Stratigraphy and structural geology of the Rice Lake mine trend, Rice Lake greenstone belt, Manitoba

S.D. Anderson
Manitoba Geological Survey
scott.anderson@gov.mb.ca

Introduction

The Rice Lake mine trend is located 155 km northeast of Winnipeg, Manitoba, in the central portion of the Archean Rice Lake greenstone belt of the western Superior Province.

With total production of nearly 1.6 million ounces of gold, and current reserves and resources of 3.4 million ounces in six deposits, the Rice Lake mine trend is the most significant lode-gold camp in Manitoba and is currently the focus of intensive exploration and mining activity by San Gold Corporation.

The trend is hosted by a north-younging stratigraphic succession of ca. 2.72 Ga volcaniclastic, effusive volcanic, subvolcanic intrusive and derived epiclastic rocks of the Neoarchean (2.745–2.715 Ga) Bidou assemblage, and includes several significant gold deposits, the largest of which is the San Antonio/Rice Lake deposit at Bissett.

Gold deposits in the trend consist of auriferous quartz vein systems associated with brittle-ductile shear zones and cogenetic arrays of shear and tensile fractures. These structures preferentially formed within chemically favourable or competent rock types, or along strength-anisotropies, during regional deformation under mid-crustal (greenschist-facies) metamorphic conditions.

During a four-week campaign in August 2011, the geology and structure of a roughly 6 km² area north and northeast of Rice Lake were mapped in detail (1:5000 scale) for the purpose of producing a comprehensive and up-to-date map of the entire mine trend at a scale suitable for detailed modelling of the contained gold deposits.

This poster summarizes the preliminary results of this work. For more detailed information, the interested reader is referred to reports GS-10 and GS-11 in the Manitoba Geological Survey Report of Activities 2011.

Regional setting

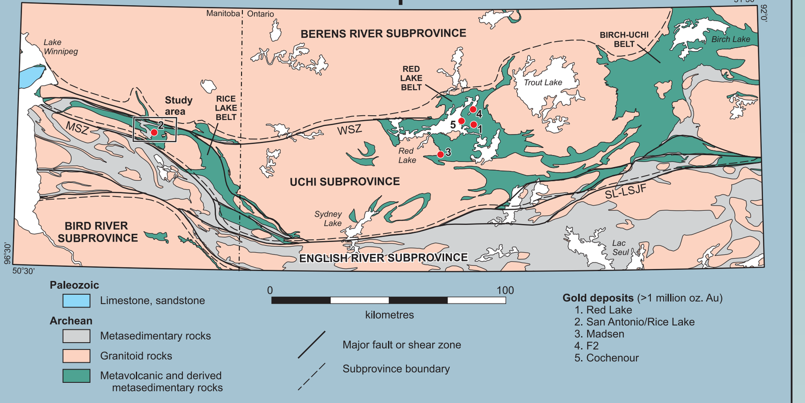
The Rice Lake greenstone belt comprises Neoarchean and Mesoarchean supracrustal rocks and associated intrusions that define the westernmost segment of the volcano-plutonic Uchi Subprovince of the western Superior Province. In Manitoba, the Uchi Subprovince is flanked to the north by the metaplutonic Berens River Subprovince and to the south by metasedimentary rocks and derived gneiss, migmatite and granitoid plutonic rocks of the English River Subprovince. The Berens River Subprovince and the Mesoarchean portions of the Uchi Subprovince constitute the continental 'North Caribou Terrane' (NCT), which is regarded as the protocratonic nucleus of the western Superior Province.

The Rice Lake belt is interpreted to record back-arc, arc and arc-rift magmatism and synorogenic sedimentation within a north-verging subduction-accretion complex that developed over a span of roughly 50 m.y. along the NCT margin. The greenstone belt is structurally bounded by regional-scale shear zones, which include the Wanipigow Shear Zone (WSZ) on the north and the Manigotagan Shear Zone on the south. Both of these structures are interpreted to record long-lived crustal-scale 'breaks' of the type associated with major orogenic gold districts in other Archean greenstone belts. In the Rice Lake area, major subsidiary structures to the WSZ include the Gold Creek, Normandy Creek and Red Rice Lake shear zones.

South of the WSZ at Rice Lake, the Rice Lake greenstone belt comprises two distinct supracrustal successions. The Bidou assemblage consists of an upright homoclinal succession of subaqueously deposited, ca. 2.745–2.715 Ga, intermediate to felsic volcaniclastic and epiclastic rocks, subordinate mafic flows and volcaniclastic rocks, and associated subvolcanic intrusive rocks. In the Rice Lake area, these rocks are divided for descriptive purposes into four lithostratigraphic units, each of which is characterized by distinctive associations of rock types. U-Pb zircon ages and geochemical signatures. These units trend generally west, dip consistently to the north and are informally termed, from south to north, the Independence Lake (IL), Rainy Lake road (RLR), Townsite (TS) and Round Lake (RL) units. Geochemical signatures indicate a systematic variation in basalt chemistry from Fe-tholeiitic (MORB-like) near the base of the succession to evolved calcalkalic (arc like) near the top, which is interpreted to indicate an extensional eruptive setting within a volcanic arc. Contact relationships and younging criteria indicate that these units define a stratigraphic succession.

