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Stratigraphy of Epiclastic and Volcaniclastic Facies Units, Northern Birch–Uchi Greenstone Belt, Uchi Subprovince

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Stratigraphy of Epiclastic and Volcaniclastic Facies Units, Northern Birch–Uchi Greenstone Belt, Uchi Subprovince

by

J.R. Devaney

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Abstract

The Mesoarchean to Neoarchean Birch–Uchi greenstone belt is an arcuate, tectonically complex portion of the western Uchi Subprovince in northwest Ontario. New sedimentologically-oriented descriptions and interpretations of the epiclastic and volcaniclastic lithofacies units in the central part of the northern Birch–Uchi greenstone belt, the Birch Lake area, help to place the area's mineralization in an improved tectono-stratigraphic context.

Felsic to intermediate, coarse to fine, pyroclastic to volcaniclastic (variably reworked by sedimentary processes) rocks are presumably of the ca. 2740 Ma Confederation assemblage. Along with associated lava flow facies of this age, these fragmental volcanic deposits appear to represent the proximal parts of a mixed volcanic-sedimentary basin. Associated wacke units, with minor interbeds and laminae of mudstone and magnetite iron formation, are generally finer grained, better stratified, more thinly bedded, and contain more sedimentary structures and graded bedding, and likely represent more distal, deep water turbiditic facies. Potential stratigraphic complexity and probable structural complexity severely limit the stratigraphic resolution possible.

In contrast with the above units, a suite of epiclastic conglomerate and sandstone facies form several distinct tectonized stratigraphic units. Clast-supported coarse polymict conglomerate with sandy interbeds have features typical of proximal braided river deposits. Sandstone–mudstone horizons likely represent more distal subaqueous basinal facies. Clast provenance appears to be highly local, with rare exposures of basin margin facies (oligomict and/or notably distinct compositions) and basal conglomerate. The sedimentological and structural evidence suggests that the sigmoidally shaped (in map view), predominantly conglomeratic units are late orogenic, deformed, dextral-sense strike-slip (pull-apart), Timiskaming-type basins of Late Archean, post-Confederation assemblage age.

To account for the belt-scale map patterns present, the following indenter or promontory hypothesis is proposed. The distribution of faults and directly related late orogenic strike-slip basins in the Birch–Uchi greenstone belt may be related to the influence of a block of presumably older crust located southeast of the greenstone belt. Northwest–southeast compression of this block against the adjacent Birch–Uchi greenstone belt could have produced a symmetric pattern of dextral faults and pull-apart basins in the northern (northeast) part of the greenstone belt, versus the sinistral faults common in the southern (southwest) part of the greenstone belt.

Three types of mineralization in the Birch Lake area of the Birch–Uchi greenstone belt are most notable. 1) Although copper-zinc volcanogenic massive sulphide mineralization is present in the southern part of the greenstone belt (the former South Bay mine), significant sulphide mineralization is not known from the presumbably broadly correlative Confederation assemblage units near Birch Lake, and stratigraphic and structural complexity limit both volcanological–sedimentological basin analysis and attempts to use predictive ore deposit models; 2) the local gold-bearing quartz veins have the structural characteristics and mineral compositions typical of mesothermal lode gold deposits; 3) significant values of platinum and palladium have been previously documented from the gabbroic part of a composite stock in the Birch Lake area.

The new interpretation of the area's pull apart basins and related strike slip faulting places the gold mineralisation in tectonic context, as part of a complex late orogenic wrenching stage (a very common scenario for Late Archean gold deposits, world-wide). Based on the presence of tellurides and other accessory minerals, the new intrusion related vein gold deposit model should also be tested in this greenstone belt.

Stratigraphy of Epiclastic and Volcaniclastic Facies Units, Northern Birch–Uchi Greenstone Belt, Uchi Subprovince

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Introduction

The Mesoarchean to Neoarchean Birch–Uchi greenstone belt (Figures 1, 2) is a large (approximately 80 km wide), arcuate, tectonically complex portion of the Uchi Subprovince (Stott and Corfu 1991; Rogers et al. 1999, 2000). As a contribution to the Western Uchi NATMAP Project, the sedimentological studies of selected younger parts of the Birch–Uchi greenstone belt in this report (and earlier preliminary reports: Devaney 1997, 1998, 1999a,b,c) and elsewhere (Devaney 1999d) should assist in deciphering the multistage stratigraphy of the complex volcanic and tectonic evolution of this greenstone belt.

Following on from the foundation provided by the recent bedrock geological studies of the Birch Lake area of the northern Birch–Uchi greenstone belt by Thurston et al. (1981), Thurston (1986), Good (1988), Beakhouse (1989), Beakhouse and McNeil (1989) and Beakhouse et al. (1989), this is a more specialized report on that same area. The following report:

1. briefly describes the predominantly supracrustal rock types within the map area (Figure 3; see map of Devaney and Crews (in press), with an emphasis on felsic to intermediate volcaniclastic lithofacies;
2. summarizes some of the sedimentological and structural evidence for the interpretation of conglomeratic units in the Birch Lake map area (Figures 2, 3) as late orogenic strike-slip (pull-apart) basins, and outlines their proposed role in the tectonic evolution of the area;
3. discusses some of the structural features in the map area; and
4. as a sequel to the compendium by Parker and Atkinson (1992) on gold deposits in the Birch–Uchi greenstone belt, this report briefly discusses some additional topics relevant to potentially economic mineralization in the map area.

Although somewhat speculative and perhaps premature, the indenter or promontory regional tectonic hypothesis presented below (see also Devaney 1998, 1999a,b,c) may help to explain the late orogenic history of the Birch–Uchi greenstone belt. Much structural and geochronological work will be required to test this hypothesis, and the results should be particularly applicable to exploration for tectonically late lode gold deposits (Devaney 1999e).

Parts of this report, mostly concerning the conglomeratic units their interpretation as pull-apart basins, and the indenter or promontory interpretation, have been taken directly from previously published sources (Devaney 1998, 1999a,c), and are re-presented herein with some additions and minor modifications.

LOCATION AND ACCESS

The Birch Lake area is located about 100 to 120 km east-northeast of the town of Red Lake in northwest Ontario. Access is generally via float plane from Red Lake, Ear Falls, or lodges along the South Bay Mine road in the Confederation Lake area (i.e., the south part of the Birch–Uchi greenstone belt). The west end of Birch Lake is also accessible from the South Bay Mine road via a series of lakes and portages along the Woman Lake–Woman River system.

The topography in the Birch Lake area is typical northwestern Ontario shield terrain. On the shores of Birch Lake and some adjacent lakes, a few commercial fly-in fishing camps and private cabins are maintained. Portages to large adjacent lakes (Springpole and Grace) were in very good condition in 1997.

ACKNOWLEDGMENTS

Senior assistant M.J. Crews and junior assistants R. Fraser, E. Greiner and K. Hynes provided fine field assistance. Senior assistant Crews mapped about half of the study area and helped with computer operations. Fraser (1998) completed a thesis on a small area of deformed metasedimentary rocks. C. van Staal and F.W. Schwerdtner offered useful comments on strained rocks during their field visits. Green Airways personnel provided various types of logistical support. P.C. Thurston edited versions of this manuscript.

General Geology

BIRCH–UCHI GREENSTONE BELT OVERVIEW

The Birch–Uchi greenstone belt (Figure 2) is the portion of the Uchi Subprovince with an arcuate, concave to the southeast, map-view form (i.e., a major oroclinal bend; cf. Marshak 1988) between the Red Lake and Meen–Dempster portions of the subprovince (Stott and Corfu 1991). Studies of the southern part of the Birch–Uchi greenstone belt, modelled by Gupta et al. (1982) as a "rootless" greenstone belt only a few kilometres thick, have revealed a long (ca. 3.0 to 2.7 Ga), multistage history of crustal development (Nunes and Thurston 1980; Stott and Corfu 1991). Based on mapping, lithogeochemistry, and radiometric dating (Thurston 1984, 1985; Stott and Corfu 1991), the supracrustal rocks of the greenstone belt were subdivided into three stratigraphic group-scale units (listed in decreasing age): the Balmer, Woman and Confederation assemblages. This three-part subdivision was applied to most of the Uchi Subprovince by Stott and Corfu (1991). The Confederation assemblage is thought to be a continental margin (Andean-type) arc succession (Stott and Corfu 1991; Stone 1998), versus the less certain tectono-stratigraphic context of the other assemblages.

Workers performing recent and ongoing studies of the southern Birch–Uchi greenstone belt (Rogers et al. 1999, 2000) and the Red Lake greenstone belt (i.e., the Western Uchi Subprovince NATMAP Project) have proposed some modifications and additions to the Balmer–Woman–Confederation stratigraphic scheme. As discussed herein, some relatively small conglomeratic units likely form a synorogenic, discontinuously distributed, post-Confederation assemblage in the Birch–Uchi greenstone belt (Devaney 1999a,b,c,d). Radiometrically dated plutons within the Birch–Uchi greenstone belt are of post-Confederation assemblage, ca. 2725–2700 Ma age (Beakhouse et al. 1999).

The northern margin of the Birch–Uchi greenstone belt forms a pattern of subregional scale cusps of supracrustal strata alternating with batholiths (Figure 2; Beakhouse 1989). Basaltic units are prominent around the periphery of the greenstone belt and may be part of the Woman assemblage (as depicted in Figure 2), but the accuracy of this stratigraphic assignment is unknown. Based on a ca. 2740 Ma age of "Shabumeni Lake [intermediate to felsic fragmental] volcanics" at a site near the northern greenstone belt margin, Beakhouse et al. (1999) suggested that Confederation assemblage age rocks make up the bulk of the greenstone belt.

STUDY AREA: BIRCH LAKE AREA, CENTRAL NORTHERN BIRCH–UCHI GREENSTONE BELT

Within the more central part of the northern Birch–Uchi greenstone belt, in the vicinity of Birch Lake, various volcanic units and related wacke-dominant sedimentary units of the Confederation assemblage (two intermediate to felsic volcanic rocks dated at ca. 2740 Ma (Beakhouse et al. 1999)), small undated intrusive bodies of gabbro and felsic porphyry, small granodiorite stocks (e.g., Horseshoe Island pluton, dated at ca. 2725 Ma (Beakhouse et al. 1999)), and conglomeratic units of probable post-Confederation age (see above) crop out (Figures 2, 3). From west to east strata generally change in orientation from northeast-striking to southeast- or east-striking (Thurston et al. 1981; Good 1988; Beakhouse et al. 1989; Devaney and Crews, in press), but the large-scale structural patterns and their potential complexity are not well understood (e.g., many of the inferred faults lie beneath covered intervals and lakes). As in most Superior Province greenstone belts, the supracrustal rocks have been metamorphosed to greenschist facies and primary (premetamorphic) fabrics are commonly well preserved at sites away from deformation zones. (For brevity, the prefix “meta” is omitted for the rocks discussed herein.)

The general geology of the central part of the northern Birch–Uchi greenstone belt was documented in detail by Thurston (1986), Good (1988) and Beakhouse (1989). The surrounding areas described in recent reports are: 1) to the north, the Casummit Lake area (Beakhouse 1994); 2) to the east, the Springpole Lake area (Good 1988; Barron 1996); 3) to the southeast, the Ferdinand Lake area (Wallace 1983); and 4) to the southwest, Honeywell and McNaughton townships (Johns 1979a,b).

Gold deposits in the Birch Lake vicinity include the Springpole Lake gold prospect (Barron 1996) and the small but high grade former Sol D’Or mine (Parker and Atkinson 1992). Volcanogenic sulphide mineralization and platinum group element occurrences have also been of interest (see “Mineralization,” below). Details on specific mineral occurrences and properties are available elsewhere, in previous reports (Good 1988; Beakhouse 1989; Parker and Atkinson 1992) and via the world wide web-accessible ERLIS and/or ERMES system.

PRESENT STUDY AND RELEVANCE TO POTENTIAL MINERALIZATION

The main purpose of the present report is to describe and interpret the Archean bedrock units of fragmental volcanic (volcaniclastic) and sedimentary facies in the Birch Lake area (study area in Figure 3) in a more detailed and specialized fashion than in the previous studies. Such knowledge is directly relevant to assessing the potential for Cu-Zn and Au mineralization in the greenstone belt. For example, study of the volcanic and related clastic and chemical sedimentary facies present and any associated synvolcanic alteration provides valuable information about the potential for volcanogenic sulphide mineralization correlative with that of the former South Bay Cu-Zn volcanogenic massive sulphide mine (Pollock et al. 1972; Urabe and Scott 1983), located in the southern part of the greenstone belt and interpreted as being within a rifted back-arc or intra-arc (sub)basin succession within the tectonized Confederation assemblage (Hollings 1998; Rogers et al. 1999, 2000; *see* also interpretation of the “sector graben” of Thurston 1985). Given the now widely appreciated importance of extensional basinal settings (Cathles et al. 1983; Wyman 1996; Lentz 1998) and the role of chemical replacement rather than exhalative deposits (Ohmoto 1996) in the creation of many economic volcanogenic massive sulphide deposits, the search for extensional basins (or subbasins) may be more of a key factor than the search for a “critical volcanogenic massive sulphide ore horizon” (i.e., a synchronous, laterally continuous stratigraphic marker bed or horizon, perhaps consisting of a distal “key tuffite” or banded iron formation unit and a proximal zone close to a volcanogenic massive sulphide deposit, volcanic centre, synvolcanic fault, or alteration pipe). Although basin analysis using sedimentology and physical volcanology is thus of great potential value in resolving the location of (sub)basins in the Confederation assemblage and their internal stratigraphic architecture, poor exposure and a largely unknown degree of structural complexity unfortunately strongly limit the degree of stratigraphic resolution possible. (This is a situation common to most northern Ontario greenstone belts: Devaney 1999f.)

Wrench Tectonics, Timiskaming-type Conglomeratic Basins, and Gold Mineralization

Regarding the search for mesothermal lode gold deposits (e.g., structurally controlled auriferous quartz or quartz-carbonate veins), gold occurrences that are probably of this type are abundant in the Birch–Uchi greenstone belt (Parker and Atkinson 1992) and, according to the standard models for this type of deposit (Card et al. 1989; Thurston and Chivers 1990; Hodgson 1993; Poulsen et al. 2000; *see also* Groves et al. 1998 and Sillitoe and Thompson 1998 regarding orogenic gold deposits), these gold occurrences should be both spatially and genetically related to the late orogenic deformation zones in the greenstone belt: for example, strike-slip faults and related complex faults or shear zones that formed during a late orogenic wrenching stage (Stott and Corfu 1991; Devaney 1999a,c,e). Wrench faulting is used in a general sense (e.g., Stott and Corfu 1991; p.226; Devaney 1999e), as opposed to more specialized uses of the term (e.g., distributed shear during wrenching, versus strain-partitioned deformation during strike-slip faulting: Miller 1998, Figure 2).

As outlined below, the conglomeratic units of the Birch–Uchi greenstone belt are interpreted as late orogenic, deformed strike-slip (pull-apart) basins, commonly known in Ontario as Timiskaming-type basins (Thurston and Chivers 1990; Williams et al. 1992; Mueller and Corcoran 1998), an interpretation which provides both the local and regional context for associated mesothermal gold deposits. Even if deformation zones are not exposed, or are poorly exposed, recognition of probable strike-slip basins implies the presence of major strike-slip fault systems bounding the conglomeratic units. Furthermore, recent syntheses of strike-slip tectonics and late orogenic wrenching stages (e.g., Sylvester 1988; Nilsen and Sylvester 1995; Devaney 1999e) imply that the following other processes likely accompanied strike-slip faulting and related clastic basin formation, and that they are all broadly interrelated:

1. development of local transpressional zones (Tikoff and Greene 1997; Dewey et al. 1998), including pop-up or positive flower structures (Sylvester 1988);
2. dip- to oblique-slip motions (e.g., high-angle reverse faults, and vein flats produced by vertical extension (Sibson et al. 1988));
3. development of local transtensional zones, which may include sites for pluton and dike intrusion at depth and pull-apart basins and volcanic centres at the (paleo)surface (D’Lemos et al. 1992);
4. fault (or, at depth, shear zone) reactivation;
5. motion of large (subprovince scale) crustal blocks and indenters; and
6. relative motions of small (kilometres to tens of kilometres) intraorogenic blocks, flakes and schollen (Dewey and Sengor 1979) which form a three-dimensional network of structural domains likely to have been complexly and episodically deformed (e.g., such block domains may have undergone stages of rotation, translation, downdropping, uplift, and fragmention).

Along with recognition of the fact that many strike-slip faults flatten listrically at depth into detachment surfaces (Sylvester 1988; Devaney 1999e) which may underlie the blocks described in point 6 above, the set of factors listed above provide a more complete and contemporary view of the model or scenario for Timiskaming-type sequences and related gold mineralization.

Other models relevant to gold mineralization in the Birch Lake area are the alkalic-type epithermal scenario (Richards 1995), applied to the Springpole gold-fluorite deposit (location in Figure 3) by Barron (1996), and perhaps also the new intrusion-related vein gold systems model (Sillitoe and Thompson 1998; Lang et al. 2000), which may help to account for the presence of tellurides and other accessory minerals in the quartz veins at some of the area's gold occurrences.

Description and Interpretation of Pyroclastic to Volcaniclastic Facies and Related Wacke Units

The term "volcaniclastic" is used herein to refer to fragmental, apparently volcanic rocks which may be either primary pyroclastic facies or pyroclastic material which was reworked to varying degrees by sedimentary (secondary) processes (e.g., Smith and Landis 1995, Figure 7.22). Because many supposedly pyroclastic deposits in Archean greenstone belts of northern Ontario, and elsewhere, lack unequivocal evidence of hot genesis and/or emplacement, and because sedimentary (cold) gravity flow deposits have many of the same depositional fabrics as pyroclastic flows (which were hot during at least some point in their transport history), interpretation of some volcaniclastic rocks as pyroclastic deposits can be problematic and uncertain (Cas and Wright 1987; Stix and Gorton 1991; Devaney 1999f). Thus, many supposedly pyroclastic facies may in fact be proximal sedimentary facies in volcanic basins, versus the generally thinly bedded wacke units typically considered as representative of distal sedimentary facies. The term epiclastic is used by some workers as synonymous with sedimentary and by others (and herein) to refer to clastic rocks "derived by weathering and erosion of preexisting rocks," versus volcaniclastic detritus which initially formed as a result of "fragmentation by volcanic processes unaided by weathering" (Smith and Lotosky 1995, p.91).

