Record of Precambrian orogenic unroofing preserved in fluvial strata of western Nunavut

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Abstract: Fluvial sandstone in the Kilohigok and Elu basins of western Nunavut record deposition related to the amalgamation and tenure of the Nuna supercontinent. The ca. 1.9 Ga Burnside River Formation was sourced by erosional unroofing of the nearly coeval Thelon Orogen, about 250 km away, in a regime of crustal flexure. This proximally sourced sandstone contains abundant clustered channel forms that point to high-magnitude discharge and sediment yield in weakly mobile channels. By comparison, the ca. 1.6 Ga Ellice Formation was sourced by the erosional unroofing of the ca. 1.8 Ga Trans-Hudson Orogen, about 1000 km away, in a geodynamic regime of thermally driven sagging. The distally sourced Ellice Formation contains some rare and nonclustered channel forms that point to lesser discharge and sediment yield in mobile channels. Provenance analysis and plate models support links between the fluvial style of the Burnside River and Ellice formations and orogenic unroofing facilitated by Hadley-cell atmospheric circulation at tropical paleolatitudes.

Résumé : Dans les bassins de Kilohigok et d'Elu, dans l'ouest du Nunavut, des grès fluviatiles témoignent de la sédimentation associée à l'assemblage et à l'existence du supercontinent Nuna. Les matériaux de la Formation de Burnside River, qui remonte à environ 1,9 Ga, proviennent de la dénudation par érosion de l'orogène de Thelon, d'un âge à peu près semblable et éloigné d'environ 250 km, dans un régime de flexure crustale. Ces grès à source proximale renferment d'abondantes formes de chenaux groupés, qui sont l'indication de forts débits et de grandes charges de sédiments dans des chenaux peu mobiles. En contrepartie, la Formation d'Ellice, qui remonte à environ 1,6 Ga, tire ses matériaux de la dénudation par érosion de l'orogène trans-hudsonien, distant d'environ 1000 km et âgé d'environ 1,8 Ga, dans un régime géodynamique d'affaissement de source thermique. La Formation d'Ellice, aux matériaux de provenance distale, contient peu de formes de chenaux et ceux-ci ne sont pas groupés, ce qui indique des débits plus faibles et des charges moindres de sédiments dans des chenaux mobiles. L'analyse de la provenance et les modèles de plaques soutiennent les liens entre le style fluvial des formations de Burnside River et d'Ellice et la dénudation orogénique, qui a été facilitée par la circulation atmosphérique liée aux cellules de Hadley aux paléolatitudes tropicales.

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INTRODUCTION

The erosional unroofing of orogenic edifices is widely recognized as a primary control on the delivery of detritus toward sedimentary basins downslope of mountain ranges (Summerfield and Hulton, 1994; Walling and Webb, 1996; Willett, 1999; Syvitski et al., 2003; Garzanti et al., 2007). Through self-sustained isostatic uplift and removal of progressively lower crustal panels (Beaumont et al., 1992; Hoffman and Grotzinger, 1993), erosional orogenic unroofing was responsible for global-scale mass transfer of sediment (Syvitski et al., 2003). The highest rates of sediment yield were recorded in the forelands of young orogenic belts facing moist atmospheric circulation systems (Métivier et al., 1999; Syvitski et al., 2014).

The modes and tempos of orogenic unroofing are dictated by an orogen's width, crustal thickness, and associated metamorphic gradients as well as by the prevailing climate and biogeomorphic setting at the time (Beaumont et al., 1992; Hoffman and Grotzinger, 1993; Willett, 1999; Syvitski et al., 2003). An overarching goal of Precambrian geology is to decipher secular trends in planetary, crustal, and surface processes through the study of Earth's rock record. Questions linger about the evolution of orogenic style through time (e.g. Percival et al., 2012; Weller and St-Onge, 2017) as well as the influence of diverse micro- and macroscopic biotic communities on surface weathering (Eriksson et al., 1998; Long, 2011; Ielpi et al., 2018a). A topic of particular interest to sedimentologists is the comparison between fluvial strata deposited before and after the early Paleozoic radiation of macroscopic life — and, specifically, vascular vegetation — across Earth's continents (Davies and Gibling, 2010; Santos et al., 2017; Ielpi 2018; Ganti et al., 2019; Ielpi and Lapôtre, 2020). Fluvial strata are important for their ability to record information about provenance and physical processes at the time of deposition.

This paper presents a summary of three field seasons of study (2014–2016) in the Kilohigok and Elu basins of western Nunavut, Arctic Canada (Fig. 1), as part of the second phase of the Geo-mapping for Energy and Minerals program of the Geological Survey of Canada. Studies included thematic sedimentology of terrigenous sandstone deposits, characterization of their provenance, and assessment of their potential for uranium enrichment. Here the focus is on a sedimentological and depositional-architectural characterization of two well preserved Paleo- to Mesoproterozoic sandstone units of the Burnside River and Ellice formations. Aspects of sedimentation in two basin tracts interpreted to be occupying proximal and distal locations to their upland source areas are discussed, and the relationship between depositional style as well as patterns of orographic precipitation and orogenic unroofing are assessed. This study ultimately serves to demonstrate that, once integrated with provenance data, fluvial sedimentary records can be interrogated to test and refine extant paleogeographic and paleoclimate models.

GEOLOGICAL SETTING

Laurentia, the ancestral core of North America, preserves an assemblage of crustal blocks that are inferred to have amalgamated during a time of global orogenesis at ca. 2.1 to 1.8 Ga (Hoffman, 1988; Zhao et al., 2002; Pehrsson et al., 2016), and that resulted from the collision of pre-existing crustal blocks, including the Superior, Hearne, Sask, Wyoming, Rae, and Slave cratons (Bleeker, 2003; Pehrsson et al., 2013). Products of this amalgamation are a set of highly deformed and metamorphosed sutures between pre-existing cratons (inferred to represent the roots of now deeply eroded orogenic belts; e.g. Berman et al., 2013) and widespread, poorly deformed, and weakly metamorphosed sandstone, shale, and carbonate strata (inferred to represent, in turn, the remnants of large sedimentary basins developed during supercontinent amalgamation, tenure, and breakup (e.g. Young et al., 1979; Rainbird et al., 1996; Davidson, 2008). Causal links between the repeated erosional unroofing of orogens in the Canadian Shield and the development of large syn- to postorogenic basins are supported by provenance analysis (McCormick, 1992; Rainbird and Young, 2009; Rainbird et al., 2017).

Sedimentary basins preserved on the Slave Craton in western Nunavut include the Kilohigok and Elu basins (Fig. 1), which record fluvial-eolian to shallow-marine deposition at ca. 2.0 to 1.8 Ga and 1.6 to 1.3 Ga, respectively (Campbell, 1979; Campbell and Cecile, 1981; Grotzinger and McCormick, 1988; Bowring and Grotzinger, 1992; Heaman et al., 1992; Ielpi and Rainbird, 2015, 2016). Theories proposed to explain the development of such basins included failed rifting and intracratonic extension (Hoffman, 1973; Campbell and Cecile, 1981). The Kilohigok Basin is hypothesized to have been a foreland basin, produced by crustal flexure accompanying loading of the Rae Craton (upper plate) onto the Slave Craton during the Thelon Orogeny (Grotzinger and Gall, 1986; Grotzinger and McCormick, 1988; Tirrul and Grotzinger, 1990). The Elu Basin is considered to be one of a family of intracontinental basins formed by thermal subsidence following the Hudsonian Orogeny and amalgamation of the Nuna supercontinent (Rainbird and Young, 2009; Rainbird et al., 2014; Ielpi and Rainbird, 2015).

