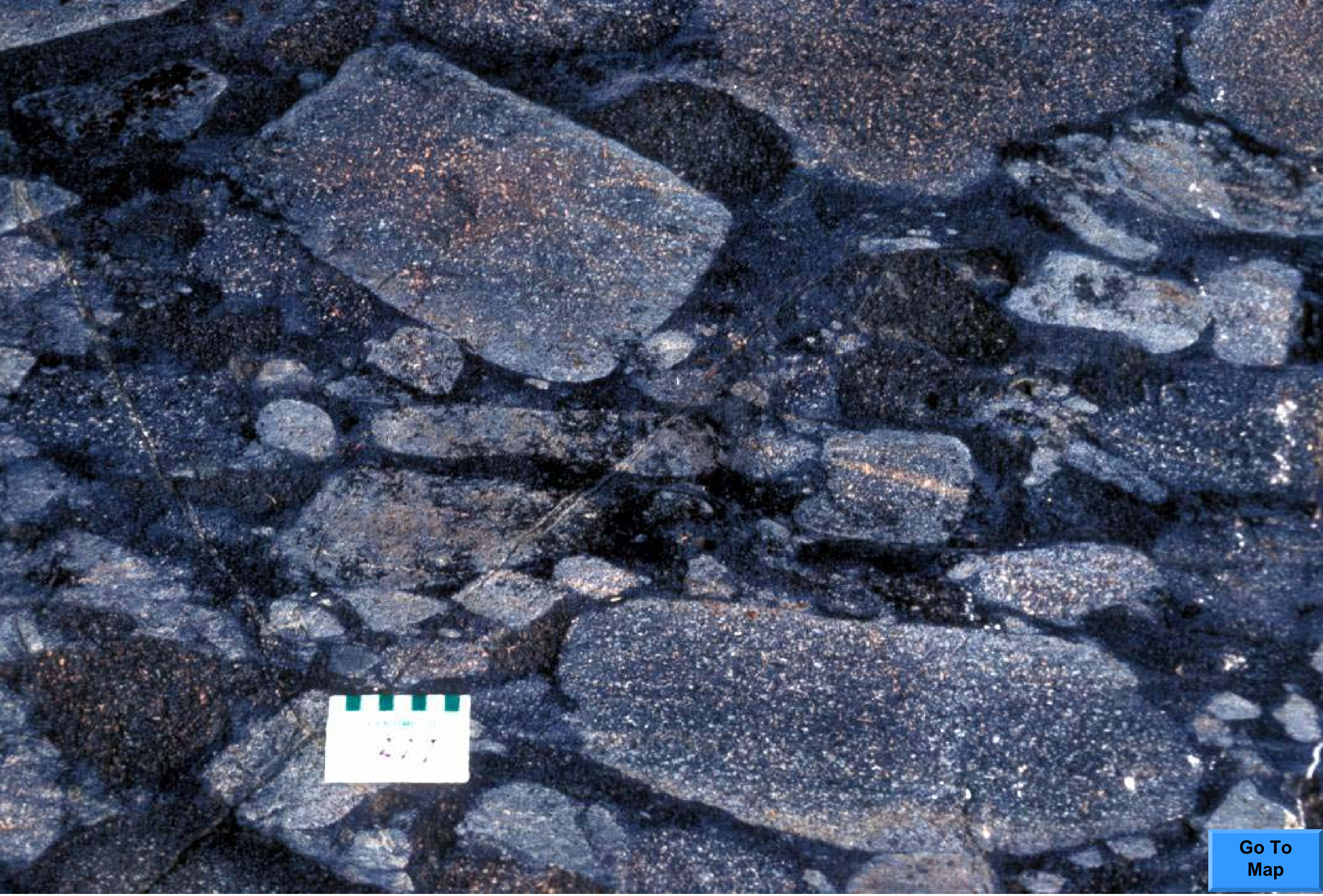

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Figure 20: Framework-supported, heterolithic, trachyandesite cobble- to boulder-conglomerate (unit S2a). Note the joint-bounded (rectilinear) character of the subrounded volcanic cobbles and their uniformly plagioclase-phyric texture. UTM Zone 14U, 448028E, 6066177N.

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Figure 21: Polygonally jointed, massive rhyolite (unit S4b). Light-coloured domains are remnants of the original joint columns. Note zonation of alteration about the remnants of the joint columns. UTM Zone 14, 4501589E, 6065147N.

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Figure 22: Framework-supported, heterolithic, intermediate to felsic cobble- to boulder-conglomerate (unit S4a). This unit occurs as screens between massive rhyodacite, along the shoreline and to the east in the area north of Stuart Lake. UTM Zone 14U, 449652E, 6067009N.

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Figure 23: Turbidite sediment showing AB or ABC Bouma divisions (unit B1a). A postdepositional calcsilicate (epidotic) concretion straddles the contact between two cyclic sedimentary units. UTM Zone 14U, 441425E, 6065006N.

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Figure 24: Contact between two cyclic turbidite units (unit B1a). The basal, graded (A) division of the upper unit has scoured the underlying siltstone; a lensoid raft of siltstone (vaguely defined) within the scoured zone was probably emplaced by slumping of the partly consolidated sediment substrate during deposition of the graded deposit. Note the flame structure within mudstone of the older turbidite unit, and the calcsilicate concretion in the upper cyclic unit. UTM Zone 14U, 441446E, 6065072N.

