Constraints on the timing of crustal imbrication in the central Trans-Hudson Orogen from single zircon $^{207}Pb/^{206}Pb$ ages of granitoid rocks from the Pelican thrust zone, Saskatchewan

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Abstract: The Pelican thrust is a major ductile high-strain zone in the Reindeer Zone, Trans-Hudson Orogen, northern Saskatchewan. It is interpreted as the main sole thrust separating stacked juvenile Paleoproterozoic allochthons and underlying Archean microcontinental crust in this central part of the orogen. Exposed nonmylonitic rocks in the footwall of the thrust consist of the Sahli monzocharnockite and the smaller, more highly retrograded MacMillan Point granite. Protomylonitic to ultramylonitic gneisses in the thrust zone derive from a variety of prethrust protoliths. A footwall ''internal suite'' mainly comprises quartzofeldspathic orthogneisses (''Q'' gneisses) and high-grade migmatitic paragneisses. Hanging-wall ''external suite'' mylonitic gneisses include feldspar-porphyroclastic hornblendic grey gneisses probably derived from arc plutons, and laminated amphibolites derived from volcanic rocks. The overlying allochthon mainly comprises protoliths equivalent to those of the porphyroclastic orthogneisses and laminated amphibolites, together with interfolded and overlying Paleoproterozoic paragneisses of the Kisseynew domain. The Sahli monzocharnockite yields $^{207}Pb/^{206}Pb$ zircon and whole-rock Rb–Sr ages of ca. 2500 Ma, and the ''Q'' gneisses give $^{207}Pb/^{206}Pb$ zircon ages of up to ca. 2900 Ma, implying that most of the internal suite (footwall) mylonite protoliths are Archean. In contrast, external suite (hanging wall) porphyroclastic orthogneisses yield ca. 1880–1840 Ma $^{207}Pb/^{206}Pb$ zircon ages. Main, peak-metamorphic displacement on the Pelican thrust is interpreted to have occurred mainly between 1840 and 1820 Ma, as indicated by $^{207}Pb/^{206}Pb$ zircon ages from small, highly deformed synthrusting granite–pegmatite neosomal bodies in the thrust zone. Undeformed postcollisional granites and pegmatites were emplaced ~1789 Ma. Total duration from arc development to completion of arc–continent collision was ~100 Ma. The Pelican thrust zone may be similar in significance and style to younger, major, ocean closure related thrusts such as the Frontal Pennine thrust of the western Alps and the Main Mantle, Main Boundary, and Main Central thrusts of the Himalayas. As for the Pelican thrust, these displace oceanic rocks over older basement.

Résumé : Le chevauchement de Pelican a créé une zone majeure de déformation ductile intense, à l'intérieur de la Zone de Reindeer de l'orogène trans-hudsonien, dans le nord de la Saskatchewan. Il est interprété comme le principal décollement qui sépare les piles de roches allochtones juvéniles d'âge Paléoprotérozoïque d'avec la croûte sous-jacente d'un micro-continent archéen dans cette région centrale de l'orogène. Les lithologies non-mylonitiques exposées dans le compartiment inférieur du chevauchement sont formées de la monzocharnockite de Sahli et du moins volumineux massif granitique de MacMillan Point beaucoup plus rétrograde. Les gneiss dans la zone de chevauchement présentent une structure qui varie de protomylonitique à ultramylonitique, et ils dérivent de divers protolithes formés avant le chevauchement. Une « suite interne » qui affleure dans le compartiment inférieur est constituée principalement d'orthogneiss quartzofeldspathiques (gneiss « Q ») et de paragneiss migmatitiques de gradient élevé. Une « suite externe » de gneiss mylonitiques apparaît dans le compartiment supérieur, on y trouve des gneiss gris à feldspath porphyroclastique avec de la hornblende qui dérivent probablement de plutons d'arc, il y a en plus des amphibolites laminées issues de roches volcaniques. L'allochtone sus-jacent est formé principalement de protolithes équivalents à ceux des orthogneiss porphyroclastiques et des amphibolites laminées, il inclut aussi des paragneiss paléoprotérozoïques sus-jacents du domaine de Kisseynew qui exhibent des plis simultanés d'orientation différente. La monzocharnockite de Sahli a fourni des âges $^{207}Pb/^{206}Pb$ sur zircon et Rb–Sr sur roche totale autour de 2500 Ma, et les gneiss « Q » ont donné des âges $^{207}Pb/^{206}Pb$ sur zircon allant jusque vers 2900 Ma, ce qui implique que la majorité des protolithes des mylonites de la suite interne (compartiment inférieur) datent de l'Archéen. D'autre part, les orthogneiss porphyroclastiques

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de la suite externe (compartiment supérieur) ont procuré les âges $^{207}Pb/^{206}Pb$ sur zircon beaucoup plus jeunes de 1880 à 1840 Ma. Les âges $^{207}Pb/^{206}Pb$ sur les zircons extraits de corps intrusifs de granite–pegmatite dans la zone de chevauchement, intensément déformés durant la phase de chevauchement, permettent d'affirmer que la phase culminante de métamorphisme due au déplacement majeur du chevauchement de Pelican a eu lieu principalement entre 1840 et 1820 Ma. Des granites et pegmatites non-déformés, mais postérieurs à la collision, furent mis en place il y a environ 1789 Ma. La durée totale, de la naissance de l'arc jusqu'à la collision arc–continent complétée, est estimée à environ 100 millions d'années. La zone de chevauchement de Pelican reflète un contexte tectonique et un style ressemblant à une importante fermeture océanique associée à des chevauchements, à la manière du chevauchement frontal pennique des Alpes occidentales, et dans les Himalayas aux Grands chevauchements du manteau, bordier et central. À l'instar du chevauchement de Pelican, ces derniers ont aussi transporté des roches océaniques sur un socle plus ancien.
[Traduit par la rédaction]

Introduction and geological background

The Reindeer Zone is the main internal component of the Saskatchewan–Manitoba segment of the Paleoproterozoic Trans-Hudson Orogen (Lewry and Stauffer 1990), which extends from Greenland through Canada into the north-central United States. The zone mostly comprises 1.91–1.76 Ga rocks, most of which have suspect, and probably exotic Paleoproterozoic provenance relative to adjoining reworked Archean continental margin components of the orogen, namely, the Cree Lake Zone and Churchill–Superior Boundary Zone (Fig. 1). No pre-orogenic continuity is documented across either the Wathaman Batholith, to the northwest (Meyer et al. 1992; Stauffer 1984), or across faults and shear zones defining the margin of the Churchill–Superior Boundary Zone to the southeast. The Reindeer Zone includes Paleoproterozoic arc volcanic rocks with ages of ~1.91–1.88 Ga (e.g., Baldwin et al. 1987), early oceanic arc plutons, and later successor arc plutons ranging in age from ca. 1.92 to 1.83 Ga (e.g., Van Schmus et al. 1987), broadly coeval or younger volcanogenic metasediments, some deposited as late as 1.85–1.84 Ga, late syntectonic molasse deposits, and late-tectonic to posttectonic intrusions generally younger than 1.8 Ga.