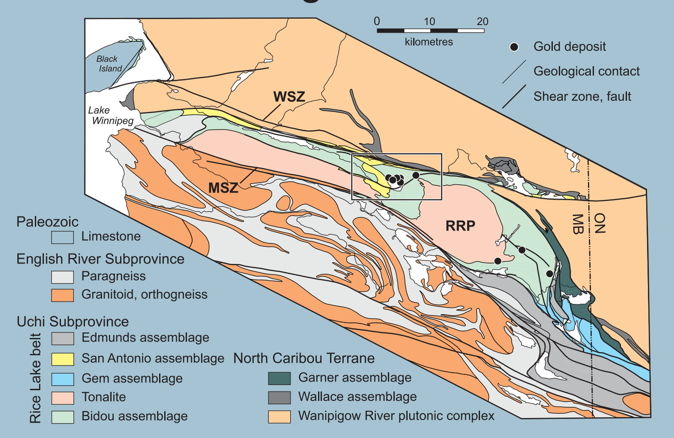
The Bidou assemblage is intruded in its lower portions by synvolcanic tonalite-granodiorite plutons of the ca. 2.725–2.715 Ga Ross River plutonic suite, and all of these rocks are unconformably overlain by terrestrial and marine siliciclastic rocks of the San Antonio assemblage, which has a maximum depositional age of ca. 2.705 Ga and was deposited shortly after cessation of major volcanism.

Uchi Subprovince



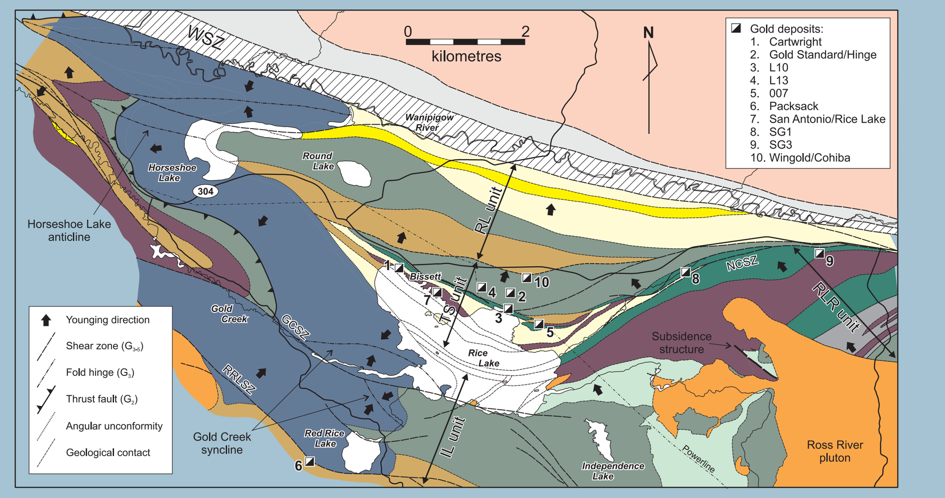
Regional geological setting of the Rice Lake greenstone belt in the western Uchi Subprovince, showing the locations of the major gold deposits. Abbreviations: MSZ, Manigotagan Shear Zone; SL-LSJF, Sydney Lake - Lake St. Joseph Fault; WSZ, Wanipigow Shear Zone.