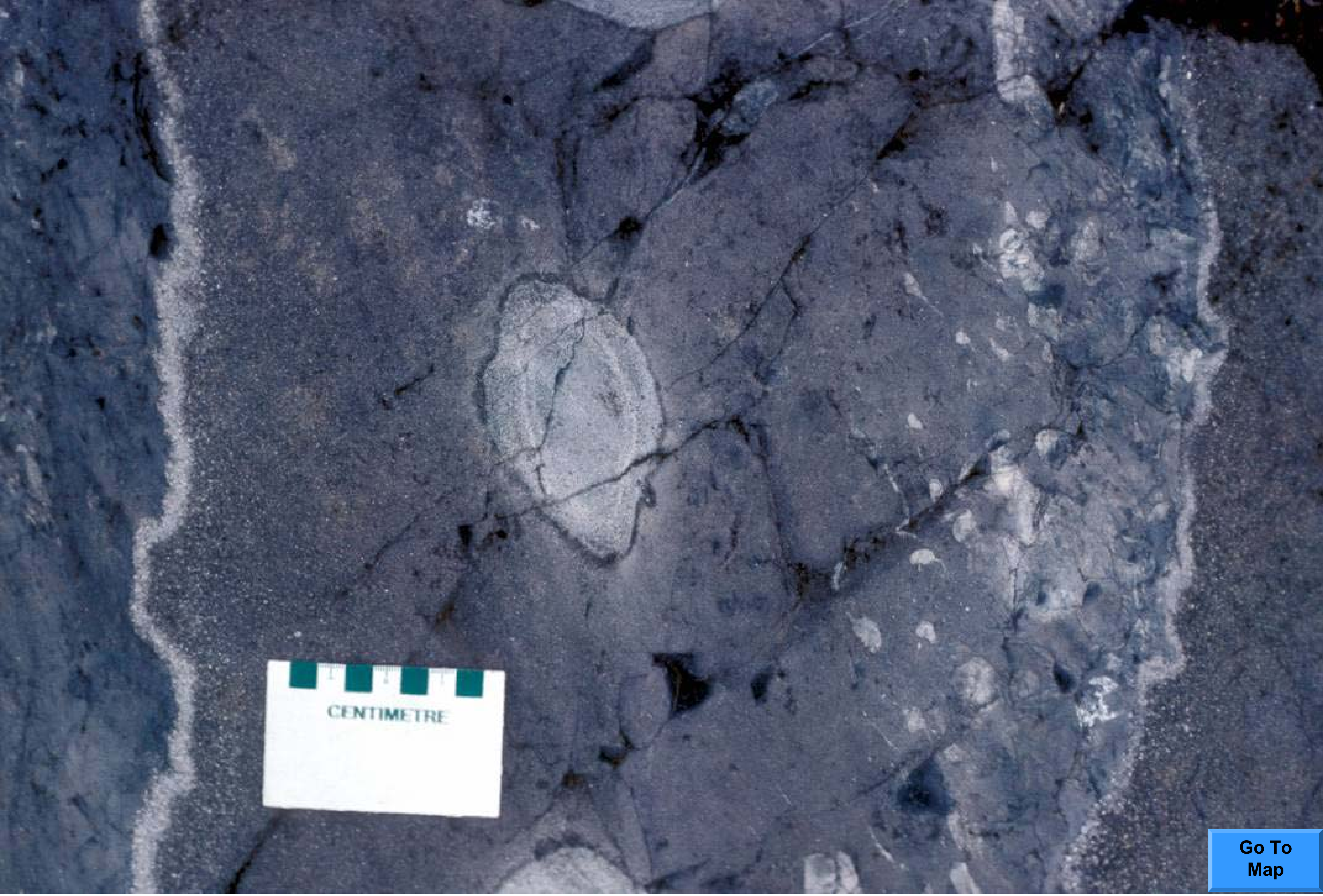

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Figure 25: Turbidite deposit showing ABDE Bouma divisions and a calcsilicate concretion (unit B1a). Irregular, very pale gray to white fragments in the upper part of the deposit are interpreted a rip-ups derived from the uppermost E-division of the underlying turbidite unit. UTM Zone 14U, 442055E, 6066300N.

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Figure 26: Part of a turbidite sequence, showing flame structures at the contact between two cyclic units (unit B1a). Note the stratabound sedimentary folds within white, cherty laminae of division E in the unit at left. UTM Zone 14U, 442055E, 6066300N.

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Figure 27: Flame structure at the contact between two cyclic turbidite units (unit B1a). UTM Zone 14U, 443953E, 6064539N.

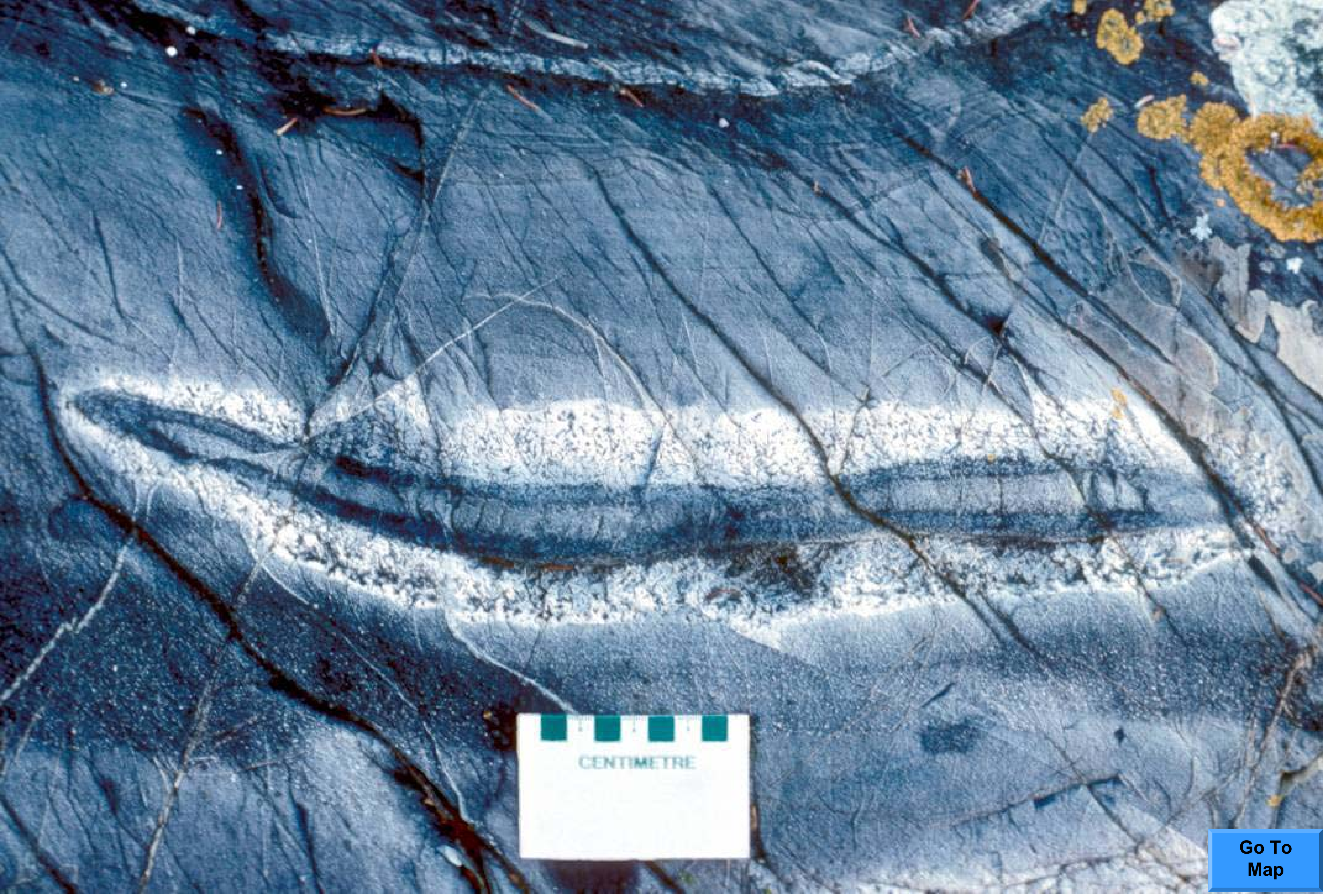

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Figure 28: Calcsilicate concretion within the lower part of a cyclic turbidite unit, at an intermediate stage of development (unit B1a). An elongate, white domain of feldspathic alteration with randomly distributed amphibole porphyroblasts is cored by unaltered grey siltstone. UTM Zone 14U, 445522E, 6061596N.

