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Canadian Tectonics Group Fall Workshop 2019, Cormack, Newfoundland

Oral session, October 6

8:30 am – Workshop opening remarks

8:40 am – Corrigan, David and van Rooyen, Deanne
The Labrador Traps: remnant of a ca. 2.17 Ga large igneous province in the Labrador Trough

9:00 am – White, Shawna et al.
Cambrian through Devonian sedimentary succession of the Laurentian margin in western Newfoundland: the effects of an irregular margin geometry on provenance

9:20 am – Gunawardana, Hiruni, et al. (P. McCausland presenting)
Paleomagnetism of the Devonian McAras Brook Formation, Nova Scotia

9:40 am – Bethune, Kathryn, et al.
Structural-tectonic evolution of the Santoy shear zone, a splay of the Tabbernor fault zone: late-orogenic gold controlled by a crustal-scale fault in the Reindeer zone of the Trans-Hudson orogen

10:00-10:30 am – coffee break

10:30 am – Phillips, Noah, et al.
To D or not to D: Re-evaluating the role of constrained comminution in cataclastic deformation

10:50 am – Gudmundson, Greg et al.
The role of structures in the development of Unconformity-related uranium deposit in the Athabasca Basin (Saskatchewan)

11:10 am – Duvall, Michael, et al. (J. Waldron presenting)
Transverse structures developed during India – Asia collision in the Ganga foreland basin, Nepal

11:30 am – Wrap-up and end of meeting

Posters:

Archibald, Donnelly, et al. Testing the slab-failure model for the tectonic setting of the Donegal batholith, Ireland

Metteer, Samuel, et al. Strength implications of multi-stranded pseudotachylyte faults within mylonites of the Norumbega Shear Zone, southern Maine

Soukup, Maya and Beranek, Luke Preliminary insights into the stratigraphy and detrital zircon U-Pb-Hf provenance of Ediacaran to Cambrian rift and passive margin deposits, Humber Margin, western Newfoundland

White, Shawna, et al. An Archean basement connection between the southern Abitibi and Pontiac Subprovinces: insights from new mapping in the Cobalt region, Northern Ontario

Testing the slab-failure model for the tectonic setting of the Donegal batholith, Ireland

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The Silurian to early Devonian Donegal batholith (Ireland) is a classic example of a composite batholith. Regional syntheses indicate the batholith intruded metamorphosed Dalradian marine siliciclastic rocks intercalated with carbonate and volcanic rocks. Zircon U-Pb data indicate batholith emplacement occurred over approximately 30 myr between ca. 430 and 400 Ma i.e. during and after the Scandian phase (ca. 440-415 Ma) of the Caledonian orogeny marked by the collision of Baltica and Laurentia.

In accretionary orogens, magmatism commonly post-dates the main orogenic event. The model commonly invoked to generate post-collisional granitoid magmas is by the tectonic process of “slab-breakoff” or “slab-failure”. In this model, incipient melting is caused by asthenospheric (convective mantle) upwelling of hot, mafic magmas due to oceanic “slab-failure” following subduction cessation. The upwelling asthenosphere underplates and melts the continental lithospheric mantle (CLM) or the oceanic slab melts to generate the mafic magmas. Irrespective of the source, the mantle-derived mafic magmas fractionate and/or melt the continental crust to generate granitoid magmas that can ascend to shallower crustal depths to form composite batholiths.

Recently, data from the Cordillera were used to develop lithogeochemical discriminators to distinguish slab failure rocks from rift or arc-related rocks. New lithogeochemical data from the Donegal batholith are consistent with a slab-failure tectonic setting, which is associated with the Baltica-Laurentia collision. Taken together, data and our syntheses of isotopic and lithogeochemical data indicate that emplacement of the batholith resulted from episodic magma pulses sourced from the asthenospheric mantle, CLM, and/or lower crust following Silurian Iapetus Ocean closure.

Structural-tectonic evolution of the Santoy shear zone, a splay of the Tabbernor fault zone: late-orogenic gold controlled by a crustal-scale fault in the Reindeer zone of the Trans-Hudson orogen

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The Santoy shear zone in northeast Glennie Domain is host to several gold deposits, including the Santoy Zone 7, Zone 8 and Gap (Zone 9) deposits. Structural analysis and complementary U-Pb dating provide constraints on the timing and mechanisms of shear zone development. Titanite and zircon in the calc-silicate assemblage associated with shear zone-hosted quartz veins have been dated at ca. 1755 Ma, indicating that mineralization took place relatively late in the tectonic evolution.