Rice Lake greenstone belt

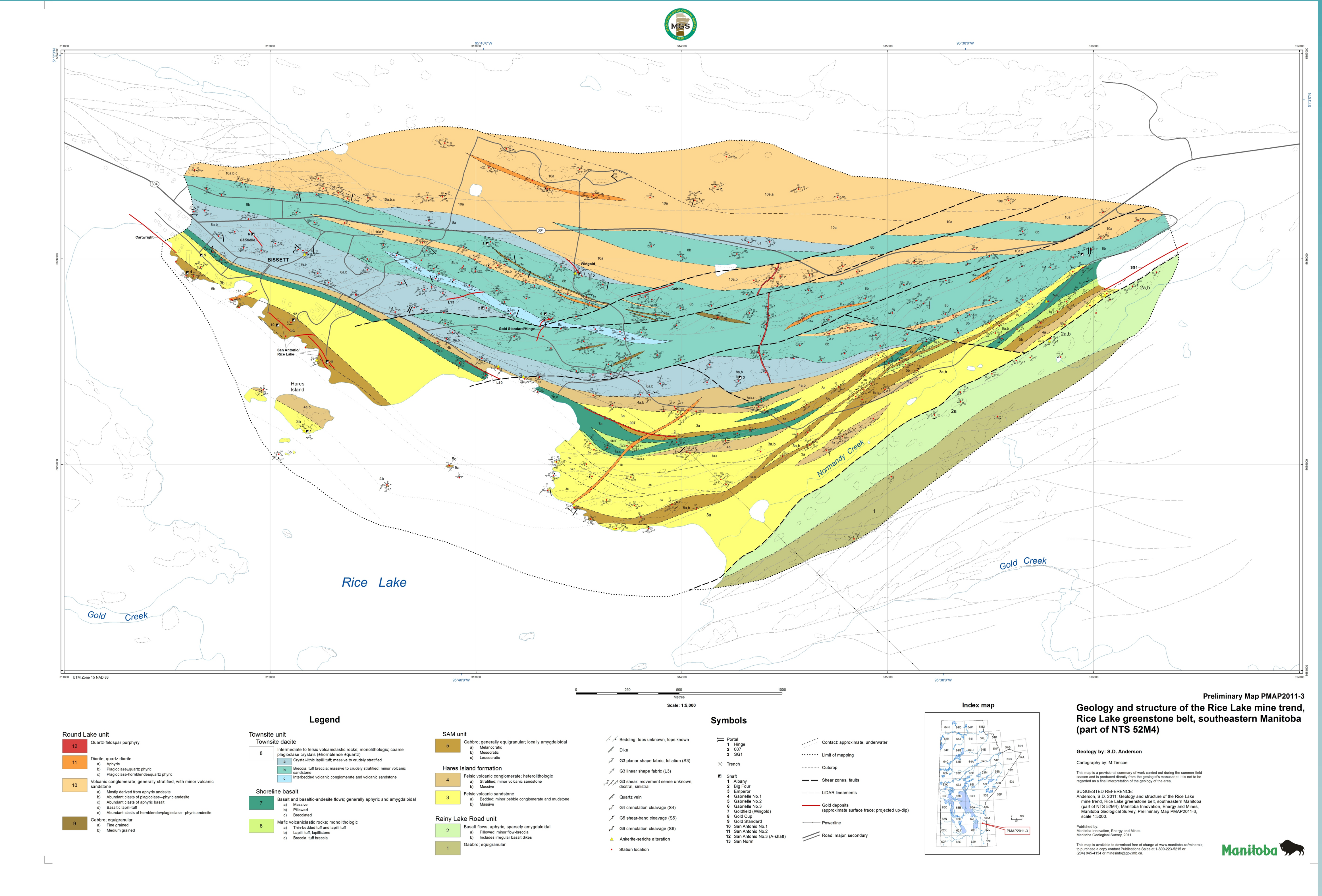


Simplified geology of the Rice Lake belt, showing the principal lithotectonic assemblages, major gold deposits and location of the study area. Abbreviations: MSZ, Manigotagan Shear Zone; RRP, Ross River pluton; WSZ, Wanipigow Shear Zone.

Rice Lake area



Simplified geology of the Rice Lake area, showing the locations of the Independence Lake (IL), Rainy Lake road (RLR), Townsite (TS) and Round Lake (RL) units of the Bidou assemblage, and the major gold deposits. Abbreviations: GCSZ, Gold Creek Shear Zone; NCSZ, Normandy Creek Shear Zone; RRLSZ, Red Rice Lake Shear Zone; WSZ, Wanipigow Shear Zone (indicated by hachured pattern).



Local geology

The TS unit was the main focus of the 2011 mapping program, as it is the major host to gold mineralization in the Rice Lake area and largely defines the mine trend. This unit is ca. 1.3 km thick at Rice Lake and tapers out toward the east along strike, possibly as a result of structural thinning near the confluence of the WSZ and Normandy Creek Shear Zone. To the west, this unit is truncated from the north by a deep erosional scour at the base of the Round Lake unit and from the south by the basal unconformity of the San Antonio assemblage.

Felsic volcanic sandstone (unit 3) and heterolithic volcanic conglomerate (unit 4) constitute the lower section of the TS unit, where they define three distinct coarsening upward cycles and are interpreted to represent suprafan-lobe and channel-fill deposits, respectively, in a progradational submarine fan system. Using local mine terminology, these rocks correspond to the 'Hares Island formation'.

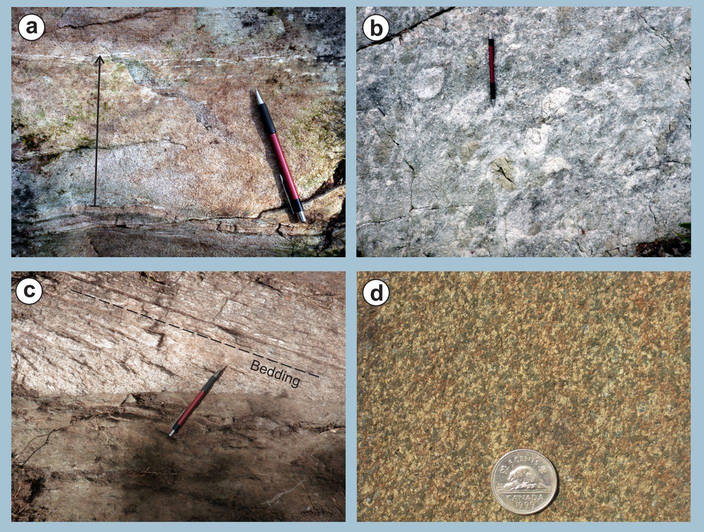
The epiclastic rocks contain a unimodal population of ca. 2.724 Ga detrital zircons and are intruded by sills and slightly discordant dikes of gabbro (unit 5), the thickest of which is informally referred to as the 'SAM unit'. The gabbro is of transitional tholeiitic-calcalkalic affinity and is chemically similar to overlying mafic volcanic rocks, suggesting a comagmatic relationship.

The uppermost cycle of the submarine fan succession is interstratified near its base with volcaniclastic rocks (unit 6) and associated pillowed, massive and brecciated flows (unit 7). These rocks vary in composition from basalt to basaltic-andesite to andesite, and are collectively referred to as the 'Shoreline basalt'. The volcaniclastic rocks appear to represent resedimented and in-situ hyaloclastite deposits.

The upper section of the TS unit consists of coarsely plagioclase-phyric, intermediate to felsic volcaniclastic rocks, which are referred to as the 'Townsite dacite' (unit 8). Thick intervals of massive crystal-lithic lapilli-tuff (subunit 8a) at the base of this unit are interpreted to represent primary pyroclastic or resedimented grain-flow deposits. Overlying coarse monolithic breccia and tuff breccia (subunit 8b) are interpreted to represent secondary mass-flow deposits that were generated by gravitational instability of the partially indurated primary pyroclastic or syneruptive sedimentary deposits. Inter-layered volcanic conglomerate and thin-bedded volcanic sandstone define a distinctive, newly-recognized, subunit (8c) in the medial portion of this unit, and are interpreted to represent more strongly reworked debris flow deposits.

