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Structure of the high-grade Opatica Belt and adjacent low-grade Abitibi Subprovince, Canada: an Archaean mountain front*

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Abstract—Plutonic gneisses in the Archaean Opatica Belt in Canada record crustal-scale, WSW-vergent (i.e. longitudinal), high-temperature D_1 ductile shearing. Similar structures occur in adjacent greenstone belts, but only in narrow amphibolite facies zones near the base; metavolcanics in the greenschist facies portions do not record penetrative D_1 structures. The greenstone belts are interpreted as allochthonous on the gneisses; they form the uppermost D_1 thrust sheets. SSE-vergent (i.e. approximately transverse) D_2 thrusting imbricated the Opatica Belt and formed a large antiform—either a culmination or an antiformal stack—in the southern Opatica. The imbricated Opatica Belt wedged under the northern part of the Abitibi Subprovince and created a tight syncline with NNW-vergent D_2 thrusts (interpreted as backthrusts) on its northern limb. The Opatica Belt–Abitibi Subprovince contact, therefore, resembles some Phanerozic mountain fronts. Further southwards-propagating imbrication of the crust beneath the Abitibi Subprovince created a S-vergent foreland fold and thrust belt in the overlying greenstones. High-grade Opatica gneisses and adjacent low-grade Abitibi greenstones contain complementary structural patterns and may therefore represent the internal and foreland parts of an Archaean mountain belt, similar in many respects to Phanerozoic examples.

INTRODUCTION

OUR knowledge of the distribution and geometry of the structures in many old cratons is biased towards the metavolcanic and metasedimentary belts—primarily because these contain the ore deposits. The neglect of the high-grade metaplutonic gneiss terrains has two important consequences. (1) Most of the cratonic areas are not well documented because metavolcanic and metasedimentary belts form only a small proportion of the total area, 25% in the Superior Province (Card 1990). (2) Because most of the metavolcanic and metasedimentary belts contain low-grade (typically greenschist facies) metamorphic assemblages their structures are, necessarily, only representative of shallow crustal levels; thus the structure of the middle crust exposed in the high-grade terrains of the cratons remains poorly known.

Many shallow-level greenstone belts are characterized by steeply dipping structures (Anhaeusser *et al.* 1968, Anhaeusser 1985, Daigneault *et al.* 1990) attributed to pluton emplacement, or to the sinking of dense greenstone material into a 'granitic' crust. In contrast many high-grade gneiss terrains in cratonic areas contain subhorizontal foliations attributed to nappe formation, or to high-temperature ductile thrusting (Bridgwater *et al.* 1974). In some gneiss terrains the flat-lying structures have been overprinted by subvertical ones similar to those in the greenstone belts (Bridgwater *et al.* 1978). Three models have been proposed to explain why greenstone belts represent shallow crustal levels. (1) Greenstone belts formed on granitic crust in elongate fault controlled basins (Windley & Bridgwater 1971). (2) Crustal material was underplated to the greenstones (Holland & Lambert 1975). (3) Greenstone belts were tectonically emplaced onto 'granitic' crust. Since Schwerdtner (1990) demonstrated that diapirs cannot explain Archaean strain patterns, and isotopic studies (e.g. Dupré & Arndt 1990) showed that many greenstone belts did not form on granitic crust, attention has returned to an allochthonous origin for greenstone belts (e.g. Jackson & Sutcliffe 1990). Stowe (1971) and Coward (1976) showed that greenstone belt sequences in the Rhodesian craton were thrust over gneissic basement prior to the deformation responsible for the steeply-dipping structures, but they did not relate structures formed at high temperatures in the middle crust to those formed in the shallow crust.

The objectives of this paper are: (1) to document the structures formed in a high-grade metaplutonic gneiss belt and to relate their development to the structures formed at shallower crustal levels in adjacent low-grade greenstone belts; and (2) to evaluate the similarity of these structural patterns with those in Phanerozoic mountain belts. Structural mapping undertaken on three traverses across the contact between low-grade Abitibi Subprovince greenstones and into the high-grade gneisses of the Opatica Belt (Canada) forms the basis of this study. The Opatica Belt–Abitibi Subprov-

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*LITHOPROBE contribution No. 361.

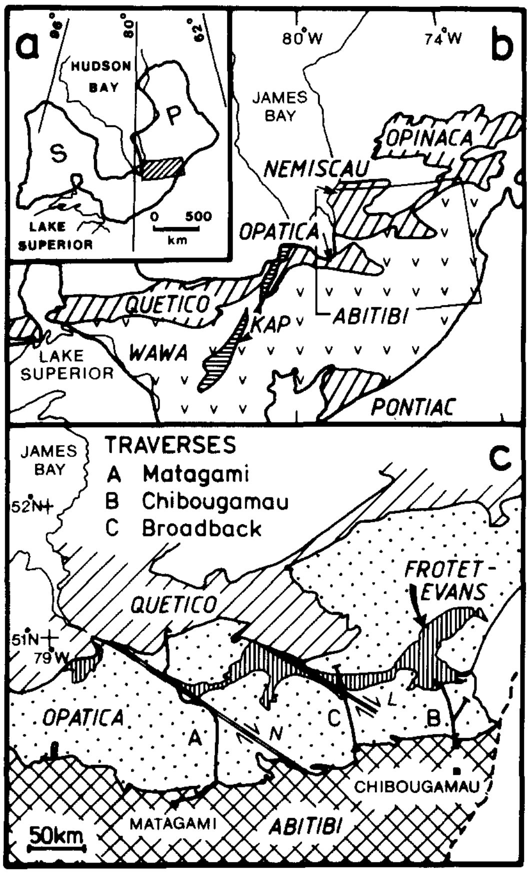

Fig. 1. (a) Location of the study area in the Superior Province. (b) Subprovince boundaries and names as used by Card & Ciesielski (1986); KAP = Kapuskasing structure. (c) Belt boundaries and names as used in this study, showing the location of the three structural traverses across the Opatica Belt and the contact with the northern Abitibi Subprovince; N = Nottaway River shear zone, L = Lucky Strike River shear zone.

ince contact has been mapped at a fourth location some 130 km farther westwards as part of a study of structures in the northern Abitibi Subprovince; those results (Lacroix & Sawyer work in preparation) are similar to ones reported here.

REGIONAL SETTING

Defining the Opatica Belt

There is some dispute concerning the location of the northern boundary of the Abitibi Subprovince. The compilation maps of the Superior Province by the Geological Survey of Canada (GSC) workers (Card & Ciesielski 1986, Card 1990) place the northern boundary (Fig. 1b) of the Abitibi Subprovince at the southern edge of the Quetico–Opatica–Nemiscau–Opinaca (hereafter abbreviated to Quetico) metasedimentary belt. In contrast the maps of the Ministère de l'Énergie et Ressources du Québec (MERQ) (Avramtchev & Lebel-Drolet 1979, Gobeil & Racicot 1983, Hocq 1990) place the northern limit of the Abitibi some 200 km farther south (Fig. 1c), close to where it was placed by Stockwell (1964). The region between the boundaries proposed by the GSC and MERQ consists predominantly of metaplutonic rocks with a structural style and metamorphic grade that differs considerably from the Abitibi Subprovince. Therefore, this paper follows the current MERQ subdivisions of the Superior Province, and terms these metaplutonic rocks the Opatica Belt (Fig. 1c).

Principal units in the Opatica Belt

Five main groups of plutonic rocks have been recognized (Sawyer & Benn 1992) and serve as time markers in the structural history. (1) The Lac Rodayer Pluton (Fig. 2) ranges in composition from leucotonalite through quartz diorite to gabbro; it is separated from the other suites by the Lac Rodayer Thrust. (2) The most voluminous suite, which occurs in the central portion of the Opatica Belt, comprises grey leucotonalites and leucogranites with minor amounts of more mafic types including diorite and gabbro. This suite, informally termed the grey gneisses, is strongly foliated. (3) A tonalite–melatonalite–gabbro (TMG) suite intrudes the grey gneisses and is also strongly foliated. Some plutons contain cm-scale compositional layering that ranges from melagabbro to leucotonalite (<1% mafics). (4) A monzodiorite–granodiorite–tonalite–diorite (MGTD) suite of plutons occurs near to the Opatica Belt–Abitibi Subprovince contact (e.g. Barlow, Canet and Ouescapis plutons). Some of these plutons contain portions where magmatic fabrics are preserved, but mostly all contain crystal plastic strain fabrics. (5) A pink leucocratic granite suite is generally not strongly deformed. A 40 km-wide region north of Matagami (Fig. 2) is dominated by diatexite migmatites—the *in situ* products of partial melting of the more fractionated members of the grey gneisses (Sawyer work in preparation). Pink and grey leucogranite dykes, sills and small plutons which represent mobilized anatectic melts occur throughout much of the Opatica Belt. Preliminary U-Pb ages from zircons (Davis work in progress) indicate that the Lac Rodayer Pluton is considerably (>100 Ma) older than suites 2, 3 and 4 which have ages of between 2740 and 2690 Ma. The pink leucogranite suite is some 10–15 Ma younger.

A sequence of volcanic (Fe-rich basalts with minor rhyolites), sedimentary (semipelites and iron formation) and gabbroic rocks, called the Frotet–Evans Greenstone Belt (Simard 1987), lies along the centre of the Opatica Belt (Fig. 1c).

Metamorphism in the Opatica Belt

The presence of garnet + hornblende + andesine and hornblende + andesine ± clinopyroxene assemblages throughout the Opatica Belt gneisses indicates amphibolite facies metamorphic conditions. Widespread anatexis in the central Opatica Belt north of Matagami (Fig. 2) indicates upper amphibolite conditions there, and temperatures in excess of 650–700°C. Migmatites are less extensive on the other traverses. Many outcrops exhibit some minor retrogression, typically the development of greenschist facies assemblages along late shear planes.

In the east, where the Frotet–Evans Belt is widest, Simard (1987) has noted greenschist, or subgreenschist facies assemblages in the centre, increasing to amphibolite facies adjacent to the Opatica Belt. Farther westwards the Frotet–Evans Belt rocks north of Matagami all contain amphibolite facies assemblages, and although surrounded by partially melted grey gneisses the metasediments show no evidence of partial melting, but they are intruded by pink leucogranite dykes. This steep metamorphic gradient across the Opatica Belt–Frotet Evans contact may have been attenuated by the Nottaway River shear zone (Fig. 2). Greenschist facies assemblages are characteristic of the northern Abitibi Subprovince (Jolly 1978).