GENERAL CHARACTERISTICS OF PYROCLASTIC TO VOLCANICLASTIC FACIES

The following lithofacies characteristics are common to the many outcrops mapped as pyroclastic rocks in the Birch Lake area; *see also* Table 1.

A standard variety of pyroclastic to volcaniclastic lithofacies crop out: tuff (composed largely of sand-sized grains), lapilli-tuff (similar to a pebbly sandstone), lapillistone (similar to a clast-supported fine pebble conglomerate), and tuff-breccia. Tuff is very coarse- to fine-grained, with coarse and poorly sorted beds common. Composition is estimated as intermediate to felsic, with quartz granules (in felsic tuff) and white feldspar (e.g., in feldspar crystal tuff) notable at some sites. Clasts in the lapilli-tuff to tuff-breccia are a largely oligomict population of white weathering intermediate to felsic clasts, with minor felsic porphyry clasts, rare intraclasts, and rare banded iron formation clasts (probable intraclasts; Photo 1). Synvolcanic alteration is locally present (*see* "Mineralization," below), but does not appear to be intensely developed, excepting some sites near iron formation units.

Stratification in coarser facies is commonly defined by vague alternation of coarser and finer beds, versus thin bedding and lamination in tuffs. Coarser units tends to be thickly bedded, and some outcrops display massive and monotonous tuff. Few of the thin tuff beds are graded, and the grading is typically subtle (e.g., more subtle than in the local wackes).

Outcrops which contain massive, nonbedded fragmental facies are problematic. An unstratified horizon could represent the interior portion of very thick pyroclastic flow or mass flow bed which is thicker or wider than the width of a typically small (<10 m) outcrop (Devaney 1999f), or the stratification could be extremely subtle. Deformation (e.g., shearing and transposition along layering) could easily have obscured or destroyed originally subtle stratification.

GENERAL CHARACTERISTICS OF WACKE-DOMINANT FACIES UNITS

The following lithofacies characteristics are common to the many sites mapped as wackes in the Birch Lake area; *see also* Table 1.

Wacke beds are coarse- to fine-grained, with grain size commonly proportional to bed thickness: for example, pebbly coarse-grained beds are tens of centimetres thick, coarse-grained beds are centimetres thick, and fine-grained beds are laminated. Grading is most common in thin beds with coarse-grained bases.

The clasts in the pebbly wacke beds are small felsic pebbles (or lapilli) and feldspar granules. Coarse quartz grains are notable in some beds. Importantly, these compositional characteristics are identical to those of the local tuff to lapillistone beds.

Horizons of wacke-mudstone contain fine-grained sand and siltstone and/or argillite. Interbeds of magnetite banded iron formation are generally rare and thin, and form only a very minor amount (<10%) of outcrop sections, typically as thin beds or laminae alternating with thin fine wacke beds. Very rarely, small outcrops display horizons with about 33% magnetite banded iron formation. Very rarely, micro-laminated magnetite laminae caps mudstone laminae in graded beds (e.g., at northeast Birch Lake, 1.0 km southeast of Green’s camp), illustrating the past role of the magnetite chemical sediment as background sedimentation (e.g., Barrett and Fralick 1985).

PROXIMAL VOLCANICLASTIC FACIES VERSUS DISTAL SEDIMENTARY FACIES

Table 1 summarizes the small-scale physical features, and larger scale contrasts or patterns, of volcaniclastic and sedimentary lithofacies observed in the map area in rocks which are presumably part of the Confederation assemblage. Such features and patterns are consistent with those of standard depositional models of volcanic basins (Easton and Johns 1986; Cas and Wright 1987; McPhie et al. 1993; Smith and Landis 1995) and case studies of ancient volcaniclastic rocks (Busby-Spera 1985, 1986, 1988; Houghton and Landis 1989). Although distinguishing tuffs from wackes is commonly problematic in Archean greenstone belts, use of grain-scale petrographic criteria (Easton and Johns 1986, Table 1.12; McPhie et al. 1993), bed- to outcrop-scale features (*see* Table 1), and regional context provided by any laterally and/or vertically continuous stratigraphic sections (which unfortunately are very rare in poorly exposed and tectonized areas such as northern Ontario) can all assist in the task.

Of all the criteria listed in Table 1, the presence of the same clast composition in both the volcanic (pyroclastic–volcaniclastic) and wacke facies units, with the latter having less abundant, generally smaller clasts, most directly indicates a correlation between the two. The general rarity of a sedimentary clay component in the various wacke-dominant and volcaniclastic units is consistent with the likely derivation of the units from pyroclastic material (e.g., subaqueous tephra, or subaerial tephra little affected by chemical weathering?). Although most features of the volcaniclastic facies are not diagnostic of any specific depositional environment, rare interbeds of magnetite banded iron formation indicate subaqueous accumulation of exhalatively sourced chemical sediments. The more distal wacke-dominant facies are typical of Archean turbiditic facies suites (e.g., Ojakangas 1985; Eriksson et al. 1994). (No features specifically suggestive of storm deposits, which may include graded beds, were recognized.)

Since volcanic vent-proximal areas tend to have high depositional slope angles, frequent earthquakes, and slumps of unwelded pyroclastic deposits, proximal facies may contain substantial amounts of material reworked by sedimentary processes. More distal facies can vary from partly volcanic to wholly sedimentary. In a regional sense, the distal facies may be more medial than distal if the most distal facies are unexposed or outside the study area.

OTHER FACIES, ROCK TYPES AND FEATURES

Northern Birch Lake Area

At northeast Birch Lake (1.0 km northeast of Dole Lake), beds of tuff-breccia reported by Good (1988) to be inversely graded appear to be crudely bedded rather than graded.

One outcrop displays several rusty clasts and a magnetite clast, suggesting erosional reworking of exhalative beds. Rare angular to diamond-shaped (rhombic outline; presumably polyhedral in three dimensions) clasts may represent fragments supplied from former jointed lava flow facies.

Primary fabrics in minor interlayered mafic rocks are difficult to identify owing to deformation; potential pillows and vesicles were noted in some outcrops.

Wagner Bay Area

A distinct unit of volcanic clast conglomerate is exposed on islands north and west of the polymict conglomerate unit in central Wagner Bay. Clast composition appears to be generally oligomict and intermediate (dark blue-grey fresh surfaces), with some felsic and porphyritic clasts. Thick beds of clast-supported conglomerate are composed of fine pebbles, with few cobbles and boulders. Wacke interbeds vary from pebbly and coarse to fine, and thickly to thinly bedded, with grading, scours, intraclastic bed soles, pebble bands, soft-sediment folds, load structures, and current ripples (with most apparent paleocurrents approximately to the north, as estimated from flat two-dimensional outcrop surfaces). One graded-stratified conglomerate to sandstone bed and one fining-upward sequence metres thick (e.g., sequence of: cobble conglomerate, finer conglomerate, coarse pebbly sand, finer sand) were observed.

These coarse, thick beds of volcanic clast conglomerate and the sandy (wacke) interbeds suggest sedimentary reworking of coarse volcaniclastic material in a high-energy submarine environment, such as a channel on a deep sea ramp or fan (e.g., Hein 1984; Busby-Spera 1985; Eriksson et al. 1994). The noted fining-upward sequence could be a channel fill. Turbidity currents deposited the pebbly graded-stratified and sandy graded beds (e.g., with rippled BC, CD Bouma sequences). These or other currents scoured the sea floor and deposited sandy ripples. Either slumps along channel margins or other depositional slopes, or loading of the section, may account for the penecontemporaneously folded strata.

The lithofacies within this small (areally restricted), distinctive unit of volcanic clast conglomerate and wacke contrast with both the less well stratified pyroclastic to volcaniclastic facies (potentially more proximal facies) and the finer grained wacke-dominated units (likely lower energy, more distal resedimented facies) of the Birch Lake area.

Northern and Central Parts of South Bay

Wackes in this area form thinly to thickly (10 cm to tens of centimetres) bedded sand-dominated sections with minor mudstone interbeds. Well defined grading is common. Centimetre-scale sedimentary structures are cross-lamination (ripples), scours, loads and intraclasts. Some thin mudstone interbeds display loaded or convoluted laminae (likely the result of soft-sediment folding, with some odd wispy lenses as injection or slump fabrics). At southwest South Bay, just east of a locally prominent shore cliff of felsic porphyry, a small outcrop contains three different types of top indicators (small scours, large load structures, and grading, all to the southeast) in a well preserved cross-section a few metres thick.

In the outcrop area studied by Fraser (1998), where Exit Bay joins with South Bay, the local wacke-dominant facies contains thin cross-laminated, fine-grained interbeds which display well defined foreset laminae and cross-sectional ripple forms, including centimetre-scale trough cross-strata, climbing ripples (ripple drift cross-lamination), and flaser bedding (mud drapes on ripples, in a sand-dominated bed: Reineck and Singh 1980). Top directions form the ripple laminae agree with those shown by the local normal (fining upward) graded bedding.

At Exit Bay (an eastern extension of South Bay), one unusual outcrop within the local wacke section contains clasts of siltstone to wacke, which likely form an intraclastic breccio-conglomerate. It is poorly bedded, and varies from matrix- to loosely clast-supported. The intraclasts are internally laminated, including pre-erosional folded laminae. Rare felsic volcanic granules are also present. This intraclastic breccio-conglomerate is interpreted as a mass flow deposit, perhaps generated by slumping of compacted muddy sediments.

At western Exit Bay, a small conglomeratic unit (exposed on several small islets) has notably small clasts (fine pebbles, few cobbles), mostly volcanic clasts (minor gabbroic and chert clasts too), generally thin (1–10 cm) beds, and some vague or diffuse stratification. Sandy interbeds contain lamination and scours. The interpretation of this equivocal conglomeratic unit is problematic; it may be a coarse volcaniclastic deposit related to the synvolcanic wacke and volcaniclastic facies (*see* Table 1), or it may be a distal subaqueous facies correlative with the local, coarser and more thickly bedded fluvial conglomerates (see below).

One very unusual tiny outcrop (few metres wide) in the central South Bay islands contains a poorly sorted boulder breccia, with two 1.3 by 0.9 m and 1.5 by 1.0 m clasts. Clast distribution is bimodal, with a matrix of small pebbles (or lapilli) similar to the larger framework clasts. Some angular (polyhedral) clasts have straight-edged margins, and some clusters of clasts display an interlocking fabric (i.e., jigsaw or crackle-breccia fabric). Compositions of the clasts resemble the local felsic porphyry, tuff, lava and flow-banded lava facies. This rock is not thought to be a debris flow (it lacks matrix-supported fabric), an epithermal breccia (no hydrothermal alteration and brecciation recognized), or an autoclastic flow breccia (rock has a polymict, not oligomict, composition). It is interpreted to be a talus (scree) or avalanche deposit (cf. Cas and Wright 1987; p.298–302); very coarse, ultraproximal detritus accumulated via rockfall and slumping near the base of a (paleo)slope, with some kinetically fractured and partly disaggregated clasts (jigsaw fabric), and smaller clasts infiltrated between the framework clasts to produce the poorly sorted but bimodal fabric. However, the timing of the inferred talus deposition is not known; it could be either a synvolcanic deposit, or the result of postvolcanic, synorogenic erosion of a basement inlier (e.g., subaerial erosion of a bedrock high during pull-apart basin development; see below).

Within an outcrop of supposedly metasedimentary carbonate (marble) of Beakhouse (1989) and Beakhouse et al. (1989), the carbonate appears to have been injected in *lit-par-lit*, vein-like fashion along layers in the local wacke unit. Thus the carbonate is likely a carbonatized shear zone.

Along with felsic volcaniclastic rocks and a very thin polymict conglomeratic unit, the felsic porphyry, felsic volcanic and gabbroic rocks described in the two paragraphs below are part of the "varied rock types subarea" in Figure 3.

At southwest South Bay, a small felsic porphyry body (feldspar porphyry, quartz-feldspar porphyry) contains 1–2 mm subhedral white plagioclase grains. Adjacent along strike to the southwest are felsic volcanic rocks of obscure origin, with one site of presumed "interflow" sedimentary facies: fine-grained, laminated to thinly bedded tuff, with grading and one pyritic lamina. The timing of the presumably intrusive, undated felsic porphyry is uncertain; it is not known whether the porphyry might be synvolcanic and subvolcanic, or postvolcanic and synorogenic (e.g., the small felsic porphyry bodies commonly intruded along the fault margins of pull-apart basins: Mueller et al. 1991; Mueller and Corcoran 1998).

Local mafic rocks include both pillowed basalt (e.g., eastern Exit Bay) and gabbroic intrusions. The gabbroic intrusions may be potentially important as relatively late transtensional sills (Devaney 1997, p. 46), consistent with the presence of late gabbroic bodies elsewhere in the Uchi Subprovince (e.g., Stott and Corfu 1991, p. 184), but such a speculative interpretation would require radiometric dating and further mapping for testing.

Southern Felsic Volcanic (Rhyolitic) Unit

This rhyolitic unit is located south of southwest South Bay (Figure 3). (The following is based on observations of one large, particularly good outcrop between Grace Lake and the southernmost part of South Bay; similar lava facies are seen at South Bay.) The felsic volcanic rock in this area is a highly siliceous, brittle and fractured lava facies with flow banding and some faintly porphyritic texture. Autoclastic breccia fabric varies from incipient brecciation along specific flow band horizons (the result of differing viscosities of the lava flow layers), to well defined jigsaw-clast (crackle breccia) fabric, some of which is laterally transitional in outcrop to bedded breccio-conglomerate (a facies change to locally reworked flow-top rubble beds?).

There is an erosion surface developed on the rhyolitic unit, overlain by felsic volcanic clasts (including basal clasts derived from the adjacent bedrock) in a sandy matrix, and at one site sandstone infills an obvious large crack in the underlying fractured rhyolite. At the 100 m scale, this contact between the rhyolite and the conglomerate or sandstone (wacke) is tightly folded.

Within the sedimentary sequence overlying the rhyolitic lava unit, a great variety of conglomeratic and arenitic beds are present, and rapid facies changes over only a few metres are characteristic. The local conglomerate or breccia beds are rich in flow banded clasts, and also contain clasts of tuff, white felsic volcanic rock and greenish sandy intraclasts. Beds of tightly clast-supported fine pebble breccio-conglomerate and intraclastic breccia are evidence of local sedimentary reworking. Sandy horizons include thick (10–30 cm) graded wacke beds (mass flow beds, not necessarily turbiditic), some greenish fine-grained wacke (the probable source of the local green intraclasts), and structures suggestive of penecontemporaneous deformation (soft-sediment folds, pod-shaped injections of conglomerate into sandstone, coarse sandstone loaded or injected into finer greenish sandstone) during slumping.

The rhyolitic composition and commonly angular shape of the clasts signifies a local source for the lithoclasts and intraclasts, and some beds near the basal contact are physically linked to their source rock. The wide variety of sedimentary facies present resulted from a variety of sedimentary processes (current reworking, mass flows) in a highly proximal setting, and the very rapid facies changes and potential slump deposits may reflect the local paleotopography (depositional slopes) on a lava flow, dome, or bedrock high. However, evidence regarding a subaerial versus subaqueous setting is equivocal (glassy quenched fragments were not recognized), and it is uncertain whether the erosion and sedimentation at this site was during volcanism or long after.

Western Birch Lake Area

The volcanic rocks in this area (area 1 in Figure 3) are notably felsic (e.g., quartz and feldspar phyric, white weathering, waxy fresh surfaces, brittle). As also noted by Thurston (1986) and Beakhouse (1989), the local lava flow facies, abundantly exposed in the western peninsula, are massive, flow banded and autobrecciated. Chloritic veins and disseminated sulphide minerals (pyrite, chalcopyrite; rusty weathered surfaces) are common. Along with the associated pyroclastic or volcaniclastic facies and felsic porphyries (coarse, with 2–10 mm feldspar phenocrysts) that crop out along the western bays of Birch Lake, this western area presumably represents a felsic volcanic centre (Beakhouse 1989), but stratigraphic relationships with the other major synvolcanic stratigraphic units in the study area, the volcaniclastic and wacke-dominant ones to the south and east, are uncertain. Linear segments of the Swain Lake deformation zone both bound and cross-cut this felsic volcanic area and/or centre (Beakhouse 1989).

STRUCTURAL FEATURES

The following are the more common and important small-scale hard-rock deformation structures observed in the volcaniclastic and wacke units:

1. cleavage or schistosity: commonly axial planar to small folds; slip along cleavage oblique to bedding in wacke-mudstone horizons can produce at bed contacts 1–10 cm structures which superficially resemble sedimentary load or flame structures; Good (1988) and Fraser (1998) described areas with two cleavages (S_1, S_2), but detailed stuctural analysis was not part of the present study;
2. quartz veins: these vary from planar (fracture filling) to sigmoidal (tension gashes) to tightly folded; some veins along schistosity planes are boudinaged;
3. folded bedding: folds are typically tight, and small folds are obviously easier to recognize than very large ones in the commonly small (<10 m wide) outcrops available; west- to northwest-plunging folds are notably common; closely spaced top reversals (e.g., over 2 to 50 cm across strike) signify missing or rare fold hinges (e.g., transposed and translated away, or obliterated by shearing) in very tight to isoclinally folded sections;
4. shear fabric: includes sigmoidally folded, intensely developed schistosity (e.g., S-C fabric); augen or lensoid shapes (bed shreds) reflect the slicing up of beds during transposition of layering; a south Wagner Bay outcrop identified by Good (1988) as containing cross-laminated ironstone consists of tectonically truncated bedding; rotated porphyroclasts (feldspar phenocrysts as hardbodies in porphyry) were noted at west Birch Lake; commonly, small feldspar porphyry bodies are highly strained, with well developed schistosity, augen and sigmoid fabrics, and such rock bodies may have been more competent and brittle than their surrounding lithologies; and
5. brittle deformation features such as fractures and minor (1 cm to 1 m) apparent dextral offsets are notable: e.g., Fraser 1998; see Structural Geology of conglomeratic units, below.