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Figure 29: Diabase (unit L1c) intruded by felsic porphyry. The felsic veining was evidently fracture controlled, but the agmatitic pattern has been influenced by partial assimilation of the mafic hostrock by the porphyry. UTM Zone 14U, 435999E, 6062154N.

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Figure 30: Diabase (unit L1c) with hornblende pseudomorphs after pyroxene and wispy feldspathic veinlets derived from subparallel thermal contraction fractures. UTM Zone 14U, 441224E, 6061795N.

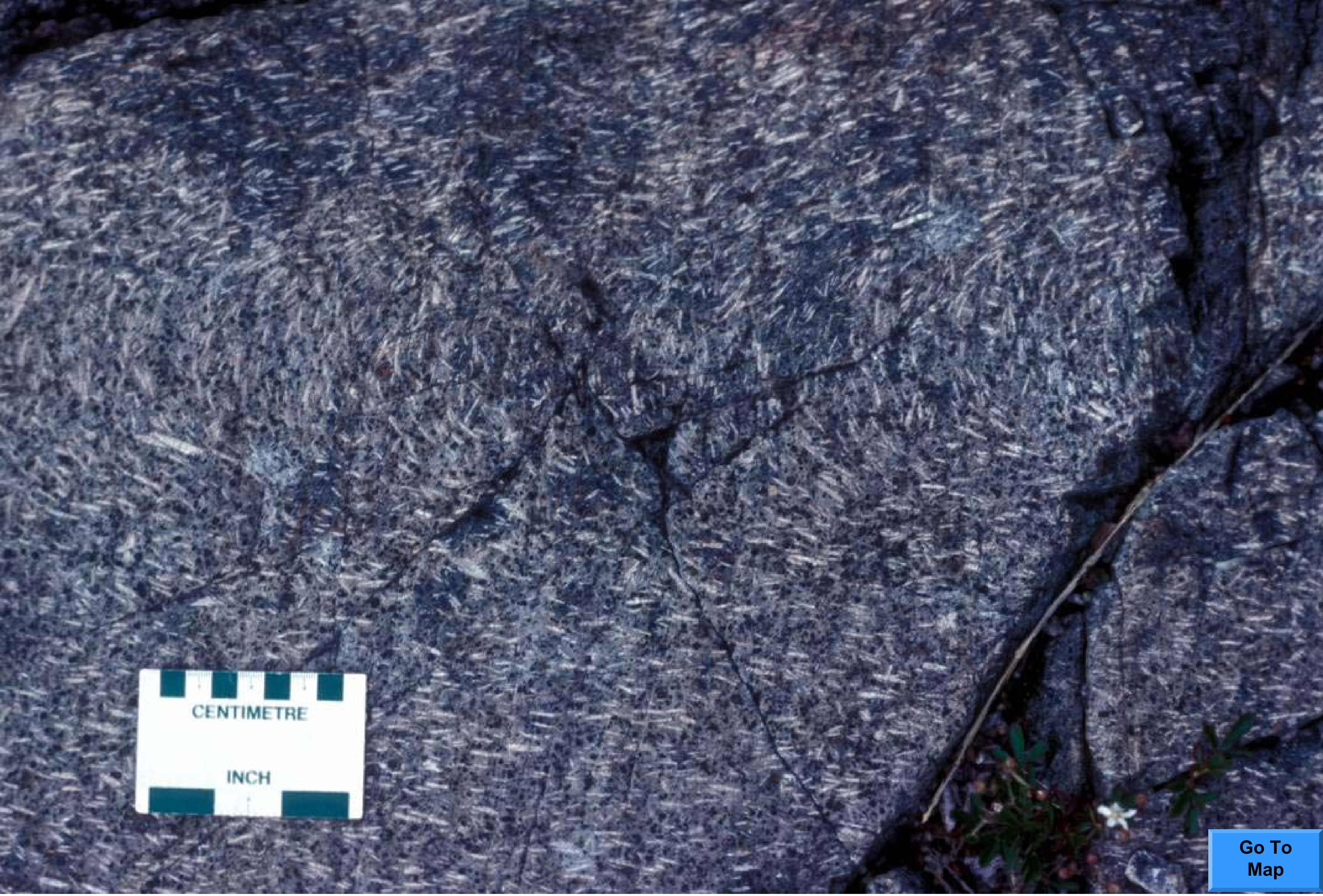

Figure 31: Trachytic diabase (unit L1d) with flow-oriented plagioclase laths (1–2 cm long) and pyroxene phenocrysts altered to hornblende. UTM Zone 14U, 438683E, 6062180N.

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Figure 32: Megaphyric, cumulophyric diabase (unit L1e). Note that large plagioclase phenocrysts locally display synneusis texture and are partially resorbed, whereas smaller plagioclases are aggregated in round cumulophyric bodies, one of which (at lower right) is partly dislocated. The diabase also contains 2–5 mm pyroxene phenocrysts altered to hornblende. UTM Zone 14U, 441521E, 6061775N.

MARGINAL NOTES

Geological setting

The southern Wekusko Lake map area (NTS 63J12NW), which is located 20 km southeast of Snow Lake, Manitoba, is a 240 km^2 portion of the eastern part of the Flin Flon Belt, lying within the Paleoproterozoic Trans-Hudson Orogen. Supracrustal rocks of the Flin Flon Belt are part of a structurally complex collage of diverse components, most of which have counterparts in modern oceanic arcs, such as the Tonga-Kermadec arc (Ewart and Hawkesworth, 1987) and the Fiji arc (Gill, 1987). These components include 1) geochemically distinctive volcanic assemblages of juvenile arc, arc rift, ocean floor and oceanic island affinity; 2) sedimentary and minor volcanic deposits of both turbidite and molasse (fluvial to shallow-marine) type; and 3) plutonic intrusive rocks. Numerous studies over the last decade (David et al., 1996; Lucas et al., 1996; NATMAP Shield Margin Working Group, 1998) have chronicled a detailed magmatic and tectonic history spanning a period of approximately 100 million years (1.91–1.81 Ga), which includes the inception of arc magmatism (1.91–1.88 Ga), subsequent ‘successor arc’ magmatism and sedimentation (1.87–1.84 Ga), and collisional orogeny (1.84–1.81 Ga).