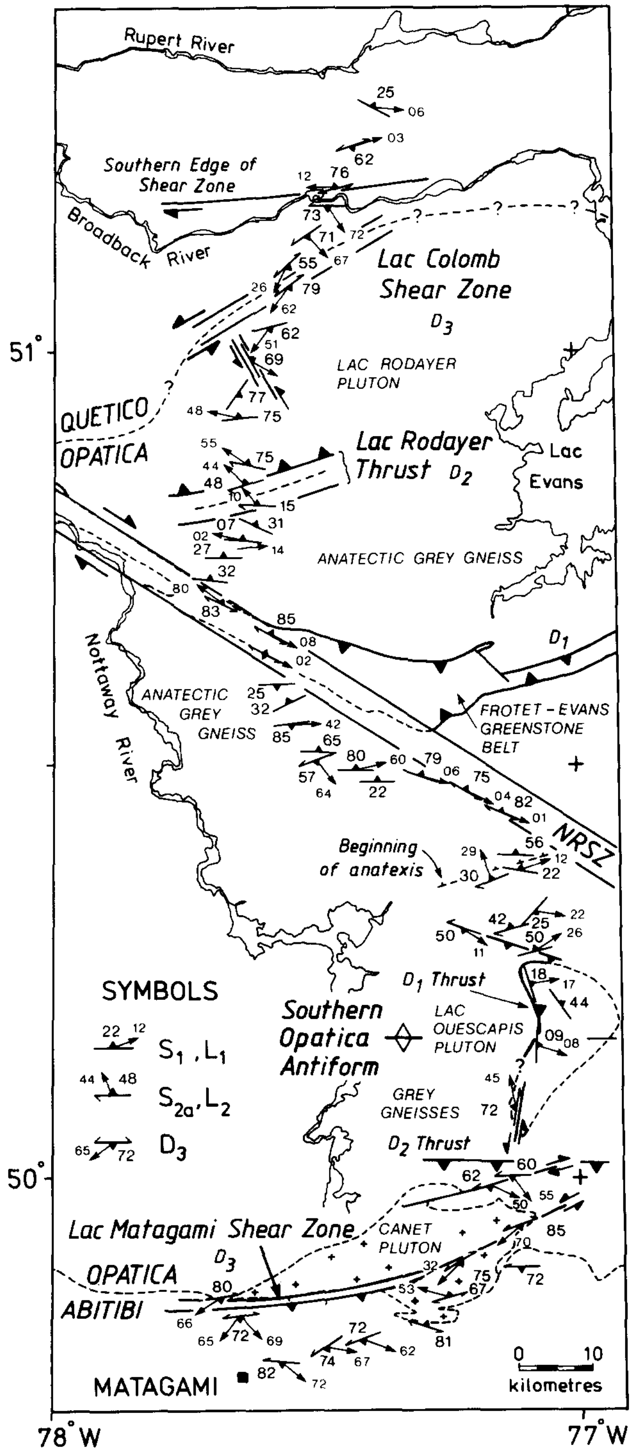

Fig. 2. Structural map showing the orientation of the principal foliations and stretching lineations on the Matagami traverse along the Matagami–Radisson paved road.

STRUCTURE

This study is based on data collected from all three traverses shown in Fig. 1(c). Only maps for the Matagami (Fig. 2) and Chibougamau (Fig. 3) traverses are presented here, because the Broadback traverse (Benn *et al.* 1992, fig. 6) contains a large proportion of pink granite plutons.

The principal observations in the field were the orientations and superimposition of planar and linear structures; therefore a D_1, D_2 and D_3 notation is used. Structures believed to be related are distinguished as, for example, S_{2a} and S_{2b}, etc. All orientations given for planar structures are azimuth of the dip direction and the dip; spherical plots are projections of the lower hemisphere onto Lambert equal-area nets (Fig. 4).

D$_1$ *structures*

On all three traverses the first 10–20 km north of the Abitibi greenstones consists of variably deformed MGTD suite plutons. North of these plutons the Opatica Belt consists of pervasively deformed grey gneisses and TMG suite plutons that generally contain a single, penetrative and moderately-dipping foliation (S_{1a}). This foliation has been folded into small- and large-scale D_2 folds such that the poles to S_{1a} define great circles on the stereograms (Figs. 4a, b & k). At the outcrop scale S_{1a} is defined by a strong preferred orientation of biotite and hornblende, and by the elongation of quartz grains. In some leucocratic gneisses quartz ribbons and long tails of dynamically recrystallized grains associated with feldspar porphyroclasts (Fig. 5a) define S_{1a}. Many of the feldspar porphyroclasts were derived from disrupted pegmatites, but others are original phenocrysts. There is a range of microtextures from: (1) textures in which feldspars are dynamically recrystallized and quartz has undergone grain boundary migration and grain growth (Fig. 5b) to form scattered large, elongate and embayed grains that, in some cases, enclose mica fish; to (2) restored, or annealed microtextures, in which quartz and feldspar are equant with essentially straight grain boundaries. The textural diversity is consistent with deformation and recrystallization at high temperature (e.g. Urai *et al.* 1986), thus S_{1a} is interpreted as a high-temperature foliation developed during a mid-crustal deformation that locally produced mylonites.

The S_{1a} planes contain a broadly WSW–ENE trending (ranging from SW–NE to W–E) stretching lineation (L_{1a}; Figs. 4a, b & k and 5c). Associated kinematic indicators, such as mica-fish, porphyroclasts and sigmoidal deflections of foliation observed in thin section, and winged inclusions, offset veins and fold asymmetry in outcrop indicate top-to-the-west-southwest shear sense (Fig. 5d). The lineation is defined by either: trains

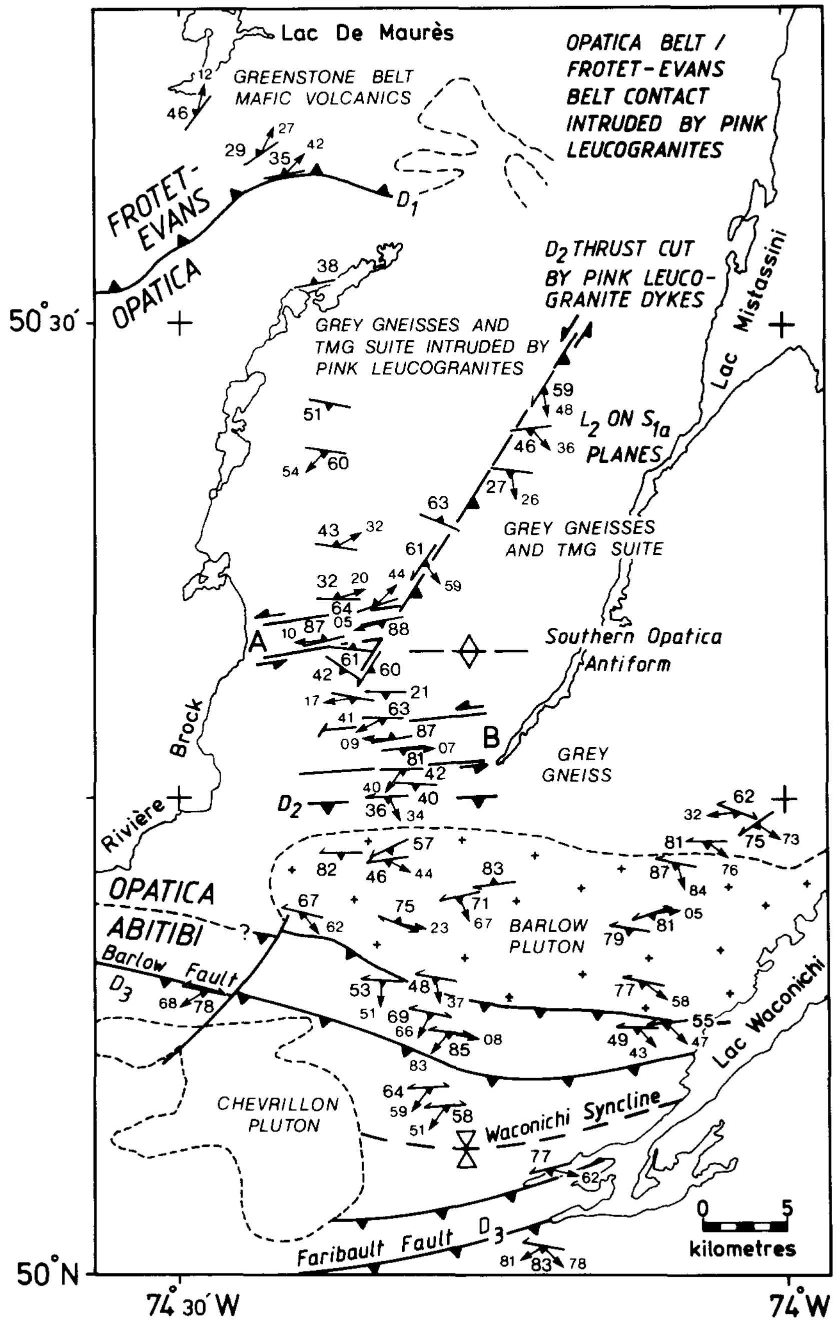

Fig. 3. Structural map showing the orientation of the principal foliations and stretching lineations on the Chibougamau traverse (logging roads 10, L-208 and L-230); symbols as for Fig. 2.