Rare dark (mafic?), thin, low-dipping dikes (e.g., at northwest Superstition Lake) are of specific interest because, like some of the quartz veins in the Birch Lake vicinity (*see* "Gold" mineralization discussion, below), the low dips may reflect late orogenic vertical extension and concurrent development of low dipping extensional fractures (Sibson et al. 1988), consistent with localized transpression during regional wrench tectonism.

Large scale structural features such as the Swain Lake deformation zone and a large anticlinal fold nose near southwest Birch Lake were documented by Beakhouse (1989; Beakhouse et al. 1989). The outline of the felsic volcanic Western Peninsula area (Figure 3; Beakhouse 1989), interpreted as a fault-bounded scholle by Devaney (1999a,b,c; see Figure 2b, and "Indenter or Promontory Regional Tectonic Hypothesis" below), shows up well on regional aeromagnetic maps (Figure 1).

West of a large, northwest trending, folded basaltic unit between Springpole and Birch lakes mapped by Good (1988), moderately west-dipping (20–45^{o}) wacke strata at southeast Wagner Bay contrast greatly with the steeply dipping strata in the rest of the greenstone belt. The somewhat triangular Wagner Bay area (area 2 in Figure 3) is structurally complex and worthy of future detailed structural study.

Top indications for the study area are summarized in Table 2.

COMMENTS ON THE LOW LEVEL OF STRATIGRAPHIC RESOLUTION

Despite the recent multiple efforts to map the geology of the Birch Lake area, including the present study's specialized sedimentological and volcanological approach, potential stratigraphic complexity and probable structural complexity severely limit the stratigraphic resolution of the basinal history of the volcaniclastic and related wacke-dominant units. Although general contrasts between proximal volcaniclastic and distal sedimentary facies have been documented in Table 1, the somewhat monotonous character of the proximal volcaniclastic lithofacies, the rarity of dated rocks, and the absence of at least a few obvious distinct, laterally continuous (at the 10 km or more scale) volcaniclastic stratigraphic units or horizons makes recognition of the probable structural repetition of units difficult. It is notable that most of the faults or deformation zones depicted on previous geological maps of the area are inferred, largely unexposed features, and thus the structural history of the area is only poorly constrained. (Specialized detailed structural analysis would improve, but likely not solve, this problematic situation.)

Although felsic volcanic and porphyritic rocks at western Birch Lake represent a ca. 2740 Ma, Confederation assemblage volcanic centre (Beakhouse 1989; Beakhouse et al. 1999), and the surrounding undated, synvolcanic (presumably Confederation assemblage), volcaniclastic and wacke-dominant stratigraphic units to the south and east (Figure 3) contain the types of features to be expected in facies distal to such a centre (Table 1), evidence for a direct chronostratigraphic correlation between the western felsic volcanic centre and the surrounding units is presently equivocal. The felsic volcanic centre area is both bounded and internally divided by the Swain Lake deformation zone; potential offset along such a major structural break makes any precise source to basin correlation uncertain.

Petrographic and geochemical analysis have the potential to outline compositionally distinct stratigraphic units (e.g., cryptic chemostratigraphic units), but such work can be overly expensive or time consuming, with no guarantee of unequivocal results, particularly in areas for which the history of faulting and folding is poorly constrained (or unconstrained).

Compositionally distinct volcaniclastic units within the Confederation assemblage have been recognized in the southern Birch–Uchi greenstone belt (Thurston 1985), most notably at Lost Bay (Stix and Gorton 1991; Rogers et al. 1999, 2000). However, the southern part of the Birch–Uchi greenstone belt is an area of fairly linear, laterally continuous stratigraphic units (Figure 2; Thurston 1984; Rogers et al. 2000), it has a longer history of detailed study, and it probably displays better preserved stratigraphic patterns than at Birch Lake, where many tectonized stratigraphic units converge in a somewhat triangular, tectonically complex area. As noted previously (Devaney 1997, p.46) and below (*see* "Mineralization"), the interpretation of a small caldera by Atkinson and Storey (1997) is not supported by the data presented herein.

The lack of stratigraphic resolution may be in part a problem of scale; the study area may be far too small. In order to recognize patterns within large, linear basins or subbasins (e.g., along-strike variations in arc stratigraphy, with basins preserved as tectonized sequences in orogenic belts), a subprovince scale of view might be necessary. This contrasts greatly with the situation for small pull-apart basins (typically only kilometres to a few tens of kilometres long), which usually display more abrupt proximal to distal facies changes and thus reveal more recognizable stratigraphic patterns.

Description and Interpretation of Conglomeratic Units

SEDIMENTOLOGY

Facies and Paleoenvironmental Interpretation

Epiclastic conglomeratic and arenitic (meta)sedimentary rocks in the Birch Lake area form several distinct tectonized stratigraphic units (Figures 2, 3; Good 1988; Beakhouse et al. 1989; Devaney 1997, 1998). Clast-supported polymict conglomerate is very coarse (cobbles common, few boulders) and varies from massive to crudely bedded to locally well bedded. Thin sandstone lenses and interbeds with rare cross-beds and ripples form a minor amount (normally <20%) of most of the conglomeratic outcrops (Photos 2, 3, 4). These facies display features such as fining-up sequences (metres thick) and rare small channels (metres wide, less than 1 m thick) which, along with the absence of features such as well developed graded bedding, strongly suggest that these conglomerates and interbedded sandstones are proximal braided river deposits (e.g., via criteria of: Hein 1984; Nemec and Steel 1984). As documented in numerous articles (e.g., in Miall 1978) and easily observable in modern gravelly rivers at low stage, in the gravelly braided river environment:

1. the intermittent rolling (traction) of clasts over other clasts along gravelly riverbeds produces clast-supported fabric;
2. multiple scales of laterally shifting, broad shallow channels produce thin, erosionally based conglomeratic lenses; where aggradation (vertical accumulation) exceeds erosion over the long term, gravelly deposits with sandy to muddy interbeds are preserved;
3. intraoutcrop scale variations in bedding (Photos 2, 3) and sorting (the standard deviation of clast size) reflect local variations in flow competency (the ability to transport a given size clast), the coarseness of gravel available for transport and hydrodynamic sorting (e.g., winnowing of a finer subpopulation of clasts from a coarser, more poorly sorted subpopulation of clasts, with both subpopulations potentially from the same gravel bar);
4. in areas of reduced flow power (e.g., following high stage gravel transport, or in partly blocked channels), low energy streamflow transports sand and fills in channels with it; cross-beds reflect the migration of dunes down the channels, and erosion surfaces (including pebble bands as erosional lag horizons) and mud drapes (Photo 4) may mark pauses in the downstream accretion of the thin channel

sandbodies; slight currents produce only rippled or flat laminated sand beds; very thin and/or very rapid streamflow produces upper flow regime horizontal (plane bed) to low angle (antidune) laminae;

5. a highly local (individual channel scale) decrease in flow competency can produce a fining upward sequence of gravel and/or sand; the ubiquitously shallow channels produce only thin sequences; and
6. mud settles out in slack water pools and abandoned channels (Photo 5); erosion of dried out or viscous, compacted muddy beds produces intraclasts, which may include angular blocks derived from slumping of erosional channel margins.

In cross-sections of conglomerate, or mixed conglomerate and sandstone, the commonly seen pattern of coarser conglomerate beds being thicker versus finer conglomerate beds being thinner (e.g., Photo 6) is a primary sedimentological relationship, and recognition of this pattern shows that such beds constitute an undisturbed stratigraphic section and are (most likely) not tectonically transposed slices.

Locally, an uncommon subfacies of fine pebble conglomerate with improved sorting and clast rounding (Photo 7) suggests deposition in a more distal setting (fluvial, lacustrine or shallow marine: e.g., Nemec and Steel 1984).

Thick horizons of sandstone and mudstone (e.g., tens of metres thick), which contain rippled (cross-laminated) and sharp-based laminae and thin beds (Photos 8, 9) are found within the predominantly conglomeratic units. These finer grained horizons are likely the most distal facies, deposits of various shallow water (lacustrine or marine) processes, and may record transgression and submergence phases (Devaney 1997) in the more central (nonmarginal) parts of the former basins.

Small areas or basins filled with fan-delta or braid delta successions commonly contain such a range of proximal to distal facies (listed above) in prograded and retrograded intervals (Ethridge and Wescott 1984; Nilsen and McLaughlin 1985; McPherson et al 1987; for Archean examples, see: Nocita and Lowe 1990; Mueller et al 1991; Mueller and Corcoran 1998), and such a scenario is suggested for the Birch Lake conglomeratic basins.

Provenance (Clast Composition)

The polymict conglomerate beds consist mostly of felsic volcanic (rhyolitic) and felsic porphyry clasts, with lesser amounts of quartz, chert and magnetite iron formation clasts, and very rare granitoid, basaltic and gabbroic clasts.

This provenance appears to reflect derivation from sources that were (and still are) highly local within the northern Birch–Uchi greenstone belt (e.g., in the Birch Lake area, rhyolite and felsic porphyry units are presently adjacent to some of the conglomeratic units: Good 1988; Beakhouse et al. 1989). Granitic and basaltic units are also present within the Birch Lake area, but are more abundant near the present margin of the northern Birch–Uchi greenstone belt, suggesting that any granitic or basaltic paleoexposures in both marginal and internal areas supplied few clasts to the conglomeratic units or basins. The highly local derivation of the conglomerate, best seen in the exposures of basin marginal facies (see below; Devaney 1998), helps support the interpretation of the conglomeratic units as pull-apart basins (see below).

Provenance of Marginal Facies

Oligomict (monomict) clast compositions are rare and are only locally present at or very near (uncertainty owing to lack of exposure) the margins of some of the conglomeratic units or basins (for localities cited below, *see* Devaney and Crews, in press; *see also* the maps of Beakhouse et al. 1989 and Good 1988). One outcrop area (west Louwag Lake) contains felsic porphyry lithoclasts only (Photo 10), and another contains oligomict beds of angular rhyolitic clasts (southern South Bay; Photo 11) and is almost in contact with a rhyolitic outcrop at the edge of a map-scale rhyolitic unit. (This latter site is interpreted as a highly proximal, basal horizon.) One outcrop is unusually rich in black chert clasts (west Superstition Lake; Photo 12), and exposures near one basaltic unit are unusually rich in dark, apparently basaltic, clasts (west Satterly Lake). Gabbroic clasts are prominent at Cromarty Lake (Devaney 1999d). Oddities include one small outcrop with small, angular to round clasts of fine grained sedimentary rock (e.g., laminated wacke–siltstone) and felsic volcanic rock only, and one small outcrop of coarse felsic breccia (clasts up to 1.5 m; see above) which may represent a talus breccia (both sites in central South Bay).

The above compositions likely reflect highly proximal depositional sites with small drainage (paleo)basins which supplied (in most cases) only one or two clast lithologies, versus the case for more polymict conglomerates supplied by rivers that likely drained larger (paleo)basins.

Also present at or near the margins of some of the conglomeratic units are rare exposures in which the clasts appear to be polymict but are of an atypical and more volcanic composition (e.g., southwest part of the unit northwest of Springpole Lake; west Satterly Lake, different from the exposures with basaltic clasts noted above). However, it is not known whether these specific sites are older volcaniclastic stratigraphic units or marginal facies coeval with the more typical conglomeratic units. (At central Wagner Bay, an oligomict volcaniclastic conglomeratic unit is thought to be part of an older intermediate volcanic succession and unrelated to the adjacent polymict conglomeratic unit; *see* “Wagner Bay Area,” above.)

Basal Conglomerate Exposures

Only three small outcrops (at South Bay) display exposures of basal conglomeratic facies in sharp contact with felsic volcanics. One outcrop contains oligomict conglomerate with angular rhyolitic clasts (Photo 11; as noted above, a short covered interval obscures the basal contact here) and top indicators face away from the contact, and the other two outcrops are of polymict conglomerate and coarse, quartz-rich tuff. At one site, grains in the sandy matrix areas of the conglomerate appear to be identical to those of the adjacent quartzose tuff (less than 1 m away), suggesting that the sharp contact between the felsic tuff and the conglomerate (Photo 13) is an erosion surface (i.e., an unconformity at the basin margin).

Near Springpole Lake, Barron (1996) described a basal conglomerate horizon with trachyte clasts, and noted local evidence of synsedimentary trachytic intrusions and volcanism.

Pull-apart Basin Interpretation

The facies variation over small (kilometre-scale) areas from proximal fluvial to distal aquabasinal (lacustrine or marine) deposits, the local provenance of the clasts (including distinctive highly proximal marginal subfacies), the limited strike extent (mostly only kilometres long) of the conglomeratic stratigraphic units, and the wholly or partly sigmoidal (lazy-Z shaped) map pattern of these units (Figures 2, 3; see structural discussion below) suggest deposition in a series of late orogenic, dextrally transtensional pull-apart basins (e.g., via criteria of Nilsen and McLaughlin 1985; Nilsen and Sylvester 1995). This interpretation confirms Thurston’s (1986; Thurston and Chivers 1990) assessment of the Birch Lake area polymict conglomeratic units as Timiskaming-type sequences.

Given that the study area has been eroded to a peneplane exposing greenschist facies rocks, the conglomeratic units represent the roots of partly removed basin successions; whether the basins were truly separate and isolated drainage systems, or formed a system of fluvially linked subbasins, is beyond the resolution of the data.

The term pull-apart basin is used herein as a general term; in better exposed areas, a greater subdivision of types of transtensional structures and strike-slip basins is possible (Nilsen and Sylvester 1995).

Pull-apart basins should be bounded by faults and unconformities, but exposures of the exact boundaries are very rare in the study area; instead, the presence of covered intervals is characteristic. Structural features at unexposed boundaries are thus not available for observation and much of the fault-bounded aspect of the pull-apart basin model must be interpreted or inferred. (Note that this limitation imposed by covered intervals and a low abundance of sites with potentially critical outcrop evidence is typical of exposure quality and quantity in northern Ontario greenstone belts.) Some relevant aspects of the structural geology of the study area are outlined below.

Stratigraphic Nomenclature

These conglomeratic units (pull-apart basins) are probably not part of the Confederation assemblage of Stott and Corfu (1991), the youngest of the three defined assemblages in the Birch–Uchi greenstone belt. Instead, these conglomeratic units are likely part of a fourth, younger, presently unnamed assemblage (Devaney 1999a) of relatively limited distribution (Figures 2, 3) and potentially correlative with the conglomeratic Billett assemblage present along regional strike to the east, in the Meen–Dempster greenstone belt of central Uchi Subprovince (Stott and Corfu 1991; Stott 1996).

Inferred Age of the Conglomeratic Units

The conglomeratic units are undated, but because rhyolitic units in Birch Lake area are ca. 2740 Ma old (Beakhouse et al. 1999) and the rhyolite clasts in the conglomerate appear to have been locally derived, the conglomerate should be younger than its presumably ca. 2740 Ma clasts.

Rocks in the Springpole area of Birch Lake (Figure 3) are of interest because there an episode of magmatism and sedimentation appear to have been coeval. The Springpole gold deposit has been interpreted as part of an alkalic (trachyte, lamprophyre) “high-level porphyry and breccia pipe complex” with “both intrusion-related and epithermal types” of gold mineralization (Barron, 1996, p.237). Barron discounted a Timiskaming-type pull-apart basin setting for this 2757–2715 Ma alkalic volcanic complex and the adjacent coeval polymict conglomerate unit, but the conglomerate in the Springpole area appears identical to the other polymict conglomeratic units (pull-apart basins) in the Birch Lake area. Geochronological work on the volcanic and plutonic rocks of the Birch–Uchi greenstone belt by Beakhouse et al. (1999) suggests that the young end of the Springpole rock age range (ca. 2715 Ma) should be a late tectonic age.

Despite Barron’s interpretation of epithermal, rather than mesothermal, mineralization, the geology of the Springpole area rocks conforms with much of the fault-bounded pull-apart basin scenario typical of late orogenic Timiskaming-type assemblages (e.g., Card et al. 1989; Wyman and Kerrich 1989a, Thurston and Chivers 1990). Shoshonitic lamprophyre intrusions from the Springpole area are described by Wyman and Kerrich (1989b) and are thought to be spatially and temporally associated with major, late orogenic faults (Wyman and Kerrich 1989a,b).

Another conglomeratic unit interpreted as a pull-apart basin is located at Sundown Lake, about 10 km southwest of the study area (Devaney 1999d). This conglomeratic unit is cross-cut by, and within the metamorphic aureole of, the 2702.7–2699.4 Ma Okanse Lake pluton (dated by Beakhouse et al. 1999), indicating that this conglomeratic unit, and perhaps also the other similar ones in the Birch Lake area to the northeast, are older than ca. 2700 Ma.

If the proposed correlation of the Birch Lake conglomeratic units with the Billett assemblage to the east (see above) is at least roughly correct, the estimated ca. 2720 Ma age of the Billett assemblage (Stott and Corfu 1991, Figure 6.18c) may serve as an approximation of the older end of the age range of the Birch Lake conglomerates. Thus the timing of the strike-slip basin development can be estimated as during ca. 2720–2705 Ma period, which is in general agreement with the database for the Birch–Uchi greenstone belt and the rest of the Uchi Subprovince (Stott and Corfu 1991; Corfu et al. 1995; Beakhouse et al. 1999). Although pull-apart basins can also form as intra-arc basins during active volcanism stages (e.g., Hathway 1993), the sedimentological arguments listed above and the structural evidence listed below favour a postarc, late orogenic wrenching scenario for the conglomeratic units.