Basin stratigraphy

The Kilohigok and Elu basins together encompass about 10 km of strata exposed for about 800 km along strike (Campbell and Cecile, 1976; Campbell, 1981; Grotzinger and McCormick, 1988), although a composite stratigraphic section can only be reconstructed in the central Bathurst Inlet area (Fig. 2). Sedimentary rocks in the region are mainly underlain by late Archean (ca. 2700–2580 Ma; Sherlock et al., 2012) granitoid rocks, gneiss, and intervening metasedimentary and metavolcanic panels (Culshaw and van Breeman, 1990; Sherlock et al., 2012). In the Kilohigok Basin, fluvial to tide-dominated shallow-marine conditions

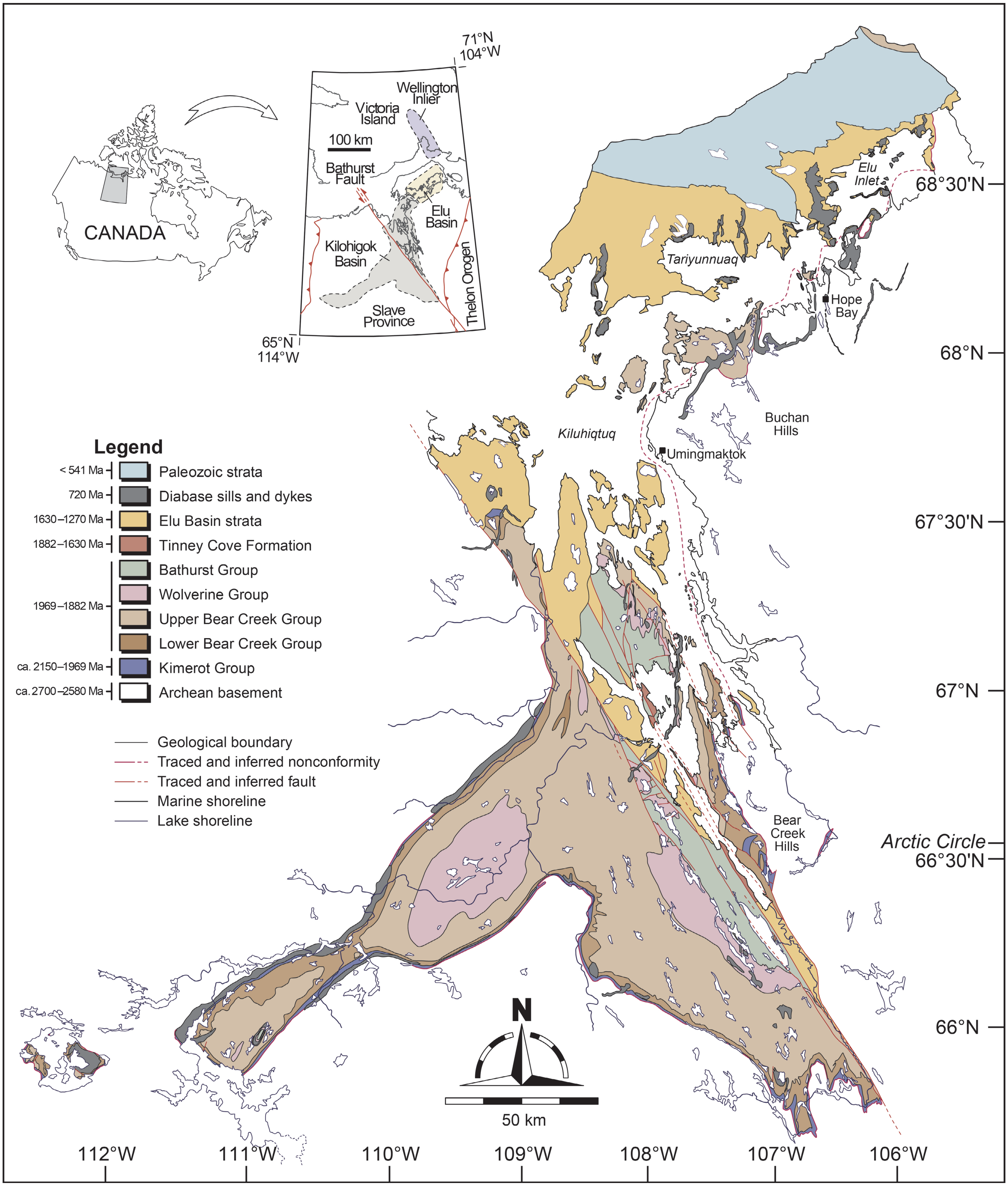

Figure 1. Geographic and geological setting of the Kilohigok and Elu basins, western Nunavut (*modified from* Campbell and Cecile, 1976; Ielpi et al., 2017a).