The Santoy shear zone likely initiated as a splay of the Tabbernor fault during the late stages of D3 folding, as strain localized along the western limb of the Carruthers Lake synform. Strain was partitioned into weaker mafic volcanic rocks in contact with more competent granitoids. During D3 the S2 foliation, along with subparallel and discordant quartz veins, were folded about N-plunging F3 folds. These folds were progressively tightened toward a ‘central auriferous zone’, in which highly sheared and altered mafic volcanic rocks, transposed tonalitic sheets/dykes, were invaded by an anastomosing network of fault-fill veins. Deformation occurred by a combination of pure and simple shear, with dextral-reverse displacement and tectonic transport along the N-plunging lineation. Calc-silicate layers/lenses show well-developed boudinage structures. High fluid pressures, coupled with mechanical anisotropies of the tonalite dykes/sheets, are inferred to have played a role in cyclic failure and vein emplacement. The ore bodies were strongly influenced by the D3 strain regime with ore shoots elongated along L3. An upper limit to mineralization is provided by the ca. 1736 Ma age derived from a crosscutting but weakly folded non-mineralized pegmatite. Later development of discrete foliation-parallel ductile-brittle faults, with evidence of two slip lineations and sulphide remobilization, indicate sequential reactivations of the Tabbernor fault.

This study demonstrates that D3 was much longer lived than previously thought, with an estimated extent from ca.1770 Ma, based on regional metamorphic ages, to ca. 1736 Ma. It also reinforces results of a previous thermochronological study indicating a substantial difference in cooling/exhumation histories across the Tabbernor fault, with the west side showing a prolonged uplift history relative to rapidly exhumed, higher grade rocks on the eastern side.

In conclusion, the Santoy gold deposits have all the hallmarks of mesothermal, orogenic-style gold deposits. The associated distinctive calc-silicate alteration implies somewhat deeper mineralization depths than is typical of such deposits. The Tabbernor fault thus represents a deep-seated, crustal-scale fault whose future gold prospectivity should not be overlooked.

To D or not to D: Re-evaluating the role of constrained comminution in cataclastic deformation

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Cataclasis is a fundamental mechanical mechanism shaping fault-rock evolution which describes fracturing and particle size reduction during sliding along a fault interface. This process is recorded in part by the evolution of particle size distributions with continued slip, and controls fault-rock porosity, permeability, frictional resistance to sliding, and the formation of new surface area (which consumes a portion of the earthquake energy budget). Thus, mechanistic models of cataclastic deformation are essential for understanding the evolution of fault rocks in the brittle crust. The most accepted model for cataclasis is "constrained comminution", which predicts a power-law (fractal) distribution of grain sizes described by a scaling factor D. These D-values are routinely used to describe the evolution of particle size distributions with increasing strain. In this contribution, we test for the presence of power-law scaling in ~50 samples from previously published naturally and experimentally deformed fault rocks, thereby assessing the validity of the constrained comminution model. We employ a well-established statistical approach which determines a best-fit power-law function for a particular data set, and then compares that fit to other possible distributions. We find that power-law distributions are a poor fit to each data set. Thus, the examined fault rocks are not consistent with having formed through constrained comminution. Log-normal and stretched exponential distributions are generally a better fit to each data set. We examine possible mechanisms that could produce these alternative distributions, including the density of internal flaws and preferential fracturing of larger grains (protected fines), and discuss how these particle size distributions may evolve with increasing strain.

The role of structures in the development of Unconformity-related uranium deposit in the Athabasca Basin (Saskatchewan)

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Although the main guides for exploration of Unconformity-related deposit in the Athabasca Basin remain mineralogical and geochemical pathfinders vectoring towards uranium ore bodies, the role of the structures is emphasized following the discovery of major basement-hosted deposits.