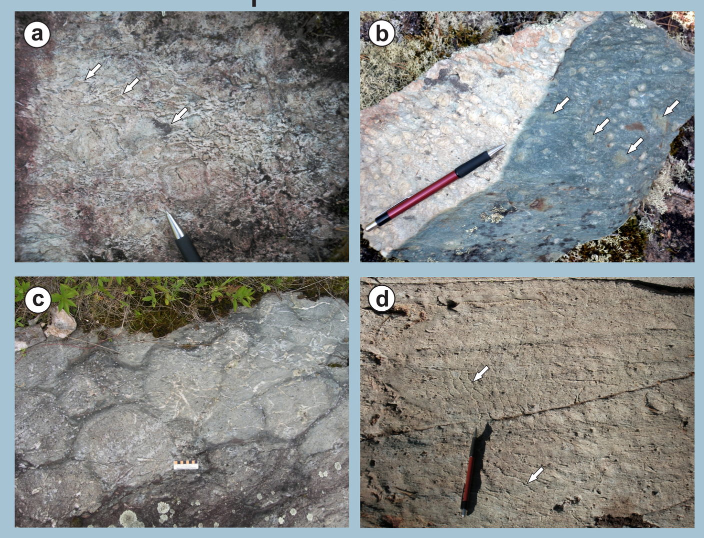
The TS unit is overlain by heterolithic volcanic conglomerate (unit 10) at the base of the Round Lake unit. All of these rocks are intruded by mafic, intermediate and felsic dikes and lesser sills of map units 9, 11 and 12, respectively.

Map units 3, 4 and 5



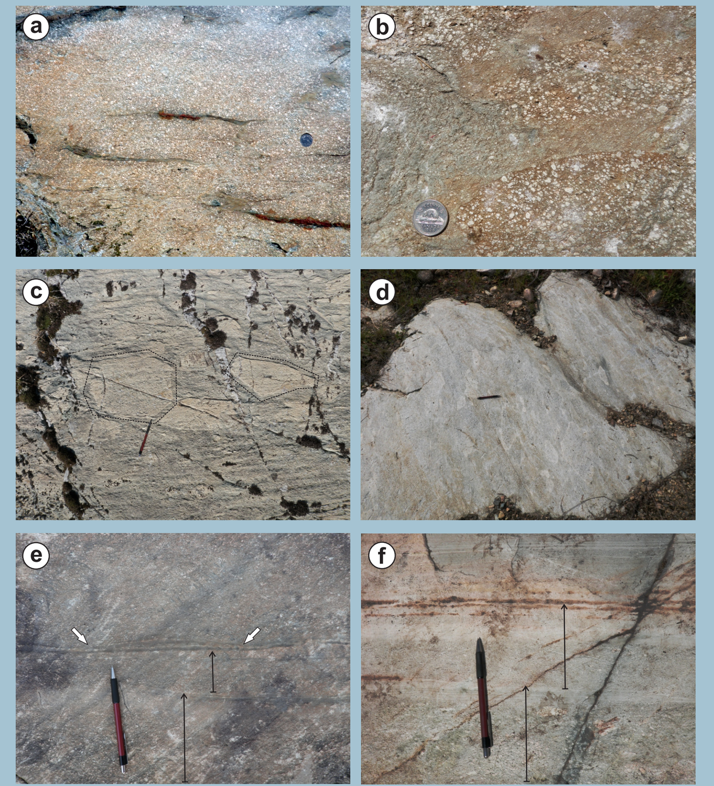
Outcrop photographs of rock types in units 3, 4 and 5: a) bedded felsic volcanic sandstone (subunit 3a), east of Rice Lake; normally graded beds (arrow) indicate tops to the north (indicated by pencil); b) volcanic conglomerate (unit 4), east of Rice Lake; note the abundant clasts of pale green epidotized basalt; c) sharp, planar geological contact of a mesocratic gabbro dike (subunit 5b), east of Rice Lake; note angular discordance to bedding (indicated by dashed line) in the adjacent felsic volcanic sandstone (subunit 3a); d) mesocratic gabbro (subunit 5b), east of Rice Lake.

Map units 6 and 7



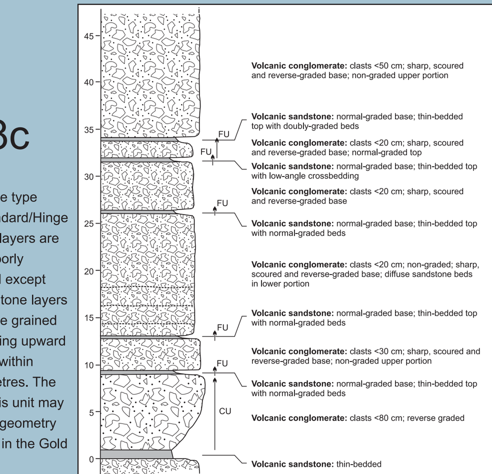
Outcrop photographs of rock types in units 6 and 7: a) basaltic lapilli tuff (subunit 6a) from the type locality of unit 6, east of Rice Lake; note shard-like cuspate lapilli (arrows) and possible quenched margins on the large lapillus above the pencil tip, which are indicative of primary hyaloclastite; b) basaltic lapilli tuff (subunit 6b), east of Rice Lake; strongly epidotized lapilli indicated by arrows; c) pillowed basalt (subunit 7b), east of Rice Lake; d) basalt flow (subunit 7a), east of Rice Lake; note the recessively weathered amygdules (dark pits) and quartz-filled thermal contraction fractures (indicated by arrows).