Fig. 4. Stereograms for the Matagami (a–j) and Chibougamau (k–o) traverses. D_1 *structures*. (a), (b) & (k) ● = poles to S_{1a} foliation, × = stretching lineation L_{1a}, △ = hinges of F_1 folds. (a) & (k) Data from the non-anatectic grey gneisses on both limbs of the Southern Opatica Antiform (SOA), the great circles represent the axial plane of the SOA. (b) Data from the anatectic gneisses north of the SOA, the great circle is the axial plane to small-scale D_2 folds. (1) D_1 sinistral strike-slip shear zones, ● = poles to S_{1b} foliation, × = L_{1b} stretching lineation, △ = hinges of F_{1b} folds. D_2 *structures*. (c) & (h) ● = poles to S_{2b} foliation, × = lineation L_{2b}; (c) biotites in Opatica gneisses and pink leucogranite intrusions, and (h) subvertical, dextral shears. (f), (g) & (m) ● = poles to S_{2a} foliation, and × = L_{2a} stretching lineation on SSE-vergent D_2 shear zones, ○ = poles to S_{2a} foliation, and + = L_{2a} lineations on NNW-vergent D_2 shears, △ = hinges of F_2 minor folds, □ = axial planes of F_2 minor folds. (f) & (m) Grey gneisses on both flanks of the SOA; in (f) some S_{2a} planes are folded and now dip southwards, but in (m) all SSE-vergent shears are from the S-dipping limb of the SOA and now dip to the southeast. (g) Anatectic grey gneisses, all of the SSE-vergent data are from the Lac Rodayer Thrust. (d) NNE-trending sinistral strike-slip shears; ○ = poles to, and * = lineations on ductile shears containing anatectic melt, ◑ = poles to, and + lineations on amphibolite facies ductile shears, ● = poles to, and × = lineations on greenschist facies (D_3) brittle shears. (o) NNE-trending sinistral shears; ○ = poles to cm-scale subvertical shears associated with D_2 thrusts, ● = poles to D_3 shear planes and × = stretching lineations on D_3 shear planes. D_3 *structures*. (e), (i), (j) & (n) ● = poles to foliation/mylonite, × = stretching lineation. (e) Nottaway River shear zone (dashed field contains steep lineations at the northern edge of the shear zone, i.e. reoriented L_{1a}), ○ = poles to crenulation cleavage and △ = hinges to kink folds. (i) Greenschist facies, D_3 minor shears in the Lac Rodayer Pluton. (j) Lac Colomb shear zone. (n) Northwest-vergent D_3 shears in the Barlow Pluton and adjacent northern Abitibi metavolcanics.

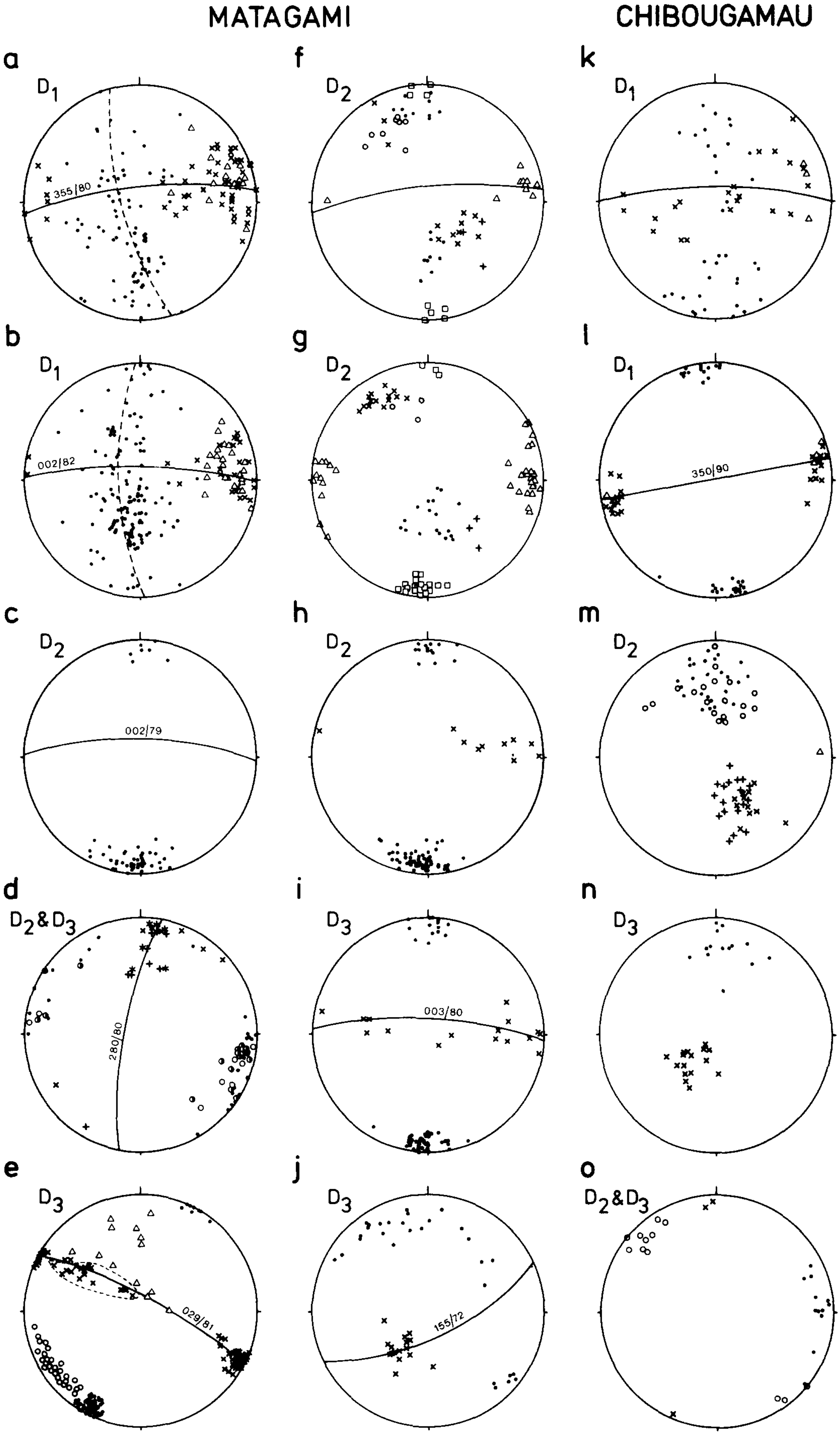
MATAGAMI
CHIBOUGAMAU
a
D1
355/80
f
D2
k
D1
b
D1
002/82
g
D2
l
D1
350/90
c
D2
002/79
h
D2
m
D2
d
D2&D3
280/80
i
D3
003/80
n
D3
e
D3
029/81
j
D3
155/72
o
D2&D3

Fig. 4.

of aligned feldspar fragments and elongate feldspars; or elongate aggregates of hornblende and biotite. Biotite basal planes lie in S_{1a}; this enables L_{1a} to be distinguished from later intersection lineations (e.g. S_{1a} cut by foliations associated with the (NRSZ) where the biotite basal planes are subvertical.

Locally, compositional layering has been disrupted by centimetre- to metre-scale, tight to isoclinal F_1 folds that generally have attenuated limbs, or are rootless. Their axial planes lie parallel to S_{1a}, and the hinges are parallel, or subparallel to L_{1a}, indicating that the folds underwent a progressive rotation of hinges towards parallelism with the shear direction, and axial planes rotated to the bulk shear plane.

Several wide, sinistral shear zones that contain a subvertical S_{1b} foliation and a subhorizontal L_{1b} stretching lineation (Fig. 4l) are present in the eastern Opatica Belt and deform an earlier foliation, or banding, that is equated with S_{1a}. In shear zone A (Fig. 3), S_{1a} is isoclinally folded with subhorizontal hinges and axial planes parallel to S_{1b} (Fig. 5e). Most plagioclase and hornblende porphyroclasts are symmetrical, and the asymmetrical ones give either a dextral or a sinistral shear sense. This variation of shear sense may be due to a partitioning of strain into zones of dominantly coaxial deformation and others of dominantly non-coaxial deformation. Shear band, where developed, give consistently sinistral shear sense (Fig. 5f), and are regarded as more reliable than the porphyroclasts. In a second shear zone (B in Fig. 3) developed in quartz-rich plutonic rocks, S_{1b} is defined by quartz ribbons that have recrystallized into large grains (8 mm compared to 0.25 mm for the groundmass). Where S_{1a} is preserved between two intense zones of S_{1b} strike-slip shearing, the older foliation is folded and crenulated such that the axial-plane traces are slightly oblique in a clockwise sense (up to 15°) to the shear zone boundaries—consistent with sinistral shearing. These shear zones have been cut by pink leucogranite dykes that are intruded along D_2 structures, and reworked by D_3, E-trending, subvertical, dextral strike-slip shears that are recognized because they contain gouge and greenschist facies mineral assemblages.

D_2 *structures*

Two sets of structures comprise D_2. (1) Structures related to wide D_2 reverse shear zones, e.g. the shallow- to moderately-dipping S_{2a} foliation and its associated L_{2a} stretching lineation. (2) Widespread minor structures that partially overprint the D_1 structures away from D_2 thrusts, e.g. the S_{2b} biotite foliation, associated folds and L_{2b} lineation.

There are two sets of contemporaneous D_2 shear zones, one with dips to the northwest (Fig. 5g) and the other with dips to the southeast (Figs. 5h and 6a); the latter occur in the southern Opatica Belt and northern Abitibi Subprovince. Offset veins, sigmoidal foliation domains, winged inclusions and, where developed, *C–S* fabrics indicate reverse displacement for both sets of shears (folded D_2 shear zones are discussed below). Stretching lineation (L_{2a}) trends are to the north-northwest or south-southwest (Figs. 4f, g & m), respectively. The D_2 shear zone rocks in the Opatica contain mid- or upper-amphibolite facies mineral assemblages in which quartz ribbons or elongated quartz grains have recrystallized into large, lobate grains (Fig. 6b) with little undulose extinction. However, late D_2 shears, such as the Lac Rodayer Thrust (Fig. 2), contain mylonites in which elongate quartz grains exhibit undulose extinction, deformation bands, polygonal subgrains, localized shear band structures, and a grain-size reduction at the borders of old grains. In comparison, the SE-dipping D_2 shear zones in the Abitibi Subprovince greenstones are fine-grained, contain *C–S* fabrics (Fig. 6a) and have lower amphibolite or greenschist facies mineralogies—indicative of deformation at lower temperatures.