The zone is divisible into several more-or-less well-defined lithostructural domains (Fig. 1). Some domain boundaries are gradational; others are defined by early ductile shear zones (Lewry et al. 1990). Geochemical, radiometric age, and other isotopic data indicate that most of these rocks formed in an oceanic to transitional, subduction-related arc geotectonic setting with variable, but generally minor input from Archean sources. Most of the zone is thus interpreted as a tectonically dismembered collage of accreted juvenile terranes (Lewry et al. 1990). Structural syntheses (Lewry et al. 1990) and isotopic data from late-tectonic to posttectonic granites (Bickford et al. 1990) indicate that most of the exposed Reindeer Zone southeast of the Wathaman Batholith is now an allochthonous, complexly refolded stack of early, southwest-vergent ductile nappes and imbricated thrust sheets that were emplaced across a lower plate (micro)continental margin in late stages of orogenic closure and terminal collision (Lewry et al. 1994). In Saskatchewan, Archean basement rocks are documented only in the Hanson Lake and southwest Glennie domains. In both cases, they occupy lowest exposed structural levels and are separated from overlying Paleoproterozoic allochthons by thick mylonitic gneiss zones. It is with one such mylonitic décollement zone, the Pelican thrust, that this paper is concerned.

The Pelican thrust (formerly Pelican "slide" of Lewry et al. 1989, and others) is a several kilometre wide, complexly refolded ductile high-strain zone in the Hanson Lake Block (Figs. 1, 2) that separates allochthonous Paleoproterozoic arc-related plutons and metavolcanic and metasedimentary rocks from Archean rocks of the Sahli and MacMillan Point inliers (Lewry et al. 1989) (Fig. 2). The thrust zone has been seismically imaged in the course of the THOT Lithoprobe project (Lucas et al. 1994). Although refolded, the thrust is thought to have originated as a gently dipping structure along which major displacement occurred during terminal orogeny in the Trans-Hudson Orogen (Lewry et al. 1989), and is thus considered to be one of the most important structures in the central part of the orogen.

Main rock types

Archean Basement—the Sahli and MacMillan Point inliers

The Sahli granite (Fig. 2) is mostly homogeneous monzocharnockite containing orthopyroxene, clinopyroxene, hornblende, minor garnet, perthitic K-feldspar, antiperthitic plagioclase, and quartz, with combined mafics typically from 10 to 20% of the rock. The protolith was evidently originally coarse grained, with subhedral K-feldspar phenocrysts 2–4 cm long, but now consists of a fine-grained metamorphically recrystallized aggregate. Fresh, unretrogressed parts of the body weather white–cream, but are a waxy green colour in fresh surface. Marginal parts of the body typically have a pronounced L–S fabric and are generally pink, with the pyroxenes being partly to totally replaced by aggregates of hornblende, biotite, garnet, and magnetite.

The much smaller MacMillan Point body (Fig. 2) is an almost entirely retrogressed pink granitic gneiss invaded by late pink pegmatite melt components: only minor remnants of material similar to the Sahli monzocharnockite are exposed.

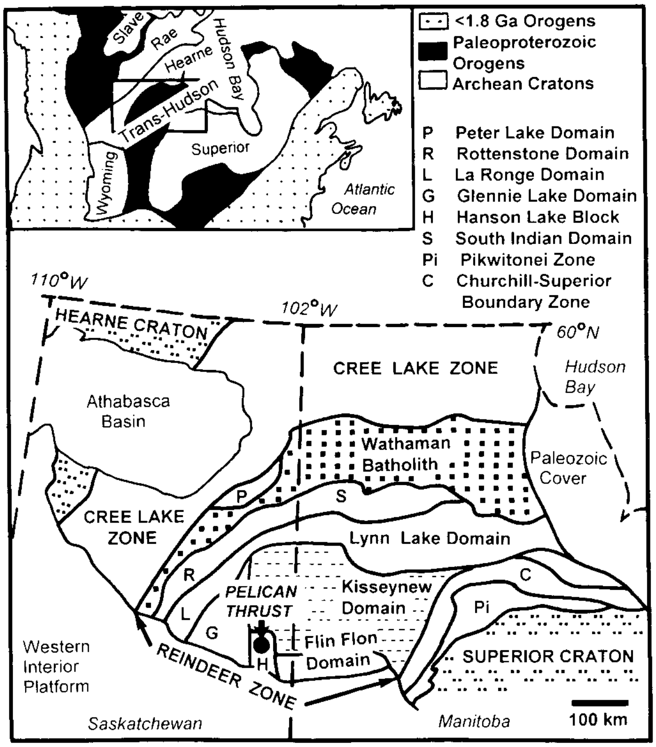
Highly strained rocks of the Pelican Thrust

On the basis of systematic detailed remapping of much of the Hanson Lake Block (Lewry 1990; Shi and Lewry 1991; Ashton et al. 1993; Ashton and Shi 1994; Ashton and Balzer 1995), highly strained protomylonitic to ultramylonitic rocks of the Pelican thrust can be subdivided into an "internal (footwall) suite" and an "external (hanging-wall) suite" (Ashton et al. 1993).

Internal suite

The internal suite mostly comprises two main, highly strained

Fig. 1. Major lithotectonic subdivisions of the Trans-Hudson Orogen in northern Saskatchewan and Manitoba (after Lewry et al. 1987; Bickford et al. 1990; Fedorowich et al. 1995).



rock units: migmatitic metagreywackes and "Q" gneisses, along with some other minor rock types.

Migmatitic metagreywackes: Metatexitic to diatexitic, variably mylonitised, mainly pelitic to psammopelitic aluminous metagreywackes generally contain 30–80% granitic–pegmatitic leucosome. The paleosome generally includes 20–25% biotite, 10–15% garnet, minor sillimanite, and graphite. A well-defined biotite–garnet–(sillimanite) melanosome is commonly associated with, and is complementary to the quartzofeldspathic leucosome. The latter occurs as variably concordant to discordant, folded, and boudinaged layers and lenses typically up to 10 cm thick.

Calc-silicates and impure marbles occur in several isolated exposures within the aluminous wacke assemblage, generally close to the sheared contact with the Sahli monzocharnockite.

"Q" gneisses: Mainly fine- to medium-grained leucocratic quartz–feldspar gneisses, termed the "Q" gneisses (Macdonald 1974; Macdonald and MacQuarrie 1978), are complexly interdigitated, on all scales, with the metagreywacke migmatites of the internal suite. Outcrops of this unit are commonly complex, with a 20–50% pink to white granitic partial melt leucosome fraction and variably well-defined biotite- and (or) magnetite-rich melanosmal laminae. In most localities, all components are very highly strained, and paleosome and leucosome are highly transposed to form banded to laminated quartzofeldspathic mylonites. Dismemberment of pegmatitic leucosome components commonly results in centimetre-scale feldspar porphyroclast trains.