STRUCTURAL GEOLOGY

Because the intent of this study is to focus on the Archean sedimentary history of the Birch Lake area, the structural geology of this study area (Figure 3) has not been examined in detail. The structural features documented on previous maps (Thurston et al. 1981; Good 1988; Beakhouse et al 1989), supplemented by the author's field observations, have been used as part of the foundation for the structural–stratigraphic synthesis and interpretations of pull-apart basins and their regional significance (Devaney 1997, 1998, 1999a,b,c,e). Selected relevant structural aspects are briefly noted below.

Map-view Form of the Conglomeratic Units, and Rarity of Direct Evidence for Fault-bounded Basins

The map-view forms (outlines) of the conglomeratic units (Figures 2, 3), as previously mapped (Good 1988; Beakhouse et al. 1989) and discussed below, are somewhat sigmoidal, including potentially coalesced sigmoidal units to the southwest.

As noted above, most portions of the boundary zones of the tectonized conglomeratic units or basins are not exposed, and the probable presence of faults along the margins of these units must be largely inferred. These margins are located at or near major lithotectonic contacts, and would likely have been sites for faulting during regional deformation episodes. The map-view characteristics of the five different conglomeratic units (Figures 2, 3) are described below; note that almost all of the boundaries of these units on published maps are drawn through covered areas between outcrops.

1. North of Springpole Lake (Good 1988): no mapped fault boundary; much potential evidence is underwater; long straight shoreline at north margin, suggestive of a fault; no good sigmoidal outline of this conglomeratic unit, but the somewhat rhombic outline on the maps of Good (1988) and Barron (1996) could be the east part of a sigmoidal pull-apart basin (with its west end underwater).
2. Wagner Bay island (Good 1988): the margin is probably completely unexposed (underwater and on the island); note the crudely sigmoidal outline of this conglomeratic unit on the map of Good (1998).
3. Satterly Lake (Good 1988): partial sigmoid shape (northwest end poorly defined or formerly eroded?); adjacent to the west, some fragmental rocks mapped as volcanic by Good (1988) may instead be sedimentary and related to pull-apart basin development; Good's (1988) map shows two

orthogonal cross-faults (younger faults?) at and near the unit margin. The eastern part of this conglomeratic unit, in the Cromarty Lake area, is described by Devaney (1999d).

4. South Bay (Beakhouse et al. 1989): this conglomeratic unit is partly separated from the one to the south (#5, below) by a sigmoidal felsic volcanic map unit (Figure 3; see also Thurston et al. 1981) which may be a horst-like basement block of Confederation assemblage rock “poking up through the younger metasediments” (Thurston 1986, p.27); scattered occurrences of conglomerate (thin units) and breccia north of the main conglomeratic unit may have been deposited along or near multiple fault strands or splays (e.g., a “stepped basin margin” similar to the “Ridge basin” model of Nilsen and McLaughlin 1985, Figure 15) in an area typified by thin units of a wide variety of lithologies (“varied litholgies” subarea in Figure 3).
5. Grace and Bobarris lakes (Thurston et al. 1981; Beakhouse et al. 1989): the southwest margin is a mapped deformation zone (small-scale dextral fabrics observed) that is well defined geophysically (OGS 1997); together, units 4 and 5 may form a complex strike-slip basin, partly bounded to the northwest by the Swain Lake deformation zone (Beakhouse 1989) and similar in outline to the small-scale rhombic pull-apart structures of Peacock and Sanderson (1995), rather than two simple pull-apart basins or subbasins.

It is suggested that, despite the paucity of exposures of the boundary zones and the lack of detailed structural studies, the conglomeratic units can be reasonably interpreted as strike-slip basins (specifically, late orogenic fault- and unconformity-bounded pull-apart basins; also, the strike-slip component may actually be oblique-slip), based on the sedimentological evidence, the inferred (and rarely observed) faulted unit boundaries, and the crudely sigmoidal, lazy-Z shaped map outlines suggestive of dextral transtensional motions.

These pull-apart basins can be considered to represent large-scale tension gashes, or dilational gaps at fault releasing bends (Sylvester 1988), that were open to the surface and were filled with clastic sediment. Unlike small-scale (1 mm to 1 m) structural data, pull-apart basins that are kilometres wide and 5–10 km long are so large that they are not likely to be obliterated by any subsequent tectonism. Thus, if these pull-apart basins were indeed very late tectonic features, their large-scale form (dextral transtensional sigmoidal map pattern) may have been at least partly preserved. (However, structural studies may be required to investigate whether originally straight units were later folded or kinked into sigmoidal shapes.)

Another tectonized pull-apart basin sequence is thought to be present southwest of the study area, in the Sundown Lake area (Devaney 1999d). The map view outline of the north-striking conglomeratic unit at this site is slightly sigmoidal (Johns 1979b) and suggestive of sinistral motions during basin development, which is consistent with the documented predominance of late tectonic sinistral offsets in the north- to northeast-striking units of the southern Birch–Uchi greenstone belt (*see* “Indenter or Promontory Regional Tectonic Hypothesis,” below). Interpretation of conglomeratic facies farther to the southwest at Woman Lake as late orogenic deposits is more equivocal (Devaney 1999d).

Small-scale Dextral Features

Small (intraoutcrop) Z-folds and dextral offsets (Photo 14), mostly observed in the “older” (preconglomeratic unit) wackes (e.g., Fraser 1998), are present, but whether such apparent dextral motions were synchronous with pull-apart basin development is not known.

Deformation Within the Conglomeratic Units

As is typical of strata throughout most Archean greenstone belts, bedding and schistosity in the conglomeratic units generally dip very steeply (70–90°) and strike at least approximately parallel to the curvilinear boundaries of the lithotectonic units. In the southwest conglomeratic units, newly mapped top indicators (summarized in Table 2) appear to define parts of several laterally continuous homofacing panels (e.g., north-facing versus south-facing; the term "homofacing" is from Stott and Corfu 1991, p. 193), but the scarcity of outcrop and top indications offers only a very vague suggestion of anticline-syncline patterns.

The state of penetrative deformation of the predominantly coarse clastic metasedimentary rocks in the conglomeratic units is very variable, both spatially and in intensity. Some rocks appear nearly undeformed penetratively, some display small-scale (intraoutcrop) folding and axial-planar cleavage (best seen in the thinner bedded and finer grained rocks; Photo 15), and some clasts are oblate (flattened in the plane of schistosity) or, rarely, prolate.

The best examples of prolate clasts (at Louwag Lake) are oriented subvertically, suggesting that some local vertical stretching of clasts occurred during regional wrenching (i.e., an increment of more orthogonal transpression (e.g., Tikoff and Greene 1997; Dewey et al. 1998), as part of the mix of transpression and transtension that constitute strike-slip wrenching). In general, oblate clasts appear to be far more common than prolate clasts in the tectonized conglomeratic units, but the absence of good three-dimensional exposures in most outcrops severely limits the mapping of clast fabrics.

Note that the pull-apart basin model predicts that there would commonly be increments of transtensional and transpressional strain in the development of a pull-apart basin, including segmentation or strain partitioning of such a basin (Nilsen and Sylvester 1995). Such multiple and locally variable strain increments would help to account for the variable nature of the deformation style within the conglomeratic units of this study.

Although strike-slip basins are also known to have formed as a variant of the rift basins in extensionally collapsed orogenic belts (e.g., Dewey 1988; Windley 1995; Devaney 1999e), the penetrative deformation, steep dips and commonly variable top indications in Archean strike-slip basin sequences indicate basin-scale tight folding (or other rotation) and schistosity development during regional compression or transpression rather than extensional orogenic collapse. (Very Late Archean (<2.65 Ga) and post-Archean intracratonic deformation of Superior Province supracrustal sequences is thought to be volumetrically negligible.)

Sigmoidal Trends of Schistosity in Older Bedrock Units

At South Bay (Beakhouse et al. 1989), the trends of bedding and schistosity in turbiditic wacke units and other lithotectonic units appear to have been folded or kinked into kilometre-scale sigmoidal, lazy-Z shapes (Figure 4).

This suggests that the lazy-Z shaped sigmoidal schistosity trends present in the bedrock units surrounding the conglomeratic units, trends which are very similar in form to the sigmoidal outlines of the similar to larger scale conglomeratic units, were produced by dextral motions that postdated or were coeval with the development of the main schistosity in the area. It is envisioned that the bedrock basement (schistose and previously tectonized bedrock?) was dextrally wrenched and faulted, creating sigmoidal lenses in the older bedrock basement and opening up pull-apart basins at the same time. Subsequent deformation compressed or transpressed the fill of the pull-apart basins, imparting a variable degree of schistosity to the clastic rocks within the basins, and was likely a further increment of strain in the surrounding older units.

Distinguishing Between Older and Younger Sedimentary Units

(The following paragraph is taken, with minor modifications, from Devaney 1999d, p.18–7.) Archean workers often lump various metasedimentary map units together in their descriptions and interpretations of study areas, but in some cases, deformed conglomerates and adjacent map units of deformed sandstones (e.g., "wackes" and any related siltstone–slate facies) might represent *separate* map units of different ages, particularly where older "wacke" units may have formed the basement to pull-apart basins. This may be the case at some sites in the Birch–Uchi greenstone belt; younger conglomerates and related, more distal sandstone facies would lie unconformably above older clastic rocks, but potential older-versus-younger relationships might not be readily discernable in tectonized and poorly exposed areas (e.g., consider the rarely seen basal unconformities of supposedly unconformably based, Late Archean synorogenic basins), causing some workers to lump sedimentary units of different ages together. Given the potential complexities of late orogenic episodes of compression, transpression and transtension, which may include multiple incremental stages of deformation of pull-apart basins (Devaney 1999e), structural fabrics in younger conglomeratic basin fill may be difficult to distinguish from those in older "basement" strata, particularly where they are coplanar (or nearly so) owing to intense deformation and rotation of fabrics.

Indenter or Promontory Regional Tectonic Hypothesis

Supracrustal assemblage ages in the Uchi Subprovince (Stott and Corfu 1991, Figure 6.3) suggest a structural offlapping of assemblages (Rogers et al. 1999, 2000) and/or early orogenic, broadly north-vergent thrust-stacking (Williams et al. 1992, Figure 25.10b), followed by late orogenic wrench faulting (Stott and Corfu 1991; Corfu et al. 1995). Evidence for the supposed thrust stacking and other early orogenic deformation stages is poor (or subtle?), perhaps the result of strong overprinting by later tectonic events.

The large-scale map patterns of geological units in and marginal to the Birch–Uchi greenstone belt are shown in Figures 1 and 2 (see also: Stott and Corfu 1991; Beakhouse 1989, Figures 5, 6). In the southwest part of the belt, structurally offlapping assemblages (cf. Williams et al. 1992, Figure 25.10b) young away from the Trout Lake Batholith (Stott and Corfu 1991, Figure 6.5) and late sinistral-sense structural features are well preserved (Fyon and Lane 1985; Fyon and O'Donnell 1986; Crews et al. 1997; van Staal 1998; Crews 1999; Rogers et al. 1999). As outlined below, it is suggested that the large-scale map patterns faithfully record the late orogenic, approximately northwest–southeast compression (present geographic coordinates used herein) of a previously tectonized and heterogeneously structured area.

As shown in Figure 2, the Jeanette Lake granitoid complex (JLGC: Beakhouse 1989, Figure 6; or "Bamaji–Blackstone batholith" of Stott and Corfu 1991, Figure 6.2) is envisioned as a structurally competent microcontinental block (see below); the arcuate and/or protrusional outline of folded strata northwest of the Jeanette Lake granitoid complex (Figures 1, 2) suggests that this supposedly competent block extends below wacke metasediments. It is thought that this block was forced northwestward, causing either broad folding of the Birch–Uchi greenstone belt around an incoming indenter (the Jeanette Lake granitoid complex) or increased compression of the Birch–Uchi greenstone belt around an already adjacent basement promontory (the Jeanette Lake granitoid complex). Within the Birch–Uchi greenstone belt, many faults and other structures appear to directly reflect this regional geometry (Figure 2). In the west to southwest parts of the greenstone belt, late faulting within the predominantly north-trending units of the greenstone belt is predominantly sinistral (Fyon and Lane 1985; Fyon and O'Donnell 1986; Crews et al. 1997; van Staal 1998; Crews 1999; Rogers et al. 1999). In the north to northeast parts of the greenstone belt, the best preserved (and therefore likely latest) faulting is predominantly dextral (i.e., the northeast part is a mirror image of the faulting in the southwest part), as evidenced by outcrop-scale folds and offsets (Fraser 1998) and the presence of dextrally sigmoidal fault-bounded conglomeratic pull-apart basins (less than 10 km long; loosely analogous to large-scale tension gashes: Figures 2b, 3) filled partly with locally derived polymict conglomerate. Sedimentological evidence (see above) indicates that these are late (post-Confederation assemblage), Timiskaming-type pull-apart basins ("late, fault-bounded and unconformable basins" of Williams et al. 1992, Table 25.2) which may be correlative with the conglomeratic Billett assemblage (Stott and Corfu 1991; Stott 1996) in the central Uchi Subprovince. In the northwest part of the Birch–Uchi greenstone belt there was presumably more orthogonal compression of approximately northeast-trending stratal packages. Note the paucity of late granitic plutons in the northwest part of the greenstone belt (a convergent zone?) versus the greater abundance of such plutons in the supposedly more extensional or transtensional zones (e.g., areas of strike-slip in the west or southwest parts of the greenstone belt; cuspate areas of structural divergence, such as near the Mink Lake stock in Figure 2a).

In the northwest part of the greenstone belt, the Western Peninsula subarea (Figure 3; Beakhouse 1989; Devaney 1997) is considered to be a small-scale block of relatively competent felsic metavolcanic rocks both bounded and internally divided by deformation zones. It is suggested herein that as a result of northwest–southeast compression, this structurally competent felsic unit acted as a scholle (structural flake or block: term of Dewey and Sengor 1979), termed the Western Peninsula Scholle (WPS in Figure 2b), which experienced tectonic wedging or lateral escape to the northeast, from a zone of convergence and compression to an adjacent zone of extension and structural divergence along lithological contacts and faults (the Swain Lake deformation zone of Beakhouse 1989).

The map pattern of the proposed indenter or promontory flanked by symmetric and opposing sinistral versus dextral fault systems (Figure 2b) is similar to larger-scale indenter map patterns seen in some younger orogens (e.g., Matte 1986; Nijman and Savage 1989; Ratschbacher et al. 1991a,b, Laubscher 1992) and some Archean orogens (e.g., Krapez and Barley 1987; Stott and Corfu 1991; Williams et al. 1992; Corfu et al. 1995). Note that indenter blocks need not be accreted exotic terranes, but can be the result of self-indentation of orogenic units around an obstacle-like crustal block (e.g., Henderson et al. 1990; Vauchez et al. 1994). Also, because the curvilinear pattern of the greenstone belt's tectono-stratigraphic units arcs through more than 90° (from north-trending, to northeast-trending, to east-southeast trending: Figures 1, 2), the sinistral versus dextral symmetry in the greenstone belt is not the product of a tectonically late, large-scale conjugate fracture pattern with the orientation of conjugate fracture patterns common elsewhere in Superior Province (i.e., east-trending dextral faults versus northeast-trending sinistral faults: Williams et al. 1992, p.1271, 1288, 1289 and Figure 25.10e).

In contrast to the interpretation above, Good (1988), Beakhouse (1989), and Beakhouse et al. (1999) stressed the potential causative role of belt-marginal granitoid intrusions in the late, D_2 deformation of the northern Birch–Uchi greenstone belt. However, most granitoid specialists currently view pluton and batholith intrusion as accompanying, rather than causing, regional deformation or orogenesis (e.g., Pitcher 1987; Hutton 1988, 1992; Glazner 1991; D'Lemos et al. 1992; Lacroix et al. 1998; McNulty et al. 1998).

It is also of interest to note that if the cuspate north margin of the Birch–Uchi greenstone belt (Figure 2) defines a north-northwest-trending lineament, many of the plutons and gold occurrences in the greenstone belt (in Figure 2a) appear to be distributed along lines approximately parallel to that same lineament direction. If regional orogenic compression or transpression was to the north-northwest (or northwest), as is commonly thought for the Uchi Subprovince and surrounding Superior Province areas (Stott and Corfu 1991; Williams et al. 1992; Corfu et al. 1995), structural theory predicts that there would have been significant extension orthogonal to the compression direction (e.g., Rothery and Drury 1984, Figure 3), and this hypothesized extension along presumed crustal fractures (lineaments) might have allowed and localized the intrusion of synorogenic plutons and auriferous fluids.

The late orogenic wrench tectonic scenario applied to the Uchi Subprovince (Stott and Corfu 1991) is most likely equivalent to the D_2 deformation episode of Beakhouse et al. (1999). The timing of this wrenching stage, which encompasses interrelated complex faulting, strike-slip basin development, plutonism, gold mineralization and the effects of the indenter or promontory proposed herein, is estimated at ca. 2720–2705 Ma (*see* "Inferred Age of the Conglomeratic Units," above) for the Birch–Uchi greenstone belt. The wrenching stage may be of longer or shorter duration in other parts of the Uchi Subprovince (e.g., younger wrenching stages: Corfu et al. 1995), and some events or processes may have been diachronous. Because of the geometrical complexities of wrenching within an orogenic belt that is both locally and regionally heterogeneously structured or segmented (e.g., Devaney 1999e), significant variations in timing and structural style within the Uchi Subprovince should be expected. Also, the potential structural heterogeneity within a single belt and the commonly incremental nature of wrench tectonic deformation suggest that extrapolating cross-cutting relationships from one part of a belt to another may be unreliable in detail. (Rather than a simple D_2 or D_3 late tectonic episode, a deformational episode may actually consist of a great many small increments which vary in their degree of development within a single belt. Some effects of such an episode may be only local rather than belt-wide, and thus data regarding ages of rocks and cross-cutting relationships may in some cases appear to conflict).

