Intracratonic basin processes from breakup of Kenorland to assembly of Laurentia: new geochronology and models for Hurwitz Basin, Western Churchill Province[1]

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During the assembly of Laurentia, the Western Churchill Province (Rae and Hearne domains) formed a central strip along which the Slave, Superior, Saskatchewan and Wyoming cratons were welded (Hoffman, 1988). Caught between Trans-Hudson orogen (ca. 1.92-1.69 Ga) on the east, and Taltson/Thelon orogen (ca. 2.0-1.9 Ga), Wopmay orogen (ca. 1.97-1.84 Ga) and the Nahanni terrane (docked to western Wopmay orogen after ca. 1.84 Ga) on the west, the Hearne and Rae domains were subjected to a complex sequence of post-ca 2.0 Ga tectonic processes historically referred to as the "Hudsonian Orogeny". Continental and marine deposits of the Hurwitz Group, preserved in a northeast-trending train of outliers from northern Saskatchewan to Hudson Bay, record an intracratonic basin that covered much of the Hearne domain. Until recently, the entire Hurwitz Group was considered to have been deposited before "Hudsonian" events, in the interval ca. 2.45-2.11 Ga. Hurwitz Basin was thus regarded to have evolved during initial breakup of the Neoarchean supercontinent Kenorland, before ca. 2.1 Ga, when daughter fragments started to disperse. However, new geochronologic data indicate that upper Hurwitz Group strata were deposited after ca. 1.91 Ga.

The Hurwitz Group lies unconformably above an Archean basement that includes: ca. 3.3-3.0 Ga gneisses; ca. 2.79-2.66 Ga volcanic, siliciclastic and chemogenic rocks (Ennadai-Rankin greenstone belt); and ca. 2.74-2.50 Ga plutonic and gneissic rocks (Davis et al., this volume). Angular unconformity bounded siliciclastic wedges of uncertain age and tectonic significance (Montgomery Group) locally intervene between Archean basement and the Hurwitz Group. The Hurwitz Group is unconformably overlain by the Kiyuk Group, a ca. < 1.90 to > 1.82 Ga succession of conglomerate, arkose and arkose-clast breccia deposited in a partitioned non-marine basin. The Kiyuk Group and its substrate are cut by NW-vergent thick-skinned thrusts related to Trans-Hudson orogen. These thrusts may be the surface expression of NW-vergent crustal imbricates defined by seismic data (Ross et al., 1995) along strike to the southwest (east Alberta orogen). Deformed Hurwitz Group strata are cut by ca. 1.83 Ga feeder dykes to ultrapotassic flows of Baker Lake Basin, likely formed during extrusion of Western Churchill crust during orogenic squeezing on both flanks. The maximum age of Hurwitz Basin is set by the ca. 2.45 Ga Kaminak dykes that cut basement rocks but not the Hurwitz Group. Previously, Aspler and Chiarenzelli (1998) considered that the entire Hurwitz Group was deposited before ca. 2.11 Ga, the age of gabbro sills within (and deformed with) the Hurwitz Group. This was a mistake.

Preliminary results from an integrated geochronologic study of the Hurwitz Group, including SHRIMP determinations from detrital zircons in arenites, Sm/Nd analyses of mudrocks, and Pb-Pb data from carbonate rocks, document a previously unrecognized break (up to 200 My) within the Hurwitz Group. This break necessitates reappraisals of relationships between processes in Hurwitz Basin and events in bounding orogens, mechanisms of Hurwitz Basin subsidence, and correlations of Paleoproterozoic sequences, both within North America and worldwide. Lithostratigraphic units in the Hurwitz Group define four major sequences. We maintain that sequences 1 and 2 (Noomut, Padlei, Kinga and Ameto formations) were deposited during Kenorland breakup. However, deposition of sequences 3 and 4 (Watterson, Ducker and Tavani formations) overlaps with convergence on the western flank of the Rae domain, and either late rifting or convergence on the eastern margin of the Hearne domain.