The generally fine grained, mylonitic "Q" gneisses were interpreted as psammitic paragneisses by early workers (e.g., Macdonald 1974; Macdonald and MacQuarrie 1978). However, details of mineralogy and geochemistry, along with plentiful examples of local strain gradation into less-deformed protoliths observed by the present authors and others (e.g., Lewry et al. 1989; Lewry 1990) indicate that most, if not all of these rocks, were derived from initially coarse-grained plutonic granodiorite–tonalite protoliths. Analyzed samples of these rocks yielded an Al_2O_3 to CaO + K_2O + Na_2O molecular ratio of <1, consistent with them being orthogneisses rather than paragneisses. Also, highly fractionated rare earth element (REE) patterns with light rare earth element (LREE) enrichment (La_N up to ~100), low heavy rare earth elements (HREE) (~1), and positive Eu anomalies are all incompatible with formation via sedimentary processes (Sun et al. 1991, 1992).

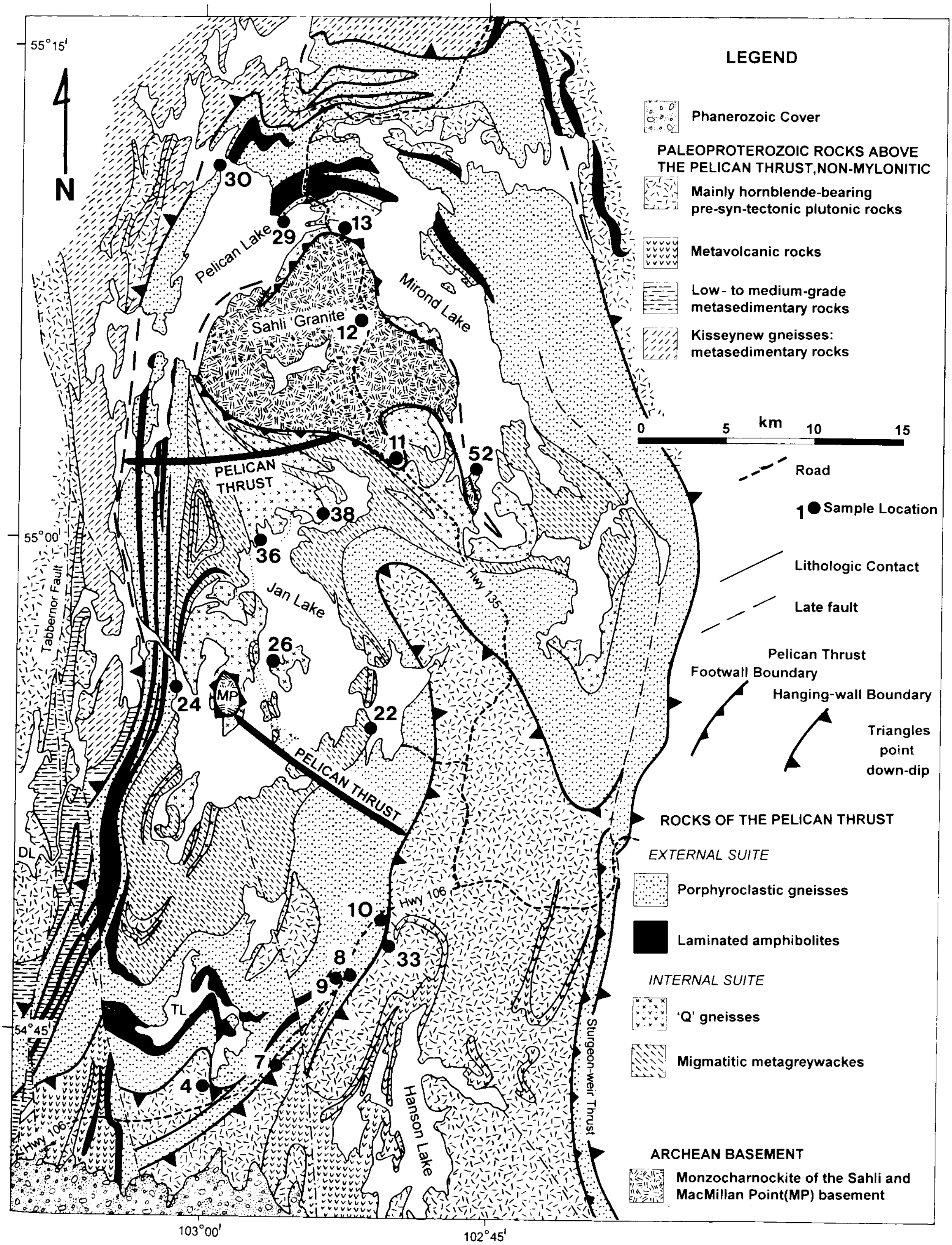
Other rock types of the internal suite: Partly retrogressed granulite-facies enderbitic sheets of granitic to gabbroic composition are included in the internal suite in the south Mirond Lake area (Ashton et al. 1993; Ashton and Shi 1994). A widespread suite of diabase to gabbroic intrusive sheets are emplaced in both the metagreywacke migmatites and "Q" gneisses. They are penetratively foliated and lineated, folded, boudinaged, and typically dismembered to form isolated mafic lenses.

External suite

External suite mylonites mainly comprise extremely varied feldspar-porphyroclastic grey orthogneisses, subordinate intercalated laminated amphibolites, and minor metasedimentary paragneisses. Recent work has clearly documented this assemblage as being derived from protoliths corresponding to the overlying, generally less strained arc plutonic–metavolcanic–metasedimentary assemblage (e.g., Ashton et al. 1993).

Porphyroclastic orthogneisses and paragneisses: Most of the mylonitic external suite comprises prominently feldspar-porphyroclastic mylonitic grey gneisses. These generally have a fine-grained plagioclase–K-feldspar–quartz–biotite–hornblende groundmass containing ovoidal to rounded K-feldspar and, less commonly, plagioclase porphyroclasts ranging in size from "beads" less than 0.5 cm across, to ovoidal, commonly winged, porphyroclasts 10–15 cm across in some localities. Commonly, the groundmass can be differentiated into darker grey, more mafic paleosomal laminae and light grey – pink leucosomal lenses and laminae. Syndeformational to postdeformational hornblende blastesis is a characteristic feature, particularly in spatial association with the leucosomal folia. Many outcrops contain centimetre- to metre-scale mafic blocks and schlieren, multicrystalline ultramafic lenses and clots, and varied later granitoid neosomal sheets. On the basis of geochemistry and locally unequivocal strain gradation, most of the rocks in this unit are interpreted as partly remelted and mylonitized granodioritic–tonalitic orthogneisses derived from plutonic protoliths equivalent to those in the overlying, less-strained Paleoproterozoic arc assemblage, into which they can generally be traced with decreasing regional strain (Lewry et al. 1989; Ashton et al. 1993). Most

Fig. 2. Geological map of the Pelican thrust zone, showing the locations of samples listed in Tables 1 and 2.



of the mafic schlieren are interpreted as country-rock xenoliths, but at least some of the ultramafic hornblendite clots may represent melanosomal restite aggregates.

Some porphyroclastic gneisses are more biotite rich and contain minor graphite and garnet. These appear to derive from sedimentary wackes, rather than plutonic protoliths. The relative regional abundance of orthogneiss and paragneiss protoliths is currently uncertain.