Some NW-dipping (i.e. SE-vergent) D_2 reverse shear zones have been folded so that they now dip to the south and their kinematic indicators would suggest normal fault movement. There are two examples in the northern Opatica Belt. (1) The Lac Rodayer Thrust which has been folded by low-amplitude flexures with steep N-dipping axial planes, so that locally southerly dips occur. (2) The Quetico metasediments between the Opatica Belt and the Broadback River (Fig. 2) are multiply deformed. The earliest preserved structures in the metasediments are SE-dipping mylonites (with a SE-trending stretching lineation and a top-to-the-southeast shear sense) that dip under the Lac Rodayer Pluton and are correlated with D_2. The asymmetry of superimposed D_3 minor folds indicates that the S_2 mylonites have been folded to dip southwards on the flank of a D_3 antiform (Fig. 7). Removing the effects of D_3 folding suggests that the Lac Rodayer Pluton was thrust to the southeast over the southern edge of the Quetico metasediments during D_2 and that Quetico metasediments underlie part of the Lac Rodayer Pluton. Should the D_2 mylonites in the

Fig. 5. (a) Feldspar porphyroclasts with recrystallized tails parallel to S_{1a} foliation in grey gneisses, tails indicate sinistral shear sense on the horizontal plane; north to the top and scale in centimetres. (b) Photomicrograph of recrystallized quartz ribbon defining S_{1a}, note bulges due to grain boundary migration; scale bar is 0.5 mm. (c) L_{1a} stretching lineation consisting of biotite and hornblende aggregates trending to the west on subhorizontal S_{1a} planes in grey gneisses. (d) Photograph of an asymmetric mafic inclusion in grey gneiss, looking northwards at a vertical face parallel to the L_{1a} lineation, showing top-to-the-west shear sense; scale bar is 15 cm. (e) Tight to isoclinal folding of the S_{1a} in a compositionally layered tonalite gneiss, foliation in a sinistral strike-slip shear zone, the S_{1b} mylonite foliation is marked by trains of hornblende and plagioclase porphyroclasts in the upper left. (f) S_{1b} mylonites with hornblende porphyroclasts and sinistral shear bands; top-to-the-north. (g) Mafic layer in leucotonalite within the SSE-vergent D_2 Lac Rodayer Thrust showing top-to-the-southeast shear sense; outcrop face is subparallel to L_{2a}, north to the right. (h) Reoriented, SSE-vergent S_{2a} mylonites on the southern limb of the Southern Opatica Antiform, note top-down-to-the-south shear sense; north to the right. In this and Fig. 6, all scale rules are numbered in cm, unless otherwise stated.

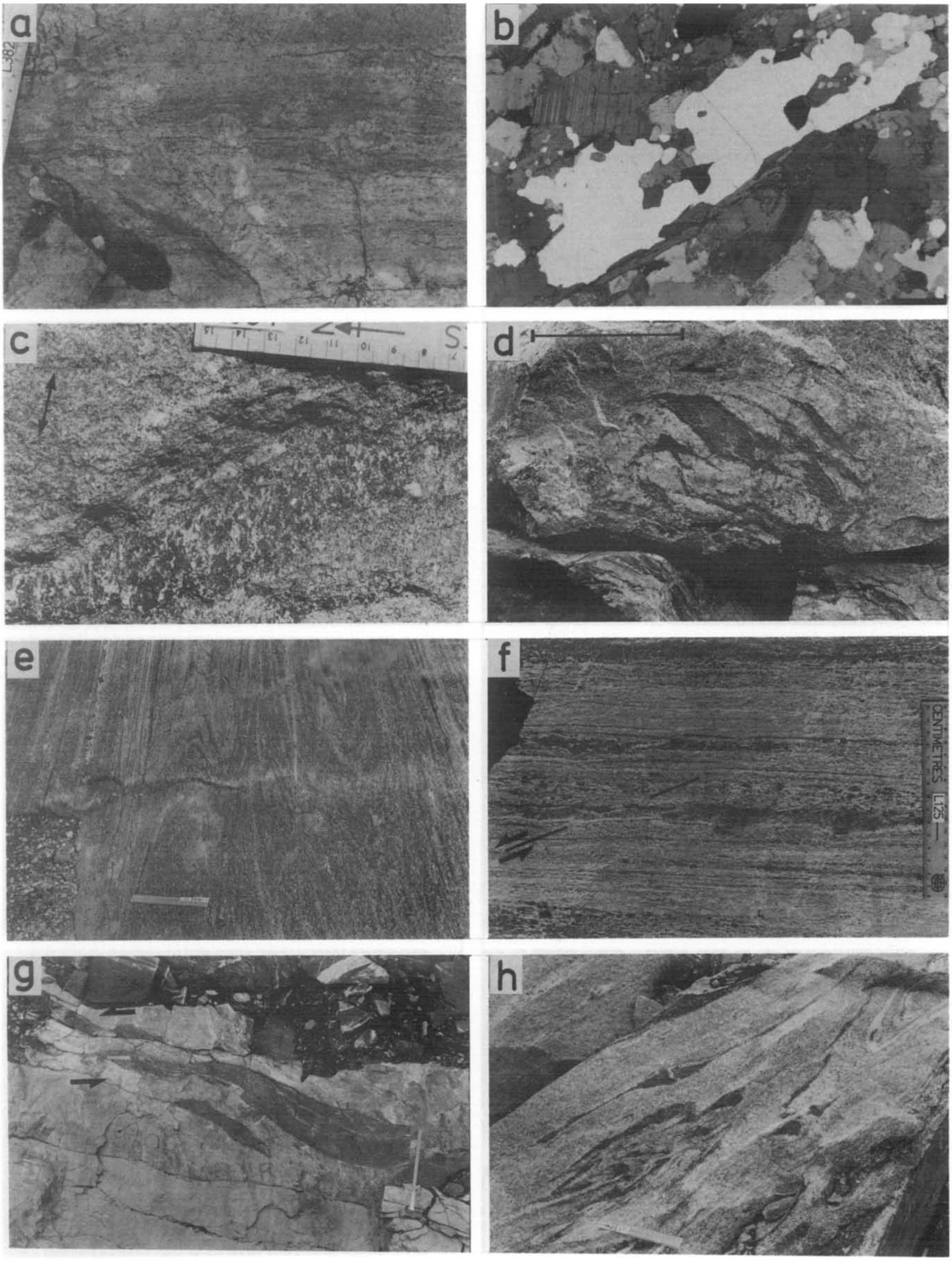

Fig. 5.

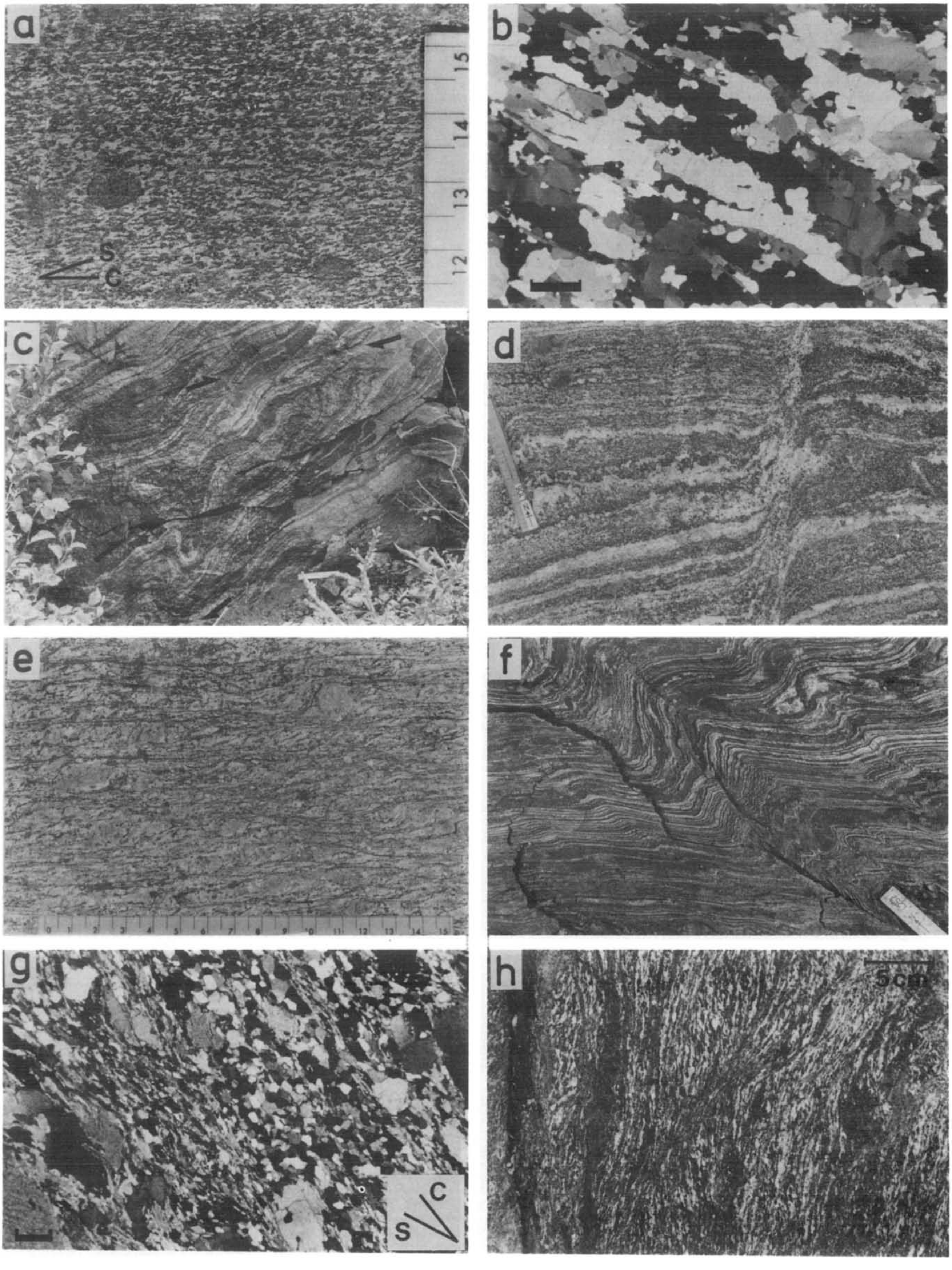

Fig. 6.