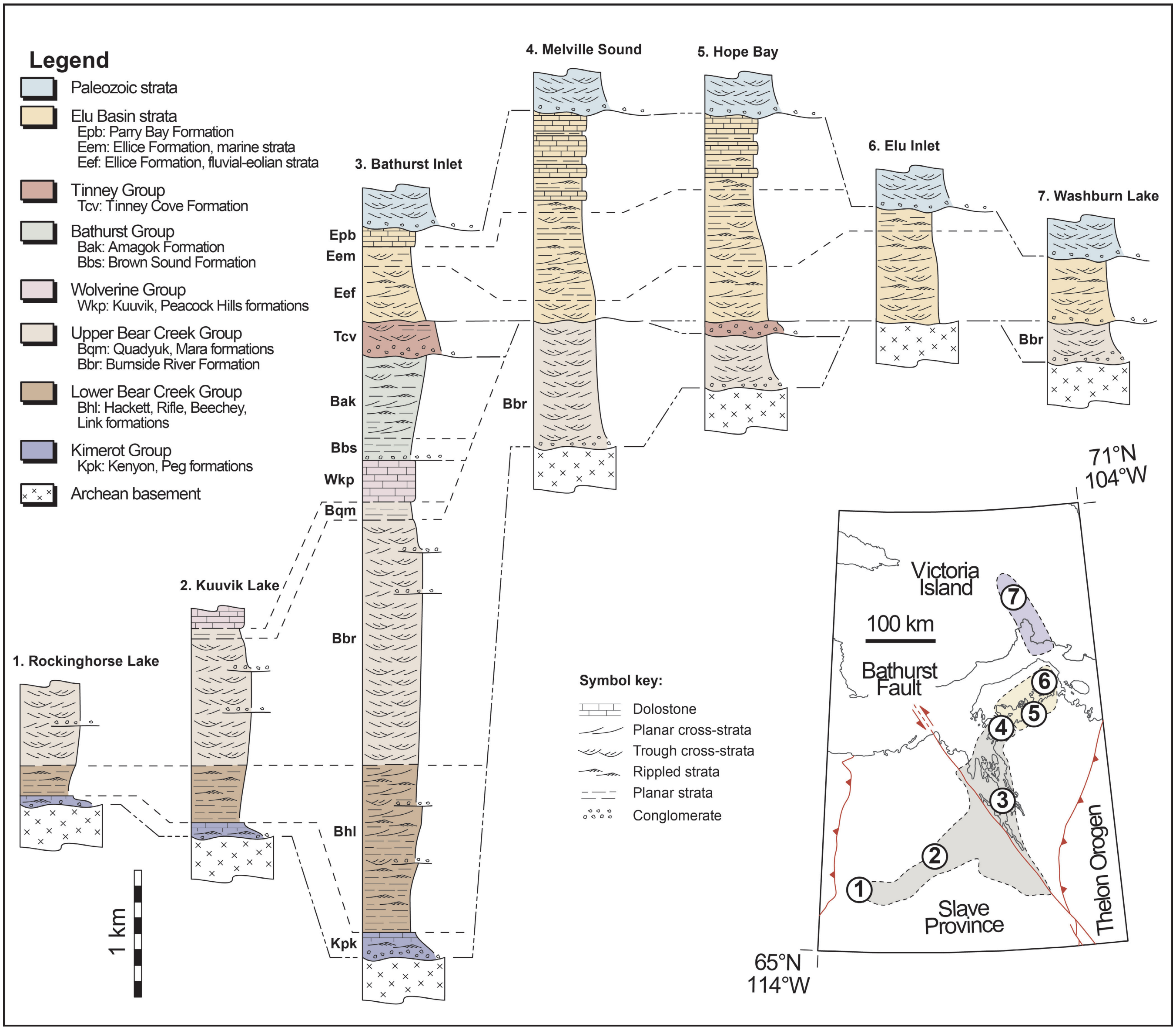

Figure 2. Simplified stratigraphic sections through the Kilohigok and Elu basins, western Nunavut (*modified from* Campbell and Cecile 1976, 1981; Grotzinger and McCormick, 1988; Ielpi and Rainbird, 2015, 2016). The stratigraphic profile mimics grain-size-controlled weathering profiles on outcrop.

along a stable platform margin are recorded at ca. 2150 to 1969 Ma (Bowring and Grotzinger, 1992; Bradley, 2008; Sheen et al., 2019) by conglomerate, sandstone, and dolostone of the Kimerot Group (Fig. 3a; Grotzinger and Gall, 1986). Although the geodynamic significance of the Kimerot Group and broadly correlative successions preserved on the Slave Craton (e.g. the East Arm Basin; Sheen et al., 2019) is being re-evaluated, these units have previously been interpreted to represent rifting and drifting along a Slave Craton passive margin (Grotzinger and Gall, 1986). The overlying Bear Creek, Wolverine, and Bathurst groups (1969–1882 Ma; Bowring and Grotzinger, 1992) are composed of a largely clastic succession that transitions upsection from deep- to shallow-marine facies (Fig. 3b), and thick terrestrial sandstone, with minor conglomerate (e.g. the Burnside River Formation; Fig. 3c, d). These groups are inferred to represent crustal flexure and foredeep development in response to collision between the Slave and Rae cratons (Grotzinger and McCormick, 1988; Grotzinger et al., 1989; Tirrul and Grotzinger, 1990), an inference substantiated by geochronological constraints pointing to nearly synchronous Thelon Orogeny and Bear Creek Group deposition (Bowring and Grotzinger, 1992; Berman et al., 2015).

The transition from Kilohigok Basin to Elu Basin deposition is placed at the regionally unconformable boundary between the Bathurst Group and overlying Tinney Cove Formation (the latter dated at 1882 to 1630 Ma; Bowring

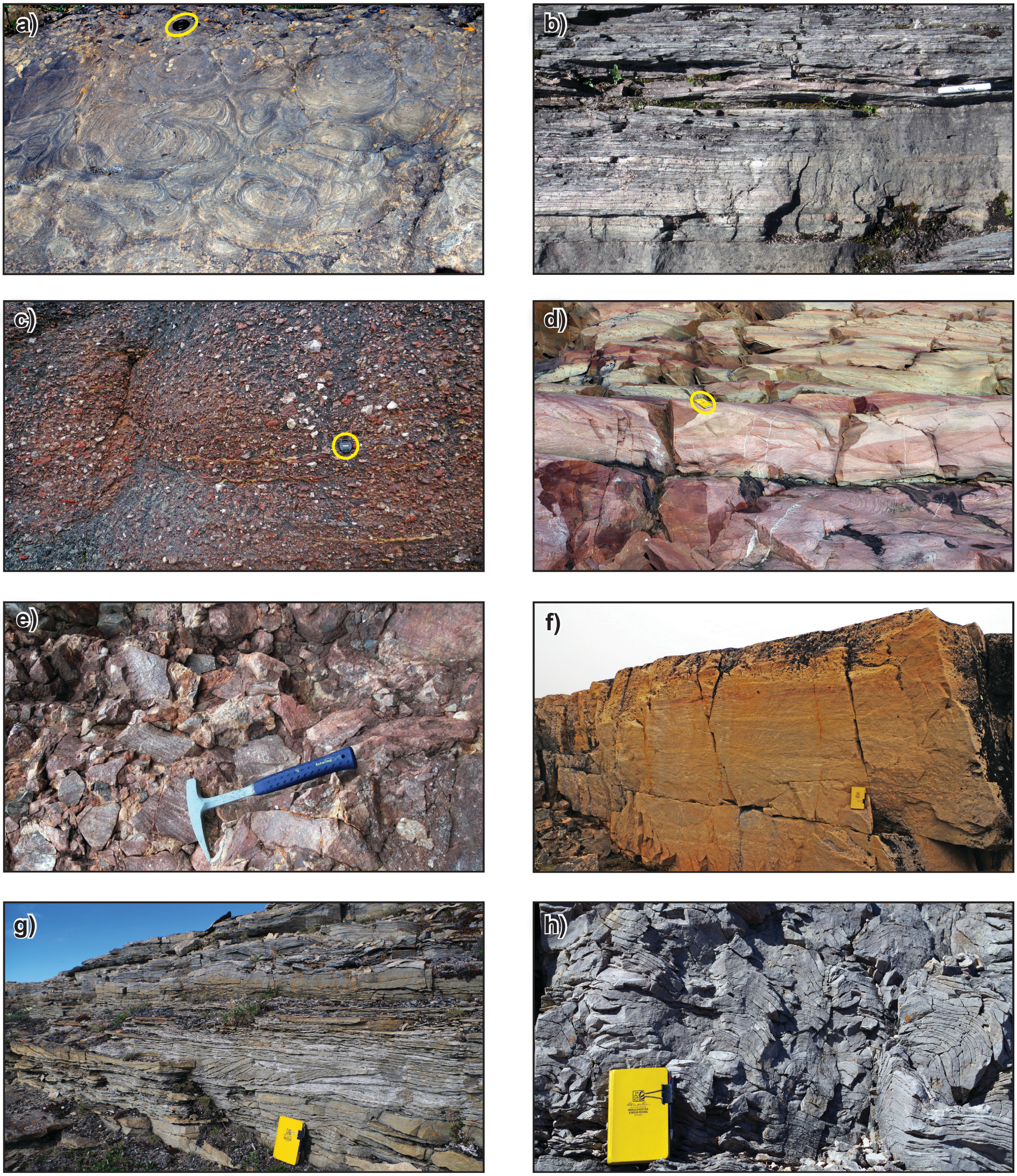
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Figure 3. Representative field photographs of the stratigraphy in the Kilohigok and Elu basins, western Nunavut: **a)** intertidal stromatolitic dolostone, Peg Formation, Kimerot Group; lens cap for scale (about 5 cm in diameter and circled in yellow); NRCan photo 2019-739; **b)** deep-marine (i.e. below wave base) shale and sandstone, lower Bear Creek Group; marker for scale (10 cm long); NRCan photo 2019-752; **c)** extrabasinal pebble-conglomerate of alluvial fan origin, Burnside River Formation, upper Bear Creek Group; lens cap for scale (about 5 cm in diameter and circled in yellow); NRCan photo 2019-753; **d)** cross-stratified sandstone of fluvial origin, Burnside River Formation, upper Bear Creek Group; field book for scale (about 10 cm long and circled in yellow); NRCan photo 2019-757; **e)** intrabasinal scree-slope breccia (individual clasts are derived from the underlying Burnside River Formation), Tinney Cove Formation; hammer for scale (about 30 cm long); NRCan photo 2019-740; **f)** planar-bedded and cross-stratified fluvial sandstone, Ellice Formation, Elu Basin; field book for scale (about 9 cm long); NRCan photo 2019-756; **g)** cross-stratified sandstone and planar-bedded dolostone of shallow-marine origin, Ellice Formation, Elu Basin; field book for scale (about 9 cm long); NRCan photo 2019-754; **h)** inter- to subtidal stromatolitic dolostone, Parry Bay Formation, Elu Basin; field book for scale (about 9 cm long); NRCan photo 2019-755. All photographs by A. Ielpi.