Throughout most of the extent of the Pelican thrust, the porphyroclastic grey gneisses incorporate a subordinate pink granite–pegmatite neosome component, occurring as discontinuous, boudinaged to totally dismembered and transposed *lit-par-lit* bodies. This neosome is interpreted (Lewry et al. 1989; Lewry 1990; Ashton et al. 1993) as a locally derived early high-strain anatectic melt fraction.

Laminated amphibolites: Fine-grained, laminated "straight gneisses," comprising black amphibolites, mesocratic hornblendic, locally diopsidic gneisses, and subordinate grey to pink felsic units, interbanded on a centimetre to several metres scale, form a locally significant part of the external-suite mylonites. They are thought to have been derived mostly from metavolcanic protoliths equivalent to those in the overlying allochthons, but may also incorporate some early mafic dykes and intercalated–transposed granodiorite–granite sheets.

Late-thrusting to postthrusting intrusive rocks

Throughout the area, both mylonitic rocks of the Pelican thrust and overlying allochthonous arc rocks are intruded by small, weakly foliated to unfoliated pink to white leucogranite and granitic pegmatite bodies. Such late-thrusting to postthrusting bodies have been assigned to the "Jan Lake suite," which comprises peraluminous bodies emplaced at ca. 1780 Ma (Bickford et al. 1987).

Summary of structural and metamorphic features

A dominant early regional foliation and coeval isoclinal intrafolial folding, both in the Pelican thrust zone, and adjacent less highly strained rocks are generally ascribed to a D_1-D_2 deformational continuum. Within the Pelican thrust zone and locally in overlying rocks, a prominent early stretching lineation and associated coeval shear-sense indicators, such as rolled porphyroclasts, indicate southwest-directed tectonic transport during early deformation phases (e.g., Ashton et al. 1993). An overturned tight to isoclinal, southwest-vergent D_3 fold set, deforming prior mylonitic foliation, was also recognised by Ashton et al. (1993) and Ashton and Shi (1994). The D_1-D_3 structures are deformed by upright to overturned northerly trending D_4 regional folds and a generally open northeast-trending D_5 fold set.

Peak or near-peak, upper amphibolite to granulite facies metamorphic conditions, with associated generation of anatectic melt neosome fractions in both paragneisses and quartzofeldspathic orthogneisses, appear to have persisted throughout much of the D_1 to D_3 interval (e.g., Lewry et al. 1989; Ashton et al. 1993).

The aluminous wackes offer the best criteria for determination of structural sequence and age relationships in the Pelican thrust zone. Age relations between leucosome, main mylonitic foliation and intrafolial folds are variable. Locally, a well-preserved early gneissic foliation (S_1) is parallel to both transposed primary layering (mostly defined by psammitic layers) and anatectic melt *lits*. Coeval F_1 isoclinal to rootless fold closures, defined either by primary layering or early leucosome *lits*, are present in only a few localities. These fabric elements are generally transposed into a dominant S_2 foliation that is axial planar to pervasive tight to isoclinal F_2 folds. Later generations of anatectic *lits* are both parallel to and crosscut the S_2 foliation. In the Mirond Lake area, and locally elsewhere (Ashton et al. 1993; Ashton and Shi 1994), these D_1-D_2 structures are refolded by tight, southwest-vergent overturned F_3 folds. Open to tight, north–south-trending, upright F_4 minor folds refold all of these earlier fabric elements, and locally have a good axial-plane schistosity (S_4).

Such relationships suggest that the D_1-D_2 structures represent a ductile high-strain continuum that proceeded under very high metamorphic grade anatectic conditions. The amount of regional bulk strain represented by the D_1-D_2 mylonitic transposition fabric is unquantifiable but probably very large. Given the high biotite content, very high metamorphic temperatures, and consequent high proportion of incorporated anatectic melt present during deformation, kinematic fabrics are likely to be essentially "strain-insensitive," in the sense that beyond fairly moderate values of strain rate and bulk strain the fabric will not vary to any appreciable extent. It thus seems likely that major regional translation took place along this thrust zone.

Methodology

Samples of the various highly strained intrusive rocks and anatectic neosome components within and adjacent to the Pelican thrust zone were collected throughout the Hanson Lake Block (Fig. 2), with the principal aims of constraining the timing of movement on the thrust zone and establishing the duration of main thermotectonic events in this part of the Trans-Hudson Orogen. Zircons from samples of the following rock units were dated by the $^{207}Pb/^{206}Pb$ evaporation technique (Ansdell and Kyser 1993) : (*i*) Sahli monzocharnockite; (*ii*) "Q" orthogneisses of the internal suite; (*iii*) highly strained to mylonitic, grey, porphyroclastic, tonalitic–granodioritic and granitic orthogneisses of the external suite and immediately overlying allochthon; (*iv*) small, highly boudinaged, foliated to mylonitic synthrusting(?) granite–pegmatite *lits* within the mylonitic orthogneisses; and (*v*) weakly foliated to undeformed late-thrusting to postthrusting granite pegmatite dykes of the Jan Lake suite which cut the mylonitic foliation of the thrust zone.

Separated zircons include brown, pale yellow, and colourless varieties, ranging in morphology from elongate to stubby prismatic crystals (Table 1). Euhedral, nonmagnetic translucent zircons were preferentially selected for analysis and attempts were made to ensure that no visible inclusions or obvious inherited cores were present. Selected zircons were analyzed using the single zircon Pb-evaporation technique developed by Kober (1987) and modified by Ansdell and Kyser (1993). After preheating at low to intermediate temperatures to remove common Pb from the margins and from internal cracks and metamict zones, Pb from the zircon was then evaporated onto an ionization filament in progressively higher temperature steps and analyzed using a secondary electron multiplier. Usually, the oldest age is obtained from

Table 1. Pb isotopic data of zircons for the Sahli monzocharnockite and the "Q" gneisses.