Sequence 1: Noomut, Padlei and Kinga formations

The early stages of sedimentation in Hurwitz Basin were characterized by low relief and rates of subsidence that rarely progressed beyond the intensity of regional sagging. The Noomut, Padlei and Kinga formations define a conformable sequence in which successive units radially onlap a low-relief basement. During stage 1, polymictic conglomerate (lower Noomut Formation) was deposited in paleovalleys incised into Archean basement, and subarkose to quartz arenite ± quartz pebble conglomerate (upper Noomut Formation) was deposited on a low relief sand plain. Abundant first-cycle quartz-rich sandstones resulted from intense chemical weathering (humid climate; high atmospheric CO_2) in low relief source areas and at sites of temporary storage, as well as to repeated fluvial and eolian reworking. Stage 2 marks a shift toward cold (glacial ?) climates as indicated by dropstones, greywacke (till ?) pellets and possible ikaite pseudomorphs in Padlei Formation lacustrine rhythmites, substantiating interpretations of a worldwide early Paleoproterozoic glacial episode (e.g. Young, 1970; Martin, 1999). Stratified conglomerates and sandstones in the Padlei Formation were deposited on a low-relief fluvial plain, but thick laterally extensive conglomerates recently recognized near the northwestern limit of the basin suggest fault-generated surface relief. Stage 3 (Kinga Formation) represents a return to wet/warm conditions with fluvial (± eolian) deposition of subarkose and quartz arenite on a low relief sand plain (Maguse Member). Locally preserved dolostone beds recently found in the Maguse Member signify a short-lived regional marine incursion. Regional sagging culminated with sheet deposition of supermature quartz arenites in a series of shallow-water lakes, ultimately blanketing an area of at least 100,000 km^2 (Whiterock Member). Local cherts at the top of the Kinga Formation (Hawk Hill Member) formed by spring discharge due to regional, gravity-driven, convective groundwater flow. SHRIMP study of three samples from sequence 1 yielded exclusively Archean zircons (Davis et al., this volume).

Sequence 2: Ameto Formation and emplacement of gabbro sills

The basal contact of the Ameto Formation marks a dramatic change in depositional regime. Beneath this contact, the Whiterock Member comprises up to 450 metres of supermature quartz arenite and is completely devoid of mudrocks, whereas above the contact, the Ameto Formation contains up to 1500 metres of mudstone, siltstone and very fine-grained arkose. Furthermore, in contrast to the Whiterock Member which contains mainly well-rounded monocrystalline quartz grains, the Ameto Formation bears abundant angular to subangular quartz and feldspar. Although abrupt, the transition is conformable because Ameto Formation mudrocks concordantly drape Whiterock Member ripples or mantle chert mounds of the Hawk Hill Member. In the lower part of the Ameto Formation, sharp-based, graded, very fine sandstone/siltstone to mudstone fining upward sequences and delicate rhythmites reflect periodic interruption of below storm wave base suspension sedimentation by mass flow pulses. In the upper part, local hummocky cross-stratified beds and wave-rippled dolosiltites indicate deposition between storm and fairweather wave base; rare stratiform stromatolites suggest microbial mat colonization at photic water depths. The abrupt change from emergent to shallow-water deposition of the Whiterock Member to deep-water sedimentation of the Ameto Formation is interpreted to reflect sudden drowning in the central part of Hurwitz Basin. The appearance of angular and labile grains in the Ameto Formation likely represents concurrent arching and erosional stripping of basement near the margins of the basin; however basin-margin paralic and continental facies are not preserved. Pelitic rocks from the base and top of the Ameto Formation yielded $\varepsilon Nd^{2.2}$ values of - 6.1 and - 5.1 respectively (± 0.8, 1σ), indicating derivation from Archean sources. Locally, the Ameto Formation contains mafic volcanic rocks (Happotiyik Member). These are distinct from regionally distributed (minimum 450 x 175 km) podiform gabbro sills (to 250 m thick) that typically form multiple bodies within weak Ameto pelites, but also cut underlying units. Feeder dykes have been recognized, but are rare. Delicate rhythmites in contact with the gabbros lack soft sediment deformation structures, and hence sill emplacement was likely post-lithification. Based on 13 regionally representative samples, the Hurwitz gabbros are continental tholeiitic basalts and trachybasalts (3.6 to 6.6 wt % MgO). MORB-normalized incompatible element patterns are parallel, displaying enrichments in K, Th, Ba and light REE's (La/Sm_{mn} = 3.0 - 3.7) and slight depletions in Nb and Zr. The gabbros are isotopically homogeneous, with average $\varepsilon Nd^{2.11}$ values of + 0.41 (± 0.71, 1σ). These data suggest that the gabbros are melts of a lithospheric mantle that was enriched in large ion lithophile and REEs relative to depleted upper mantle during an Archean subduction-related metasomatic event (see Cousens et. al., this volume; Sandeman et al., this volume).