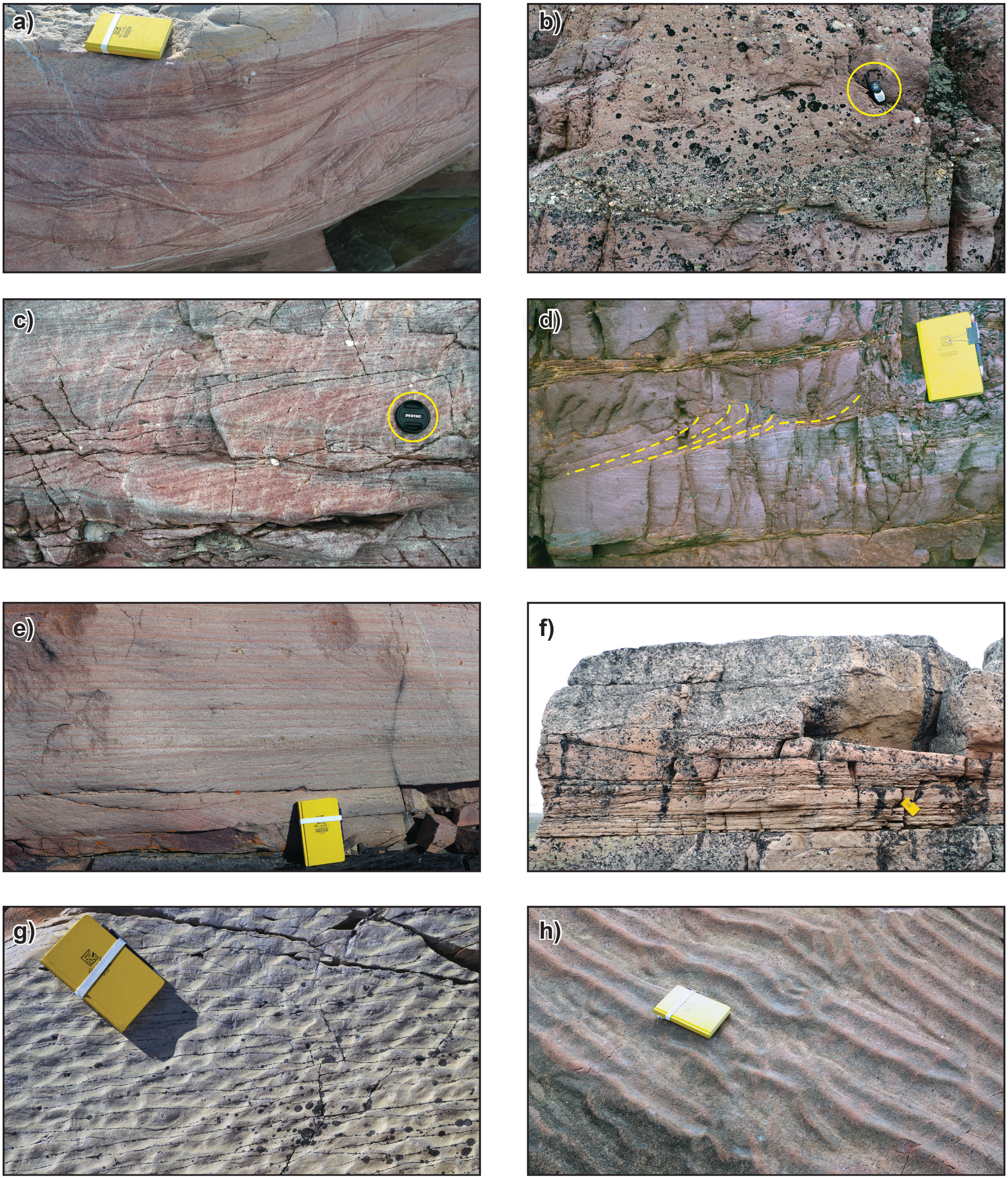
and Grotzinger, 1992). The Tinney Cove Formation records the localized deposition of scree-slope breccia and conglomerate units overlain by immature terrestrial sandstone (Fig. 3e; Campbell, 1978). Although inferring a geodynamic setting from such geographically and stratigraphically limited deposits is fraught with uncertainty, the Tinney Cove Formation can be tentatively related to extensional block-faulting of older Kilohigok Basin strata in the aftermath of the amalgamation of the supercontinent Nuna (Rainbird et al., 2014). Such a hypothesis is consistent with the stratigraphic development of the overlying Elu Basin strata (bracketed between 1630 and 1270 Ma; Heaman et al., 1992; Rainbird et al., 2014), which is proposed to record thermally driven intraplate sagging and the establishment of a widespread terrestrial to nearshore-marine depression (e.g. Ellice Formation; Fig. 3f–h; Rainbird et al., 2014; Ielpi and Rainbird, 2015).