Testing of the indenter interpretation, in which the undated Jeanette Lake granitoid complex is a microcratonic block around which the Birch–Uchi greenstone belt was compressed, requires dating of both the Jeanette Lake granitoid complex and the various fault and/or shear zones in the greenstone belt. Wallace (1983) mapped tonalitic gneisses and undeformed granitoids in the Jeanette Lake granitoid complex. Tonalitic gneisses dated at 2.8–2.9 Ga are present to the east along regional strike in the central Uchi Subprovince (Pembina, Quarrier gneisses: Stott and Corfu 1991; Stott 1996) and to the west (Trout Lake Batholith: Noble 1989). Based on the sporadic presence of such relatively old gneissic areas in the southern half of the Uchi Subprovince, gneissic areas interpreted herein as microcratonic blocks which formed nuclei for subsequent granitic batholithic complexes, it is suggested that any older parts of the Jeanette Lake granitoid complex may be correlative or similar to these 2.8–2.9 Ga gneissic rocks.

As microcratonic blocks, these gneissic areas might represent a fragmented southern margin of the cratonic Berens River Subprovince (e.g., fragmented via any rifting associated with Balmer assemblage deposition?), a fragmented continental basement upon which Confederation assemblage continental (Andean-type) arc supracrustal successions were deposited. During the subsequent regional transpression of the Uchi Subprovince, any deformation involving the south margin of the Berens River Subprovince, either as a heterogeneously structured basement beneath Uchi stratigraphic assemblages or as isolated indenter-like blocks within the Uchi Subprovince, would likely have been complex, but this aspect of the regional structural development is largely unconstrained and unknown.

LARGER SCALE REGIONAL FRAMEWORK

Based on similarities with some orogenic belt models, particularly those for doubly vergent orogens (Willett et al. 1993; Windley 1995, Figures 8.10, 14.5; van Kranendonk and Wardle 1996), and incorporating the results of previous summaries of northwest Ontario geological evolution (Stott and Corfu 1991; Williams et al. 1992; Corfu et al. 1995; Stone 1998), it is suggested that following north-directed (north-dipping) subduction of oceanic crust below the Uchi and Berens River subprovinces and during the ca. 2.73–2.67 Ga period of northwesterly-directed regional transpression, the western Uchi and English River subprovinces were together transpressed, complexly deformed and intruded by plutons to form an orogenic belt between hinterland blocks of the Winnipeg River and central Wabigoon subprovinces to the south and a Berens River Subprovince foreland block to the north (Devaney 1999a, Figure 18.3; cf. Stott and Corfu 1991, Figure 6.33; cf. Corfu et al. 1995, Figure 8; cf. Stone 1998, Figure 27). The presence of any microcontinental blocks within the Uchi Subprovince (see above) would be "local" (individual belt scale, 50–100 km scale) complicating factors in the larger Uchi–English River orogenic belt pattern. Although the English River Subprovince may have initially accumulated as an accretionary prism, it appears to be preserved as a multiply tectonized, migmatized "remnant ocean basin" (term of Ingersoll et al. 1995).

The waning stages of orogenic belt development represent the transition to cratonization. In the Birch–Uchi greenstone belt, the ca. 2700 Ma Okanse Lake pluton is of sanukitoid affinity (Beakhouse et al. 1999). Sanukitoid plutons are considered to represent late orogenic to postorogenic mantle-derived magmas (Stern and Hanson 1991; Rapp 1997). This may be because once a stable thick crust has formed, magmas from near the base of the crust can then be delivered upward along major transcrustal fracture conduits. (Similar arguments have been advanced for the commonly late tectonic context of lamprophyre intrusions: e.g., Wyman and Kerrich 1989a.) Thus the Okanse Lake pluton is presumably a product of magmatism in a nearly or fully cratonized setting.

Mineralization

The following is a brief summary of some aspects of mineralization in the study area, with comments incorporating some very recent mineralization models and interpretations.

GOLD

Parker and Atkinson (1992) summarized the descriptive data on sites of gold mineralization throughout the Birch–Uchi greenstone belt, and the following highlights are based on their descriptions of the gold occurrences in and near the present Birch Lake study area.

The most common type of gold occurrences in the Birch Lake area appear to be mesothermal lode gold deposits (i.e., epigenetic, in structurally controlled quartz vein systems). Gold-bearing quartz or quartz-carbonate veins commonly contain accessory sulphide minerals, especially pyrite and arsenopyrite, and tourmaline. Rare telluride minerals are reported from three sites, including the Springpole gold prospect and the former Sol D'Or mine (Parker and Atkinson 1992). The auriferous veins are in or near outcrop-scale zones of shearing, fracturing and, less commonly, brecciation. Fracture-filling veins near quartz porphyry dikes or other intrusions may be the result of structural competency contrast (i.e., brittle felsic porphyry bodies more fractured than the country rocks). Low-dipping quartz veins are notable at a few gold-mineralized sites, and may reflect vertical extension near high-angle reverse faults (e.g., model of Sibson et al. 1988), which may be parts of transpressional pop-up structures (Devaney 1999e). Many of the vein-hosted gold occurrences are proximal to the major, large-scale structural features in the area (e.g., the Swain Lake deformation zone and a fault near Bobarris Lake: Parker and Atkinson 1992, Figure 4).

Other local types of gold occurrences are in:

1. sulphidized, brecciated and quartz-veined iron formation units;

2. sulphide-rich alteration zones (e.g., potential subexhalite or volcanogenic massive sulphide-related synvolcanic alteration zones), in which gold mineralization could be either synvolcanic (e.g., Poulsen et al. 2000) or epigenetic (in the latter case, a structurally weak altered zone may have been prone to synorogenic shearing and quartz veining);
3. a sulphide-bearing gabbro phase of the Horseshoe Island stock (Beakhouse 1989);
4. areas near the margins of granodiorite intrusions (Horseshoe Island and Greencamp stocks: Beakhouse 1989; Parker and Atkinson 1992); and
5. the northwest Springpole Lake area, interpreted as an alkalic intrusion-related and epithermal setting by Barron (1996), with associated carbonatite-hosted fluorite; such a type of gold deposit is considered unusual for Superior Province; as discussed by Devaney (1999a,c) and above (*see* "Inferred age of the conglomeratic units"), the tectono-stratigraphic setting of the Springpole auriferous alkalic complex may have been a late orogenic pull-apart basin.

Although some gold occurrences are located near intrusive bodies (4, above), the location of these stocks may have been ultimately determined by the spatial distribution of the major faults, or releasing bend (dilational jog) sites along the faults (Sylvester 1988; D'Lemos et al. 1992; Devaney 1999e), in the study area.

As discussed previously (Devaney 1997, 1998, 1999a,c,e) and herein, interpretation of the polymict conglomeratic units in the Birch Lake area as Timiskaming-type sequences deposited in pull-apart basins implies that major strike-slip fault systems were active during a late orogenic wrenching stage. Mesothermal lode gold deposits are typically thought to have developed during such late wrenching stages of greenstone belt development (Card et al. 1989; Thurston and Chivers 1990; Stott and Corfu 1991; Williams et al. 1992; Hodgson 1993; Groves et al. 1998), with much strike-slip faulting and other related faulting, complex deformation and pluton intrusion (Devaney 1999e) synchronous with, and either directly or indirectly related to, the gold mineralization.

The recently developed intrusion-related vein gold deposit models (Sillitoe and Thompson 1998; Lang et al. 2000; Poulsen et al. 2000) should be tested in the Birch Lake area. Given the presence of rare but potentially important indicator minerals such as tellurides, molybdenite and scheelite (Parker and Atkinson 1992, p.271 and p.233, respectively), which are thought to be associated with the intrusion-related types of aurifeous quartz vein deposits, the new models may be applicable to some of the mineralized sites. (See also discussion of the molybdenite-gold-scheelite-bearing Mink Lake stock by Burrows and Spooner (1987)).

PLATINUM AND PALLADIUM

Interest in occurrences of platinum group elements hosted in mafic intrusive rocks is currently (in the year 2000) intense. Within gabbro of the Horseshoe Island stock at west Birch Lake (Beakhouse 1989; Parker and Atkinson 1992, p.139), the PT zone contains gold and disseminated sulphide minerals, and significant subsurface occurrences of platinum (Pt) and palladium (Pd) include the following: "Diamond drilling conducted at the PT zone by Bond Gold Canada Inc. in 1987 intersected 5.8 g/t Au, 4.4 g/t Pt, 3.4 g/t Pd, 9.4 g/t Ag, 0.8% Ni and 0.9% Cu across 1.5 m" (Parker and Atkinson 1992, p.141).

VOLCANOGENIC SULPHIDE MINERALIZATION

Although the presence of rhyolitic lava flow facies, felsic porphyries, and coarse pyroclastic rocks (Thurston 1986) seem to indicate that the "Western Peninsula" area at west Birch Lake represents a felsic volcanic centre (Beakhouse 1989) of ca. 2740 Ma age (Beakhouse et al. 1999), and despite a broad similarity with the volcanic lithofacies assemblage at the former South Bay mine in the south part of the greenstone belt (Pollock et al. 1972; Urabe and Scott 1983; Thurston 1985; Devaney 1999d), significant amounts of volcanogenic sulphide mineralization are not known from the Birch Lake area (Beakhouse 1989).

Because of structural complexity, potential proximal-distal stratigraphic relationships (e.g., as in Table 1) between the Western Peninsula felsic volcanic centre and the pyroclastic or volcaniclastic units in the surrounding Birch Lake area are not reliably known, and the nature of the local volcanic-sedimentary basin is unknown. (Contrast this with the setting of the coeval South Bay volcanogenic massive sulphide deposit, which was, according to Hollings (1998) and Rogers et al. (1999, 2000), likely a back-arc or intra-arc rift basin or subbasin.) As noted in Devaney (1997), the suggestion by Atkinson and Storey (1997) that the conglomeratic and other sedimentary units at South Bay of Birch Lake might represent caldera infill facies is not supported by data collected during the present study; as discussed herein, the local polymict conglomerate–sandstone units are interpreted as postarc, late orogenic pull-apart basins. The question whether the Western Peninsula volcanic centre was subaerially eroded, thus potentially removing and destroying any mineral deposits and alteration zones, is unresolved; no unconformity was recognized, and stratigraphic resolution is poor. No alteration pipes or significantly large intensely altered zones of the types known to form below volcanogenic massive sulphide deposits have been documented from the Birch Lake area volcanic rocks. (Some appropriate types of alteration, such as chloritization and sericitization, are known from small areas around Birch Lake; see Parker and Atkinson (1992).) Also, present considerations suggest that an *economic* volcanogenic massive sulphide deposit would have to be near the surface and mineable by open pit methods, and there are no known geophysical anomalies suggestive of a large, near-surface metallic body (volcanogenic massive sulphide orebody) in the Birch Lake area.

Thus the potential for Cu–Zn volcanogenic massive sulphide mineralization in the Birch Lake area appears to be poor, although increased subsurface exploration and drilling could significantly change this assessment.

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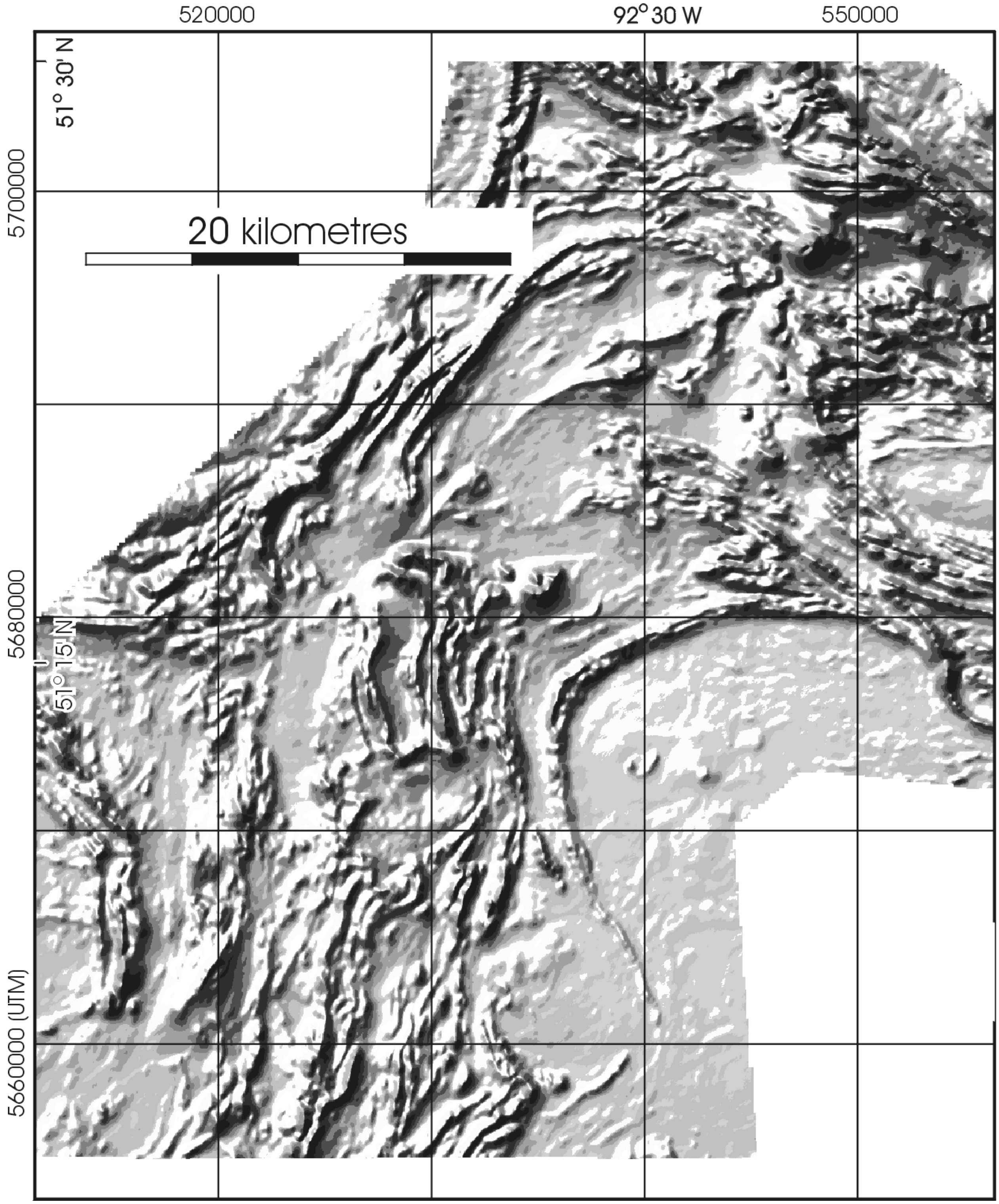

Figure 1. Shaded relief total field aeromagnetic pattern of the Birch–Uchi greenstone belt (from Ontario Geological Survey 1997); light tones have higher magnetic susceptibility (e.g., metabasalts), dark tones have the least magnetic susceptibility (e.g., metawackes, granitoids); compare with Figure 2.

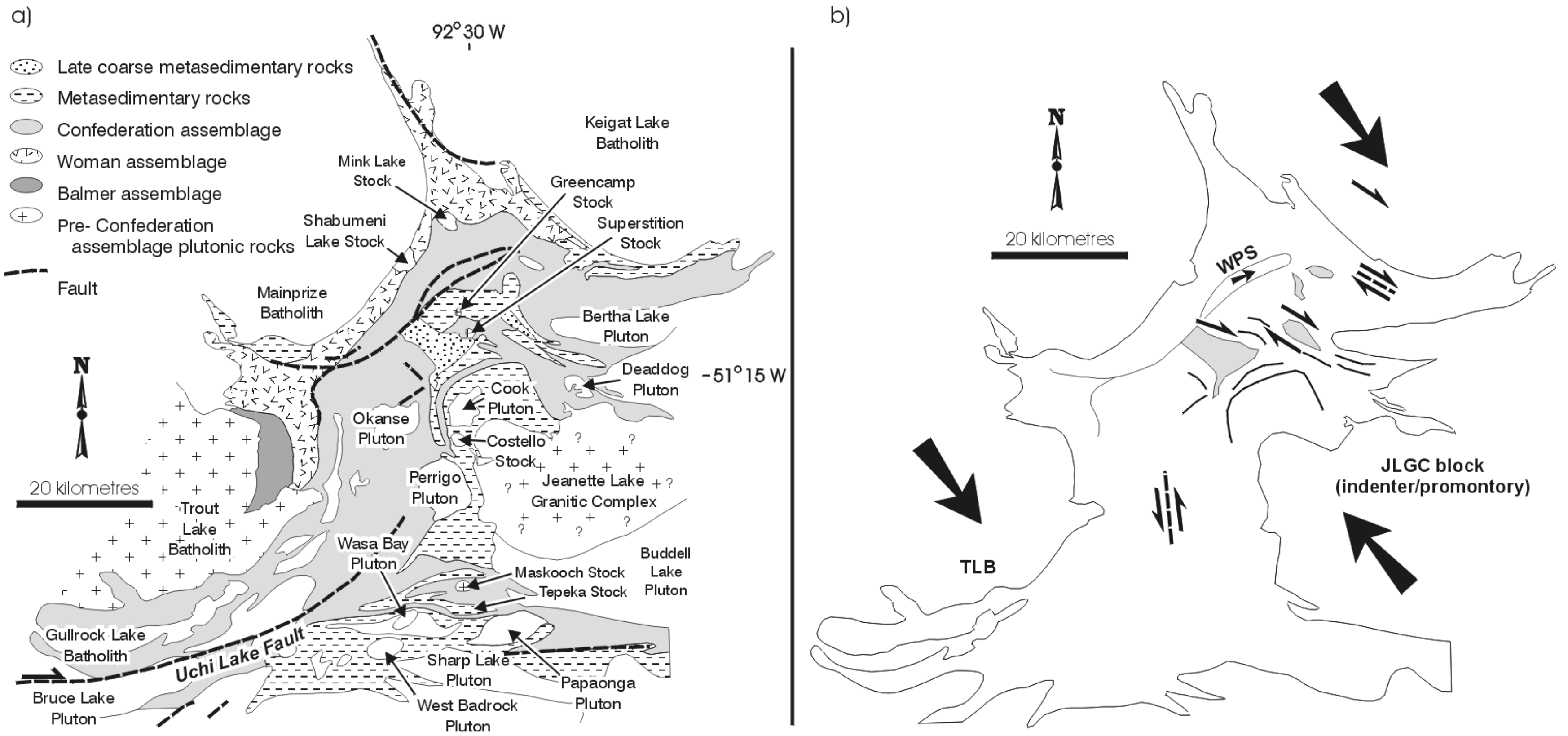

Figure 2. Geological map (a; after Stone 1998, Figure 5) and interpretative cartoon map (b) of late orogenic structural components of the Birch–Uchi greenstone belt and surrounding areas. In b: large arrows indicate northwest-southeast regional compression and/or transpression. Abbreviations: WPS, Western Peninsula Scholle; JLGC, Jeanette Lake granitoid complex; TLB, Trout Lake Batholith. Stippled areas are conglomeratic dextral pull-apart basins (outlines of units or basins noted in text are, from upper right to lower left: vague (north of Springpole Lake), sigmoidal (Wagner Bay island), partial sigmoid (Satterly Lake), coalesced sigmoids (South Bay and Grace Lake; see Figure 3).