Sample[a]	Description[b]	Evaporation temp. (°C)[c]	^{208}Pb/^{206}Pb (±2σ)	^{207}Pb/^{206}Pb (±2σ)	Age (Ma) (±2σ)
Sahli monzocharnockite					
PS12(1)	Semi-euh, rounded edge, stpr, dark, cloudy, med	1640 (4)	0.1547±10	0.1367±13	2186±18
PS12(2)	euh, lgpr, cl, sm	1570 (1)	0.1479±6	0.1565±4	2419±4
PS12(3)	euh, lgpr, br, sm	1485 (1)	0.2074±85	0.1637±17	2495±16
PS12(4)	euh, lgpr, cl, med	1670 (3)	0.2135±20	0.1671±36	2527±36
"Q" gneisses					
PS13A(1)	euh, lgpr, br, vsm	1550 (1)	0.0575±60	0.1543±12	2394±13
PS13A(2)	euh, stpr, br, sm	1540 (2)	0.0070±8	0.1877±16	2723±12
PS13A(3)	euh, stpr, br, med	1520 (2)	0.1381±27	0.1938±18	2775±16
PS13A(4)	euh, stpr, cl, sm	1470 (1)	0.0999±34	0.2233±40	2794±31[d]
PS26B(1)	euh, lgpr, br, vsm	1585 (2)	0.0719±12	0.1405±15	2234±18
PS26B(2)	euh, lgpr, br, sm	1590 (1)	0.0150±17	0.1505±13	2352±14
PS26B(3)	euh, stpr, cl, vsm	1500 (1)	0.0301±29	0.1612±20	2467±20
PS26B(4)	euh, stpr, light br, med	1545 (2)	0.0152±2	0.1289±18	2084±24
PS26B(5)	euh, stpr, light br, sm	1580 (1)	0.0304±28	0.1525±7	2374±8
PS36B(1)	euh, lgpr, cl, med	1580 (3)	0.0452±18	0.2108±35	2912±14
PS36B(2)	euh, stpr, cl, med	1545 (3)	0.0429±12	0.2085±18	2894±14
PS38(1)	euh, stpr, cl, med	1540 (2)	0.1843±18	0.2101±11	2906±8
PS38(2)	euh, stpr, cl, sm	1530 (2)	0.1250±20	0.2120±20	2920±16
PS52(1)	euh, stpr, cl, sm	1500 (1)	0.0824±20	0.2031±20	2852±15
PS52(2)	euh, lgpr, cl, sm	1530 (1)	0.1963±20	0.2080±9	2890±18

[a] Zircon sample number is given in parentheses.

[b] euh, euhedral; lgpr, long prismatic (length/width > 2.5); stpr, stubby prismatic (length/width < 2.5); cl, colourless to pale yellow; br, brown; med, medium size (300–400 μm long); sm, small size (200–300 μm long); vsm, very small size (100–200 μm long).

[c] Values in parentheses indicate number of steps as described by Kröner and Todt (1988). Multiple scans (up to 40) used at each step.

[d] ^{204}Pb/^{206}Pb = 0.00221 ± 88, age corrected for ^{204}Pb using Stacey and Kramers' (1975) model Pb at 2750 Ma.

the highest temperature steps and is interpreted to represent Pb from the core of the zircon crystal (Ansdell and Kyser 1993) that has been least affected by Pb loss. ^{204}Pb/^{206}Pb ratios of zircons were generally less than 0.0001 and thus no common Pb correction was made to the ^{207}Pb/^{206}Pb ages. All errors reported are at the 95% confidence level (Tables 1, 2). The precision and accuracy of this technique have been tested in this laboratory using zircons from rocks that had been dated using high-precision conventional U-Pb techniques (Ansdell and Kyser 1991, 1993). Only the higher temperature steps are reported in Tables 1 and 2.

Results

Sahli monzocharnockite

Four zircons from one sample of partially retrogressed Sahli monzocharnockite were analyzed (Table 1; Fig. 3). The oldest ^{207}Pb/^{206}Pb ages, 2527 ± 36, 2494 ± 16, and 2419 ± 4 Ma, were obtained from long euhedral prismatic zircon grains. An age of 2186 ± 18 Ma from a slightly rounded zircon grain (Table 1) may represent Pb loss due to later metamorphism. Bell and Macdonald (1982) reported a whole-rock Rb–Sr isochron age of 2410 ± 40 Ma for the Sahli "granite," and Lewry et al. (1987) reported an imprecise U–Pb zircon upper intercept of 2680 ± 280 Ma with a lower intercept of 1960 ± 150 Ma from six highly discordant zircon fractions. These data suggest that the Sahli monzocharnockite was either emplaced or underwent very high grade metamorphic recrystallization in the late Archean – earliest Paleoproterozoic. However, our data provide no evidence of an expected later Paleoproterzoic metamorphic overprint.

"Q" gneisses

Fifteen euhedral single zircons derived from five samples of this unit (Table 1; Fig. 3) yielded ^{207}Pb/^{206}Pb ages ranging from 2920 ± 20 to 2084 ± 24 Ma: 9 of the 15 gave ages greater than 2700 Ma. These data strongly suggest that the "Q" gneisses are derived from Archean plutonic protoliths rather than late Paleoproterozoic intrusive rocks as previously thought (Lewry et al. 1989; Lewry 1990). Both the zircon morphology and geochemical–isotopic character of the "Q" gneisses, summarized above, make it unlikely that the analyzed zircons are detrital or are otherwise inherited from older source rocks.

Porphyroclastic orthogneisses

^{207}Pb/^{206}Pb ages of 14 zircons from five samples of por-

Table 2. Isotopic data of zircons for granitoids from the Pelican thrust.

Sample[a]	Description[b]	Evaporation temp. (°C)[c]	^{208}Pb/^{206}Pb ($\pm 2\sigma$)	^{207}Pb/^{206}Pb ($\pm 2\sigma$)	Age (Ma) ($\pm 2\sigma$)
Porphyroclastic orthogneisses					
PS7A(1)	euh, stpr, cl, med	1550 (1)	0.0298±7	0.1103±1	1804±3
PS7A(2)	euh, stpr, cl, med	1585 (3)	0.0085±2	0.1106±4	1809±7
PS7A(3)	euh, lgpr, cl, med	1570 (2)	0.0508±1	0.1141±6	1866±9
PS8A(1)	euh, lgpr, cl, med	1540 (2)	0.0057±7	0.1100±2	1799±2
PS8A(2)	euh, stpr, cl, med	1610 (2)	0.0129±2	0.1128±4	1845±6
PS10A(1)	euh, stpr, light br, sm	1625 (1)	0.0141±20	0.1104±14	1807±23
PS10A(2)	euh, stpr, br, sm	1510 (2)	0.0254±2	0.1114±4	1822±7
PS10A(3)	euh, stpr, br, sm	1540 (1)	0.0252±18	0.1149±13	1879±20
PS10A(4)	euh, stpr, light br, med	1570 (3)	0.0761±8	0.1133±3	1853±5
PS10A(5)	euh, stpr, light br, med	1550 (3)	0.0635±1	0.1145±2	1872±3
PS24C(1)	euh, stpr, cl, med	1555 (1)	0.1761±12	0.1130±5	1849±7
PS24C(2)	euh, stpr, br, med	1540 (1)	0.1049±32	0.1119±4	1831±4
PS30B(1)	euh, stpr, cl, med	1600 (4)	0.0653±4	0.1117±2	1827±4
PS30B(2)	euh, stpr, cl, med	1570 (1)	0.0629±5	0.1124±8	1838±13
Prethrusting granitoid					
PS4(1)	euh, stpr, br, sm	1450 (1)	0.0622±55	0.1125±12	1840±19
PS4(2)	euh, stpr, br, sm	1580 (3)	0.0980±10	0.1127±3	1843±5
PS4(3)	euh, lgpr, cl, med	1630 (1)	0.0519±12	0.1134±9	1854±19
Synthrusting pegmatite					
PS9C(1)	euh, lgpr, br, sm	1555 (1)	0.0149±2	0.1112±4	1820±6
PS9C(2)	euh, stpr, br, med	1445 (1)	0.0475±9	0.1120±9	1832±14
PS29(1)	euh, stpr, cl, med	1510 (1)	0.0281±22	0.1119±8	1831±12
PS29(2)	euh, stpr, cl, sm	1500 (1)	0.0200±7	0.1120±12	1832±20
PS29(3)	euh, lgpr, cl, med	1560 (1)	0.0621±11	0.1123±12	1837±19
PS30C(1)	euh, stpr, cl, med	1620 (2)	0.0601±8	0.1102±10	1803±16
PS30C(2)	euh, stpr, cl, med	1580 (2)	0.0358±6	0.1107±13	1811±22
PS30C(3)	euh, stpr, cl, med	1580 (1)	0.0561±10	0.1125±7	1840±12
Late-thrusting pegmatite					
PS11C	euh, stpr, cl, med	1620 (1)	0.0438±16	0.1091±10	1784±18
Postthrusting pegmatite					
PS33	euh, stpr, br, sm	1580 (2)	0.0145±3	0.1076±3	1759±5
PS22B(1)	euh, stpr, br, sm	1560 (1)	0.0331±10	0.1089±10	1781±18
PS22B(2)	euh, stpr, cl, med	1480 (1)	0.0387±7	0.1092±12	1786±20