The southern Wekusko Lake map area contains no less than five distinct tectonostratigraphic supracrustal components (south Wekusko Lake, Hayward Creek, Puella Bay, Burntwood Group, Missi Group), together with parts of several large granitoid intrusions. The area is divided by a major, north- to north-northeast-trending fault, the ‘Crowduck Bay Fault’ of Ansdell and Connors (1993), into western and eastern parts that contain significantly different stratigraphic and structural components. The fault, which extends from the northeast corner to the south margin of the map area, traverses the south Wekusko Lake ocean floor basalt sequence (units F1 to F3) and separates the 1.88 Ga Hayward Creek juvenile oceanic arc volcanic rocks (units J1 to J4) to the west from the 1.876 Ga Puella Bay epiclastic and volcaniclastic ‘successor basin’ deposits (units S1 to S4) to the east. The fault also marks the eastern boundary of a domain of 1.85–1.84 Ga (David et al., 1996) Burntwood Group greywacke, siltstone and mudstone turbidite and derived paragneiss (units B1a and B1b) more than 10 km wide. The area east of the fault is dominated by a sequence of Missi Group fluvial-alluvial sedimentary (units M1 and M2) and volcanic rocks of a similar 1.85–1.83 Ga age (Ansdell et al., 1992). The Missi Group has been interpreted as a possible continental facies equivalent of the marine-facies Burntwood Group (Lucas et al., 1996).

Geochemical data for volcanic rocks in the south Wekusko Lake area (south Wekusko Lake, Hayward Creek, Puella Bay suites) are contained in MGS Data Repository item 2005003[1], which also provides extended element geochemical plots, lithological details of the analyzed rocks, and field photographs showing details of selected rock units in the map area. These geochemical plots and field photographs are referenced as Figures 1–32 in the following text.

Description of units

Oceanic volcanic, sedimentary and intrusive rocks (units F and J; >1.88 Ga)

Most of the supracrustal components of the Flin Flon Belt range in age from 1.91 to 1.88 Ga (Lucas et al., 1996) and represent the products of ocean floor volcanism and arc magmatism (Syme and Bailes, 1993; Stern et al., 1995a, b). Variations in lithology and geochemical associations demonstrate that these sequences are disparate parts of various ocean floor and arc assemblages, tectonically juxtaposed during intraoceanic accretion at ca. 1.88–1.87 Ga, and subsequent continental collision at ca. 1.84–1.79 Ga (Lucas et al., 1996). The arc and ocean floor assemblages vary in their potential to host volcanogenic massive sulphide (VMS) deposits, with most VMS deposits associated with arc volcanic assemblages (Syme and Bailes, 1993).

South Wekusko Lake ocean floor volcanic and intrusive rocks (units F1–F3)

This sequence comprises pillowed (Figures 1–3), aphyric, tholeiitic basalt flows (unit F1), related gabbro sills (unit F2) and mafic phyllonite (unit F3). The basalt domain is up to 4 km wide and forms an east-facing sequence at the south end of Wekusko Lake and a west-facing sequence on the east shore of Wekusko Lake. Similar to other ocean floor assemblages in the

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[1] MGS Data Repository item (DRI) 2005003 is available on-line to download free of charge at www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Industry, Economic Development and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

Flin Flon Belt, the south Wekusko Lake assemblage is devoid of felsic volcanic rocks and volcaniclastic units, except for volumetrically minor autoclastic facies of mafic flows. South Wekusko Lake basalt is characterized by a flat to slightly negatively sloping rare earth element (REE) profile, similar to that of N-MORB but with relatively elevated light rare earth element contents (Figure 4, plot a). The south Wekusko Lake basalt is geochemically akin to normal and enriched mid-ocean ridge basalt (N- and E-MORB; Stern et al., 1995b) of the 1.90 Ga (Stern et al., 1995b) Elbow-Athapapuskow ocean floor assemblage of the south-central part of the western Flin Flon Belt, and may represent a tectonic remnant of that ocean floor terrane.

Hayward Creek juvenile arc volcanic, intrusive and sedimentary rocks (units J1 to J4)

The Hayward Creek domain (Gilbert, 1994) is dominated by volcanic fragmental rocks. It consists of a lithologically diverse suite of basalt (unit J1), mafic fragmental rocks (unit J2), mixed felsic flows and fragmental rocks (unit J3), and volcaniclastic greywacke and mafic tuff (unit J4). The mafic flows (unit J1) are typically massive and aphyric to plagioclase-phyric types with local zones of flow breccia; pillows occur only sporadically in these flow units (Figure 5). The mafic flows constitute approximately one-third of the Hayward Creek assemblage and are typically intercalated with subordinate, lensoid rhyolite units (Figures 6–8) and heterolithic volcanic fragmental deposits of possible mass-flow and turbidity-current origin. Volcaniclastic and epiclastic rocks (units J2 and J4) vary from coarse volcanic breccia and lapilli tuff, largely localized in the north and central portions of the Hayward Creek domain (Figures 9–12), to finer grained tuff, crystal tuff and related turbidite deposits in the southwest (Figure 13). The mafic volcanic and volcaniclastic-epiclastic deposits are overlain, at the north margin of this domain, by a conspicuous (>200 m thick) unit of extrusive rhyolite and related felsic volcaniclastic rocks (unit J3; Figures 14–16).

The Hayward Creek juvenile arc volcanic rocks display elevated contents of light rare earth elements (LREE), high Th and depleted high-field-strength elements (HFSE; Figure 4, plots b and c). They are geochemically akin to 1.89 Ga (David et al., 1996) volcanic rocks of the Snow Lake arc assemblage of Bailes and Galley (1999); Nb depletion and high Th/Nb ratios that are characteristic of the Snow Lake arc assemblage are probably also typical of the Hayward Creek volcanic rocks, although Nb analytical data are not available for the latter suite. Their transitional, tholeiitic to calcalkaline geochemical affinity and trace-element signature, together with the prevalence of fragmental lithological types, are most similar to the upper, geochemically more evolved and volcaniclastic-dominated part of the Snow Lake arc assemblage (Bailes and Galley, 1996).

Because the Snow Lake arc assemblage contains most of the VMS deposits in the eastern Flin Flon–Snow Lake belt (*see* Bailes and Galley, 1999), the Hayward Creek suite is considered to provide above-average potential for the discovery of base-metal mineral deposits. Zones of pervasive silicification and epidotization, which are common in the Hayward Creek juvenile arc rocks, are attributed to early sea-floor alteration but could also be partly due to synvolcanic hydrothermal systems.