The structural evolution is first deciphered at the regional scale using geophysical datasets. Predictive maps based on magnetic interpretation are produced and characterize large corridors of low magnetic Paleoproterozoic metasediments, the Wollaston domain, flanked by Archean TTG domes, the Mudjatik domain. Compilation of geological and structural information collected during exploration program enables the definition of a well constrained strain field in which deeply rooted anastomosing shear zones were developed during a long lasting period of compression related to the 1.8 Ga Trans-Hudsonian orogens.

At the project scale, for example along the Sue trend, this tectonic evolution is marked by the thrusting of Archean orthogneiss over Paleoproterozoic metasediments along steeply dipping graphite-rich fault systems. Foliation is penetrative and extension is mainly vertical, probably developed in a transpressional tectonic context. The widespread incipient melting conditions observed parallel to the foliation are characteristic of mainly vertical-driven tectonics. Structural data measured on cores and determined by borehole imagery illustrates in 3D modeling the localization of basement-hosted orebodies along these graphitic shear zones, and of unconformity and perched mineralization in the basin. The presence of these orebodies along structures that are both present in the basement and in the basin, and the offset of the unconformity, points out the significant reactivation of the 1.8 Ga Trans-Hudsonian, Pre-Athabasca, inherited fault system.

At the scale of a drill hole fence, for example across the Cigar North conductor, the fluid-channeling role of these faults can be illustrated through an analysis of the transition from ductile to brittle structures and the interaction with hydrothermal alteration. Retrograde metamorphism appears to have played a significant role in enhancing rheological contrasts between “strong” silicified and “weak” chloritized para and orthogneisses. Cataclastic graphitic shear zones show several stages of reactivation likely responsible for the pluri-decametric offset of the unconformity. Understanding the role and influence of these fault systems in the initiation and sustainability of large fluid convection cells involving brines from the basin and potential fluid sources from the basement is considered to be key to understand the formation of Unconformity-related deposit.

Preliminary insights into the stratigraphy and detrital zircon U-Pb-Hf provenance of Ediacaran to Cambrian rift and passive margin deposits, Humber Margin, western Newfoundland

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Field and detrital zircon U-Pb-Hf studies of Ediacaran to lower Cambrian rocks in western Newfoundland were initiated in summer 2019 to test competing rift models for eastern Laurentia, constrain the timing of rift and passive margin deposition, and investigate proposed stratigraphic correlations between units of the Humber platform and Humber Arm allochthon. Detrital zircon U-Pb-Hf studies will be conducted in combination with thin section petrography and SEM-MLA micro-analytical imaging methodologies to constrain the composition and provenance of rock units. Fluvial units of the Bradore Formation (Labrador Group) and Oldhamia-bearing slope deposits of the allochthonous Blow Me Down Brook Formation (Curling Group) are associated with ca. 555-550 Ma igneous successions and predicted to yield syn-depositional, Ediacaran-Cambrian detrital zircon grains that will constrain the maximum depositional ages of immature syn-rift rock units in the Indian Head Range, Bay of Islands, and Gros Morne regions. The Summerside Formation (Curling Group) turbidite strata along the shores of Humber Arm, which are locally dominated by detrital feldspar, have previously yielded Ediacaran to early Cambrian palynomorph assemblages and may be in part correlative with these syn-rift units. Platformal quartz arenite of the Hawke Bay Formation (Labrador Group) and overlying limy sandstone of the March Point Formation (Port au Port Group) crop out on the western Port au Port Peninsula and should contain polycyclic detrital zircon grains that mark the early Cambrian transition to thermal subsidence and long-term sediment recycling along the nascent Humber margin. Quartzose sandstone units of the Irishtown Formation overlie syn-rift slope successions of the Humber Arm allochthon and are potential deep-water equivalents to these mature lower Cambrian platformal strata.

Depth-dependent extension models that feature either simple shear, low angle detachment faulting or modern North Atlantic-type crustal thinning, hyperextension, and mantle exhumation have been proposed to explain the tectonic evolution of the Humber margin. Each of these plate tectonic scenarios makes specific predictions about the timing, spatial location, and paleogeography of Humber margin basins. We expect the new stratigraphic and detrital zircon UPb-Hf datasets to test and further develop these rift models and complement published studies on the Ediacaran to Cambrian rift to drift history of western Newfoundland.