Map unit 8



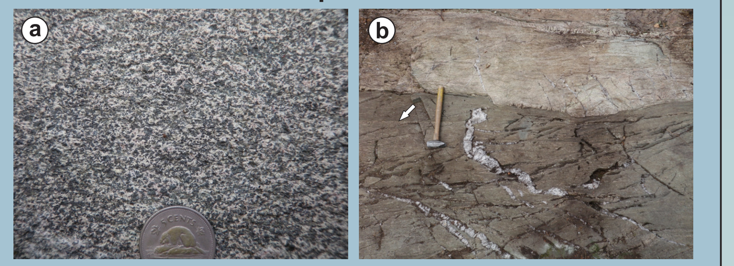
Outcrop photographs of rock types in unit 8: a) massive crystal-lithic lapilli tuff (subunit 8a), north of Rice Lake; includes wispy rip-up clasts of subphitic mudstone; b) brecciated crystal-lithic lapilli tuff (subunit 8b), north of Rice Lake; clast margins vary from sharp to gradational; c) joint-bounded blocks (outlined) of crystal-lithic lapilli tuff in crudely stratified tuff breccia (subunit 8b), northeast of Rice Lake; d) volcanic conglomerate of subunit 8c, north of Rice Lake; e) contact between volcanic conglomerate (top) and volcanic sandstone (bottom) of subunit 8c; volcanic sandstone beds are normally graded (indicated by black arrows), whereas base of volcanic conglomerate is reversely graded; f) fine- to coarse-grained, normally graded beds of volcanic sandstone (subunit 8c), north of Rice Lake.

Subunit 8c



Measured section of subunit 8c at the type locality, 100 m west of the Gold Standard/Hinge deposit. The volcanic conglomerate layers are heterolithic, matrix supported and poorly sorted, and are internally unstratified except where indicated. The volcanic sandstone layers are planar bedded, medium to coarse grained and pebbly. Arrows indicate coarsening upward (CU) and fining-upward (FU) trends within individual layers. Vertical scale is metres. The pronounced primary anisotropy in this unit may have influenced the distribution and geometry of the auriferous quartz-vein system in the Gold Standard/Hinge deposit.

Map unit 9

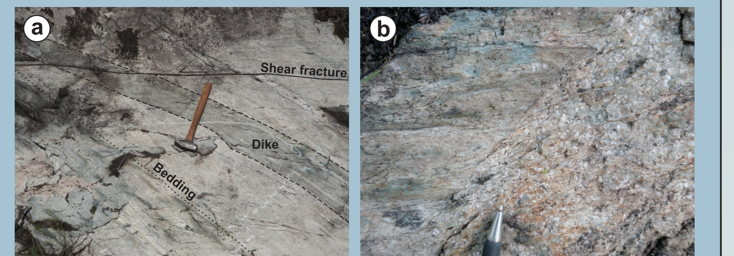


Outcrop photographs of rock types in unit 9: a) medium-grained gabbro (subunit 9b), northeast of Rice Lake; b) compound gabbro dike, northeast of Rice Lake; sharp contact between early medium-grained gabbro (bottom) and later fine-grained gabbro (top) is indicated by arrow; external contact of dike is sharp and planar.

Map unit 10

Outcrop photographs of rock types in unit 10: a) heterolithic volcanic conglomerate (subunit 10a) with thin-bedded layer of volcanic sandstone, north of Rice Lake; b) angular to subrounded clasts of crystal-lithic lapilli tuff in heterolithic volcanic conglomerate of subunit 10b, just above the base of the 40 m thick interlayer of heterolithic volcanic conglomerate in unit 8, north of Rice Lake.

Map units 11 and 12



Outcrop photographs of rock types in units 11 and 12: a) aphyric diorite dike (subunit 11a) cutting at a shallow counterclockwise angle across bedding in an outcrop of crudely stratified breccia (subunit 8b), northeast of Rice Lake; b) sharp, planar contact between quartz-feldspar porphyry (right; unit 12) and heterolithic volcanic conglomerate (left; subunit 10a), northeast of Rice Lake; note that the regional foliation in the country rock passes continuously across the contact and is slightly refracted.

Manitoba

Structural overview

Deformation structures throughout the Rice Lake mine trend were examined in detail during the 2011 mapping program in order to gain an improved understanding of the structural evolution, particularly as it relates to the structure, style, kinematics and structural timing of quartz-vein systems. On the basis of prevailing orientations, the mine trend is divided into two structural domains (western and eastern).

Structural overprinting relationships indicate six distinct generations (G_1–G_6) of ductile and brittle-ductile deformation structures in the Rice Lake area; however, only the G_3 and G_4 fabrics are pervasive in the mine trend and are described further here.

Ductile G_3 structures

G_3 structures consist of a pervasive S_3-L_3 shape fabric defined by flattened and stretched clasts and pillows, and a continuous foliation of fine-grained chlorite, actinolite and sericite. S_3 crosscuts primary structures at a shallow (~5°) counter-clockwise angle; no examples of mesoscopic F_3 folds of bedding were observed. In some locations, the rocks are L>S tectonites. The G_3 fabric locally intensifies into narrow (<2 m) mylonite zones that record sinistral-reverse non-coaxial shear. Outside these zones, the G_3 shape fabric is less intense and generally symmetric; hence, G_3 strain appears to have been strongly partitioned on a macroscopic scale.