SEDIMENTOLOGY

Thick and regionally extensive fluvial sandstone units like the Burnside River and Ellice formations often exhibit a limited number of sedimentary facies in outcrop (Miall, 1996). Such sedimentary facies point to shared physical processes that are common to most fluvial systems irrespective of their planform (Brierley and Hickin, 1991; Ethridge, 2011). It is rather the appreciation of depositional architecture, at scales varying from that of metres to kilometres, and paleoflow analysis that allow for the eventual inference of (pre-vegetation) fluvial style (Long, 2011; Hartley et al., 2015; Ielpi et al., 2018b). Details about the methodological approaches employed to collect sedimentological, depositional architecture, and paleoflow data sets are contained in previous publications, to which the reader is referred (e.g. Ielpi and Rainbird, 2015, 2016; Ielpi et al., 2015, 2017a).

Analysis of the fluvial deposits of both the Burnside River and Ellice formations has revealed the common occurrence of the following facies. Cross-stratified sandstone (Fig. 3d, f, 4a), pebbly in places (Fig. 4b) and with foresets dipping at 5° to 20°, is by far the most abundant (~80% of inferred volume). Cross-sets present a predominantly trough-like (Fig. 4a) and, less frequently, planar (Fig. 4c) geometry, and range in thickness from 0.1 to approximately 1.5 m. Monotonous bedsets of cross-stratified sandstone reach up to tens of metres in thickness. In places, such cross-beds bear submetre-scale soft-sediment deformation such as, for example, overturned and dissected foresets (Fig. 4d) or, less frequently, water-escape cuspate structures. Crossbeds are interpreted as a record of the accretion and migration of dunes in subcritical flow regime (Collinson et al., 2006), and their widespread occurrence in Precambrian environments is related to deposition by sustained, perennial flows in relatively deep (>1 m) fluvial channels (Todd and Went, 1991; Nicholson, 1993; Long, 2006). Soft-sediment deformation is a common feature of prevegetation fluvial sandstone units and, when at the submetre scale, is associated with flow-induced bed shearing or dewatering soon after high bedload yield (Owen, 1995; Owen and Santos, 2014; Ielpi and Ghinassi, 2015).

Figure 4. Sedimentary facies observed in the Burnside River and Ellice formations, western Nunavut: **a)** trough cross-stratified sandstone; field book for scale (about 9 cm long); NRCan photo 2019-744; **b)** trough cross-stratified sandstone, pebbly in places; hand-held radio for scale (about 10 cm long and circled in yellow); NRCan photo 2019-745; **c)** planar-cross-stratified sandstone; lens cap for scale (about 5 cm in diameter and circled in yellow); NRCan photo 2019-746; **d)** cross-stratified sandstone with flow-induced sheared foresets (highlighted by dashed lines); field book for scale (about 9 cm long); NRCan photo 2019-747; **e)** planar-stratified sandstone; field book for scale (about 9 cm long); NRCan photo 2019-748; **f)** assemblage of planar-stratified and low-angle cross-stratified sandstone; field book for scale (about 9 cm long); NRCan photo 2019-749; **g)** current ripples preserved on a bedding plane; field book for scale (about 9 cm long); NRCan photo 2019-750; **h)** wave ripples preserved on a bedding plane; field book for scale (about 9 cm long); NRCan photo 2019-751. All photographs by A. Ielpi.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Second in order of abundance (~15% of inferred volume) is an assemblage of planar cross-stratified sandstone (Fig. 4e), pebbly in places or, rarely, arranged in wavy- and lenticular-bedded sets, and low-angle cross-stratified sandstone (i.e. foreset dipping <5°; Fig. 4f). Bedsets of planar cross-stratified and low-angle cross-stratified sandstone reach up to just under a metre in thickness. Their occurrence signifies deposition of low-relief dunes and flat-lying traction carpets in either transcritical or supercritical flow regime (represented by low-angle cross-sets and planar sets, respectively; Collinson et al., 2006). An interpretation of high-flow-strength bedforms such as antidunes preserved as wavy- and lenticular-bedded sets is also viable (Fielding, 2006). Accordingly, their occurrence in Precambrian fluvial sandstone units is traditionally interpreted to indicate episodes of ephemeral discharge (Røe, 1987; Lebeau and Ielpi, 2017) in shallow (<1 m deep) channels.

Fluvial strata of the Burnside River and Ellice formations also contain rare (~5% of inferred volume) tabular beds of rippled sandstone, a few centimetres to a decimetre thick (exceptionally up to 2 m thick). Ripples mainly point to unidirectional flow (Fig. 4g), although centimetre-thick layers preserving wave-ripple morphology (Fig. 4h) have also been observed. These deposits represent subcritical flow-regime deposition in ripple-bed configuration (Collinson et al., 2006) and are typically attributed to waning-flood and shallowing-water discharge stages (Sønderholm and Tirsgaard, 1998). The less common preservation of wave-ripple forms accordingly suggests bed reworking in wind-stressed shallow ponds that were located beside active fluvial channels (Fralick and Zaniewski, 2012).

Finally, it is important to point out that, beside the preponderance of fluvial deposits, both the Burnside River and Ellice formations contain a portion of supermature and very well sorted, fine-grained quartz arenite. These deposits feature quartz grains with frosted surface, pin-stripe stratification that is characterized by locally inversely graded laminae, within large-scale sets of crossbeds with basal deflation lags. All these features are classically related to eolian transport (Chakraborty, 1991; Cain and Mountney, 2009). Although the sedimentological features of eolian facies appear comparable in the two formations, architectural analysis of large exposures of the eolian strata using satellite imagery highlighted different relationships with adjoining fluvial strata. In the Burnside River Formation, eolian deposits appear to have been limited to simple dunes developed atop interfluves, i.e. locally developed flat surfaces found in-between entrenched channels (Ielpi and Rainbird, 2016). By comparison, areally more extensive eolian deposits of the Ellice Formation display a complex internal interstratification and were related to comparatively mature dune fields developed over larger basin tracts flanking fluvial-channel belts (Ielpi and Rainbird, 2015).

PALEOFLOW ANALYSIS

A large data set of paleoflow vectors collected from both the Burnside River and Ellice formations points to northwestward shedding of detritus (present co-ordinates; Fig. 5), a recurring theme in many Proterozoic sandstone units preserved on the Canadian Shield (Rainbird and Young, 2009; Rainbird et al., 2014, 2017). Specifically, paleofow data from the Burnside River Formation exposed in northern Kiluhiqtuq (formerly Bathurst Inlet) and Tariyunnuaq (formerly Melville Sound) indicate focused to mildly dispersed unimodal transport over the north-northeastern to west-northwestern quadrants, yet notably with a cluster of paleoflow data pointing to opposite, eastward paleoflow, in the southwestern corner of the sampled area (Fig. 5). Paleoflow data from the Ellice Formation, exposed in Tariyunnuaq and Elu Inlet, point instead to mildly dispersed, unimodal transport toward the north-northwestern to west-southwestern quadrants (Fig. 5).