Strength implications of multi-stranded pseudotachylyte faults within mylonites of the Norumbega Shear Zone, southern Maine

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The strength of plate-boundary faults and shear zones is dependent on the composition and structure of the rocks within them. Earthquakes occur in faults and modify both the mineralogy and the structure of the rock, for example, by causing frictional melting. These melts quench to form fine-grained rocks called pseudotachylytes that usually have a different grain size and mineralogy than the original rock. Earthquakes can also modify the structure of fault zones as multi-stranded webs of subparallel slip surfaces alter the orientation of anisotropic wall rock. Experiments designed to examine post-seismic strength of pseudotachylytes have reported both strong and weak pseudotachylytes at short timescales. Field studies have the potential to reveal the long-term strength contrasts between different rocks in shear zones under natural conditions.

We report detailed field observations of the geometries of pristine and deformed pseudotachylyte veins in the Fort Foster Brittle Zone, Norumbega Shear Zone, southern Maine. We show that pseudotachylyte does not appear to impact brittle reactivation potential within a fault, but pseudotachylyte effectively focuses interseismic ductile flow. We build on the work of Price et al. (Tectonophysics, 2012), who describe how to identify deformed pseudotachylytes, and propose criteria for distinguishing the degree of deformation and recrystallization. We observe multi-stranded webs of subparallel pseudotachylyte fault veins which bound rotated wall rock blocks featuring disrupted mylonitic layering, facilitated by adhesive wear causing co-seismic slip redistribution. Rotation of mylonite blocks due to slip on anastomosing curved faults results in the discontinuity of weak layers in mylonite, causing local strengthening and partitioning of post-seismic shear into neighboring wall rock. Densely grouped reworked and fresh pseudotachylyte indicate localization of rupture along these interfaces of straight planar and disrupted mylonitic fabric. Preliminary findings are that the formation of pseudotachylyte may monotonically weaken faults, due to interseismic ductile deformation, but this weakening is limited by the geometric strengthening effects countered by block rotation of multi-stranded rupture. Ongoing work includes electron backscatter diffraction (EBSD) studies to work towards quantification of strength differences between faults preserved at different stages in their seismic -interseismic healing cycles.

An Archean basement connection between the southern Abitibi and Pontiac Subprovinces: insights from new mapping in the Cobalt region, Northern Ontario

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Metal Earth is a multiyear, multidisciplinary collaboration focused on determining the factors controlling mineralization within Archean greenstone belts. As part of this larger initiative, the Cobalt Transect is working towards understanding the structural and stratigraphic controls on Ag-Co arsenide veins hosted in Precambrian units of the Cobalt region in Northern Ontario. During the early 20th Century, Cobalt was one of the most prolific silver mining areas in the world. More than 500 MoZ of Ag was produced from precious metal-bearing polymetallic veins; Ni, Bi and Co are also major constituents. With growing demand for Co, exploration has been revitalized.

The region is largely underlain by Precambrian rocks, the oldest of which are Archean volcanic and intrusive units which make up the southernmost portion of the Western Abitibi sub-province within the Superior Province. Sedimentary rocks of the Paleoproterozoic Huronian Supergroup unconformably overly the Archean basement. The 2.2 Ga Nipissing diabase intrudes both Archean basement and Paleoproterozoic cover.

The mineralized veins are hosted in all Archean and Proterozoic units, have similar mineralogy, morphological characteristics, and proximity to the Nipissing diabase sills and the regional unconformity. However, there is limited understanding of structural/stratigraphic controls on their formation. New mapping demonstrates the importance of the Archean basement in controlling the distribution and orientation of mineralized veins. Although playing a critical role in vein placement, little is known of the nature of the Archean volcanic basement in the Cobalt region. New mapping, structural analysis, whole rock geochemistry and geochronology demonstrate an Archean volcanic stratigraphy with chemical affinities and relatively young age's correlative to volcanic units exposed within the adjacent Pontiac Subprovince; we suggest a basement connection between these two regions (the Cobalt Embayment and Pontiac Subprovince) which has been masked by younger sedimentary cover.