Brittle-ductile G_3 structures

The G_3 shape fabric is overprinted by discrete brittle-ductile shear zones and shear fractures (hereafter referred to as 'shears') that are separated on the basis of orientation and kinematics into two sets ('NE' and 'NW'). Mutual overprinting relationships indicate that the sets evolved synchronously.

The NE shears cut counter-clockwise across pre-existing structures and are oriented roughly parallel to mafic and intermediate dikes, indicating that the shears were controlled, at least in part, by the anisotropy of the dikes. The NW shears cut clockwise across pre-existing structures but tend to be more variable in orientation than the NE shears; the apparent absence of a primary anisotropy in this orientation may explain this variability.

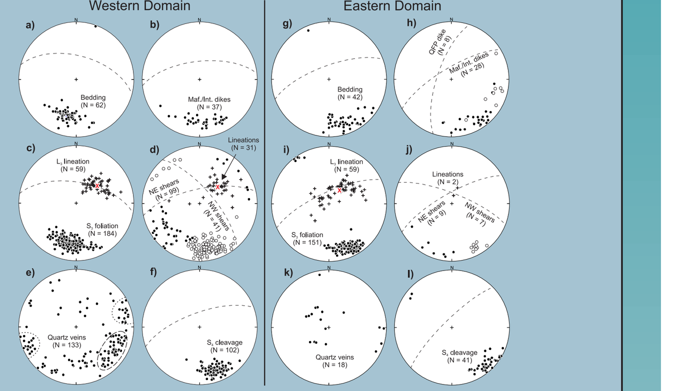
Incipient NE and NW shears are marked by en échelon arrays of shear or extension fractures, discrete slip-surfaces, and discontinuous seams of cataclasite. In later stages, the NE shears are marked by chloritic or sericitic mylonites that range up to several metres thick. The external S_3 shape fabric is either sharply truncated at the margins of the shears or is transposed into the internal fabric.

Most shears are associated with fault-fill veins and diffuse peripheral arrays of en échelon extension fractures (planar to sigmoidal). Lineations on slip-surfaces and foliation planes plunge moderately northeast, sub-parallel to pressure fringes on pyrite cubes in narrow sulphidization haloes adjacent to veins. Asymmetric fabrics, offset markers and dilational jogs indicate sinistral-reverse and dextral-normal oblique-slip on the NE and NW shears, respectively. Apparent displacements are generally less than 10 m, but range up to 50 m for major NE shears.

G_4 structures

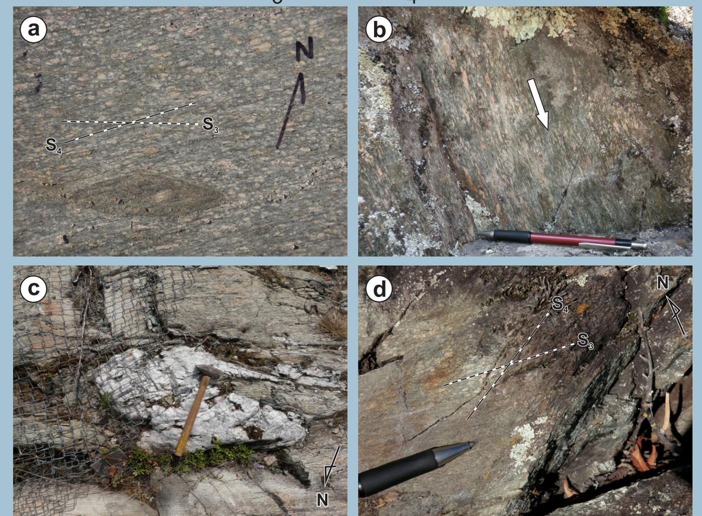
The G_3 fabric is overprinted at a counter-clockwise angle by a crenulation cleavage of the G_4 generation. This cleavage is axial planar to rare, open to tight, Z-asymmetric folds.

Orientation data



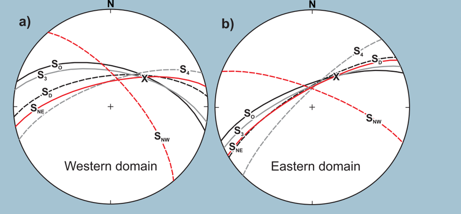
Lower-hemisphere, equal-area projections of structural data in the western (a–f) and eastern (g–l) domains of the mine trend: a) and g) poles to bedding; b) and h) poles to dike contacts; c) and i) poles to S_3; d) and j) L_3 lineations; e) and k) poles to NE shears; f) and l) poles to NW shears and S_4 cleavage.