DEPOSITIONAL ARCHITECTURE

A remarkable feature of the study area is the abundance of exposures where undeformed sections, hundreds of metres thick and several kilometres wide, can be observed (e.g. Fig. 6a). Such exceptional quality of exposure allowed the examination of depositional geometry at a scale that typically remains unresolved in Precambrian basins. Full details on the depositional architecture of the Burnside River and Ellice formations are published elsewhere (Ielpi and Rainbird, 2015, 2016) and here, only details relevant to their style of channellization are reported.

Several architectural elements were recognized with the aid of satellite-based imagery and oblique aerial photography; these included laterally continuous sand sheets, large-scale cross-stratified fluvial-bar complexes, and, perhaps most notably, active-channel forms in both formations (the latter a feature thought to be uncommon in Precambrian fluvial strata; Davies and Gibling, 2010). Channel forms consist of sand bodies floored by scoop-shaped erosional surfaces and composed of sedimentary facies pointing to the direction of active flow (as opposed to abandonment intervals; cf. Toonen et al., 2012). The discrimination between channel forms and other architectural elements, such as valley fills, relied on criteria discussed by Gibling (2006) and Gibling et al. (2011), such as: 1) the identification of fluvial bars within the channel forms, approximating the thickness of the latter; 2) the lack of stratigraphic correlation between individual channel scours; and 3) the scalar disambiguation from observed valley fills, which consistently displayed 10- to 100-fold wider geometry.

Fifty-two active channel forms were recognized in the Burnside River Formation. These channel forms are observed in distinct, narrow clusters (Fig. 6a) and are contained within stratigraphic sections underlain by a basin-floor unconformity that displays up to 250 m of relief 15 km along strike.

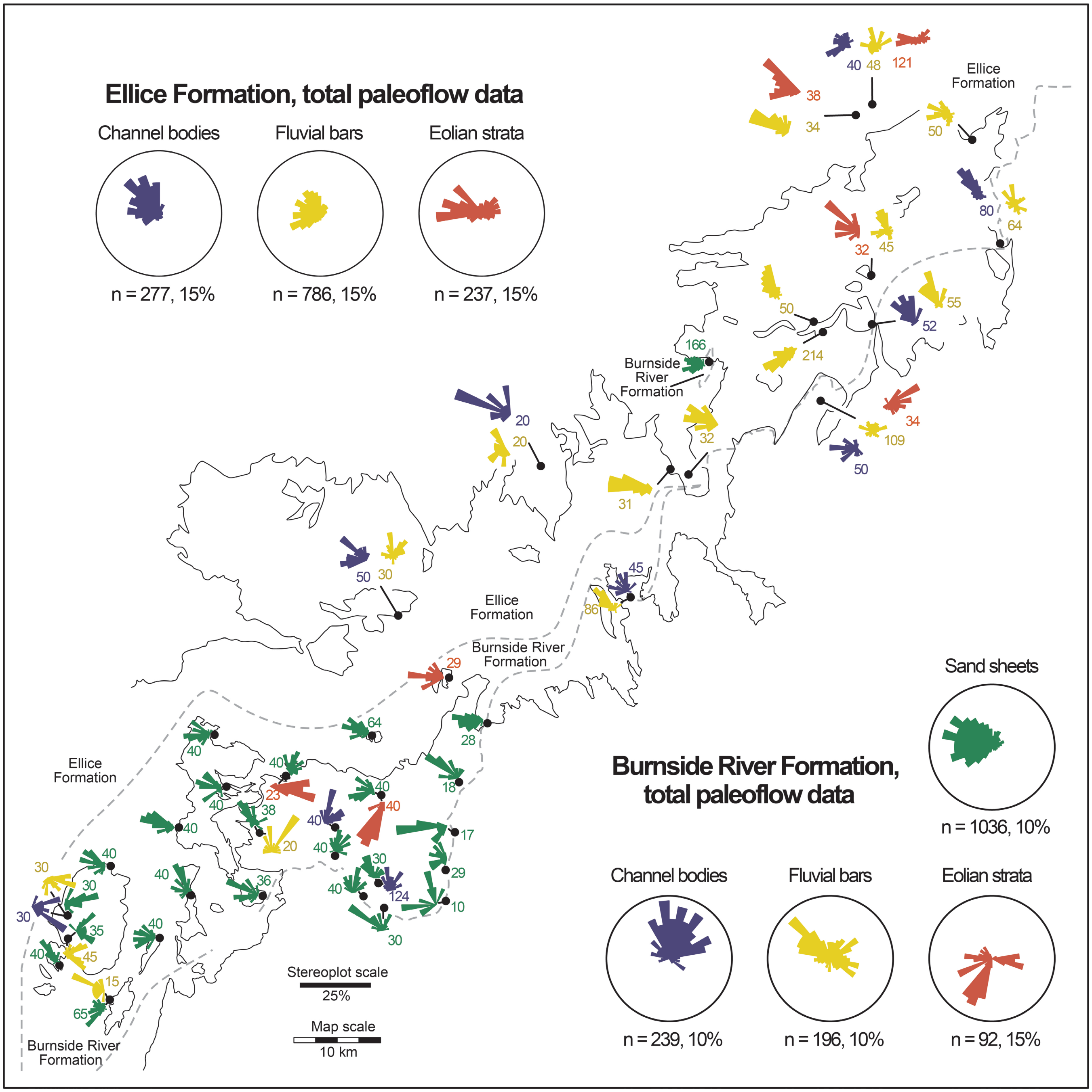

Figure 5. Graphic summary of the paleoflow data from the Burnside River and Ellice formations, western Nunavut (*modified from* Ielpi and Rainbird, 2015, 2016). Numbers next to individual stereoplots indicate number of data points.