Cambrian through Devonian sedimentary succession of the Laurentian margin in western Newfoundland: the effects of an irregular margin geometry on provenance

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Neoproterozoic to Cambrian break-up of Rodinia opened the Iapetus Ocean, forming an irregular Laurentian margin defined by NE-striking rift zones offset by NW-striking transfer faults. Detrital zircon populations from W Newfoundland indicate two distinct provenance domains in rift-to-drift rocks. A proximal western succession, dominated by Mesoproterozoic detritus, indicates derivation from local basement and the Grenville Province to the west. A distal eastern succession displays similarities with the Laurentian margin in Greenland and Scotland, with prominent 1.85 Ga peaks and many Archean grains. These contrasts may have resulted from a major NW-striking transfer fault, blocking sediment transport, between the Newfoundland Promontory and Québec Embayment.

Ordovician through Devonian closure of the Iapetus resulted in multiple orogenic episodes and development of foreland basins above the rift-drift succession. Ages of detrital zircon within the foreland succession are consistent with Laurentian sources; however, details of the distributions indicate provenance changes associated with shifting loads and sources within the orogen. Previous results from the M. Ordovician Goose Tickle Gp. show ages similar to the Humber Arm Allochthon, including a prominent peak at 1.85 Ga. Younger foreland successions (U. Ordovician – Devonian) are dominated by ages between 0.95 and 1.3 Ga, with prominent peaks at 1.0 and 1.1 Ga, typical of the Grenville Orogen, indicating a major provenance shift. Continental margin units in Québec/New England show similar signatures, suggesting derivation of the U. Ordovician Long Point Group from the SW. Within the mid-Paleozoic Clam Bank - Red Island Road succession, the absence of Gondwanan ages is consistent with underthrusting of Gondwanan microcontinents during Salinian and Acadian orogenesis. An abundance of 1.0 Ga grains in the E. Devonian Red Island Road Formation is consistent with sources in Grenville massifs in W. Newfoundland or Cape Breton Island, uplifted during Acadian inversion.

Transverse structures developed during India – Asia collision in the Ganga foreland basin, Nepal

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Foreland basin stratigraphy can be used to investigate the behaviour of basement features during continent-continent collision, and to test links between basement structure, along-strike segmentation of deformation, and lithospheric flexure in a developing orogen. The Himalayan orogen has been subdivided from east to west into along-strike segments with differing thicknesses, deformation styles, thermal evolution, and seismicity. Heterogeneities in the Indian plate, such as crustal scale basement faults and ridges, are possible controls on this lateral segmentation.

The seismic stratigraphy within and below the Ganga foreland basin across Nepal is imaged through 2D seismic reflection data. The data have been depth-converted using time-depth relationships derived from wells. Regionally interpreted surfaces include: two horizons internal to the Cenozoic succession; an angular unconformity at the base of the Cenozoic succession where older stratified units are truncated; and the nonconformity that separates sedimentary strata from acoustic basement representing Archean granitoids and Proterozoic gneisses. Because much of the foreland basin fill was deposited in fluvial environments close to sea level, thickness can be used as a proxy for subsidence rate. The horizons have been used to produce isopach maps for each of the main stratigraphic intervals. In addition, faults and deformation zones are identified in both the foreland basin strata and the underlying basement.

Our seismic interpretation shows that basement depth fluctuates dramatically, ranging from > 12 km to < 3 km. These variations define two sets of transverse depressions and ridges, and several large graben. The Cenozoic succession thins and thickens in step with the basement below, indicating that the basement features affected the rigidity of the Indian lithosphere and thereby controlled accommodation in the foreland basin.

Within the foreland basin succession, steep, strike-slip tear faults indicate that a new frontal thrust has propagated south from the main frontal thrust above a basement ridge and continues to be active beneath the Ganga Basin.