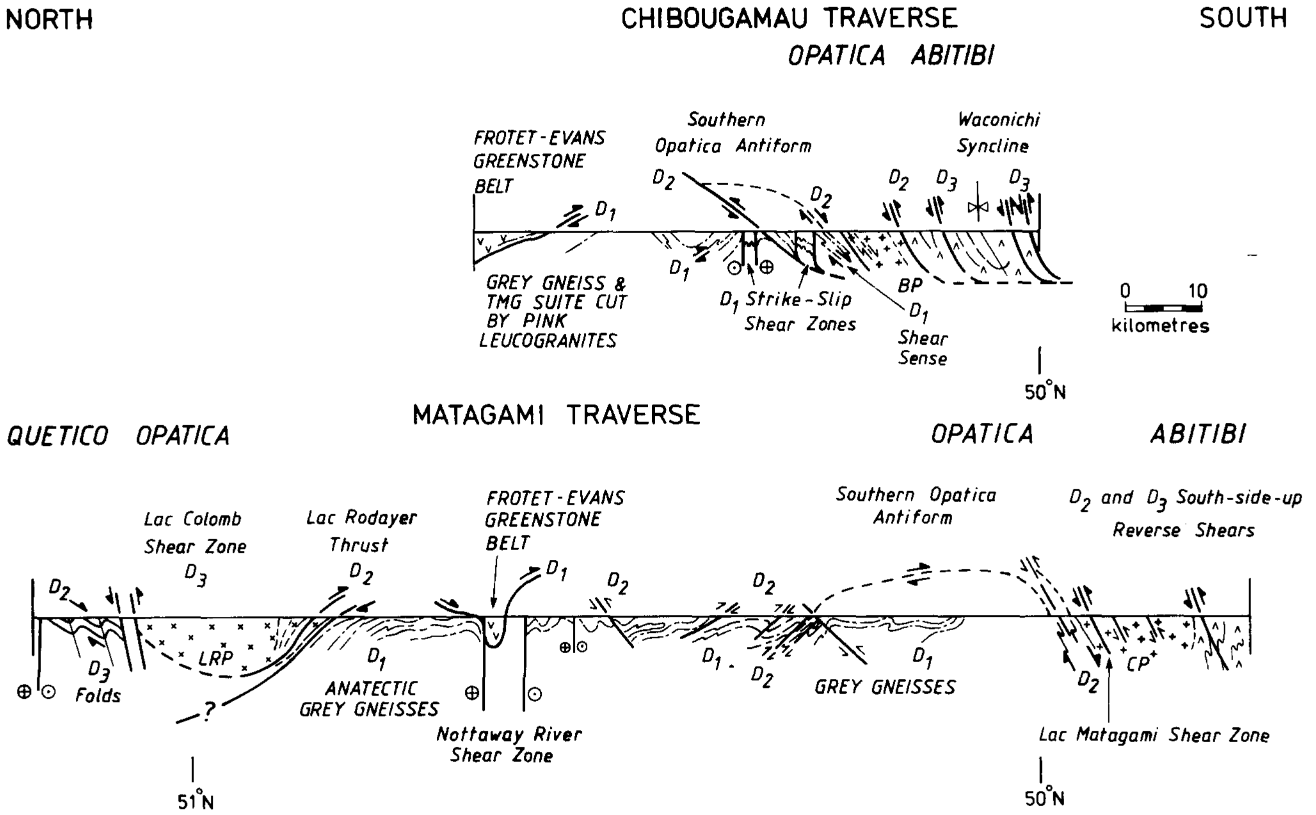

Fig. 7. Cross-sections for the Matagami and Chibougamau structural traverses; BP = Barlow Pluton, CP = Canet Pluton and LRP = Lac Rodayer Pluton. Heavy arrows refer to major structures and light arrows to minor structures.

Quetico metasediments join the D_2 Lac Rodayer thrust, then the Lac Rodayer Pluton is allochthonous to the Opatica Belt; this possibility will be tested by a LITHOPROBE seismic experiment in 1993.

The main region where initially NW-dipping D_2 structures have been reoriented is the southern Opatica Belt (Figs. 2, 3, 5h and 7). On all three traverses both the S_{1a} and S_{2a} foliations, and their associated kinematic indicators, have been rotated about a subhorizontal axis (Figs. 4a, f & k) to dip southwards immediately north of the Abitibi Subprovince in a broad, belt-scale F_2 antiform termed the Southern Opatica Antiform (SOA). Formerly SE-vergent reverse shear zones on the southern flank of the SOA are cut by SE-dipping NW-vergent reverse shears which, because they have the same SE-trending stretching lineation, are correlated with D_2 (Figs. 4f and 7). Similar SE-dipping D_2 reverse shears also occur on the north limb of the SOA, nearer to the centre of the Opatica Belt. However, those on the northern limb are deeper-level, ductile shear zones that contain anatectic melt, whereas the SE-dipping reverse shear zones on the south flank are shallower-level structures, generally with sharp boundaries, that contain lower amphibolite or greenschist facies assemblages.

The D_1 structures are preserved in the gneisses between D_2 thrusts, but they have small-scale D_2 structures superimposed upon them. The most widespread of these is a new steep northward-dipping biotite foliation (S_{2b}, Fig. 4c) present in the S_{1a} biotite folia, and also developed in pink leucogranite dykes, sills and plutons. In many outcrops the S_{1a} foliation has been deformed into SE-vergent F_2 minor folds (Fig. 6c). The fold axial planes (Fig. 4g) are parallel to the S_{2b} biotite orientation and to narrow subvertical E-trending strike-slip shears (Fig. 4h) on the fold limbs. The folds hinges are subparallel to the subhorizontal lineation (L_{2b}) on S_{2b}-parallel strike-slip shears, but are approximately perpendicular to the transport direction (L_{2a}) on D_2 thrusts. Locally, where NW-vergent D_2 thrusts are developed, minor, NW-vergent F_2 folds are present.

Fig. 6. (a) SE-dipping D_2 reverse shear zone in greenschist facies Abitibi Subprovince greenstones south of the Barlow Pluton, north to the top. (b) Photomicrograph of S_{2a} foliation in Opatica gneiss north of the Canet Pluton, note evidence of grain boundary migration; scale bar is 0.5 mm. (c) Southeastward-vergent F_2 folding of S_{1a} (lower part) and small SSE-vergent D_2 shears (upper part) in the grey gneisses on the north flank of the SAO; north to the left. (d) Ductile NNE-trending sinistral strike-slip shears containing anatectic leucosomes. (e) D_3, dextral *C–S* mylonite developed in pink anatectic leucogranite within the Nottaway River shear zone. (f) D_3 kink folds developed in Nottaway River shear zone mylonites. (g) Greenschist facies D_3, southside-up *C–S* mylonite in the Canet Pluton; top-left to bottom-right diagonal is vertical and scale bar is 0.3 mm. (h) Steeply dipping, greenschist facies reverse shears, part of a conjugate set with acute bisectrix vertical, Canet Pluton; north to the left.

D$_3$ *structures*

Many outcrops in the Opatica Belt contain subvertical strike-slip shear zones that are divided into three main sets: (1) sinistral NNE-trending (Figs 4d & o); (2) dextral E-trending (Fig. 4i); and (3) dextral SE-trending (Fig. 4e). Both the NNE- and E-trending sets formed during cooling of the Opatica; some examples are ductile shears containing anatectic leucogranite veins (Fig. 6d), and others in the same outcrops are brittle shears with slickensides, greenschist facies mineral assemblages and gouge.

The NNE- and E-trending shear zones are abundant in the Opatica (and adjacent subprovinces), but are typically decimetre- to metre-scale structures. In contrast the SE-trending dextral shear zones are fewer; the two largest (Fig. 1c), the Nottaway River shear zone (NRSZ) and the Lucky Strike River shear zone (LSRSZ), are up to 5 km wide and have dextral offsets of 20–50 km, based on the offset of magnetic anomaly patterns. The NRSZ curves to a more westerly strike at its northern end in the Quetico metasediments south of James Bay (Stott personal communication 1992) and is not, therefore, the southern continuation of the Winisk River fault as previously suggested by Card (1990) and Sawyer & Benn (1992). Both the NRSZ and the LSRSZ cross subprovince boundaries, and therefore post-date the D_2 assembly of the E-striking belts in the Superior Province.

Greenschist facies *C–S* mylonites (Fig. 6e) are developed where the NRSZ crosses pink anatectic granite; these give the same consistent dextral shear sense as late N-trending, quartz-filled tension gashes that form left-stepping arrays. Mylonites containing asymmetric porphyroclasts, boudins and folds are also developed where the NRSZ crosses the Frotet–Evans Greenstone Belt. There, all kinematic indicators are dextral and the stretching lineation subhorizontal (Fig. 4e), except near to the northern contact between the Frotet–Evans and Opatica Belts where less deformed pods of metavolcanics and metagabbro contain a steeper, W-plunging lineation (dashed field on Fig. 4e). The NRSZ mylonites developed in the Frotet–Evans Belt are locally deformed into sinistral kink-folds (Fig. 6f) that have a variably oriented axial planar crenulation cleavage (Fig. 4e). The folds are cut by small, subvertical, E-trending dextral strike-slip shear zones.

Steeply-dipping reverse shear zones are developed in the Opatica Belt near to its contact with the Abitibi Subprovince. A magmatic fabric, modified by superimposed crystal plastic strain locally preserved in the southern part of the Canet Pluton is dominated by post-solidification structures, such as a D_3 penetrative SW-plunging lineation in the rock and on S-dipping greenschist facies shear zones. Shear bands and *C–S* fabrics (Fig. 6g) in lower-amphibolite and greenschist facies D_3 mylonites indicate south-side-up movement.

The magmatic foliation in the Barlow Pluton (Fig. 3) has been almost completely overprinted by a penetrative D_2 solid-state deformation (SE-dipping foliation and SE-plunging lineation with south-side-down shear sense). The D_2 structures are overprinted by S-dipping greenschist facies D_3 shear zones that have south-side-up movement senses and SW-plunging lineations.