[a] Zircon sample number is given in parentheses.

[b] euh, euhedral; lgpr, long prismatic (length/width > 2.5); stpr, stubby prismatic (length/width < 2.5); cl, colourless to pale yellow; br, brown; med, medium size (300–400 μm long); sm, small (200–300 μm long).

[c] Values in parentheses indicate number of steps as described by Kröner and Todt (1988). Multiple scans done at each step.

phyroclastic grey mylonitic to protomylonitic gneisses from the external suite of the Pelican thrust, thought to derive from granodioritic protoliths, range from ca. 1880 to 1800 Ma (Table 2; Fig. 3). These rocks have depleted-mantle Nd model ages of 2100–1789 Ma, indicating derivation from a Paleoproterozoic mantle source (Sun et al. 1992). We therefore interpret the older zircon ages (~1880–1840 Ma, Fig. 3) as being close to primary emplacement age of the plutonic protoliths.

Younger, ~1822–1800 Ma zircons from this unit most likely represent metamorphic age because most of these zircons have more than one evaporation step with the same low ^{207}Pb/^{206}Pb ratio. An 1800+ Ma age of metamorphism in this area is compatible with a peak metamorphic age of ca. 1818 Ma in the adjacent Kisseynew domain (Ansdell and Norman 1995) and an age of ca. 1815–1800 Ma for low-grade metamorphism in the Flin Flon domain (Fedorowich et al. 1995).

Three zircons from a highly deformed, probably prethrusting pink granitic gneiss body (PS4) in the Tulabi Lake area just above the main Pelican thrust (Lewry 1990) yield ^{207}Pb/^{206}Pb ages of between 1854 ± 19 and 1840 ± 19 Ma.

Thus, we interpret these data to indicate that the porphyroclastic orthogneisses derive from ~1880–1850 Ma pretectonic plutons that were deformed and metamorphically recrystallized under high-grade conditions ca. 1820–1800 Ma. This interpreted emplacement age range is consistent with ages of arc plutons obtained throughout much of the Reindeer Zone. The metamorphic recrystallization age range also constrains main ductile deformation in the Pelican thrust zone.

Synthrusting granitoid rocks

Eight zircons were analyzed from samples of three highly deformed granite pegmatite bodies within mylonitic porphyroclastic grey granodioritic gneisses. All are highly boudinaged, dismembered, and strongly foliated, although generally not with as pronounced an internal fabric as that in the host paleosome. Field interpretation suggests that their generation and subsequent deformation are temporally related to main thermotectonism in the Pelican thrust zone. The zircons yielded $^{207}Pb/^{206}Pb$ ages of between ~1840 and 1800 Ma, six of the eight being between 1840 and 1820 Ma. We interpret these data to indicate that major high-strain deformation at $P-T$ conditions sufficient to generate anatectic melts had begun by 1840–1820 Ma.

Late-thrusting to postthrusting pegmatites

One zircon from a weakly foliated granite pegmatite dike cutting the Sahli monzocharnockite gave a $^{207}Pb/^{206}Pb$ age of 1784 ± 18 Ma (PS-11C; Table 2; Figs. 2, 3). Two zircons from an undeformed posttectonic granite pegmatite cutting the migmatitic metagreywacke yielded essentially identical ages of 1781 ± 18 and 1786 ± 20 Ma (PS-22B; Table 2; Figs. 2, 3). A zircon from a second undeformed pegmatite, cutting a granodiorite in the lowest part of the allochthon, gave a somewhat younger age of 1759 ± 5 Ma (PS-33; Table 2; Figs. 2, 3). These data are consistent with the U–Pb zircon upper intercept age of 1773 ± 9 Ma for another pegmatite of the "Jan Lake" suite reported by Bickford et al. (1987) in the same area, and provide a younger age limit on significant deformation in the area.

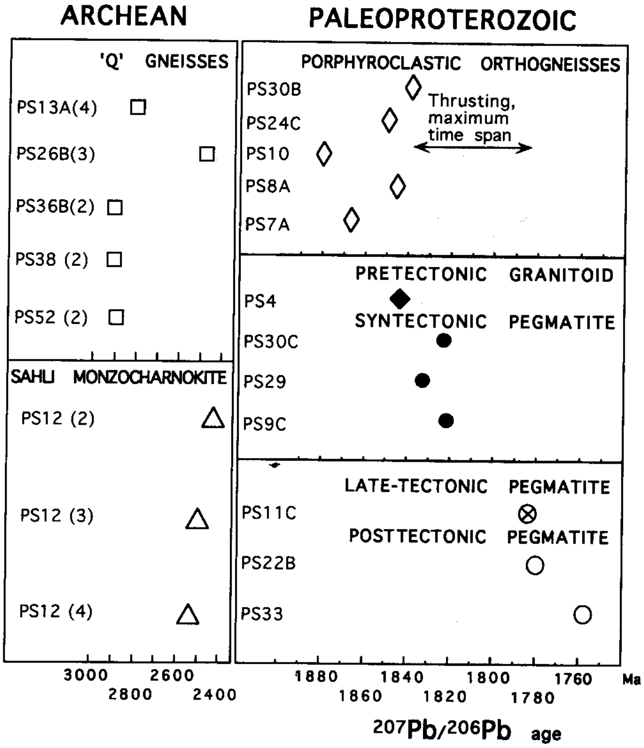
Discussion and conclusions

The main conclusions that can be drawn from the single zircon age data and field relationships presented here are as follows.

1. Data from the Sahli monzocharnockite strongly support previous evidence that this body is of Archean age. However, it is unclear whether the ca. 2500 Ma zircon ages we obtained represent primary emplacement age or the age of a later granulite-facies metamorphic overprint. We consider the latter interpretation to be more likely and suggest that initial emplacement age might be significantly older.