Paleomagnetism of the Devonian McAras Brook Formation, Nova Scotia

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Paleomagnetic constraints on the Devonian to early Carboniferous paleoposition of Laurentia remain poor, and global Devonian paleomagnetic results are difficult to obtain. Paleomagnetic study of the McAras Brook Formation (MBF) of the Antigonish Highlands in Nova Scotia seeks to determine a Devonian paleolatitudinal constraint for the Laurentian margin and possibly to assess post-depositional structural rotation of the Antigonish Highlands with respect to Laurentia. The MBF lies unconformably on the late Silurian - early Devonian Knoydart and Stonehouse formations and is overlain by sedimentary rock units of Windsor Group. Previously published U/Pb age dating of rhyolites from an adjacent rift basin at Ballantynes Cove, which has been correlated with the MBF type section, further suggests a late Devonian age of 370 Ma. In total, 276 oriented samples were obtained from the MBF from coastal and stream bed exposures, representing six basalt flows, six redbed sedimentary sites and two conglomerate field test sites. Demagnetization of MBF basalt flow samples give three Characteristic Remanent Magnetization (ChRM) directions, consistent with previously published results. Upon structural correction, the dual-polarity direction of two separate flows with significant stratigraphic separation reveals a direction at (D/I = 027/-6.3°) with a corresponding paleopole at 35.5° S, 263.5 E. Two other flows with little to no stratigraphic separation yield a direction of (D/I= 340/9.1°) with a paleopole at 45.2° S, 326.7 E. Redbeds underlying the flows have baked contacts, supporting primary ages for both these directions. A third direction obtained from two basaltic flows with no stratigraphic separation provides a direction at 251/-59° with a paleopole at 41° S, 186 E. Intraformational conglomerate sites pass statistical conglomerate tests of randomness, indicating the retention of primary remanence since their deposition. The positive conglomerate and baked contact tests indicate that remanence at McAras Brook appears to be primary, suggesting that the basalt flows have recorded unusually large secular variations of the earth's magnetic field. Recently published paleomagnetic results on Famennian-aged volcanic flows from the Urals and Kazakhstan show significant directional dispersion, suggesting that the Late Devonian geodynamo may have a strong non-dipolar contribution. It therefore may not be possible to calculate a paleolatitude constraint for the Laurentian margin from the flows at MBF. Preliminary paleomagnetic analysis of several overlying sites from the Visean-aged Windsor Group indicates northwest shallow directions, as expected from Carboniferous paleopole positions for North America. Therefore major structural rotation of the Antigonish Highlands portion of the Avalon terrane can be ruled out for this time period onwards.

The Labrador Traps: Remnant of a ca. 2.17 Ga large igneous province in the Labrador Trough

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The Corrugated Hills, a topographic feature that is part of the Howse Zone of the Kaniapiscau Supergroup, consist of well-preserved basalts that were erupted as flows and possibly shallow sills along the rifted margin of the Superior Craton during the Paleoproterozoic. A 2166 ±4 Ma U-Pb zircon SHRIMP age obtained on the Cramolet gabbro at the base of the section (previously dated indirectly at 2169 ±2 Ma), and a 2171 ±2 Ma age for a gabbro higher up in the section, suggest a relatively rapid emplacement age and potential correlation with the Biscotasing and Payne River dyke swarms in the Superior Craton, as was earlier suggested. Most of the flows are columnar and represented by medium- to coarse-grained gabbro, with poikilitic textures suggesting the crystallization sequence olivine → plagioclase → (opx/cpx). Rare hyaloclastite flows with undevitrified glass fragments are also present. Compositionally, the basalts show a tholeiitic affinity and MgO values between 5.43 to 11.24 wt%. They exhibit Zr/Y, Ti/Zr and Ti/V ratios similar to those of primitive mantle, as well as flat to slightly LREE-depleted incompatible element patterns and near-flat heavy REE patterns similar to those observed in modern mid-ocean ridge (MORB) and ocean island (OIB) basalt. On discrimination diagrams, they plot on the mantle array, between N-MORB and E-MORB, within range of Phanerozoic age continental flood basalts such as those of the North Atlantic margin. On primitive mantle-normalized multi-element plots, they show similarities with Payne River and Biscotasing dykes although the latter appear to have assimilated progressively greater amounts of continental crust. Inter-flow sediments are predominantly siliciclastic in nature and derived mostly from the Superior Craton, but include zircon grains as young as ca. 2.2 Ga. They locally include mm-sized angular basalt fragments indicating a proximal derivation contemporaneous with magmatism. Altogether, the Corrugated Hills flood basalts, previously included with the ca. 1.88 Ga Montagnais sills, represent what remains of a ca. 2.17 Ga mantle plume impinging on the eastern margin of the Superior Craton. We propose a new name, the "Labrador Traps" for this unit.