'Successor' volcanic, sedimentary and hypabyssal intrusive rocks (units S, B and M; 1.88–1.83 Ga)

Volcanic, volcaniclastic and sedimentary rocks younger that the 1.92–1.88 Ga tectonostratigraphic assemblages occur throughout the Flin Flon Belt and have been termed 'successor basin' deposits (NATMAP Shield Margin Project Working Group, 1998). These sedimentary and volcanic rocks may represent the remnants of volcanic arcs and depositional basins that were built upon accreted older 1.92–1.88 Ga oceanic assemblages. The 'successor arc and basin' deposits fall into two contrasting types: older (>1.85 Ga) marine to subaerial volcaniclastic and epiclastic deposits (e.g., Puella Bay (unit S)) and younger (<1.85 Ga) subaerial to marine deposits (e.g., Missi (unit M) and Burntwood (unit B)) derived by erosion of successor arc volcanic and plutonic rocks, as well as older tectonostratigraphic assemblages (NATMAP Shield Margin Project Working Group, 1998).

Puella Bay volcanic, volcaniclastic and sedimentary rocks (1.88–1.87 Ga; units S1 to S4)

The Puella Bay suite consists of a basal mafic mudstone (unit S1), a heterolithic trachyandesite cobble to boulder conglomerate with subordinate feldspathic arenite interlayers (unit S2), amygdaloidal aphyric to plagioclase-phyric massive andesite flows (unit S3), and scoria-rich dacitic tuff to lapilli tuff and massive dacite (unit S4). These rocks were included in the >1.85 Ga 'Schist-Wekusko Suite' that was interpreted to be part of a postaccretionary 'successor arc' succession built on the older, already accreted 'juvenile oceanic arc' (NATMAP

Shield Margin Working Group, 1998; Stern at al., 1999). Recent dating of the Puella Bay dacite (unit S4) at ca. 1.876 ±2 Ga (Ansdell et al., 1999) indicates this sequence to be transitional in age between the 1.91–1.88 Ga ‘juvenile oceanic arc’ and the 1.87–1.84 Ga ‘successor arc’ successions. It is thus uncertain whether this volcanism is part of an old ‘successor arc’ or a young ‘juvenile oceanic arc’ sequence.

The basal mafic mudstone (unit S1) forms a zone, less than 5 m wide, that is exposed in a shoreline outcrop at the northeastern boundary of the map area (Figure 17). Its contact with the structurally underlying south Wekusko Lake basalt (unit F1), located to the north, is not exposed but is interpreted to be a fault. Its contact with the directly overlying trachyandesite cobble to boulder conglomerate (unit S2) is conformable and gradational.

The base of unit S2 is a sequence of bedded mafic to intermediate siltstone, greywacke and pebble conglomerate, up 15 m wide, that grades rapidly upward into a monotonous sequence of heterolithic trachyandesite cobble and boulder conglomerate (unit S2a) several kilometres in thickness. The bedded base of unit S2 includes abundant amygdaloidal intermediate volcanic clasts and displays normal to reverse size-grading (Figure 18), scour channels and Bouma bed zonation; the latter are consistent with deposition by turbulent density currents. The overlying trachyandesite cobble to boulder conglomerate of unit S2a displays a heterolithic, dominantly matrix-supported clast population, with no obvious size-grading or layering. The andesite cobbles and boulders, which can be up to 1.7 m in size, are typically amygdaloidal, comprise aphyric to prominently plagioclase-phyric types and vary from slightly rounded to subrounded (Figures 19, 20); some clasts display slightly rounded, fracture-bounded shapes. Although not definitive, these features are consistent with attrition during subaerial transport, with subsequent redeposition by mass-wasting processes, characteristic of debris flows. The upper 200 m of this unit (S2b), which is gradational into rocks of unit S4, consists of pebble conglomerate and arenite that is composed of matrix-supported, well-rounded, intermediate to felsic clasts with local quartz pebbles and epizonal to mesozonal, granitic-textured pebbles and cobbles. The presence of well-rounded clasts, quartz pebbles, epizonal to hypabyssal felsic granitic-textured rocks, and quartz-rich arenite suggests derivation from an uplifted terrane in which clasts may have seen subaerial exposure and fluvial reworking prior to deposition in unit S2b.

Aphyric to plagioclase-phyric amygdaloidal andesite (unit S3) is volumetrically minor and typically occurs as discrete bodies in the heterolithic trachyandesite conglomerate (unit S2). Some bodies may be intrusive, but their high vesicularity, local polygonal cooling joints and lateral continuity, parallel to known bedding in hostrocks, suggest they are most likely flows.

Felsic volcanic rocks (unit S4) form the top of the exposed Puella Bay sequence. They consist of a lower layered sequence of scoria-rich dacite tuff and lapilli tuff (unit S4a) and an overlying massive dacite (unit S4b). Well-preserved scoria-rich dacite tuff and lapilli tuff, which contain a high abundance of pumiceous fragments, are interpreted to have been deposited during pyroclastic eruptions. They display an upward gradation into more massive dacite (unit S4b) with local nebulous clasts and rare polygonal joints (Figure 21). Massive dacite (unit S4b) dominates the north shore of Puella Bay, but locally includes fragmental varieties and intercalated lenses of framework-supported pebble and boulder conglomerate (Figure 22); clasts in these lenses are typically well rounded, probably due to subaerial transport.

Geochemically analyzed samples of unit S2 andesite boulders, unit S3 andesite flows and unit S4 monolithic dacite tuff and lapilli tuff are distinguished from the Hayward Creek juvenile arc tholeiite and south Wekusko Lake ocean-floor volcanic rocks by their significantly higher LREE and HFSE contents and La/Yb ratios (Figure 4, plots d–i). Their trace-element contents and steep, negative-sloping REE profiles are consistent with a geochemically evolved, calcalkaline magma source. The Puella Bay suite is characterized by a negative Nb anomaly that suggests it originated in a subduction-zone tectonic setting.

Burntwood Group (1.855–1.84 Ga; unit B) and Missi Group (1.85–1.83 Ga; unit M)

The Burntwood Group and Missi Group sedimentary rocks occur sporadically throughout the Flin Flon Belt and together are the dominant constituents of the adjacent Kisseynew sedimentary belt, located north of the Flin Flon Belt. The eastern end of the Flin Flon Belt has the highest abundance of these sedimentary rocks, which are commonly preserved with many primary sedimentary structures intact, in contrast to the strongly recrystallized paragneissic equivalents in the adjacent Kisseynew belt. The Burntwood Group includes mainly greywacke, siltstone and mudstone, with bedforms and sedimentary structures indicating deposition by turbidity currents in a submarine fan environment (Bailes, 1980a, b). The Missi Group includes subaerial alluvial and braided stream deposits of arenite and local conglomerate. Overlap in age of the 1.855–1.84 Ga Burntwood Group submarine fan deposits with the 1.85–1.83 Ga Missi Group subaerial fluvial-alluvial sandstone (David et al., 1996; Lucas et al., 1996) suggests both deposit types formed contemporaneously and represent prograding alluvial and submarine fans that fed into the adjacent Kisseynew sedimentary basin from an elevated landmass in the Flin Flon Belt. Subsequent horizontal shortening accompanying 1.84–1.81 Ga continental collision tectonics has juxtaposed the Burntwood Group and Missi Group sedimentary rocks against each other and with earlier formed assemblages. As a result, most sedimentary assemblage contacts in the eastern Flin Flon Belt are thrust faults (Connors et al., 1999).