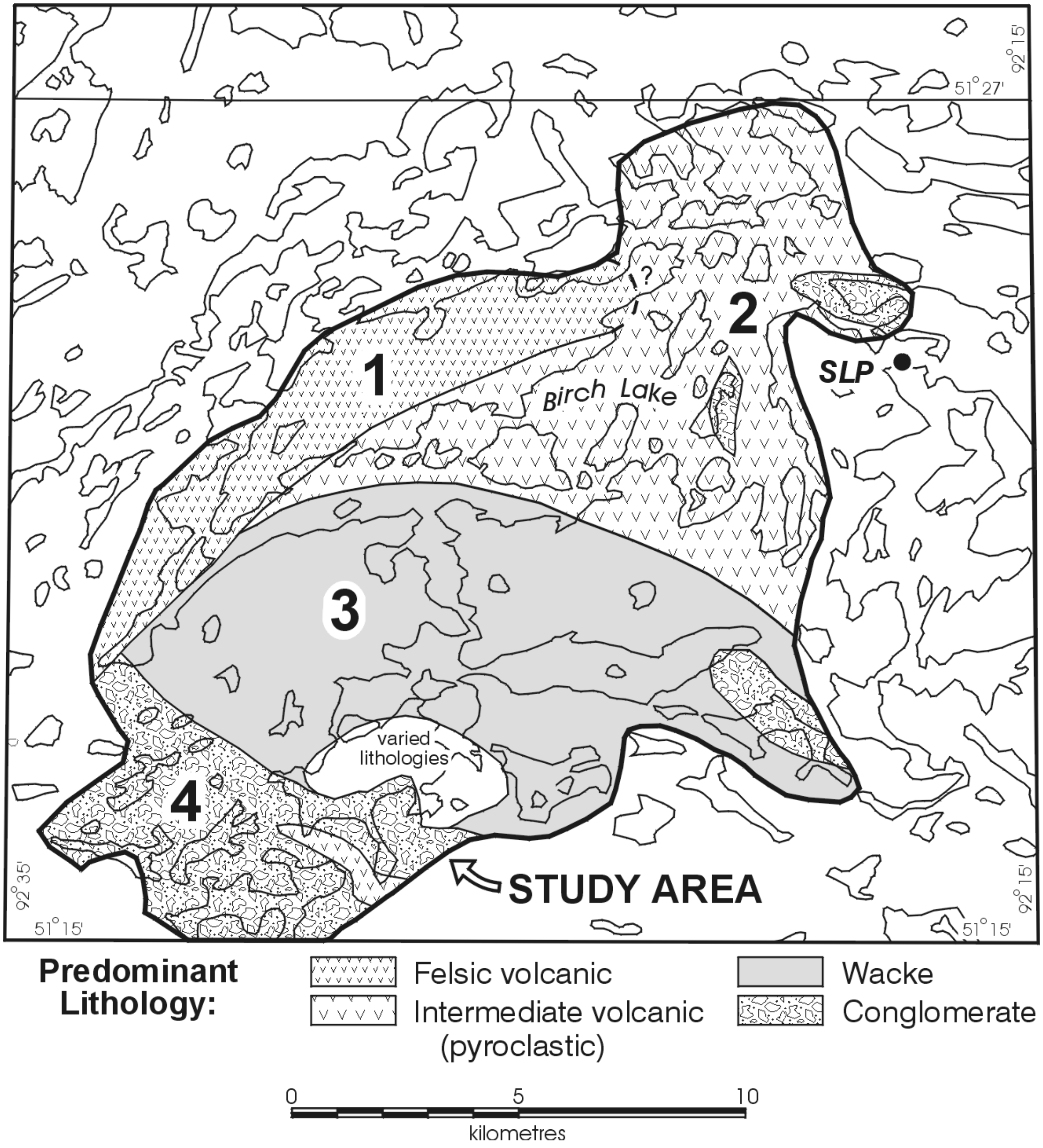

Figure 3. Simplified lithological map of the Birch Lake area, showing four studied areas composed predominantly of: 1) felsic volcanic rocks; 2) intermediate volcaniclastic to sedimentary rocks; 3) wacke ("varied lithologies" subarea at South Bay consists of gabbro, felsic porphyry, felsic volcaniclastic and lava flow facies, and polymict conglomerate); and 4) polymict conglomerate (the South Bay area is north of the sigmoidal felsic volcanic lens, and the Grace Lake area is south of it). Abbreviation: SLP, Springpole Lake gold prospect (Barron 1996).

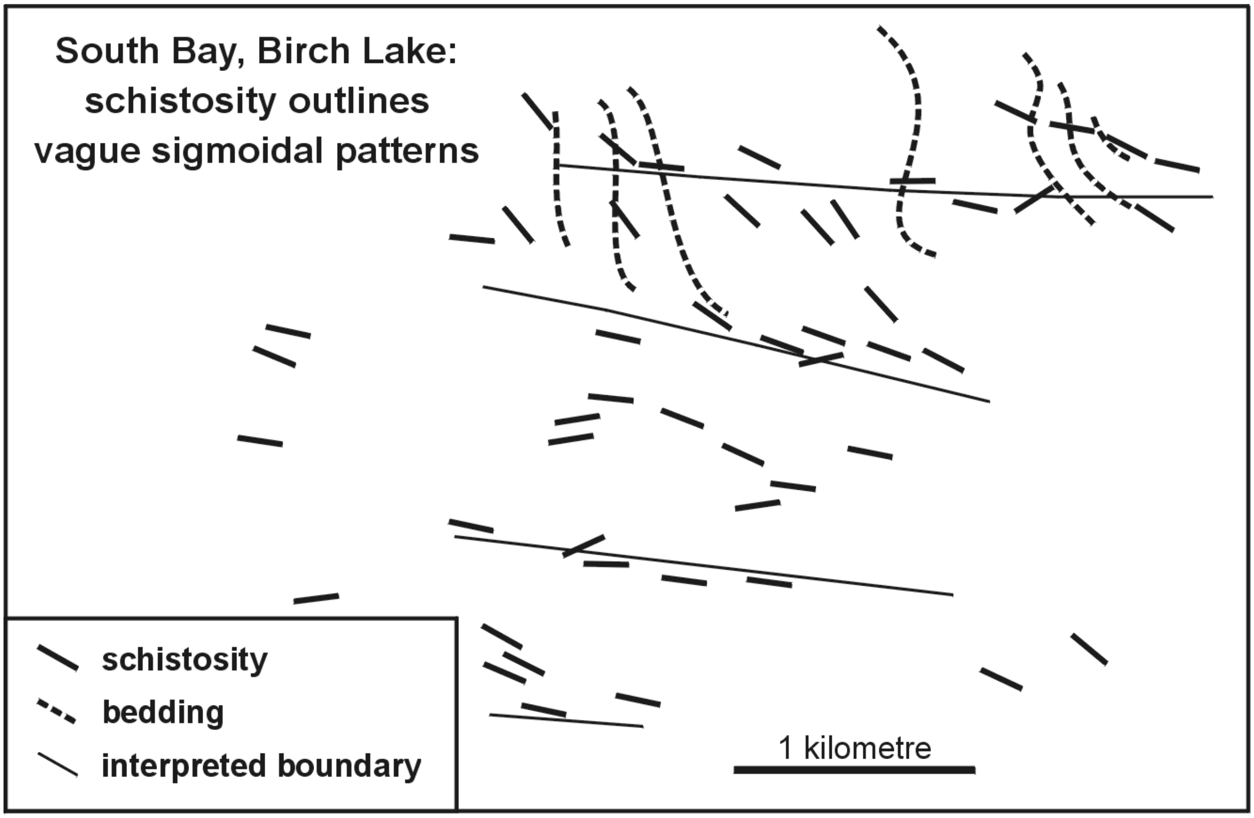

Figure 4. Folded schistosity map, central South Bay of Birch Lake area. The sigmoidal patterns suggest dextral offsets of fault-bounded panels, a larger scale mimicking of the similar dextral offsets displayed in the individual small outcrops in this area.

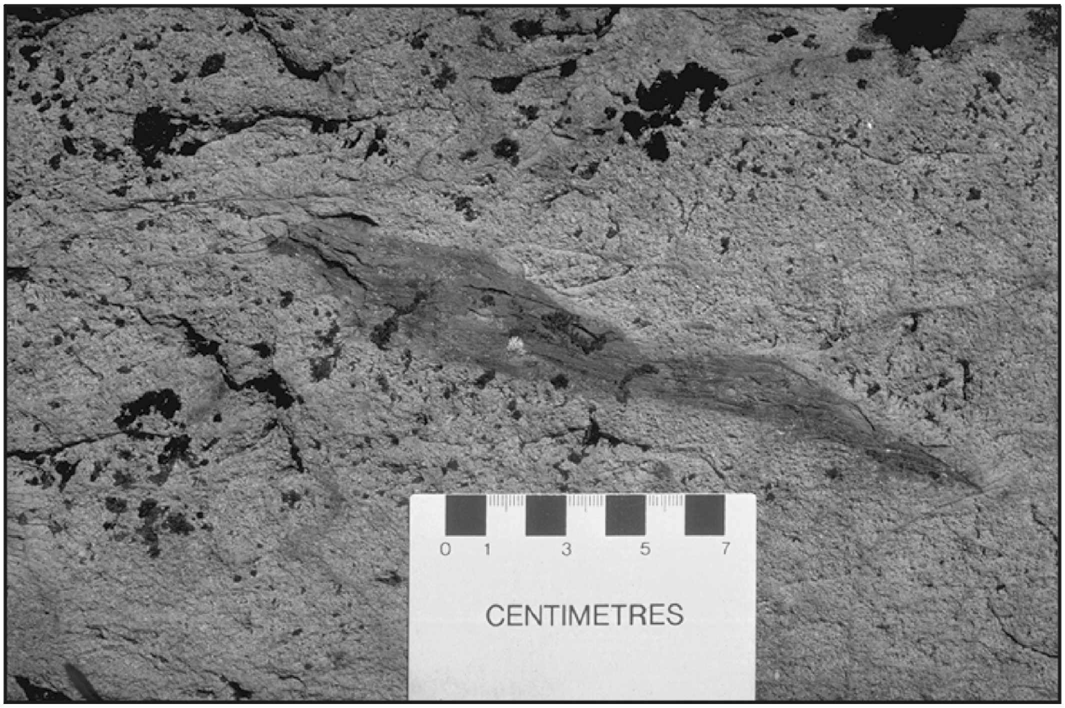

Photo 1. Laminated magnetite (banded iron formation) clast in coarse intermediate tuff, suggesting proximal volcaniclastic reworking of an exhalative horizon (versus local facies of more distal, well bedded graded wacke units). North-central Birch Lake.

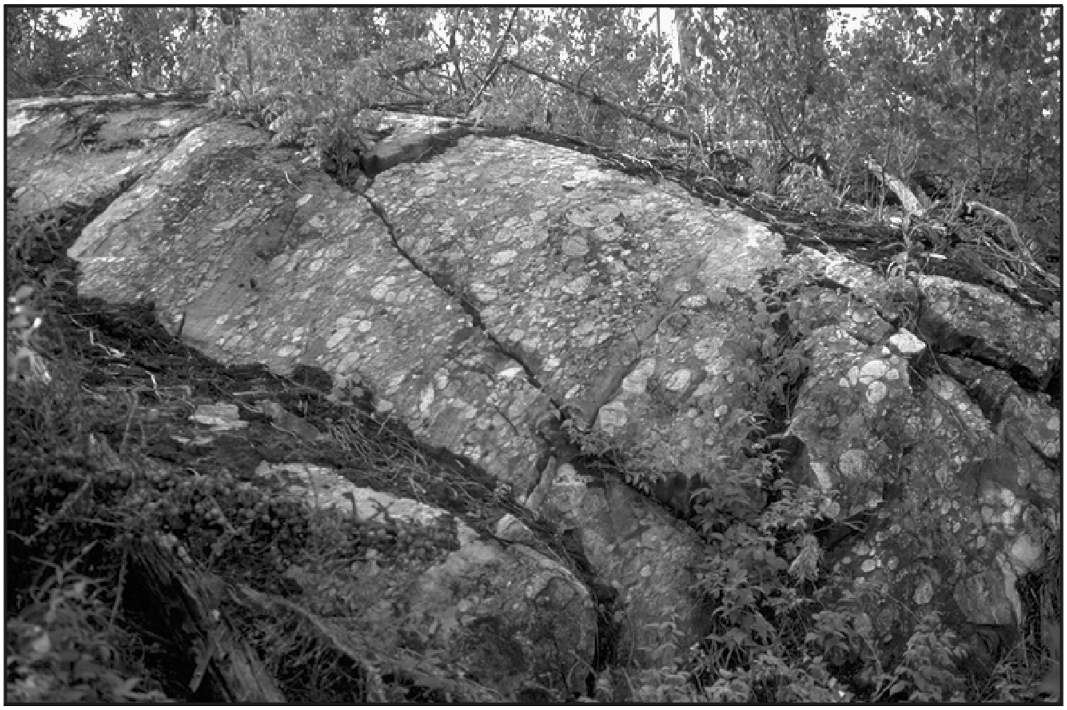

Photo 2. A moderately dipping section of crudely bedded clast-supported polymict conglomerate with sandstone interbeds, interpreted as a section of typical braided river deposits. Wagner Bay, Birch Lake.

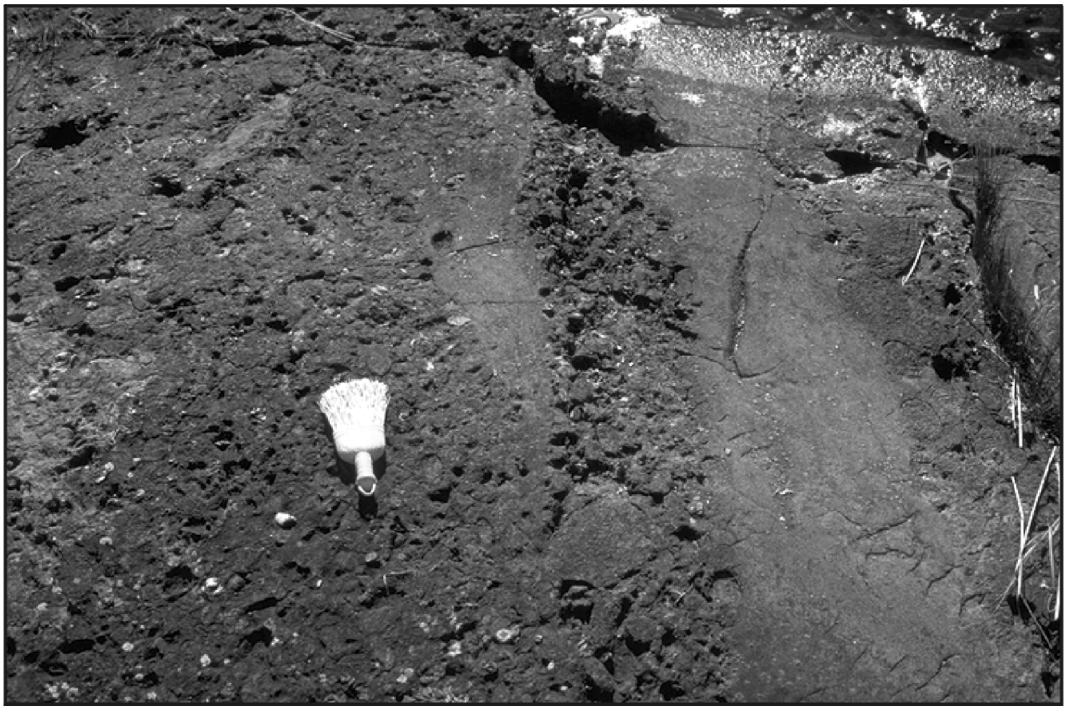

Photo 3. Interbedded clast-supported polymict conglomerate and sandstone (braided river deposits). The sigmoidal sandstone lens (right of brush) is internally cross-bedded and is interpreted as a bar-top channel fill or bar-edge sand wedge. Grace Lake.

Photo 4. Within sandy interbeds in a conglomeratic unit (braided river deposits), darker and finer sand layers (below scale card) outline increments of dune growth. Wagner Bay, Birch Lake.