Sequences 3 and 4: Watterson, Ducker and Tavani formations

Sequence 3 defines a regressive profile in which a storm dominated, low wave and tidal energy, mixed siliciclastic-carbonate ramp (Watterson and Ducker formations) was prograded by fluvial and coastal facies (lower Tavani Formation) that led away from basement-cored highs and marginal unconformities. Although evidence of cover to basement stripping is preserved in the basal Tavani Formation at the basin margins, direct field evidence of the sub-sequence 3 unconformity is lacking in the basin interior. The Watterson Formation includes three principal ramp facies: 1) outer ramp (below storm wave base) siliciclastic rhythmites ± siliciclastic and carbonate mass flows; 2) mid ramp (below fairweather wave base) siliciclastic rhythmites, low-concentration turbidites, wave-rippled dolosiltite storm beds and local stratiform stromatolite; and 3) inner ramp (subtidal) fairweather stratiform stromatolite fields with bioherms of small, stacked, symmetric domal stromatolites and storm sequences comprising fining upward stromaclast-bearing calcirudite to calcisiltite beds that contain abundant siliciclastic sand (± extrabasinal pebbles). Local lenses of Ducker Formation arkose siltstone, mudstone and stratiform stromatolite record near-shore lagoonal deposits. Tavani Formation massive and parallel-stratified arkoses (± variably desiccated and reworked mudstones) reflect unchannelized sheetfloods. Near the base of the Tavani Formation, stratiform stromatolites, conglomerates containing silicified dolomicrospar (± arkose) clasts, and sheet arkoses signify shoreline reworking of early dolomitized and silicified stromatolites. Shallow-marine carbonate rocks (± pseudomorphs after gypsum) of sequence 4 (upper Tavani Formation) are separated from continental arkoses of sequence 3 by a flooding surface that marks a late eustatic rise in sea level. The youngest detrital zircon ages ($Pb^{207/Pb206}$) from SHRIMP study (2σ errors) are: 1960 ± 22 Ma (-2.9% discordant) from near the middle of the Watterson Formation (n = 36); and 1924 ± 30 Ma (average of two points on one grain) and 1907 ± 27 (- 4.4 % discordant) from near the base of the Tavani Formation (n = 47; Davis et al., this volume). In contrast to sequence 1, samples from sequence 3 contain significant 2.4 to 2.0 Ga zircon populations. An initial attempt to date Watterson dolostones by the Pb-Pb method has yielded an imprecise age of 1839 ± 70 Ma (2σ; r^2 = 0.994; MSWD = 331; 20 fractions, 7 samples; $Pb^{206/Pb204}$ = 17.0-57.0).

Significance

Although the physical characteristics of intracratonic basins are well established, numerous mechanisms have been advocated for basin initiation, subsequent discontinuities in basin subsidence, and syndepositional arching. We infer that continental deposits of sequence 1 record initiation of Hurwitz Basin by regional sagging due to post- ca. 2.45 Ga lithospheric stretching. Lithospheric stretching is favoured because: extensive volcanic rocks are lacking at the base of the section (versus plume models); regional relationships preclude a viable means to generate intraplate compressive stress; voluminous appropriately-aged intrusive rocks are lacking (required of magmatic underplating models); and rare tuff beds in the Padlei Formation indicate thermal activity (in contrast to mantle downwelling “cold-spot” basins). Recent numerical models consider that the lithosphere retains a finite mechanical strength during extension and that basins experience a dynamic flexural response to mechanical unloading. A shallow continental depression during sequence 1 is consistent with extension of a young, warm, "orogenic" lithosphere containing intracrustal weak layers inherited from Neoarchean events. The base of the Ameto Formation records a fundamental break that signals the end of regional sagging. We infer that the Ameto Formation developed in response to a second episode of stretching during which flexural isostatic rebound led to basin-centered deepening and basin margin arching, consistent with renewed extension of a "continental" lithosphere with a cooler, stronger, less anisotropic crust. Conceivably, magmatic upwelling augmented arching: we speculate that a ca. 2.2 Ga curvilinear gabbro dyke swarm (Tulemalu) northwest of Hurwitz Basin, reflects such upwelling. Geochemical and isotopic data indicate that the Hurwitz gabbro sills resulted from melting of lithospheric mantle due to continued extension and thinning at ca. 2.1 Ga.