In the greenstones of the northern Abitibi Subprovince steeply southward-dipping reverse shears with SW-trending lineations (D_3) also overprint southerly-dipping reverse shears with southeasterly lineations (i.e. D_2 structures). Thus, some shear zones (e.g. Lac Matagami shear zone) have a later sinistral D_3 displacement superimposed on an earlier dextral D_2 shear sense. Both of these presently steeply-dipping sets of shears are cut by small-scale reverse (e.g. dip direction/value 225/10; 250/30) and normal shears with SSW- to W-trending lineations, the latter are numerous north of Chibougamau and in the Barlow Pluton. These late, flat-lying shears range from ductile to brittle and contain low-grade mineral assemblages.

The Lac Colomb shear zone consists of anastomosing D_3 mylonite zones (Fig. 4j) which have steep, southerly dips, SW-plunging stretching lineations and a south-side-up shear sense (shear bands, asymmetrical tails to porphyroclasts, offset quartz-veins). This shear zone is locally overprinted by small greenschist facies sinistral shear zones that dip steeply to the east-southeast (125/80) and subparallel to the axial planes of the F_3 folds that deform the S_{2a} mylonites in the southern Quetico (Fig. 7).

Small-scale, high-angle reverse D_3 shear zones (Fig. 6h) are ubiquitous in the Opatica Belt and form conjugate sets in which the acute bisector is vertical. These shear zones have easterly strikes and down-dip stretching lineations. In the Lac Rodayer Pluton the high-angle reverse shears are associated with narrow low-angle reverse shear zones. Both the high- and low-angle shears are greenschist facies mylonite zones less than 5 cm wide.

SYNTHESIS AND DISCUSSION OF THE STRUCTURAL HISTORY

Relationship between D$_1$ *and* D$_2$

Both D_1 and D_2 are characterized by shallow to moderately dipping foliations (S_{1a} and S_{2a}). Throughout the grey gneisses and the TMG suite the dominant stretching lineation (L_{1a}) has an ENE–WSW trend and a top-to-the-west-southwest shear sense. In contrast the main D_2 thrusts have a lineation with a NNW–SSE trend. Thus, D_1 and D_2 structures record translation directions that differ by 90°.

The styles of deformation also differ. The D_1 fabrics (e.g. S_{1a}) record a very penetrative, high-temperature deformation and recrystallization in the grey gneisses and TMG suite rocks. This uniformity of S_{1a} is similar to the homogeneous foliation type described as characteristic of the high-temperature deformation of granites, and of syntectonic plutons by Gapais (1989). This analogy suggests that the crust was already hot when D_1 began in the Opatica Belt; deformation may have occurred deep in the crust, or was synchronous with extensive plutonism. Thus, it is inferred that D_1 structures record deformation in a SW-vergent, crustal-scale shear zone; the Opatica gneisses represent the ductile mid-crustal levels where temperatures were high, and the Frotet–Evans Belt represents shallower, and therefore cooler, crustal levels. A D_1 thrust in the Opatica gneisses has been recognized west of the Lac Ouescapis pluton (Fig. 2). Crustal-scale, Archaean ductile shearing has been described from Greenland (Bridgewater *et al.* 1974) and southern Africa (Coward 1980).

In comparison the S_{2a} foliation is not pervasive, but is confined to relatively narrow (up to several km wide) shear zones in the Opatica gneisses. The D_2 microstructures indicate a more complex relationship between deformation and temperature than for D_1. The Opatica gneiss north of the Canet Pluton contains garnet porphyroblasts with D_2 tails, suggesting that shearing was post-metamorphic. In the central Opatica Belt SE-vergent D_2 thrusts have well annealed textures and are cut by pink granite dykes which are in turn truncated by later D_2 shears—suggesting that these D_2 shears formed near to the peak metamorphic temperatures. Farther north, the Lac Rodayer thrust is a post-metamorphic D_2 thrust that truncates post-D_1 anatectic structures in the footwall and places lower grade rocks onto higher grade ones.

From the field evidence D_1 structures pre-date D_2 and differ in their transport directions and styles of deformation, but it is uncertain whether they should be viewed as: (a) two separate events; or (b) as part of a single rapidly evolving event in which, perhaps, longitudinal shearing was dominant throughout much of the crust when the crust was hot, but that transverse shearing became more important as the crust cooled. U–Pb dating will determine the time interval between D_1 and D_2, and whether either is diachronous across the Opatica Belt.

Origin of D$_1$ *strike-slip shear zones*

The S_{1b} subvertical, sinistral strike-slip shears in the eastern Opatica and Frotet–Evans belts have stretching lineations (L_{1b} that are subparallel to the trend of L_{1a} on S_{1a} planes. Geometrically, the shears may be similar to lateral ramps, or transfer faults, relative to D_1 thrusts. If, during D_1 thrusting the movement direction was oblique (i.e. subparallel) to the present belt boundaries, and thrust propagation at the southern boundary slowed, then displacement may then have transferred from thrusting to strike-slip motion on subvertical planes parallel to the orogen (shear zone) boundaries. Continued oblique convergence north of the strike-slip shears then folded S_{1a} into serial fold trains that were later rotated into parallelism with, and incorporated into, the widening strike-slip shears (Fig. 8).

D$_2$ *thrusting and the Southern Opatica Antiform*

The broad Southern Opatica Antiform (SOA) is a late D_2 structure because, although S_{1a} and SE-vergent S_{2a} thrusts are folded, both limbs of the SOA are cut by late D_2 shears with the same lineation trend (Figs. 4f, 7 and 9). The Opatica gneisses, the MGTD suite plutons and the northernmost Abitibi Subprovince metabasites are deformed by SE-dipping D_2 and D_3 reverse shears, such as the Barlow Fault on the northern edge of the Waconichi Syncline (Fig. 3) and the Lac Matagami shear zone. Thus the MGTD suite and the northern Abitibi Subprovince has been displaced northwards over the Opatica Belt in a movement sense contrary to the principal D_2 transport direction in the higher grade and presumably deeper-level Opatica Belt rocks. Because of its unique size and location between opposing thrust directions the SOA is interpreted as either: (1) a ramp anticline (culmination in the terminology of Dahlstrom 1970); or (2) an antiformal stack. The SE-dipping D_2 reverse shears formed at the frontal culmination wall of the SOA can be regarded as backthrusts in the sense of Monger & Price (1979). The detailed geometry of the SOA at depth is not known, but will be examined in a LITHOPROBE seismic reflection study.

The SE-dipping D_2 shear zones on the northern limb of the SOA are associated with NW-vergent, small-scale folds. The folds nearest to SOA axis have small forelimb shears and curved axial surfaces that steepen from 10° to 40°. The axial planes and forelimb shears both dip more steeply (70°) farther north. Thus, D_2 backthrusts are shown to steepen in the transport direction on Fig. 9. The overall structural pattern on the north limb of the SOA is comparable to the development of backthrusts (Butler 1982, Cooper & Trayner 1986) in the dorsal culmination wall above a footwall ramp. Similar structures are also present on the north limb of the SOA on the Chibougamau traverse, but a much larger D_2 backthrust developed there (Fig. 7).

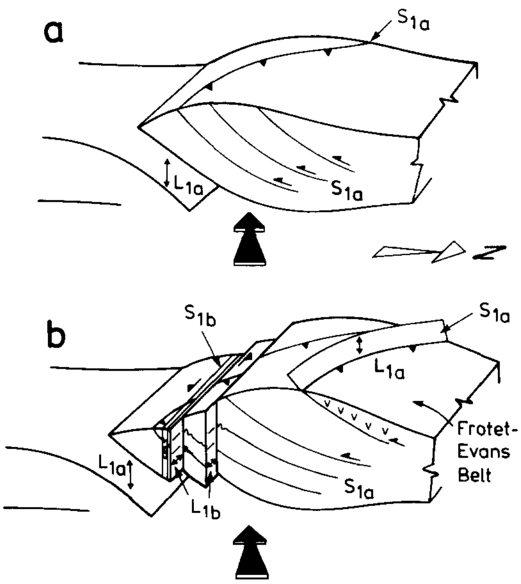

Fig. 8. Schematic diagram for D_1 WSW-vergent (parallel to L_{1a}) crustal-scale, ductile shearing on S_{1a} planes. (a) Crustal thickening; thrust surfaces are assumed to be present on the basis of zones of higher D_1 strain, e.g. the D_1 mylonites. (b) The development of E-trending sinistral strike-slip shears (S_{1b} and L_{1b}) when the southern edge of the Opatica Belt can no longer move forwards. Note Frotet–Evans Belt is the highest thrust sheet.

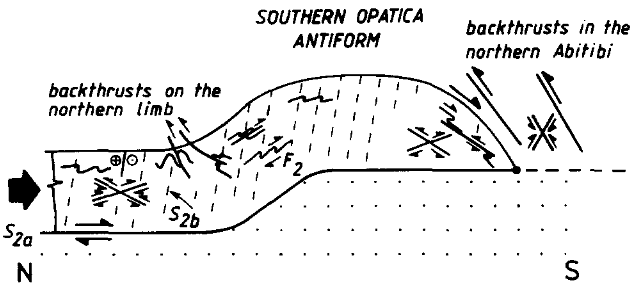

Fig. 9. Sketch showing structures associated with the Southern Opatica Antiform (shown as a ramp antiform for simplicity). Major shears in the high-grade Opatica Belt have top to the south shear sense, but those in the low-grade metavolcanics of the northern Abitibi have top-to-the-north shear senses (backthrusts). Minor structures associated with layer-parallel shortening in the Opatica Belt include the N-dipping biotite foliation (S_{2b}), dextral strike-slip shears and conjugate dip-slip shear sets. Backthrusts in the Opatica Belt occur on the dorsal wall, and are associated with N-vergent minor folds.

D_2 *layer-parallel shortening*

In most thrust belts a portion of the strain is accommodated as ductile deformation within the thrust sheets (Cooper & Trayner 1986, Geiser 1988). The widely developed small-scale structures found in the Opatica gneisses between D_2 thrust planes, the upright F_2 folds with axial planar S_{2b} foliation, and the conjugate sets of reverse shears (Fig. 9), all have orientations consistent with layer-parallel shortening of D_2 thrust sheets. Since the Lac Rodayer thrust is affected by folds, broadly coplanar with S_{2b}, some layer-parallel shortening post-dates D_2 thrusting. Typically these structures formed during metamorphic cooling and belong to the D_3 late-stage transpression.