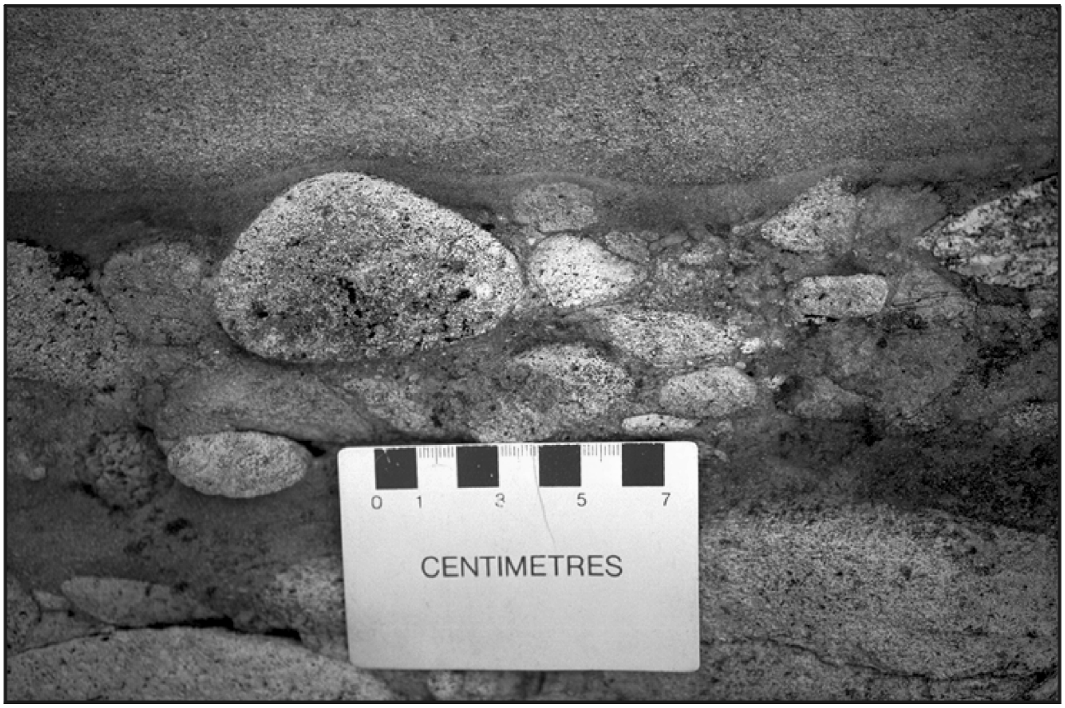

Photo 5. Darker, finer (muddy) sand draped over irregular clast topography of the underlying conglomerate bed, and capped by coarser sandstone. The dark muddy layer is interpreted as an abandoned channel fill, such as a slow or slack water pool atop a gravel bar. Wagner Bay, Birch Lake.

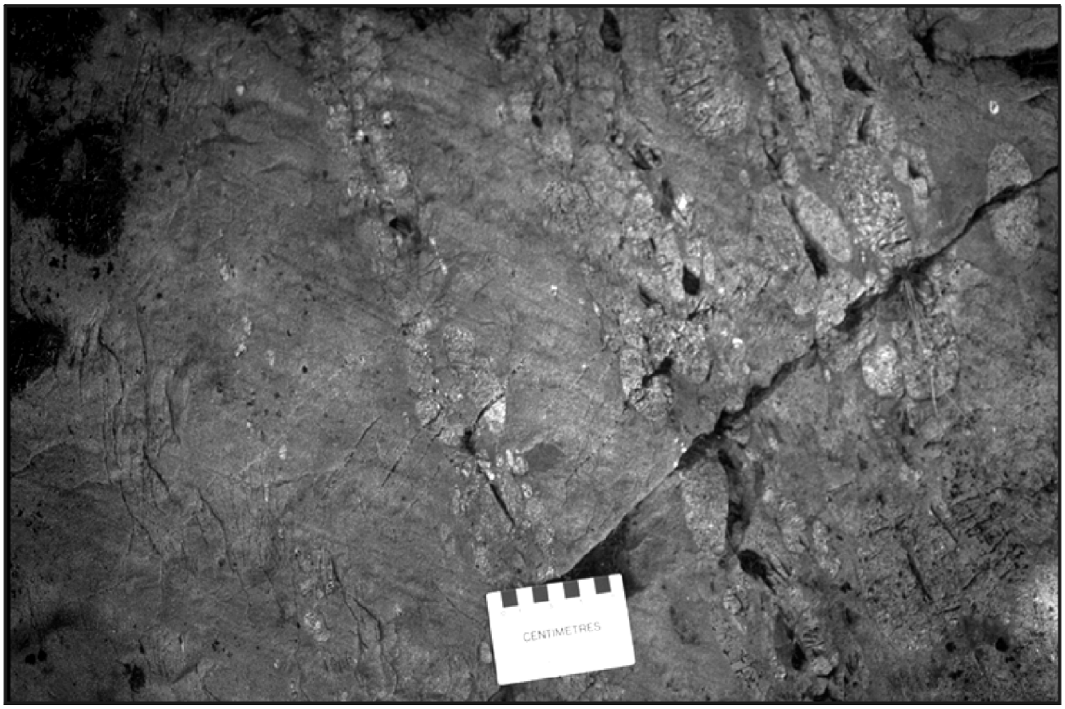

Photo 6. Note transition from pebble band (left) to thin conglomerate beds (middle) to thicker and coarser conglomerate (right), a sedimentary pattern reflecting local progradation (tops to right seen elsewhere in the outcrop) to higher-energy deposits. Grace Lake.

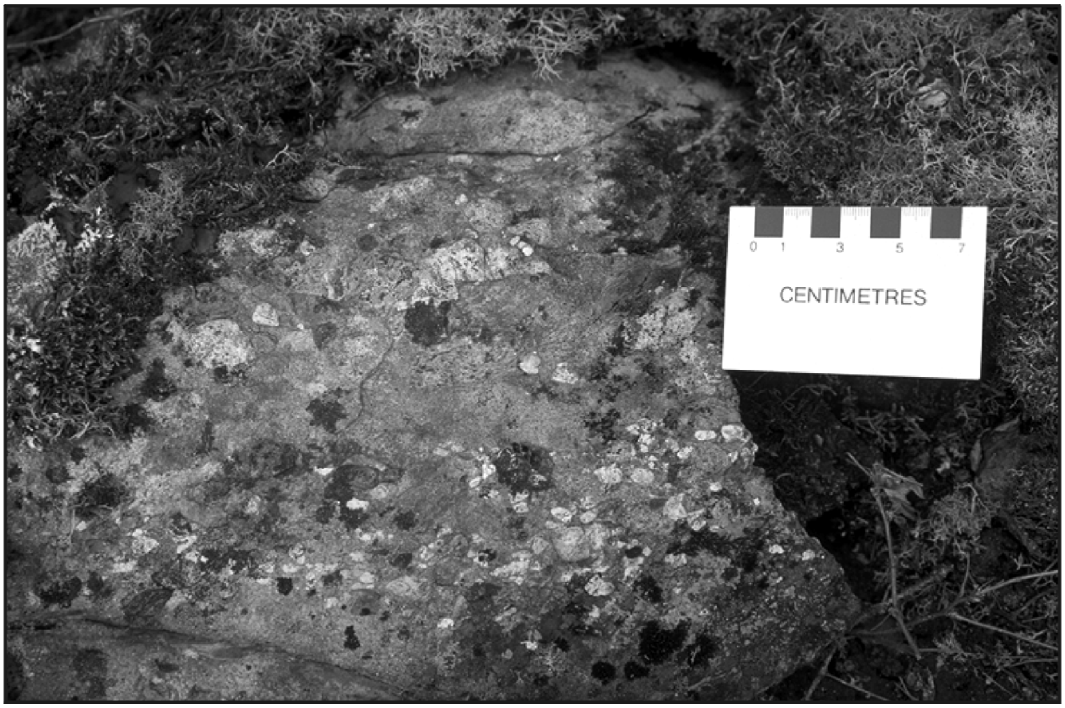

Photo 7. Fine pebble conglomerate and sandstone. Note the good rounding and sorting of the clasts, and the thin beds. The fine conglomerate beds are interpreted as more distal facies (fluvial, lacustrine or marine) than the local coarse, proximal fluvial conglomerate facies. South Bay, Birch Lake.

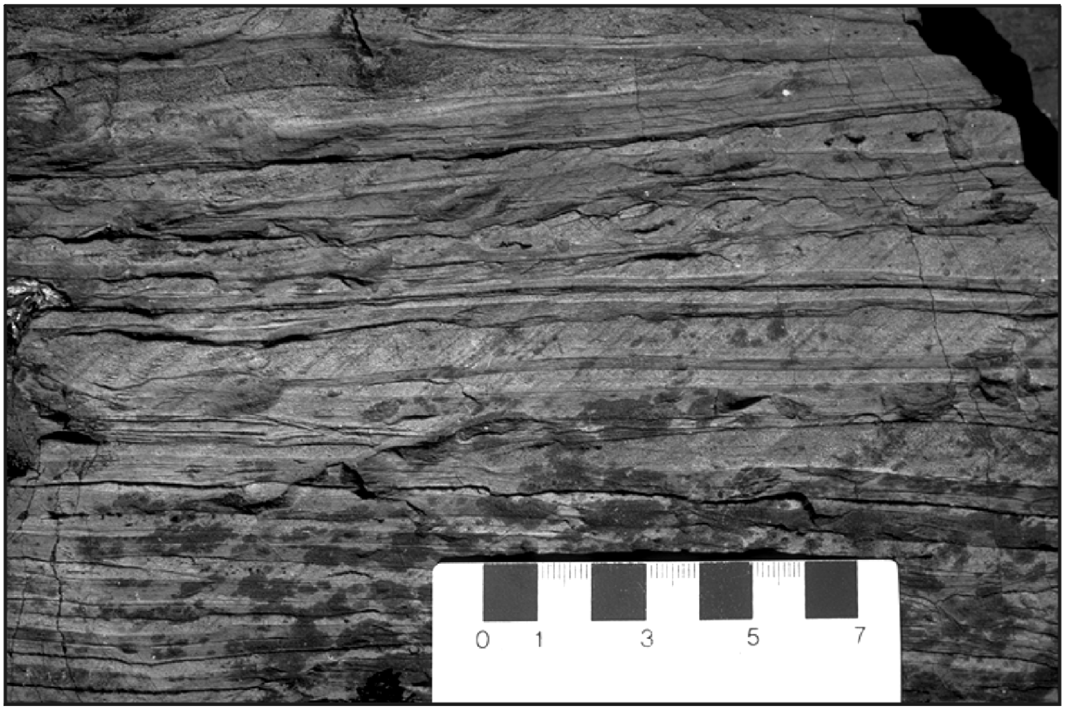

Photo 8. Laminated and cross-laminated (rippled) fine sandstone-siltstone; way up is via ripple forms and sharp-based beds. Interpreted as an overbank or lacustrine deposit in an outcrop with an upward transition from coarse fluvial to fine lacustrine or overbank facies. Grace Lake.

Photo 9. Laminated sandstone–siltstone, with cross-laminations (ripple paleocurrents to right) and grading; probably a subaqueous basinal facies. Note how the coarseness is proportional to layer thickness, and how the cleavage is better developed in the darker muddier beds. Grace Lake.

Photo 10. Oligomict (monolithic) conglomerate composed of quartz–feldspar porphyry clasts (in upper half of view) versus dark, more elongate, muddy intraclast blocks which are internally laminated and rippled. The oligomict nature of the lithoclasts suggests proximity to the basin margin and a small feeder (paleo)stream system, one draining an area of exposed felsic porphyry only. (This is in contrast with the presumably larger river systems which likely supplied the sites of the locally more common polymict conglomerates.) The intraclast blocks are interpreted as erosionally reworked fluvial overbank facies, with some blunt angular clast edges recording the shape of desiccated or slumped muddy blocks. Louwag Lake.

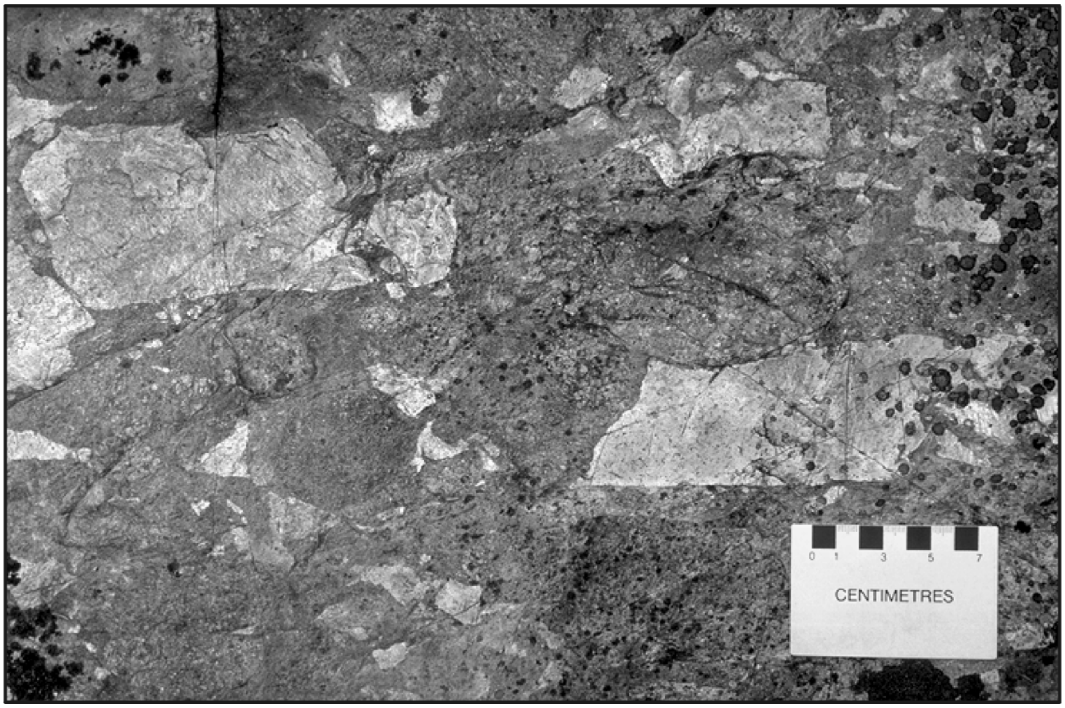

Photo 11. Clast-supported sedimentary breccia composed of angular felsic volcanic fragments. This breccia facies, located at (or very near) the base of a conglomeratic unit (at a conglomerate–rhyolite contact), is a proximal basin margin deposit of locally derived clasts. South Bay, Birch Lake.

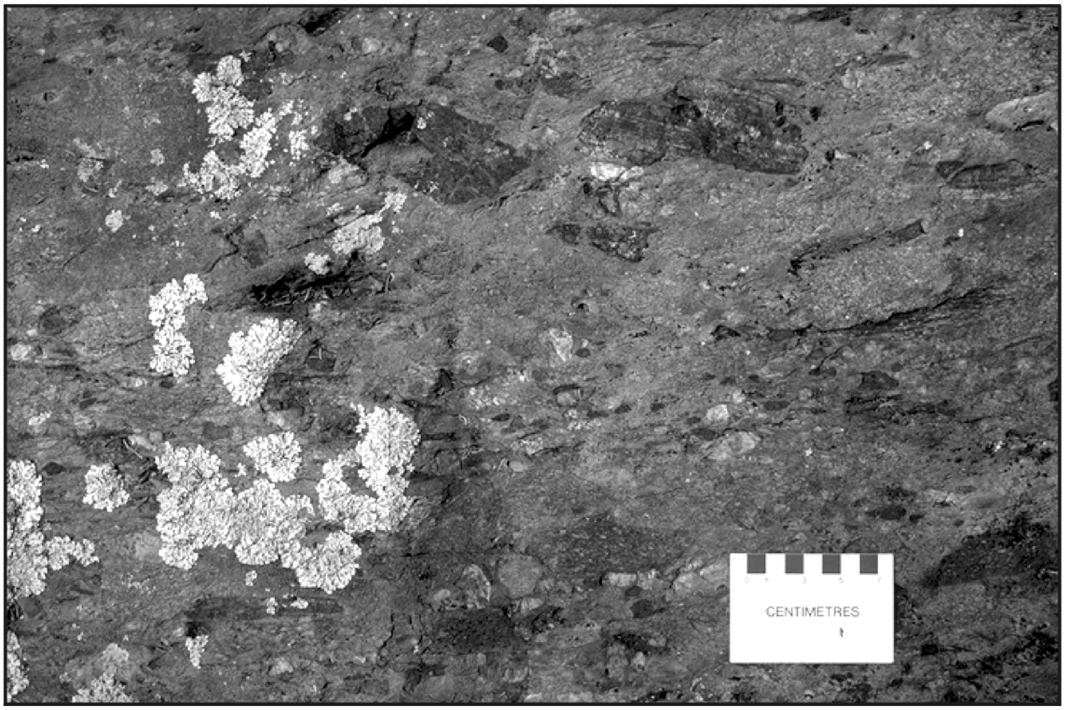

Photo 12. Polymict (heterolithic) conglomerate with an unusually high concentration of black chert clasts, suggesting proximity to an eroded source area of chert. Such local compositional variations along strike suggest variations in paleooutcrop lithologies along the pull-apart basin margin. Superstition Lake.