In the eastern Flin Flon Belt, Ansdell and Connors (1994) have postulated an older (~1.845 Ga) and a younger (~1.835 Ga) package of Missi Group sandstone, suggesting that Missi Group sedimentation is diachronous. Those exposed east of Puella Bay, in the southern Wekusko Lake map area, belong to the younger (~1.835 Ga) package. This is important, as these sedimentary rocks clearly postdate the 1.855–1.84 Ga (David et al., 1996) Burntwood Group sedimentary rocks exposed on western Wekusko Lake.

The Burntwood Group greywacke, siltstone and mudstone turbidites (unit B1a) in the Wekusko Lake area occur mainly west of the Crowduck Bay Fault, where they form a 10 km wide domain that extends from Goose Bay into the northern part of Wekusko Lake. They also occur sporadically along the west shore of the lake toward its south end, as a narrow zone of migmatitic paragneiss (unit B1b) along Hayward Creek and as a tiny fault-bounded lozenge on the west shore of Puella Bay. The main unit of Burntwood Group sedimentary rocks exposed on Wekusko Lake is internally deformed by a series of early regional (F_1) folds, cut by a series of late-tectonic granitic plutons (unit P) that were weakly recrystallized during 1.815 Ga (David et al., 1996) regional metamorphism. Most of these Burntwood Group sedimentary rocks contain well-preserved primary features, such as graded bedding, flame structures, sandstone dikes, sedimentary folds, scour structures and internal cyclic Bouma bed-zonation, consistent with deposition by turbulent density currents (Figures 23–28).

Missi Group rocks east of Puella Bay are composed mainly of massive to trough-crossbedded arenite (unit M1) but include a 200 m wide conglomerate (unit M2). The conglomerate (unit M2) is polymictic and composed mainly of well-rounded volcanic-derived clasts, together with a wide variety of accessory, pebble- to boulder-sized fragments that include greywacke, iron formation, quartz porphyry, gabbro, and massive to gneissic granitoid types. Boulders of granite up to 1 m in diameter were observed at one location on the west shore of Puella Bay. The Missi Group arenite and conglomerate exhibit features characteristic of continental, fluvial-alluvial fan deposits.

Intrusive rocks (units G, P and L; <1.84 Ga)

Mafic to felsic intrusions, occurring as dikes, small stocks and irregularly shaped intrusions, are common in the southern Wekusko Lake map area. Many of these intrusions are clearly late tectonic, as they cut across 1.84–1.83 Ga 'successor arc' plutons (unit P) and 1.855–1.83 Ga Burntwood Group and Missi Group sedimentary rocks (units B and M). The ages of other intrusions placed in unit G and intruding older assemblages are uncertain; some of these intrusions could be as old as the host volcanic assemblages.

Mafic to ultramafic intrusions (unit G)

Gabbroic intrusions within the Hayward Creek juvenile arc assemblage include several ovoid stocks and sporadic diabase dikes (unit G1). Most of these intrusions are massive, aphyric and homogeneous, but, in some cases, diverse porphyritic and leucocratic to melanocratic phases are associated together within the same gabbroic stock. The age of the intrusions is uncertain; whereas some of the units are probably synvolcanic, there is no definitive evidence for their age of emplacement.

Granitoid plutons and related rocks (1.84–1.83 Ga, unit P)

The eastern end of the Flin Flon Belt is intruded by a series of 1.84–1.83 Ga (Gordon et al., 1990; David et al, 1996) granitic plutons that postdate the 1.855–1.84 Ga (David et al., 1996) Burntwood Group sedimentary rocks. The granitic rocks form a series of oval plutons that structurally stitch together disparate lithotectonic components assembled during D_1 deformation and (perhaps earlier) crustal shortening (e.g., Snow Lake arc assemblage volcanic rocks and Burntwood Group sedimentary rocks). Observation of outcrop-scale F_1 fold structures in Burntwood Group sedimentary rocks being truncated at pluton margins is consistent with these large-scale structural relationships.

In the southern Wekusko map area, this episode of 1.84–1.83 Ga granitic magmatism is represented by a series of massive, oval, diorite to granodiorite and tonalite plutons. They include the Goose Bay porphyry (unit P1), Alward Lake pluton (unit P2), southwest Wekusko Lake pluton (unit P3), Broad Bay pluton (unit P4) and Wekusko Lake pluton (unit P5).

The Goose Bay porphyry (unit P1) is a moderately to strongly foliated, lensoid to sill-like, quartz-feldspar porphyritic felsic intrusion emplaced within the volcanic rocks of the Hayward Creek assemblage. Located along strike from Hayward Creek felsic volcanic rocks (unit J2), in the upper part of this juvenile arc volcanic sequence, this body could be the synvolcanic intrusive equivalent of the felsic volcanic rocks. However, the intrusion is provisionally interpreted to be younger in age due to the lack of definitive field or geochemical evidence to link it to the extrusive felsic rocks of unit J2.

The Alward Lake pluton (unit P2) comprises granitoid rocks and associated granitoid gneiss outcropping west of Hayward Creek and extending west beyond the map area to the south end of Tramping Lake. The pluton contains an early dioritic phase (unit P2b) that is intruded by younger quartz dioritic to leucotonalitic rocks (unit P2a). Abundant granitic to granodioritic dikes near the margin of the Alward Lake pluton are interpreted to emanate from the adjacent Wekusko Lake pluton (unit P5). Xenoliths of fine-grained sedimentary rocks and associated semipelitic paragneiss of the Burntwood Group (unit B1b) at the margin of the Alward Lake pluton constrain the age of this intrusion to the interval between the crosscutting 1.834 Ga (Gordon et al., 1990) Wekusko Lake pluton and the 1.842 Ga (Machado et al., 1999) age of the youngest detrital zircon in Burntwood Group greywacke.