Ductile G_3 and G_4 structures



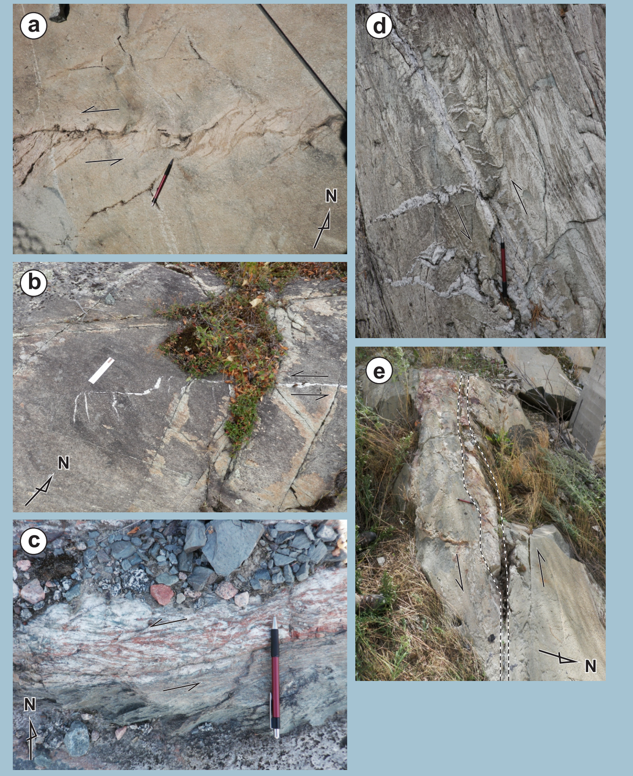
Outcrop photographs of deformation structures in the Townsite dacite: a) penetrative S_3 shape fabric (defined by flattened clasts and aligned plagioclase phenocrysts) overprinted by finely spaced S_4 cleavage, eastern domain; b) penetrative L_3 fabric defined by stretched plagioclase crystals, western domain; c) rootless, isoclinal S-fold of fault-fill vein in G_3 high-strain zone, eastern domain; the fold asymmetry is compatible with sinistral shear; d) overprinting relationships between the shape fabric in G_3 high-strain zone and the S_4 crenulation cleavage, western domain.

Summary plots: western and eastern domains

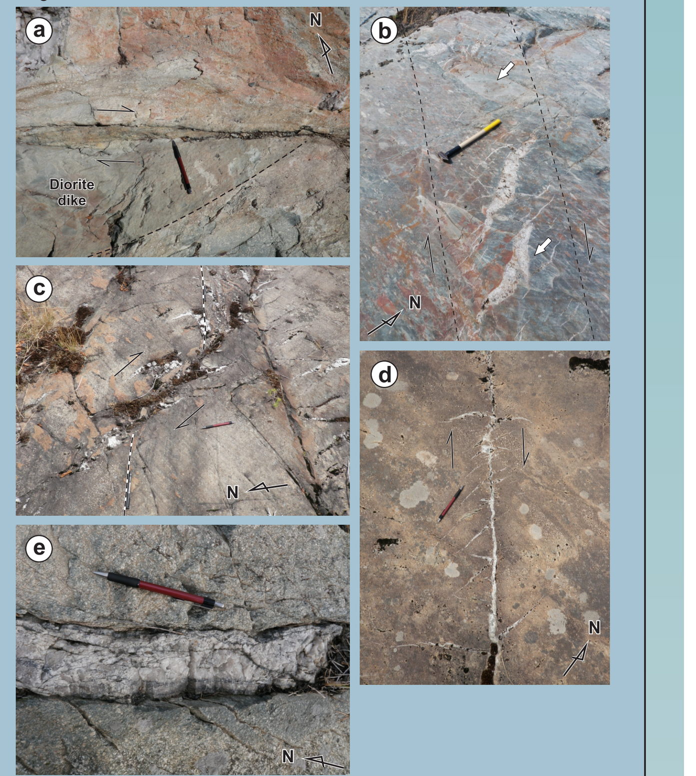


Lower-hemisphere projections showing the mean orientations of structures in the mine trend: a) western domain and b) eastern domain. Symbols: S_0, bedding and stratification (solid black lines); S_D, dike contacts (dashed black lines); S_3, S_3 planar fabric (solid grey lines); S_4, S_4 cleavage (dashed grey lines); S_{NE}, NE shears (solid red lines); S_{NW}, NW shears (dashed red lines). The systematic changes in orientation result from the open F_6 syncline in the central portion of the mine trend.

Brittle-ductile G_3 structures



Outcrop photographs of small-scale northeast-trending shears (NE shears): a) northeastern lateral tip, showing progression from en échelon sigmoidal extension and synthetic shear fractures (right) to a discrete slip-surface bounded by extension fractures (left), Hinge portal; b) southwestern lateral tip, showing wing cracks at the lateral termination of a discrete shear (arrow); c) fault-fill quartz vein, 100 m northwest of the Wingold deposit; d) vertical exposure (looking west), showing discrete shear fracture and peripheral en échelon arrays of sigmoidal extension fractures; e) fault-fill quartz vein in a sinistral-reverse shear; the A-shaft headframe.



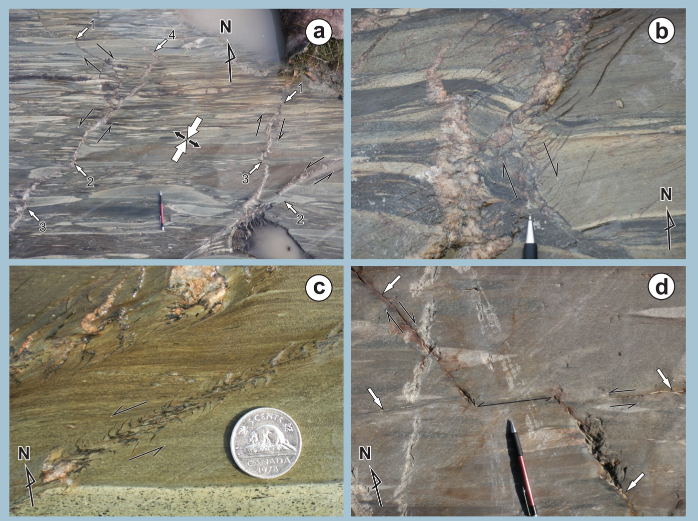
Outcrop photographs of small-scale northwest-trending shears (NW shears): a) shear showing discrete slip-surfaces and narrow seam of cataclasite, east of the Gold Standard/Hinge deposit; b) sinistral offset of a dike by a NW shear; c) extension veins associated with a NW shear; d) extension fractures and incipient shear; e) laminated fault-fill vein in a discrete NW shear, north of Rice Lake.