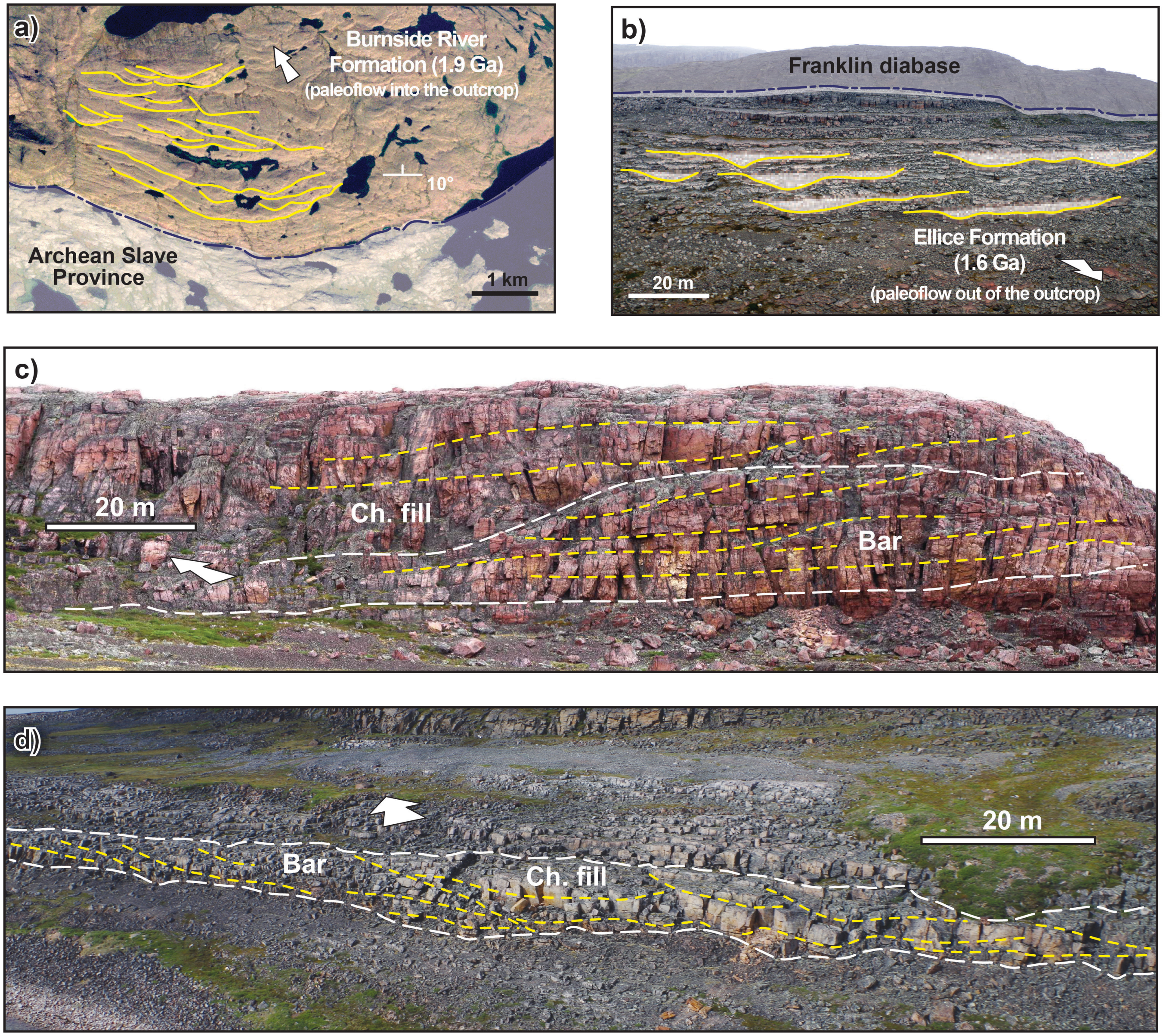

Figure 6. Depositional architecture of channel forms observed in the Burnside River and Ellice formations, western Nunavut (Ielpi et al., 2017b), including **a)** a satellite view of a cluster of channel forms in the lower stratigraphic portion of the Burnside River Formation, with individual channel forms delineated by yellow lines (note erosional relief along the unconformity with basement rocks); **b)** an oblique aerial photograph of channel forms of the Ellice Formation delineated by yellow lines and grey shading. Interpreted architectural panels showing representative examples of fluvial sediment bars (Bar) and fluvial channel fill (Ch. fill) from **c)** the Burnside River Formation and **d)** the Ellice Formation, with the white and yellow dashed lines indicating architectural-element boundaries and stratification patterns, respectively.

Such channel forms are 5 to 102 m thick and 92 to 1106 m wide. Accordingly, their aspect ratio (i.e. width to thickness) ranges from 9 to 83, averaging 37 (Ielpi et al., 2017b). Fluvial bars observed therein are less than 25 m thick and point to downstream accretion and migration, a feature consistent with dominantly low-sinuosity, weakly mobile channels characterized by a straight to braided planform (Fig. 6c). By comparison, eight active-channel forms were recognized in the Ellice Formation, within sections underlain by a basin-floor unconformity that displays up to 30 m of relief 20 km along strike. The channel forms of the Ellice Formation are not clustered (Fig. 6b), 50 cm to 7 m thick, and 5 to 400 m wide (Ielpi et al., 2017b). Their aspect ratio ranges from 6 to 57, averaging 21. Fluvial bars observed therein are less than 4 m thick and point to mixed modes of accretion and migration (dominantly downstream-lateral; Fig. 6d), which is consistent with mobile, low- to intermediate-sinuosity channels characterized by a wandering planform.

DISCUSSION AND CONCLUSIONS

Provenance

Inferences about the provenance of the Burnside River and Ellice formations are formulated based on regional basin analysis, paleoflow distribution, and detrital-zircon geochronology. Several features are consistent with a genetic link between the growth of the Thelon tectonic zone and the development of a foredeep in the Kilohigok Basin, including thickness trends, intrabasin unconformities, and kinematic indicators consistent with syndepositional crustal flexure and northwestward foredeep migration (Grotzinger and Gall, 1986; Grotzinger and McCormick, 1988; Grotzinger et al., 1989; Tirrul and Grotzinger, 1990). Combining the above with observed paleoflow trends (Fig. 5) leads to the formulation of a preferred hypothesis according to which much of the detritus from the Burnside River Formation is directly derived from erosion of the Thelon Orogen (Ielpi et al., 2017b). This inference is corroborated by upward compositional trends observed throughout the formation, such as a shift from monomictic to oligomictic conglomerate, the appearance of intrabasinal detritus, and an increase in feldspar content (Ielpi and Rainbird, 2016). Geochronological data presented in McCormick (1992) showed an important detrital-zircon age mode from the Burnside River Formation synchronous with peak metamorphism and deformation during the Thelon Orogeny (1.97–1.99 Ga), as well as older detrital ages (2.3–2.4 Ga) that the authors tentatively related to sediment sourcing from the Queen Maud Block, a crustal block exposed to the east of the Thelon Orogen and interpreted as part of the Rae Craton.

A number of regional aspects help to establish correlations between the Ellice Formation and other Canadian Shield sandstone units of similar vintage, e.g. the Barrensland Group of the Thelon Basin, the Athabasca group of the eponymous basin, and the Mountain Lake and Dismal Lakes groups of the Hornby Bay Basin (Hadlari et al., 2006; Rainbird and Davis, 2007; Rainbird et al., 2007; Ramaekers, 2010; Hahn et al., 2013). Based on shared lithostratigraphic and inferred depositional development, and basin shape, size, and thickness, Fraser et al. (1970) first inferred that such sandstone units may represent the erosional remnants of a once wider deposit that blanketed the Canadian Shield — a hypothesis supported by, among others, Gall (1994), Rainbird et al. (2007), and Rainbird and Young (2009). Such aspects are consistent with the establishment of a pancontinental depositional realm that best fits with a sag basin sustained by thermal subsidence within a supercontinent interior (e.g. Armitage and Allen, 2010). Rainbird et al. (2014) also presented detrital-zircon geochronological data from a single Ellice Formation sample, which demonstrated a composite age spread with multiple peaks at 2.6 to 2.2 Ga, a dominant peak at 1.82 Ga, and a youngest peak at ca. 1.65 Ga. These age groups were interpreted to represent, respectively, both first-cycle and reworked detritus from Archean crystalline rocks and early Paleoproterozoic cover successions (2.6–2.2 Ga), and an important contribution from the erosion of syn- to postorogenic magmatic rocks of Hudsonian affinity (1.82–1.65 Ga) (Rainbird et al., 2014). Therefore, consistent with northwestward paleoflow data (Fig. 5) and detrital zircon ages from correlative successions, the Ellice Formation is interpreted as a far-travelled and, possibly, in part polycyclic product of unroofing of the Trans-Hudson Orogen (cf. Ielpi et al., 2017b).