2. Zircon ages from the mylonitic "Q" gneisses strongly indicate that these rocks derive from Archean protoliths rather than Paleoproterozoic plutons as was expected. This in turn makes it likely that the intimately associated migmatitic metagreywackes of the internal suite are also Archean, although no ages were obtained from these. Although the original (and present) relationship between the "Q" gneisses and Sahli monzocharnockite remains unclear, it thus seems likely that the entire footwall assemblage of the Pelican thrust zone is Archean in age.

Fig. 3. $^{207}Pb/^{206}Pb$ ages of zircons from the "Q" gneisses, Sahli monzocharnockite, porphyroclastic orthogneisses, synthrusting granitoids, and postthrusting granitoids (data from Tables 1 and 2). The shaded area represents the maximum period of deformation and movement on the Pelican thrust.



3. In sharp contrast, mylonitic grey orthogneisses of the hanging-wall external suite are derived from Paleoproterozoic, juvenile arc protoliths coeval with less highly strained rocks in the overlying allochthon.

4. The juvenile arc rocks of the allochthon were tectonically emplaced along the Pelican thrust, across underlying Archean basement, between 1840 and 1785 Ma, but mainly between 1840 and 1820 Ma, as determined from the zircon ages of *lit-par-lit*, highly deformed granite pegmatite bodies within the mylonites.

5. The tectonic environment of the allocthonous rocks thus evolved from a subduction-related oceanic-arc setting prior to about 1850 Ma to an arc-(micro)continent collision setting after ca. 1840 Ma. Movement along the thrust had ceased by 1784 Ma but probably much earlier. Thermal rebound following collisional crustal thickening produced post-thrusting granitoids by about 1784 Ma.

6. The Pelican thrust is a major deformation zone in the Paleoproterozoic Trans-Hudson Orogen, and may be the main thrust zone that formed during this period of ocean closure, involving thrust stacking of Paleoproterozoic intraoceanic rocks, and their emplacement onto an adjacent Archean continental mass, as described by Ansdell et al. (1995).

7. Given the above, the Pelican thrust may have a tectonic significance similar to that of other large ductile thrusts elsewhere in the world, many of which also displace cover or juvenile materials over older basement. For example, in the Western Alps, three major Tertiary thrust systems are recog-

nized. (*i*) The early Tertiary (100? – 50 Ma) basal Austroalpine thrust emplaces the attenuated southern passive margin of the Tethys ocean over intraoceanic ophiolites and deep-water sedimentary rocks, and both on top of the Pennine domain (basement of the distal European plate and Briançonnais microplate). (*ii*) The middle Tertiary basal Pennine thrust displaces metamorphic units of the Pennine Zone northward over the Helvetic and autochthonous sedimentary cover, carrying the deactivated Austroalpine thrust system and associated ophiolite suite passively farther northward. The duration of displacement on the Pennine thrust system during the main Alpine deformation is thought to be ~40 Ma and the system was abandoned by ca. 15 Ma (Ricou and Siddans 1986; Coward and Dietrich 1989; Hunziker 1986). (*iii*) During the middle to late Tertiary terminal collision stage (30 – 0 Ma) progressively more external and deeper thrusts (Helvetic, External Crystalline Massifs, Jura) within the European plate were activated, whereby older thrust systems were refolded. Likewise, in the Himalayas, collision of the Indian and Asian continents began ~40 Ma and is ongoing. Terranes such as the Kohistan Complex, intensely deformed Late Jurassic to Late Cretaceous island-arc material, were imbricated by a series of major thrust zones, including the Main Mantle, Main Boundary, and Main Central thrusts. As in the Western Alps, intraoceanic Tethyan ophiolites and sedimentary material are thrust over older basement and later folded (Tapponnier et al. 1986; Coward et al. 1986; Gansser 1991). Although the details in each of these regions (Alps, Himalayas, Pelican thrust) are different, they all developed by the thrusting of intraoceanic rocks over basement terranes during episodes of ocean closure and continent – continent collision. In all cases, the duration of thrusting is on the order of a few tens of millions of years, suggesting that orogeny took a similar time to complete in the Proterozoic as in the Tertiary.

8. Crustal shortening along the Pelican thrust must have been accompanied by thickening of the mantle lithosphere, raising questions about delamination in the Trans-Hudson Orogen. In this regard, the upper mantle, as seismically imaged by Lucas et al. (1994), contains numerous flat reflective zones that may be interpreted as thrust structures in the mantle lithosphere.

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References

Ansdell, K.M., and Kyser, T.K. 1991. Plutonism, deformation, and metamorphism in the Proterozoic Flin Flon greenstone belt, Canada: limits on timing provided by the single-zircon Pb-evaporation technique. Geology, **19**: 518 – 521.

Ansdell, K.M., and Kyser, T.K. 1993. Textural and chemical changes undergone by zircon during the Pb-evaporation technique. American Mineralogist, **78**: 36 – 41.

Ansdell, K.M., and Norman, A.R. 1995. U – Pb geochronology and tectonic development of the southern flank of the Kisseynew Domain, Trans-Hudson Orogen, Canada. Precambrian Research, **72**: 147 – 167.

Ansdell, K.M., Lucas, S.B., Conners, K., and Stern, R.A. 1995. Kisseynew metasedimentary gneiss belt, Trans-Hudson orogen (Canada): back-arc origin and collisional inversion. Geology, **23**: 1039 – 1043.

Ashton, K.E., and Balzer, S.S. 1995. Wildnest – Tabbernor transect: Pelican Lake – Tabbernor fault area (part of 63 M-3). *In* Summary of investigations 1990. *Edited by* R. Macdonald. Saskatchewan Geological Survey, Report 95-4, pp. 13 – 22.

Ashton, K.E., and Shi, R. 1994. Wildnest – Tabbernor transect: Mirond – Pelican lakes area (parts of NTS 63 M-2 and -3). *In* Summary of investigations 1990. *Edited by* R. Macdonald. Saskatchewan Geological Survey, Report 94-4, pp. 27 – 37.

Ashton, K.E., Drake, A.J., and Lewry, J.F. 1993. Wildnest – Tabbernor transect: Attitti – Mirond lakes area (parts of NTS 63 M-1 and -2). *In* Summary of investigations 1990. *Edited by* R. Macdonald. Saskatchewan Geological Survey, Report 93-4, pp. 50 – 66.

Baldwin, D.A., Syme, E.C., Zwanzig, H.V., Gordon, T.M., Hunt, P.A., and Steven, R.O. 1987. U – Pb zircon ages from the Lynn Lake and Rusty Lake metavolcanic belts, Manitoba: two ages of Proterozoic magmatism. Canadian Journal of Earth Sciences, **24**: 1053 – 1063.

Bell, K., and Macdonald, R. 1982. Saskatchewan Shield geochronology project. *In* Summary of investigations 1982. *Edited by* R. Macdonald, T.I.I. Sibbald, D.F. Paterson, P. Guliov, and J.V. Butler. Saskatchewan Geological Survey, Report 82-4, pp. 17 – 22.

Bickford, M.E., Van Schmus, W.R., Collerson, K.D., and Macdonald, R. 1987. U – Pb zircon geochronology project: new results and interpretations. *In* Summary of investigations 1987. *Edited by* R. Macdonald. Saskatchewan Geological Survey, Report 87-4, pp. 76 – 79.