Brittle-ductile G_3 structures: overprinting and geometrical relationships

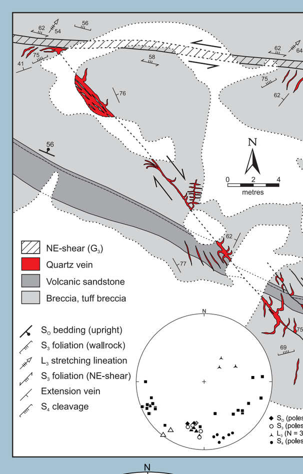
Small-scale examples of NW and NE shears in outcrop show evidence of contemporaneous development under brittle-ductile rheological conditions. This evidence includes their close spatial association, mutual crosscutting relationships and similarities in the mineralogy and style of associated extension veins.

In the western domain, the geometry and kinematics of the shears indicate that they accommodated north-northeast-directed shortening. Here, the NE and NW shears are arranged in a broadly symmetric manner to the S_3-L_3 shape fabric. Overprinting relationships indicate that this shortening likely occurred during the late increments of the deformation recorded by the S_3-L_3 shape fabric, which likewise accommodated north-northeast shortening.

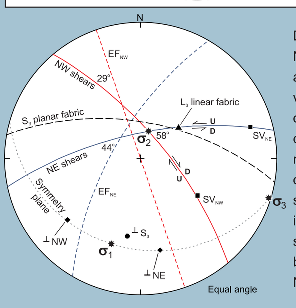
On a macroscopic scale, G_3 deformation appears to have been strongly partitioned into narrow domains of penetrative non-coaxial shear, which separate wider domains of mostly coaxial shear. The brittle-ductile nature of the late-G_3 structures may relate to transiently higher strain rates or fluid pressures, or strain-hardening effects, during the late increments of regional north-northeast shortening.



Outcrop photographs showing small-scale examples of northwest-trending shears (NW shears) and northeast-trending shears (NE shears): a) interaction of NW and NE shears, north of Bissett; flattened clasts define the S_3 shape fabric; b) NW shear showing dextral offset; c) ptygmatic folding of fault-fill veins; d) mutual overprinting relationships of northwest and NE shears (white arrows); note left-lateral offset of NW shear and right-lateral offsets of NE shears.



Outcrop map of northeast-trending shears (NW shears) in the footwall of a major northeast-trending shear (NE shear) in the Townsite dacite, approximately 400 m northwest of the Gold Standard/Hinge deposit.



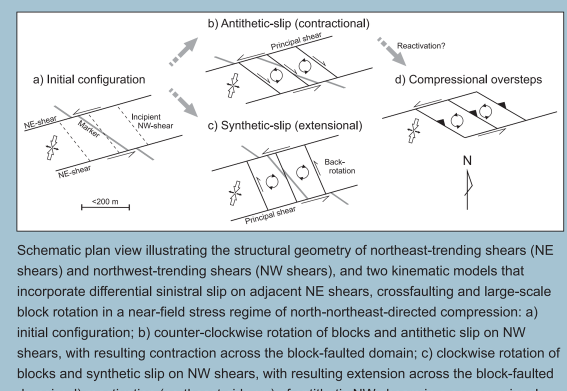
Detailed geometry of structures associated with NW and NE shears in the western domain.

Brittle-ductile G_3 structures: kinematic model and exploration significance

Mutual crosscutting relationships indicate that the NE and NW shears were coeval and at least locally formed as a conjugate set, as has been proposed for similar structures in the San Antonio/Rice Lake deposit.

In other locations, the NW shears appear to represent subsidiary structures that accommodated dextral (antithetic) slip during counter-clockwise rotation of rectilinear blocks in domains bounded by NE shears.

As shown schematically to the right, subsidiary structures may record either antithetic or synthetic slip depending on local boundary conditions, and may also be reactivated in compressional oversteps.



Schematic plan view illustrating the structural geometry of northeast-trending shears (NE shears) and northwest-trending shears (NW shears), and two kinematic models that incorporate differential sinistral slip on adjacent NE shears, crosscutting and large-scale block rotation in a near-field stress regime of north-northeast-directed compression: a) initial configuration; b) counter-clockwise rotation of blocks and antithetic slip on NW shears, with resulting contraction across the block-faulted domain; c) clockwise rotation of blocks and synthetic slip on NW shears, with resulting extension across the block-faulted domain; d) reactivation of NW shears in a compressional overstep that joins two NE shears.

In the San Antonio/Rice Lake deposit (right), NE shears appear to refract into the SAM unit across the hangingwall contact, and the resulting dilational jogs host economically important fault-fill ('16-type') veins. By analogy, locations where NE shears crosscut relatively competent rock units are thought to represent highly favourable targets for surface exploration.

NW shears host economically important stockwork-breccia ('38-type') veins that are arranged en échelon down the dip of the SAM unit or have highly variable orientations that are compatible with macro-scale block rotation. Structural domains bound by NE shears and showing evidence of block-rotation are thus considered highly favourable targets for surface exploration.