D_3 *late-stage transpression*

Metamorphic temperatures declined after D_2 thrusting and subsequent deformation (D_3) was localized into subvertical, greenschist facies shear zones characterized by *C–S* mylonites. The principal D_3 structures, sinistral NNE- and dextral SE-trending strike-slip shears (Fig. 10) are interpreted as conjugate sets. Thus, the D_3 shortening direction is inferred to have been approximately NNW-SSE oriented; i.e. subparallel to the D_2 transport direction and similar to the late Archaean compression direction found in much of the Superior Province (Park 1981, Sawyer, 1983, Dimroth *et al.* 1986, Borradaile *et al.* 1988, Hudleston *et al.* 1988). Outside the major shear zones, post-D_2 shortening in the Opatica Belt resulted in some crustal thickening on conjugate sets of steeply-dipping reverse shears and minor low-angle reverse shears (Fig. 10), and locally upright folding. Large, south-side-up, high-angle reverse shears at the Opatica Belt margins and in the northern Abitibi Subprovince are also consistent with D_3 shortening.

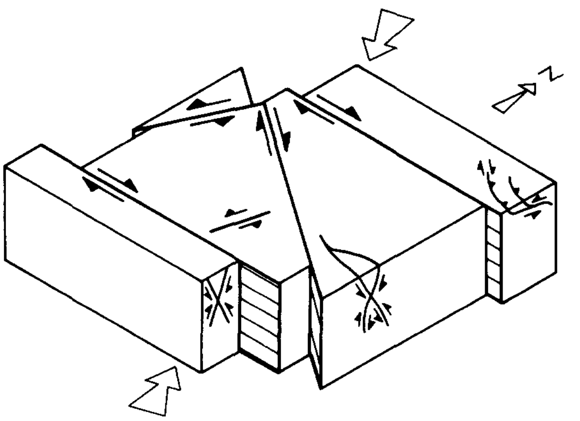

Fig. 10. Block diagram of the structures associated with D_3 transpression. Sinistral NNE-trending, dextral SE-trending and dextral E-trending strike-slip shear sets. Small-scale structures include conjugate dip-slip shear sets with their acute bisector vertical, and low-angle reverse shears in the north.

East-striking dextral strike-slip shears are common in the Opatica Belt and formed during D_2 (ductile) and D_3 (brittle–ductile and brittle, Fig. 4i). Thus, a component of NNW–SSE compression was accommodated on local belt-parallel shears in the Opatica Belt, as in the Abitibi (Robert 1989) and the southern Superior Province (Hudleston *et al.* 1988).

The sinistral kinking of the NRSZ mylonites may indicate a reorientation of the stress field with respect to the mylonite foliation such that the deformation temporarily became transtensional (e.g. Williams & Price 1990).

The D_3 deformation includes NNW–SSE compression and dextral strike-slip shearing (Fig. 10), compatible with the late phase of dextral transpression proposed for the western and southern Superior Province (Stott *et al.* 1987, Borradaile *et al.* 1988, Hudleston *et al.* 1988, Bauer & Bidwell 1990).

IMPLICATIONS FOR SUPERIOR PROVINCE

Some of the earlier models to explain Archaean structural patterns (e.g. Anhaeusser *et al.* 1968, Mareschal & West 1980) assumed a greenstone sequence over a granitic crust into which it sank, creating synclinal keels. However, geochemical (Barnes 1985) and isotopic (Dupré & Arndt 1990) studies of Abitibi komatiites found no evidence of crustal contamination, suggesting that the komatiites did not form on a continental crust. Recent potential field (Keating *et al.* 1990) and heat flow measurements (Pinet *et al.* 1991) indicate a very thin (<10 km) greenstone layer over a tonalite crust in the Abitibi Subprovince. Then, how did the greenstones come to overlie the tonalites? The addition of tonalite to the underside of greenstone belts has been proposed for the Archaean crust in general (Holland & Lambert 1975), and the Superior Province in particular (Percival & Card 1983, Corfu, 1987). Alternatively, structural (Blackburn *et al.* 1985, Schwerdtner 1990) and geochronological evidence (Davis *et al.* 1988) has been put forward to support an allochthonous origin for some greenstone belt sequences. This section examines whether the greenstone belt sequences adjacent to the Opatica Belt are allochthonous and whether the high-grade Opatica Belt and low-grade Abitibi Subprovince are different parts of an Archaean mountain belt.

Allochthonous greenstone belts

The D_1 stretching lineation and SW-transport direction in the eastern Opatica Belt are similar to those in amphibolite facies mafic mylonites at the southeastern edge of the Frotet–Evans Belt (Fig. 3). North of Matagami the contact between the Opatica and Frotet–Evans belts is obscured by the NRSZ, but restoration of the steeply-dipping foliation preserved in the pods of foliated gabbro at the northern edge of the NRSZ to a gentle northerly dip, brings their associated steep lineation to a NE-trend similar to that on the Broadback (Benn *et al.* 1992) and Chibougamau traverses. This establishes that there is a regionally consistent lineation in the higher-grade parts of the Frotet–Evans belt and that it corresponds to L_{1a} in the Opatica Belt; i.e. the Frotet-Evans belt was involved in D_1 thrusting.

Lineations with W–E to SW–NE trends (i.e. L_{1a} of this work) were first recognized in the Opatica Belt (Sawyer & Benn 1992, Benn *et al.* 1992, and this work), but have now been found over a much wider area. (1) In granulite facies Quetico metasediments between the Broadback and Rupert rivers (Fig. 2). (2) In the Abitibi Subprovince at longitude 79°W (Lacroix & Sawyer work in preparation) from amphibolite facies metabasalts at the contact with the Opatica Belt. (3) In amphibolite facies metasediments and gneisses from the Pontiac Subprovince (Benn work in preparation). From these observations it is inferred that W-vergent thrusting has affected a large part of the southeast Superior Province, including the Abitibi greenstone belt. Because penetrative D_1 fabrics are developed only in the high-grade rocks at the base of the Abitibi and Frotet–Evans greenstone belts, we conclude that both greenstone belts were transported onto tonalitic gneisses (as shown by Hocq 1990) as the uppermost D_1 thrust sheets. The lack of penetrative D_1 structures in the extensive low-grade volcanic and plutonic rock portions of the greenstone belt sheets could indicate that these parts behaved competently during translation above a ductile base. Some penetrative D_1 structures may be preserved in the less competent units.

Pre-schistosity (i.e. pre-D_2) folds (e.g. Lac Caché Synform) have been recognized in the Chibougamau area, and ascribed to "sinking of the crust under its own weight" (Daigneault *et al.* 1990). An alternative explanation is that these N-trending W-vergent open folds represent flexures of the greenstone sheet during westwards D_1 translation of the Abitibi greenstones. Subsequently these folds underwent solid-body tilting on E-trending listric D_2 shears, to give them their present northward plunges.

Different crustal levels through an Archaean mountain belt

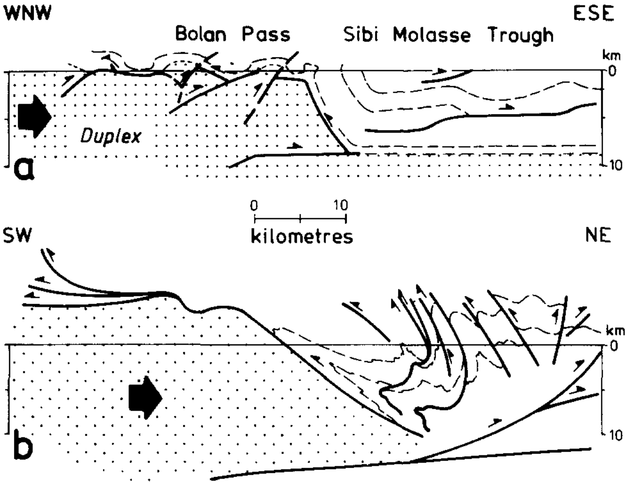

Fig. 11. Examples of Phanerozoic mountain fronts for comparison with the Opatica Belt–Abitibi Subprovince contact. (a) Kirthar thrust belt Pakistan (simplified from Banks & Warburton 1986); Jurassic to Palaeocene duplex (dotted pattern) of the Bolan Pass wedging under the Sibi Mollase Trough, note out-of-syncline thrusts. (b) Selkirk fan structure (simplified from Price 1986); note backthrusting and backfolding of out-of-syncline thrusts above and ahead of the wedge (dotted pattern).

A major reversal of D_2 structural vergence takes place across the Opatica Belt–Abitibi Subprovince contact, coincident with the juxtaposition of high-grade mid-crustal gneisses against low-grade uppercrustal greenstones. This pattern is very similar to that of Phanerozoic mountain fronts, such as the Kirthar (Fig. 11a) and Sulaimen ranges of Pakistan (Banks & Warburton 1986). In particular, it resembles the change in thrusting from NE-vergent to SW-vergent across the Selkirk fan structure in the Cordillera (Fig. 11b), where cross-cutting relationships indicate that both sets of thrusts were, in part, synchronous (Price *et al.* 1981, Price 1986). Which structural model is adopted depends upon how far under the northern Abitibi Subprovince the Opatica Belt-like structures extend. In the simplest interpretation, the southwards-advancing leading edge of the Opatica Belt wedged into the Abitibi Subprovince at the base of the greenstones and produced a structural pattern referred to as "flake tectonics" by Oxburgh (1972, 1974) or "tectonic wedging" by Price (1986). In this model the leading edge of the Opatica Belt is thickened by one or more imbricates which create the SOA, and the northern Abitibi greenstones are obducted onto the Opatica Belt along SE-dipping reverse shears acting as passive backthrusts (Fig. 12a). The seismic expressions of tectonic wedging are the distinctive 'crocodile structures' characteristic of parts of the Alps (Meissner 1989, personal communication 1991).