Mechanisms that induced crustal flexure, progradation of Tavani continental facies, and growth of the Watterson carbonate ramp during sequence 3 are enigmatic. The new geochronologic data demonstrate that basin rejuvenation occurred during post ca. 1.91 Ga shortening on the west (related to Taltson/Thelon and Wopmay orogens), and the appearance of ca. 2.4 to 1.9 Ga zircons in sequence 3 likely records stripping of sources such as in Taltson basement (McNicoll et al., in press), Taltson/Thelon orogen, and the western Rae domain. Regional boundary conditions to the south and east are uncertain. Sequence 3 may have formed during late extension related to the passive margin stage of Wollaston Basin on the eastern Hearne margin, however the possibility that sequence 3 is partly coeval with ca. 1.87-1.86 Ga approach and accretion of the La Ronge-Lynn Lake arc to the Hearne edge (see Yeo et al., this volume) cannot be ruled out. New P-T data (Berman et al., this volume) delineate a high pressure corridor (ca. 10-13 kbar) immediately northwest of Hurwitz Basin (as preserved). However, it remains unclear if implied thickening (> 15 km) was at ca. 2.5 or ca. 1.93 Ga (Berman et al., this volume). Hurwitz Basin fails to record any of the structural, metamorphic or sedimentologic effects expected to result from thickening of this magnitude. Sequence 3 strata are structurally concordant with virtually undeformed and unmetamorphosed beds in underlying units; it is difficult to envisage how lower Hurwitz Group sequences could remain undisturbed during the growth of stacked thrust sheets required to generate crustal loads in excess of 15 km, regardless if Hurwitz Basin was in the hanging wall or foot wall of such imbricates. Furthermore, sequence 3 deposits reflect relatively gentle basement arching and carbonate ramp sedimentation rather than an extensive foredeep that would be expected adjacent to dramatically loaded crust. Hence, from the perspective of Hurwitz Basin, it is simplest to suggest that thickening occurred at ca. 2.5 Ga. We infer that sequence 3 was deposited after a ca. 1.9 Ga mafic underplating, event, manifested by voluminous 1910-1902 Ma gabbroic rocks of the Kramanituar complex (near Chesterfield Inlet) and after partial exhumation of this complex at 1898 Ma (see Sanborn-Barrie, 1999).

In summary, initial Hurwitz Basin sedimentation (sequences 1 and 2) was in the interior of Kenorland during early stages of protracted supercontinent breakup (ca. 2.45-2.11 Ga), and long-standing correlations (e.g. Young, 1970) with early Paleoproterozic sequences and mafic magmatism in North America and the Baltic Shield remain valid. In North America, passive margin basins flanking the Superior Province (e.g. Huronian Supergroup) and the Wyoming Province (e.g. Snowy Pass Supergroup) defined the edges of Kenorland until ca 2.1 Ga. However, new data indicate that sequences 3 and 4 in Hurwitz Basin were deposited after ca. 1.91 Ga. Thus late Hurwitz sedimentation was broadly coeval with sequences deposited on the margins of Kenorland's daughter fragments, during late dispersal of these fragments and/or during their reassembly as Laurentia (e.g.: Wollaston Supergroup on eastern Hearne margin; Lake Harbour Group and Blandford Bay assemblage and parts of Penrhyn and Piling groups in northern Rae domain; various circum-Superior units) and with intracratonic dismemberment of the western Rae domain (Nonacho Group). Although major discontinuities in Hurwitz basin are attributed to intrabasinal tectonic processes, these may have had more global significance. Continued field, geochronologic and chemostratigraphic studies will help establish a more rigorous worldwide Paleoproterozoic sequence stratigraphy.

< 2.45 - < 1.91 Ga intracratonic Hurwitz Basin, western Churchill Province

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Biographical note

For 20 years, Larry Aspler (BSc. McGill, 1976; Ph.D. Carleton, 1985) has been undertaking basin analysis in the western Churchill Province. Contracts from the NWT Geology Division, Indian Affairs and Northern Development (Yellowknife), and the Geological Survey of Canada are gratefully acknowledged, as is current support from the newly created Canada-Nunavut Geoscience Office.