The southwest Wekusko Lake pluton (unit P3), an ovoid felsic granitoid body at the southwest end of Wekusko Lake, contains similar rock types and displays similar age relationships of phases to those in the Alward Lake pluton (unit P2). For example the southwest Wekusko Lake pluton consists of an older, subordinate dioritic phase (unit P2b) at its north, east and west margins that is crosscut by the main tonalite–quartz diorite phase of the intrusion (unit P3a). A granodiorite-granite phase (unit P3c), which is present in the north-central part of the pluton, is similar to unit P5 of the Wekusko Lake pluton. One of the more significant features of the southwest Wekusko Lake pluton is that it cuts across the contact between the Hayward Creek juvenile arc assemblage (unit J) and Burntwood Group submarine fan sedimentary rocks (unit

B). Thus, the pluton represents a piercing point that stitches together two assemblages that were likely juxtaposed along a D1 thrust fault. Although this D_1 structure was not observed during mapping, the distribution of map units here and in the map area to the north are most simply explained by the presence of such a D_1-faulted contact.

The Broad Bay pluton (unit P4), which outcrops on the southeast shore of Wekusko Lake, is a two-mica granodiorite to granite (Cerny et al., 1981) that intrudes the contact between the south Wekusko Lake ocean-floor assemblage basalt (unit F) and the younger Puella Bay 'successor arc' volcanic rocks (unit S). Although the contact between the south Wekusko Lake and Puella Bay rocks is not exposed, it is anticipated that the contact is a D_1 fault, with the Broad Bay pluton structurally stitching these assemblages together.

The Wekusko Lake pluton is a pear-shaped intrusion of massive, nonfoliated, pink-weathering granite and granodiorite (unit P5) that contains minor primary hornblende, largely altered to biotite. This one-mica intrusion, with a U-Pb zircon crystallization age of 1834 +8/–6 Ma (Gordon et al., 1990), is emplaced into isoclinally F_1 folded Burntwood Group greywacke, siltstone and mudstone (unit B1a) and occupies the core of a later, open, northeast-trending F_3 antiform (Bailes, 1992). The 1.834 Ga age of crystallization of the intrusion is penecontemporaneous with local ca. 1.835 Ga (Ansdell et al., 1992) fluvial-alluvial sedimentation in the Missi Group (unit M) exposed east of Puella Bay. Similar to other unit P plutons in the Snow Lake area, the Wekusko Lake pluton structurally stitches together various volcanic and sedimentary assemblages that were previously juxtaposed during D_1 deformation.

Late intrusive rocks (unit L)

The youngest intrusive rocks in the southern Wekusko Lake map area include diorite and quartz diorite (unit L2a), quartz-plagioclase porphyry (unit L2b), gabbro (L1a), anorthositic gabbro and quartz gabbro (unit L1b), and diabase (unit L1c, d, e); these rocks occur as minor dikes and stocks intruding the 'successor arc' granitoid plutons (unit P) and the older assemblages.

An ovoid diorite to quartz diorite stock (unit L2a) is emplaced within the Wekusko Lake pluton in the northwest corner of the map area. Plagioclase-phyric diabase dikes (L1c) that are spatially related to the stock are assumed to be genetically related to the diorite–quartz diorite.

The quartz-plagioclase felsic porphyry (unit L2b) includes at least two ages of intrusions. The younger porphyry bodies crosscut diabase intrusions (units L1c, d, e), whereas an older set of porphyry intrusions is intimately associated and probably penecontemporaneous with diabase intrusions (Figure 29). Other quartz-plagioclase porphyry dikes are clearly associated with brittle fragmentation of granitoid hostrocks (unit P) and the development of 'intrusion breccia'.

Diabase dikes (unit L1c, d, e) are common throughout the southern Wekusko Lake map area (Figure 30). Some occur as easterly- to east-southeasterly-trending swarms of narrow dikes cutting the unit P granitoid plutons. Others occur in small stocks and irregularly shaped intrusions. One of the more distinctive suites of intrusions is an east-southeast-trending swarm of trachytic diabase dikes (unit L1d), which occur throughout the western half of the map area, cutting the Hayward Creek juvenile arc (unit J), the F_1-folded Burntwood Group sedimentary rocks (unit B) and the 'successor arc' granitoid plutons (unit P). These dikes and related intrusions are straight walled, have chilled margins and are up to 70 m wide. They are characterized by tabular plagioclase phenocrysts (1–3 cm long) ± hornblende as pyroxene pseudomorphs (Figure 31). Spatially and genetically related, megaphyric, cumulophyric diabase (unit L1e) contains large (2–8 cm) plagioclase megacrysts and smaller (0.5–1 cm) plagioclase crystals aggregated in ovoid clusters up to 10 cm in diameter (Figure 32). Whereas trachytic diabase postdates the main granite-granodiorite phase of the Wekusko Lake pluton (unit P5), sporadic xenoliths of this distinctive diabase occur within late, quartz dioritic phases in both the Alward Lake (unit P2) and south Wekusko Lake (unit P3) plutons, indicating that the mafic dikes probably represent a young intrusive phase of 'successor arc' magmatism. Several east-northeast-trending dikes of very coarse grained, anorthositic gabbro and magnetite-bearing quartz gabbro, which postdate the south Wekusko Lake and Alward Lake plutons, are also interpreted to be relatively young, successor-arc intrusions.

Structural history

Numerous detailed structural studies carried out in the Flin Flon Belt (Lucas et al., 1996; Ansdell et al., 1999; Syme, 1995; Connors, 1996; Connors et al., 1999) have identified deformation events spanning early accretion (1.88–1.87 Ga) to late tectonic continental collisions (1.77 Ga). Deformation associated with rifting occurred during the waning stages of juvenile arc magmatism in the eastern part of the Flin Flon Belt; an early age for this tectonism is indicated by a U-Pb zircon age of 1.886 ± 3 Ga (Zwanzig et al., 2001) for the crystallization of one of the Josland Lake gabbro sills that postdates isoclinal recumbent folding of the early volcanic arc assemblages (Zwanzig et al., 2001). The gabbro is geochemically comparable to, and interpreted as penecontemporaneous with, arc-rift basalt in the Snow Lake arc assemblage (Zwanzig et al., 2001).

In the southern Wekusko Lake area, three deformation events (D_1–D_3) have been recognized, all of which postdate the early folding that accompanied intrusion of the Josland Lake gabbro sills (Gilbert, 1993). Structures of D_1, which are present in most supracrustal units in the eastern Flin Flon Belt (including the Burntwood Group sedimentary rocks), are ≤1.84 Ga in age. Both D_1 and D_2 are interpreted to result from the southward tectonic transport of Burntwood Group greywacke-turbidite from the Kisseynew belt over the Flin Flon Belt (Krause and Williams, 1999). The D_1 and D_2 events are characterized by tight isoclinal folding and associated low-angle 'thrust' faults. The D_3 deformation is interpreted to result from crustal shortening that occurred syn to post peak regional metamorphism (Connors et al., 1999). The latter deformational event is largely manifested by upright, open to closed folds (F_3) and associated steeply dipping faults.