However, if the SOA is a culmination, or more likely an antiformal stack, then the overall D_2 geometry of the Opatica Belt and the northern Abitibi Subprovince resembles many Phanerozoic thrust belts. Comparing the Opatica Belt with thrust belts that contain deeper crustal rocks in a foreland dipping panel, such as the Cordillera (Mattauer *et al.* 1983), particularly the Omineca Belt (Brown *et al.* 1986), the Alps (Boyer & Elliott 1982), the Pyrenees (Vann *et al.* 1986) and the Variscan (Le Gall 1992), indicates that a southward-vergent foreland fold and thrust belt could lie to the south of the SOA, i.e. in the northern Abitibi. To support such an analogy it must be shown that: (1) Opatica gneisses floor a large part of the Abitibi Subprovince; (2) the mid- to deep-crustal structure under the Abitibi contains S-vergent imbricates and/or a N-dipping sole thrust; and (3) that the structures in the greenstone belts are consistent with S-directed D_2 thrusting.

High-grade leucotonalitic gneisses similar to the Opatica gneisses occur as windows in the northern Abitibi Subprovince that extend up to 70 km south of the Opatica Belt. The Lapparent Massif (Chown & Mueller 1992) southwest of Chibougamau, is an example; its southern contact is a N-dipping mylonite zone placing gneisses southwards on to Abitibi greenstones.

LITHOPROBE line 28 (along longitude 79.5°W) in the Abitibi Subprovince shows that the mid-crust beneath the central Abitibi is dominated by gently N-dipping reflectors that are interpreted as southward-vergent imbricates by Hubert *et al.* (1992); this resembles the structural pattern reported here for the Optica Belt. Furthermore, there is a 120 km long reflector dipping at 13° to the north below the imbricates, which is interpreted to be the sole to the Opatica crustal wedge under the Abitibi.

Keating *et al.* (1990) have deduced from the Bouger gravity anomaly pattern south of Chibougamau that the supracrustal units form a tapering sheet that thickens to 5 km in the north. As the contacts between many of the units are D_2 thrusts (see Daigneault *et al.* 1990) these may also be shallow and dip northwards, i.e. consistent with a southward-vergent D_2 fold and thrust belt in the low-grade rocks of the Abitibi Subprovince.

A mountain belt model is summarized in Fig. 12. D_2 shortening in the Opatica Belt produced a SSE-vergent D_2 ductile thrusting at mid-crustal levels which deformed an earlier D_1 imbricate stack. Imbrication of D_2 thrusts in the Opatica Belt gneisses formed a large antiformal stack (SOA) which propagated southeastwards under the northern edge of the Abitibi Subprovince and deformed the cover into a shallow syncline that is the early Waconichi Syncline (Fig. 12b). Backthrusts developed at the northern edge of the syncline and shallow out-of-syncline thrusts (K) propagated southwards within the greenstone belt sequence in a manner similar to many younger mountain fronts (Fig. 11a). The SOA further underthrust the northern Abitibi as the thrust tip located at the southern edge of the SOA propagated southwards; this tightened the Waconichi Syncline in the cover sequence, formed numerous backthrusts and backfolded the out-of-syncline thrusts (e.g. Lac Sauvage and Kapunapotagen faults of Daigneault *et al.* 1990) in a process analogous to the formation of the Selkirk fan structure (Fig. 11b) in the Cordillera (Price 1986). After the thrust transporting the SOA became inactive, further D_2 shortening in the Opatica gneiss beneath the Abitibi Subprovince stepped progressively southwards on younger thrusts (Fig. 12c) creating a tapering wedge of imbricates under the Abitibi Subprovince. The response in the low-grade, upper crustal rocks to shortening in the mid-crust was to develop a S-vergent fold and thrust belt in the Abitibi greenstones, that was locally back-steepened by the growth of the mid-crustal imbricates described by Hubert *et al.* (1992). Thus, the high-grade Opatica Belt and the low-grade Abitibi Subprovince represent different parts of an Archaean mountain belt.

Most SE-vergent D_2 thrusting in the Opatica gneisses are thought to be in-sequence. However, the Lac

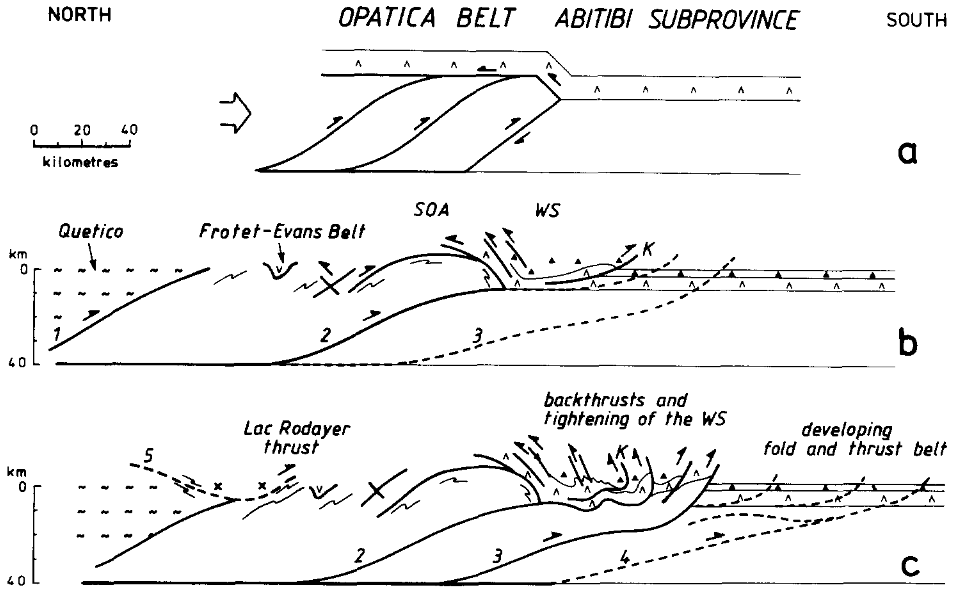

Fig. 12. (a) Simple wedging of a thickened Opatica Belt under the northern Abitibi Subprovince to produce a crocodile structure. (b) & (c) Thrust belt model. (b) Early D_2 imbrication of the Opatica Belt on SSE-vergent thrusts. The antiformal stack in the southern Opatica Belt (Southern Opatica Antiform, SOA) begins to underthrust the northern Abitibi Subprovince and forms the Waconichi Syncline (WS) and associated backthrusts and out-of-syncline thrusts (K). Dotted lines show a crustal wedge of imbricate thrust slices developing to the south. (c) Late D_2, the Waconichi Syncline is tightened and out-of-syncline thrusts are backfolded above mid-crustal imbricates carried on deeper, SSE-propagating thrusts. Dotted lines show final sole thrust. Structure south of the Waconichi Syncline is constrained by LITHOPROBE line 28. The inverted-V and triangle pattern in the Abitibi supracrustal rocks is a schematic subdivision into an upper and lower part, and does not refer to any actual stratigraphic subdivisions. Sequence of thrusting is shown 1–5.

Rodayer thrust is interpreted as out-of-sequence (Morley 1988) because it cuts down-section to place amphibolite facies tonalites onto 100 Ma younger, but higher-grade leucotonalites. The Lac Rodayer thrust sheet may have travelled 75 km, since rocks of similar age (*ca* 2.8 Ga) are not known from the Quetico (<2705 Ma), but are reported from the La Grande Belt north of the Quetico by Card (1990). A final stage of D_3 transpression post-dates the major thrusting in both the Abitibi Subprovince and the Opatica Belt.

Predictions and tests of the model

The proposed model (Fig. 12) predicts that under the northern Abitibi greenstones, and within the whole Opatica Belt, there should be N-dipping imbricates that root either in a deep sole thrust, or at the Moho. This pattern differs from that predicted by a model of craton growth by intra- or underplating of tonalite (or more mafic) magmas—these should give an overall subhorizontal crustal structure. These end-member models can be evaluated when a 250 km-long LITHOPROBE seismic reflection profile across the northern Abitibi and Opatica Belt along traverse A (Figs. 1c and 2) is completed in late 1993. Future LITHOPROBE seismic sections across high-grade gneiss and low-grade greenstone belts (e.g. Winnipeg River–Wabigoon Subprovince contact) will serve to test the general applicability of the model to other parts of the Superior Province.

Cross-sections from Phanerozoic mountain belts (e.g. Coward & Butler 1985) show that the interior regions contain deeper (i.e. older) stratigraphic units than the foreland. In many Archaean terrains a well-defined stratigraphy cannot be traced for long distances across strike. Nevertheless, an approximation of depth within the crust can be made by examining the metamorphic pressure and temperatures recorded across the Abitibi Subprovince and Opatica Belts (work in progress). Dating of metamorphic minerals can be used to constrain the metamorphic cooling T–t path, and the unroofing history compared to those of Phanerozic mountain belts.

The southward propagation of thrusting in the middle and upper crust can be tested by the dating of shear zones and synthrusting plutons. Perhaps the clearest test for southward propagation can come from dating syntectonic sediments, such as cycles 2, 3 and 4 of Mueller & Donaldson (1992).

CONCLUSIONS

Two phases of Archaean ductile thrusting are recorded in the high-grade metaplutonic gneisses of the Opatica Belt and in the adjacent greenstone belts. D_1 is a newly recognized WSW-vergent, high-temperature, crustal-scale thrusting during which the greenstone belts were emplaced on the gneisses as the uppermost thrust sheets. The D_2 structural pattern compares favourably with many features of Phanerozoic mountain belts. The high-grade Opatica Belt is interpreted as the internal part of a thrust belt, imbricated by SSE-vergent thrusts to form a crustal wedge that propagated under the low-grade Abitibi greenstone belt—which is then interpreted as a foreland fold and thrust belt. The Opatica Belt–Abitibi Subprovince contact resembles a mountain front where a southwards-dipping frontal wall of a culmination, or antiformal stack, has moved southwards under the northern edge of the Abitibi Subprovince and created a zone of backthrusting and tight synclines in the low-grade greenstone cover. Consequently the Opatica Belt and the Abitibi Subprovince are viewed as different crustal and structural levels across an Archaean mountain belt.

This paper presents a framework, testable from field and deep seismic reflection profiles, for interpreting the relationships between adjacent, parallel belts of contrasting metamorphic grade, structural style and rock type that characterize the Archaean cratons.

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