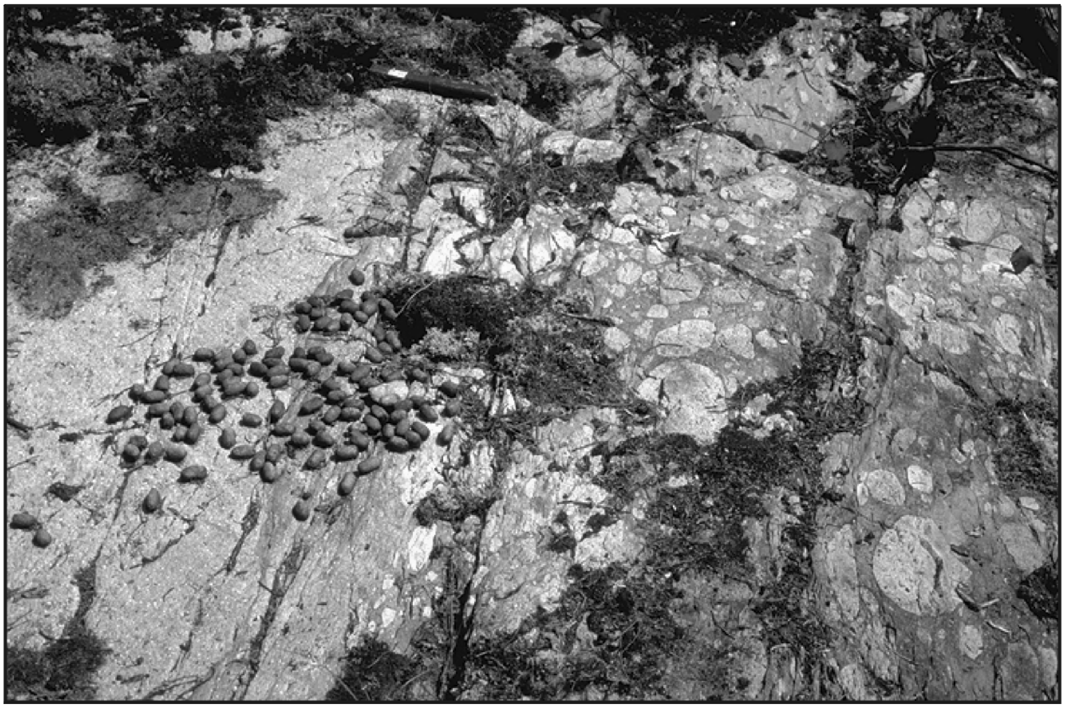

Photo 13. Sharp basal contact (top to right) of clast-supported conglomerate on coarse felsic tuff. Central South Bay, Birch Lake.

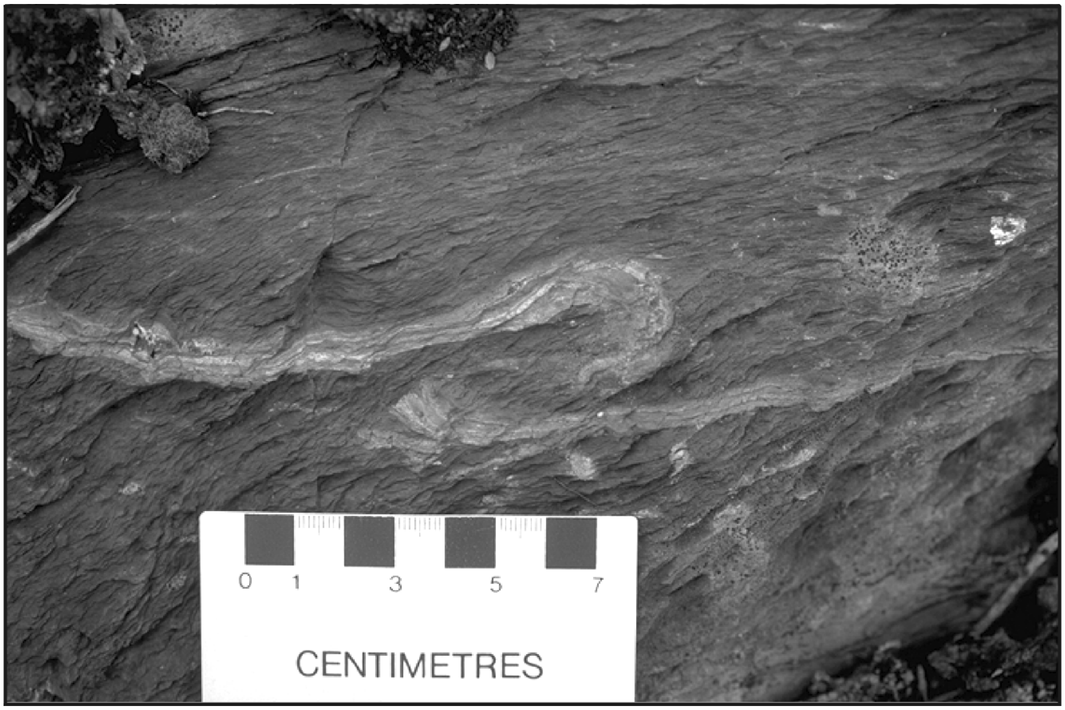

Photo 14. Dextrally transposed folded wacke bed. Northeast Birch Lake.

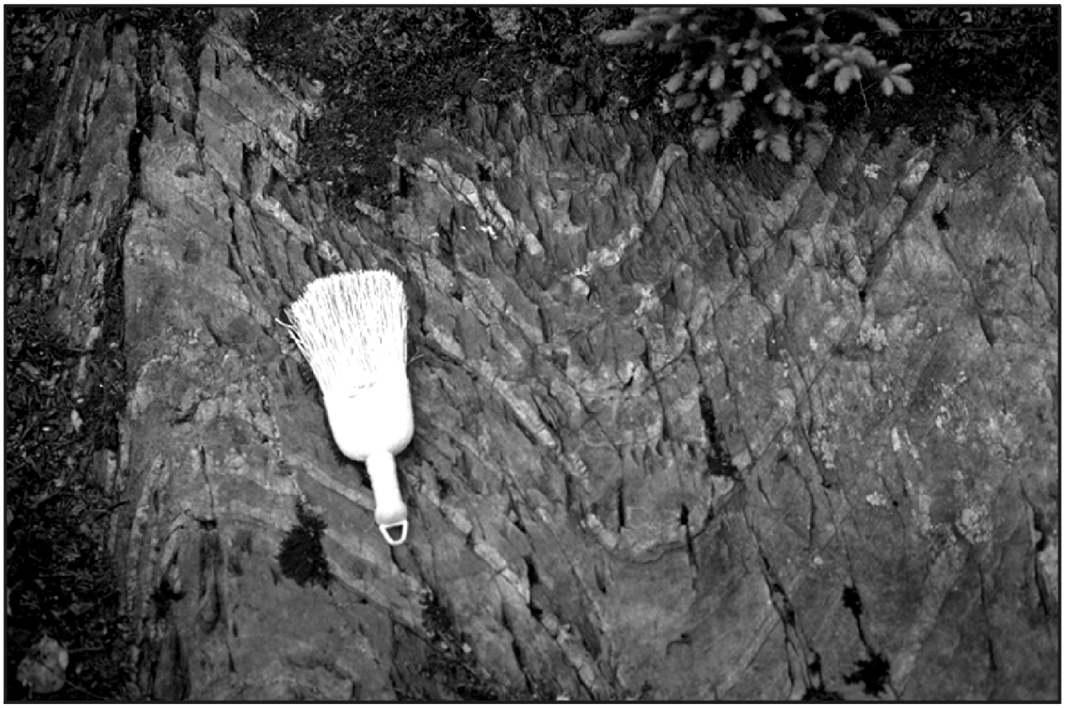

Photo 15. Tight chevron folds in thinly bedded and graded wacke–siltstone, interpreted as the subaqueous basinal facies of a pull-apart basin. Axial planar cleavage indicates structural facing to top (anticline at left, syncline to right). South Bay, Birch Lake.

Table 1. Proximal versus distal features in volcaniclastic to sedimentary facies, Birch Lake area.

Criterion	**Proximal features**	**Distal features**
Bed thickness	Thick to thin	Thin; high-energy conglomerate subfacies is thickly bedded
Stratification (outcrop scale)	Poor or vague; may be mostly mass flow deposits; may be very thickly bedded	Well stratified; mostly traction current and density current deposits
Sand grain size	Coarse; more poorly sorted	Fine; probably a better sorted subpopulation winnowed from coarser tuffs
Volcaniclastic (to pyroclastic) facies	Tuff to lapillistone; with crystal tuff, minor tuff-breccia	Wacke; note small pebbles of volcanic rocks, likely derived from proximal settings
Mudstone component	Little or no siltstone-size tuff	Mudstone (siltstone, argillite, slate)
Graded bedding	Uncommon to rare	Common and well defined, especially in thin beds (turbidites)
Chemical sedimentary facies	Rare magnetite BIF interbeds; rare BIF intraclasts	Uncommon BIF; typically *in situ*; locally, some thick interbeds of laminated BIF
Clastic sedimentary features	-Minor amount of sedimentary structures -potential pumiceous clasts uncommon and/or rare in pyroclastic rocks	-More sedimentary structures (locally common): e.g., ripples, scours, intraclasts; more thin sequences (metres thick; e.g., channel sequence) -high-energy conglomeratic subfacies, lower energy sandy turbiditic facies

BIF = banded iron formation.

Table 2. Table of selected sedimentary top indications

Location*, legend code on map	**Outcrop#, str/dip or orientation**	**Structure showing top indication**	**Comments**
NE Birch Lake. (NE of Dole Lake)			
2fgijkl	203, 286/60(ot)	GR(?)	(fining south units too?)
4cj	204, 107/75	GR	
4cdj,5ci	206, top NE	GR	
4cj	207, top NE	GR	
4cdikIJ	211, 250/70(ot)	GR	
4cj	213, top N	GR	
4c	215, top N and S	GR	Tightly folded
N Birch Lake between Birch Narrows and Johnson Island			
2-3fjJ	322, 148/70	GR	
4c	65, top N	GR	
4acdijkGHJM	66, 305/70 (tops NE and SW)	GR	Deformed turbidites: sigmoidal fabric, iso-clinal folds
4cjkJ,5ci	75, top NW	GR(?)	(in banded iron formation)
(bay near portage to Springpole Lake)			
4bHI	58, top N	LO	Load or flame structures
4abjlGKN	62, top N	FUS	
4abijGHIJKNR	64, top N	FUS	(vague)
	221, top S(?)	SS	Sharp-based coarser bed on finer bed
4abFGKN	222, top S	FUS	
Wagner Bay (central Birch Lake)			
2fgijk	11 and 12, top W	GR	(subtle)
4cd	190, 206/35	GR	
4acH(3fg?)	199, 325/45	GR	
4c,5ci	220, top SE(ot)	GR	
1ab,4dij	234, top NW	SS	(vague)
(conglomerate isle, central Wagner Bay)			
4abjkGHIJKN	99, top W	SS	
4cj	100, 180/60	GR	
4ab	104, top W	SS	
4abkGHK	106, top W	SC, SS	Sharp sole with intraclast
4cdjkHJ	107, top W	GR, SC, RI	
4abijkFGHKN, 8gW	357, 155/55	XB, SS	Vague fining-upward in channel fill
4abFGHKNR	15, 160/70	GR, SC, XB, FUS, SS	Photos 4, 5; paleocurrents to N
4abdikFGHJR	80, 146/65	SC, XB, RI	
(volcanic conglomerate isles, NW of conglomerate isle)			
4abcdijlFGHJKM	111, top W	GR, SC, RI	Graded-stratified conglomerate bed
3fgjkH	237, top E(?)	GR	
4abijlFGHM	238 and 14, 168/65	GR, LO, RI, FUS	Ripple paleocurrents to N

Table 2. *Continued.*

Location, **legend code on map***	**Outcrop#, str/dip or orientation**	**Structure showing top indication**	**Comments**
central Birch Lake			
4cdijk	155, 128/75 (tops NE and SW)	GR	Isoclinally folded
4cd	157, top S	GR	
2gGH	182, 130/ (top SW)	OTH (SC?)	Intraclastic base (probable scour)
N South Bay, Birch Lake			
4cil	297 (Green's camp W), 85/ (top S)	GR, SS	Sharp soles as part of grading
4cdjk	1, top N	GR, SC, LO	(Load structures include a loaded scour)
4cdjk	2, top N	GR, SC	Tiny scours
4c	3, 150/80	GR	
4cdj	146, top NE	GR	
Exit Bay, Birch Lake			
2gGM	8, top N(?)	GR(?)	(subtle)
4cdH	298, top N (ot)	GR	
4cj	174, 100/60	GR	
4cij	181, 86/85	GR	(in laminae)
4abijFGJKN	5, 265/ (top N)	SC, SS	
(junction of Exit and South bays)			
mostly 4cdj	Fraser (1998) thesis area, tops S to SW	GR, RI	Includes good trough ripples
Superstition Lake			
4abklGHIKNR	85, 310/ (top SW)	SC, FUS	(note black chert clasts)
4cdj	89, top SW	GR, SS	
4c	90, 200/80	GR	
Central South Bay, Birch Lake			
4cdj	26, top N	GR	
3fGH,4abdKLN	28, top S	OTH	Basal conglomerate, Photo 13
4cijkHJ	40, 310/90	GR, RI	Ripple paleocurrent to W
4cG	43, top W	GR	
4cdijIJ	98, 145/60	LO	
4cdijHIJ	114, 35/90	GR, SC, LO	
3,4cdjJ	241, 200/70	GR	
S South Bay, Birch Lake			
4bdeijGJ	144, 45/90	GR(?), LO	
4bcdijklHJ	145, top S	GR, SC	(coarsen-up sequences?)
4bjJ	159, 80/90	GR, SC	Tiny scour
4abFKN	161, 285/ (top N)	GR, SS	
4abijkGHKMRU	165, 286/90	GR, SS	
4abcdijG,3ae	166, 53/ (tops NW and SE)	GR, LO, RI, SS	Tightly folded
4cdij	167, tops N and S	GR, LO	Tightly folded, structural facing to E, Photo 15
4ab	51, top S	XB	

Table 2. *Continued.*

Location*, legend code on map	**Outcrop#, str/dip or orientation**	**Structure showing top indication**	**Comments**
4abcdeijFGHKNR	47, approx. 95/ (top S)	FUS	Fining-upward sequence cap 25 cm thick
4cdijH	45, top SW	GR, LO, RI(?)	
E Grace Lake			
4abdijGHIJKN	250, top N	GR, RI, FUS	Small channel
4abdijkFGHIJKNR	251, 250/90	XB, RI, FUS, SS	Photo 8
4abGH	255, top N	SC, XB, FUS	Fining-upward sequence cap
4abGH	258, 195/ (top W)	XB	Scoop-shaped trough cross-sets
4abijklFGKN	261, top N	XB, OTH (FUS?)	Trough cross-sets, Photo 3
4abiklFG	262, 260/90	RI	Trough cross-laminae
4deijJ	266, 205/ (top W)	LO, RI	Some load micro-structures, ripple paleocurrents to E
4bdijIJ	268, 222/ (top NW)	GR, LO, RI	Ripple paleocurrents to E
W Grace Lake			
4abiHIJ	276, top S	SC, RI, SS	
4abilGHIJKNR	277, 94/ (top S)	GR, XB, FUS	Small channels
4cdijIJ	282, 265/85	GR, RI	Small channels, paleocurrent to E, Photo 9
4ab	284, 295/ (top N)	XB	Tangential toesets
Bergstrand Lake (NW of Grace Lake)			
4bj	301, 205/90	RI	Good concave to tangential foresets
4cdij	304, 260/75(ot)	GR	(only one graded bed)
4abijGHJ	313, 30/ (top SE)	GR, SS	
Louwag Lake (NW of Bergstrand Lake)			
4abdijkFHJKLMR	330, 257/ (top N)	GR, SS	
4bdijGH	331, 285/ (top N)	LO(?), SS	
4abklFKMNR	335, 270/ (top N)	RI, SS	
4abdijkHJKN,7bY	346, 295/ (top N)	RI, FUS	
4cdijJ	350, 108/90	GR, RI	Micro-ripples

FUS, fining-upward sequence; GR, graded bedding; LO, load structure; ot, overturned strata; OTH, other structure; RI, rippled (cross-laminated); SC, scour structure; SS, sharp-soled (sharp-based) beds; STR/DIP, strike and dip measurements (using right-hand rule); XB, cross-bedded; N, NE (etc.), north, northeast (etc.).

** For legend codes, see page 48 and also Devaney and Crews, in press.*

Legend for Table 2

Rock Codes

8 Felsic to Intermediate Intrusive Rocks
("9" if late, post-tectonic)
8a Granite
8b Granodiorite
8c Tonalite
8d Diorite
8e Pegmatite
8f Aplite
8g Quartz
8h Porphyritic

7 Mafic Rocks
7a Diabase
7b Gabbro
7c Amphibolite

6 Felsic to Intermediate
(Meta-)Intrusive/Subvolcanic Rocks
6a Quartz porphyry
6b Feldspar porphyry
6c Quartz-feldspar porphyry

5 Chemical Metasedimentary Rocks
5a Chert
5b Chert and magnetite
5c Magnetite
5d Hematite
5e Pyrite

4 Clastic Metasedimentary Rocks
4a Conglomerate
4b Arenite
4c Wacke
4d Argillite/siltstone
4e Slate
4g Schist

3 Felsic Metavolcanic Rocks

2 Intermediate Metavolcanic Rocks

1 Mafic Metavolcanic Rocks
1a Massive
1b Pillowed
1c Amygdaloidal/vesicular
1d Variolitic/spherulitic
1e Porphyritic
1f Tuff
1g Lapilli-tuff, lapillistone
1h Tuff-breccia

Textural and Mineralogical Codes

i....laminated (<1 cm thick)
j....thinly bedded (1-10 cm thick)
k...medium bedded (10-30 cm thick)
l.....thickly bedded (>30 cm thick)
m...garnet porphyroblasts
n....(other) porphyroblasts
o....gneissic
q....mineral clots
r....chloritic schist
w...epidote
z....quartz-sericite schist
A...aphanitic
B...fine-grained (<1 mm)
C...medium-grained (1-5 mm)
D...coarse-grained (>5 mm)
E....pegmatoid (>1 cm)
F....boulders, cobbles, blocks, bombs (>64 mm)
G...pebbles (2-64 mm)
H...coarse-, very coarse-grained (0.5-2 mm)
I.....medium-grained (0.25-0.5 mm)
J....very fine-, fine-grained (0.06-0.25 mm)
K...clast-supported framework
L...matrix-supported
M..monolithic (oligomictic)
N...heterolithic (polymictic)
O...pillow breccia
P....hyaloclastic
Q...pumiceous clasts
R...porphyritic clasts
S...mixed composition: mafic matrix,
felsic/intermediate clasts
U...(other) volcanic breccias
V...tectonic breccias
W..vein
X...dike
Y...sill
Z....xenoliths

Metric Conversion Table

Conversion from SI to Imperial			**Conversion from Imperial to SI**		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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