Structures belonging to D_1 are common west of Wekusko Lake. They include tight isoclinal F_1 folds, which are ubiquitous in the 1.84 Ga Burntwood Group turbidites (unit B1a), as well as associated D_1 thrust faults; the latter typically define contacts between lithotectonic assemblages and are curvilinear due to subsequent folding during D_3 deformation. The Hayward Creek juvenile arc volcanic rocks west of the south end of Wekusko Lake are characterized by many early F_1 folds whose axial traces are roughly parallel to an early S_1 foliation and are conformable with the crescentic shoreline trend at the north margin of the Hayward Creek domain. The Hayward Creek Fault, which is roughly coincident with the shoreline and the folds, is interpreted to be a low-angle thrust associated with the D_1 event. The F_1 folds and D_1 thrust faults west of Wekusko Lake are bracketed in age by the crosscutting 1.84–1.83 Ga (David et al., 1996) granitic plutons (unit P) and youngest 1.842 Ga detrital zircon (Machado et al., 1999) in the Burntwood Group greywacke (unit B)

Fold structures belonging to D_2, which were first identified at Snow Lake by Krause and Williams (1999), can be demonstrated to occur locally in Burntwood Group sedimentary rocks on Wekusko Lake. Where observed, the F_2 folds are isoclinal and coaxial with F_1 folds, with their prominent axial-planar foliation and plane of flattening likely a product of combined D_1 and D_2 deformation. Both Connors et al. (1999) and Krause and Williams (1999) indicated that D_2 deformation, similar to the earlier D_1 deformation, involves low-angle ‘thrust’ faults. Connors et al. (1999) showed that ca. 1.836–1.832 Ga Missi Group sedimentary rocks (units M1 and M2) east of Puella Bay are broadly contemporaneous with the 1.84–1.83 Ga granitic magmatic event (unit P) and postdate the D_1 event affecting the Burntwood Group rocks (unit B). This has some important implications, including the interpretation of the bedding-parallel foliation and low-angle faults in the Missi Group rocks (units M1 and M2) east of Puella Bay as most likely being a product of D_2 rather than D_1 deformation.

Deformation structures of D_3 are ubiquitous in the eastern Flin Flon Belt. In the southern Wekusko Lake map area, they are mainly manifested as east-northeast-trending open F_3 folds that are syn to post peak ca. 1.810 Ga (David et al., 1996) regional metamorphism. The D_3 deformation is also manifested by S_3 foliation, which is axial planar to the folds but sometimes localized in broad strain corridors adjacent to high-strain zones such as the D_3 Crowduck Bay Fault (Connors et al., 1999). East of Wekusko Lake, an L_3 extension lineation is typically northeast to southeast plunging, whereas, west of the lake in the Hayward Creek domain, it is predominantly southeast plunging (Gilbert, 1993). The crescentic configuration of the Hayward Creek Fault and F_1 folds in the Hayward Creek juvenile arc rocks south of Goose Bay is attributed to D_3 deformation and strain associated with emplacement of the contiguous southwest Wekusko Lake pluton immediately south of the arc volcanic rocks.

Economic geology

Mineral exploration has been conducted in the southeastern part of Wekusko Lake since the 1920s. In approximately 1930, promising results were obtained from a drill program east of Broad Bay that targeted mineralized quartz veins hosted by dacitic rocks of the Puella Bay suite (Assessment Files 90573, 91882, 94397, Manitoba Industry, Economic Development and Mines). Subsequent investigations indicated that the mineralization occurs within quartz veins in a north-trending shear zone; assays yielded up to 2.7% Zn, 1.9% Pb, 149 ppm Au, 48 ppm Ag and minor Cu (location 1 in Ferreira and Fedikow, 1990). Southeast of Broad Bay, minor Au values have been reported in granodiorite-hosted quartz veins within the Broad Bay pluton (AF 92658, 92659). Mineralized intersections within felsic to intermediate tuff of the Puella Bay suite occur on the peninsula west of Puella Bay, where a 2 m wide section of 'solid graphite' contains up to 40% pyrite (AF 92429, 92430). A similar pyritic section with minor Au (20 g/t) occurs at a higher stratigraphic level within the same volcaniclastic sequence just south of Puella Bay (AF 92481). Further details of mineral exploration since 1980 in the southeastern Wekusko Lake area are provided in Assessment Files 93516, 93832, 94045, 94056, 94062, 94405, 94719.

At the southwest corner of Wekusko Lake, base-metal mineralization in Hayward Creek juvenile arc volcanic rocks was discovered in the late 1920s ('Copper-Man deposit'); the locality, 0.3 km west of the lakeshore, has subsequently been the focus of a series of exploration programs that continue to the present time. The VMS deposit is approximately 250 000 tonnes and contains Cu and Zn (average grades of 3–4 %) and minor Au, Ag and Cd (Mineral Inventory Card 450, Manitoba Industry, Economic Development and Mines, Winnipeg). In 1982, Falconbridge Nickel Mines Limited reported a 27 m long kimberlite section within diamond-drill core at the same 'Copper-Man' locality; the brecciated kimberlite occurs within Burntwood Group greywacke, just offshore from the VMS deposit. In 1993, European Ventures Inc. found diamond indicator minerals within this kimberlite (European Ventures Inc., 1993); two stratigraphically separate kimberlite units occur at the locality.

A significant economic prospect for base-metal sulphide mineralization occurs within Burntwood Group metasedimentary rocks at Goose Bay, in the western part of Wekusko Lake. At this locality, massive pyrite-pyrrhotite (with traces of chalcopyrite, sphalerite, Au and Ag) is reported in several sections of argillitic drillcore (AF 92656, 92662); these intercepts, together with the numerous formational EM anomalies that occur within the sedimentary sequence, suggest the Burntwood Group rocks may have potential to host base-metal ore deposits. This economic potential is further reinforced by the fact that stratigraphically equivalent paragneiss in the Kisseynew sedimentary gneiss domain, northeast of Wekusko Lake, contains massive sulphide deposits (Zn-Cu BUR Zone and Zn-Pb-Ag Kobar-Ruby deposit; Fedikow, 1991). In addition, the volcanic-sedimentary rock contact between Hayward Creek and Burntwood Group rocks at Goose Bay is coincident with mineralized drillcore intersections and a 2.7 km long formational EM anomaly (AF 90580, 94047); a prominent, positive aeromagnetic anomaly also extends along this contact (Geological Survey of Canada, 1992). These features indicate that the locality represents a promising target for continued exploration. Disseminated pyrite (4%) occurs over a 17 m section within basalt (unit J1), adjacent to the Goose Bay porphyry intrusion (unit P1). The mineralized rocks are part of the Hayward Creek arc assemblage, which is characterized by widespread silicic, epidotic and chloritic alteration types that are considered favourable indicators for mineralization. Similar alteration is common in juvenile arc rocks that host base-metal ore deposits elsewhere in the Flin Flon Belt.

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