Bickford, M.E., Collerson, K.D., Lewry, J.F., Van Schmus, W.R., and Chiarenzelli, J.R. 1990. Proterozoic collisional tectonism in the Trans-Hudson orogen, Saskatchewan. Geology, **18**: 14 – 18.

Coward, M., and Dietrich, D. 1986. Alpine tectonics—an overview. *In* Alpine tectonics. *Edited by* M.P. Coward, D. Dietrich, and R.G. Park. Geological Society Special Publication (London), No. 45, pp. 1 – 29.

Coward, M., Windley, B.F., Luff, I.W., Petterson, M.G., Pudsey, C.J., Rex, D.C., and Khan, A. 1986. Collision tectonics in the NW Himalayas. *In* Collision tectonics. *Edited by* M.P. Coward and A.C. Ries. Geological Society Special Publication (London), No. 19, pp. 203 – 219.

Fedorowich, J.S., Kerrich, R., and Stauffer, M.R. 1995. Geodynamic evolution and thermal history of the central Flin Flon Domain, Trans-Hudson orogen: constraints from structural development, Ar/ Ar, and stable isotope geothermometry. Tectonics, **14**: 472 – 503.

Gansser, A. 1991. Facts and theories on the Himalayas. Eclogae Geologiae Helvetiae, **84**: 33 – 59.

Hunziker, J.C. 1986. The Alps: a case of multiple collision. *In* Collision tectonics. *Edited by* M.P. Coward and A.C. Ries. Geological Society Special Publication (London), No. 19, pp. 221 – 227.

Kober, B. 1987. Single-grain evaporation combined with Pb+ emitter bedding for $^{207}Pb/^{206}Pb$ investigations using thermal ion mass spectrometry, and implications for zirconology. Contributions to Mineralogy and Petrology, **96**: 63 – 71.

Kröner, A., and Todt, W. 1988. Single zircon dating constrains the maximum age of the Barberton greenstone belt, Southern Africa. Journal of Geophysical Research, **93**: 15 329 – 15 337.

Lewry, J.F. 1990. Bedrock geology, Tulabi–Church lakes area: derivation and significance of porphyroclastic gneisses in the Pelican Window. *In* Summary of investigations 1990. *Edited by* R.A. Macdonald. Saskatchewan Geological Survey, Report 90-4, pp. 36–43.

Lewry, J.F., and Stauffer, M.R. (*Editors*). 1990. The Early Proterozoic Trans-Hudson Orogen of North America. Geological Association of Canada, Special Paper 37.

Lewry, J.F., Macdonald, R., Livesey, C., Meyer, M., Van Schmus, R., and Bickford, M.E. 1987. U–Pb geochronology of accreted terranes in the Trans-Hudson Orogen, northern Saskatchewan, Canada. *In* Geochemistry and mineralization of Proterozoic volcanic suites. *Edited by* T.C. Pharaoh, R.D. Beckinsale, and D. Rickard. Geological Society Special Publication (London), No. 33, pp. 147–166.

Lewry, J.F., Macdonald, R., and Stauffer, M.R. 1989. The development of highly strained rocks in the Pelican Window during high-grade metamorphism and pervasive anatexis. *In* Summary of investigations 1989. *Edited by* R. Macdonald. Saskatchewan Geological Survey, Report 89-4, pp. 58–65.

Lewry, J.F., Thomas, D.J., Macdonald, R., and Chiarenzelli, J. 1990. Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime? *In* The Early Proterozoic Trans-Hudson Orogen of North America. *Edited by* J.F. Lewry and M.R. Stauffer. Geological Association of Canada, Special Paper 37, pp. 75–94.

Lewry, J.F., Hajnal, Z., Green, A., Lucas, S.B., White, D., Stauffer, M.R., Ashton, K.E., Weber, W., and Clowes, R. 1994. Structure of a paleoproterozoic continent–continent collision zone: a LITHOPROBE seismic reflection profile across the Trans-Hudson Orogen, Canada. Tectonophysics, **232**: 143–160.

Lucas, S.B., White, D., Hajnal, Z., Lewry, J., Green, A., Clowes, R., Zwanzig, H., Ashton, K., Schledewitz, D., Stauffer, M., Norman, A., Williams, P.F., and Spence, G. 1994. Three-dimensional collisional structure of the Trans-Hudson Orogen, Canada. Tectonophysics, **232**: 161–178.

Macdonald, R. 1974. Pelican Narrows (West) area. *In* Annual summary of field investigations 1974. *Edited by* J.E. Christopher and R. Macdonald. Saskatchewan Department of Mineral Resources, pp. 30–37.

Macdonald, R., and MacQuarrie, R.R. 1978. Geological re-investigation mapping, Jan Lake area (part of NTS area 63M). *In* Summary of investigations 1978. *Edited by* J.E. Christopher and R. Macdonald. Saskatchewan Geological Survey, Report 78-10, pp. 16–24.

Meyer, M.T., Bickford, M.E., and Lewry, J.F. 1992. The Wathaman batholith: an Early Proterozoic continental arc in the Trans-Hudson orogenic belt, Canada. Geological Society of America Bulletin, **104**: 1073–1085.

Ricou, L.E., and Siddans, A.W.B. 1986 Collisional tectonics in the Western Alps. *In* Collision tectonics. *Edited by* M.P. Coward and A.C. Ries. Geological Society Special Publication (London), No. 19, pp. 221–227.

Shi, R., and Lewry, J.F. 1991. Origin and kinematic history of highly strained gneisses in the Jan Lake East area. *In* Summary of investigations 1991. *Edited by* R.A. Macdonald. Saskatchewan Geological Survey, Report 91-4, pp. 169–174.

Stacey, J.S., and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters, **26**: 207–221.

Stauffer, M.R. 1984. Manikewan: an Early Proterozoic ocean in central Canada, its igneous history and orogenic closure. Precambrian Research, **27**: 257–281.

Sun, M., Stauffer, M.R., Lewry, J.F., Edwards, G., Kerrich, R., and Kyser, T.K. 1991. Chemical signatures of igneous and metasedimentary rocks from the Pelican Slide area: implications for their sources and tectonic environments. *In* Summary of investigations 1991. *Edited by* R.A. Macdonald. Saskatchewan Geological Survey, Report 91-4, pp. 162–168.

Sun, M., Kerrich, R., Kyser, K., and Stauffer, M.R. 1992. Proterozoic Trans-Hudson collisional orogeny (~1.8 Ga): II. Crust–mantle interaction as monitored by Sr, Nd, and Pb isotope characteristics of pre-, syn-, and post-collisional granitoids. Eos, **73**: 617.

Tapponnier, P., Peltzer, G., and Armijo, R. 1986. On the mechanics of the collision between India and Asia. *In* Collision tectonics. *Edited by* M.P. Coward and A.C. Ries. Geological Society Special Publication (London), No. 19, pp. 115–157.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F., and Macdonald, R. 1987. U–Pb geochronology in the Trans-Hudson Orogen, northern Saskatchewan, Canada. Canadian Journal of Earth Sciences, **24**: 407–424.