Fluvial record of orogenic unroofing

Based on the available provenance data (McCormick, 1992; Rainbird et al., 2014), fluvial strata preserved in the Burnside River and Ellice formations may be related to drainage systems located about 250 km and 1000 km from their upland sediment source, respectively. Differences in their architectural style and paleochannel depths, estimated from the thickness of preserved fluvial bars (Nicholson, 1993; Chakraborty, 1999; Ielpi, 2018) are related to deposition in river tracts located in relative proximity and far away from their upper catchment basin.

Commonly preserved and well clustered channel forms in the Burnside River Formation are contained within stratigraphic sections floored by significant basement topography — features overall consistent with valley-confined fluvial systems (Heller and Paola, 1996; Ethridge, 2011). This inference is corroborated by the depositional style of fluvial bars preserved within channel forms, which points to low-sinuosity channels characterized by restricted lateral mobility (Bianchi et al., 2015; Ielpi et al., 2016). Furthermore, the relatively large scale of preserved channels (comparable in both width and inferred depth with modern 'large rivers'; *see* Latrubesse, 2015) points to drainage being focused in fluvial conduits capable of passing high-magnitude discharge and sediment supply. As originally proposed by Hoffman and Grotzinger (1993), such high-magnitude discharge and sediment supply may have been sustained by orographic precipitation and enhanced orogenic unroofing on the windward side of the Thelon mountain range (Fig. 7a), which would have been impacted by northeasterly trade-wind circulation at near-equatorial latitudes (Pehrsson et al., 2016). Despite the relatively humid climate found on the windward side of mountain ranges, eolian strata in those locations can develop as architecturally simple dunes limited to interfluves protected by erosion (Mountney and Russell, 2009).

The lack of firm geochronological constraints on the deposition of the Elu Basin strata (for which a permissible age window of about 400 Ma exists; Rainbird et al., 2014) hinders a precise paleolatitudinal positioning of the Ellice Formation's fluvial system. Laurentia is nevertheless inferred to have remained at near-equatorial latitudes from 1.63 to 1.27 Ga (Pehrsson et al., 2016), although moist trade-wind circulation could have been somewhat weakened while transecting the vast interior of the Nuna supercontinent (Fig. 7b). Accordingly, far-travelled detritus is consistent with the occurrence of rarely preserved channel forms characterized by shallower depth and both higher sinuosity and mobility than the Burnside River Formation's counterparts. Together with the observation of gentle basement topography, these features are consistent with a mid-size, unconfined fluvial system, where drainage and sediment supply are progressively reduced downstream due to hydrological loss (related, in turn, to evaporation within a dry continental interior or within-basin infiltration; Cain and Mountney, 2009) and fractionation along bifurcating channels (Latrubesse, 2015; Weissmann et al., 2015). Consistent with the hypothesis of deposition in a somewhat drier continental interior is the occurrence in the Ellice Formation of larger and architecturally complex eolian strata sets, which point to climate-controlled development of extensive dune fields adjacent to fluvial channel belts (e.g. Rogala et al., 2007).

Noteworthy corollaries to this analysis are that: 1) causal links can be tested between fluvial style, orogenic unroofing, and prevailing trade-wind generated by Hadley-cell circulation established as early as 1.9 Ga; 2) questions linger regarding the weakening and drying of trade-wind circulation across pre-vegetation supercontinent interiors; and 3) by the time of the Elu Basin's deposition, the orographic relief of the Thelon mountain range would have diminished enough to allow for the bypass of Hudsonian detritus to the Elu Basin.

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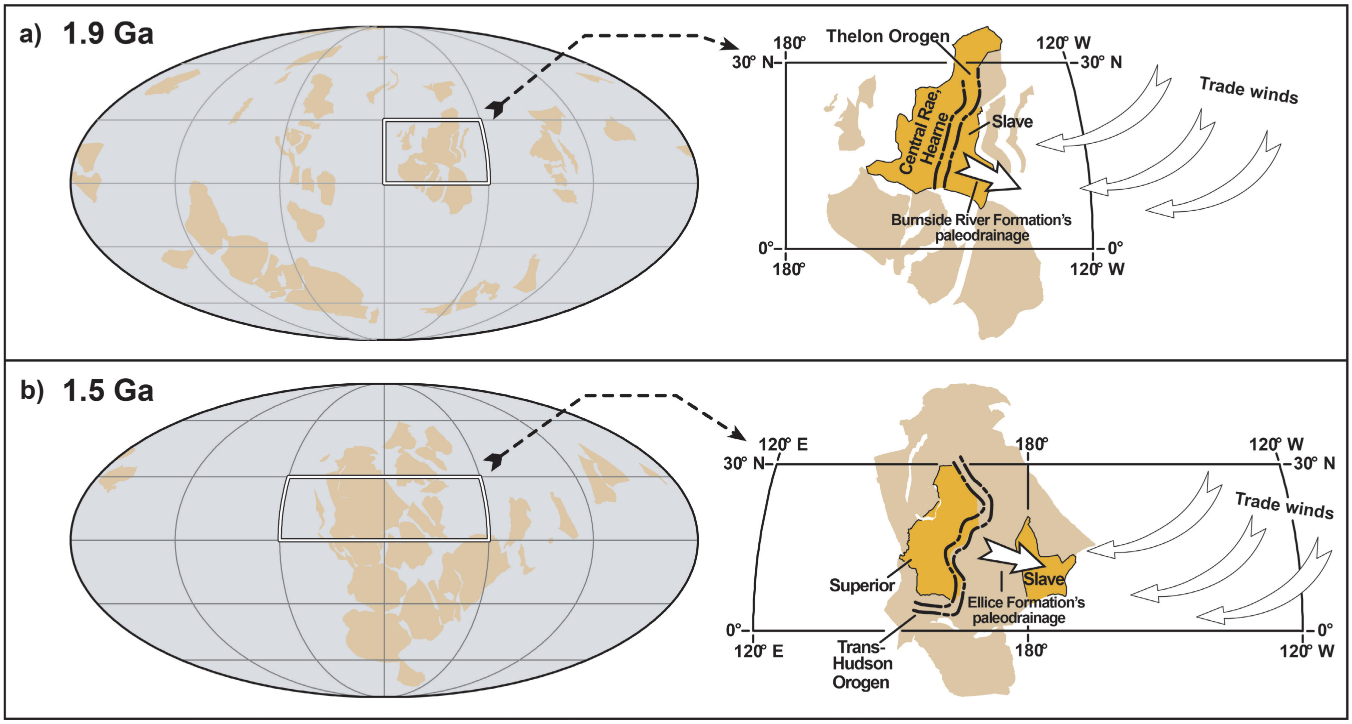

Figure 7. Paleogeographic reconstruction (*adapted from* Pehrsson et al., 2016), showing spatial relationships between orogenic ranges and trade-wind circulation at approximately the time of deposition of **a)** the Burnside River Formation and **b)** Ellice Formation in western Nunavut. *See* text for discussion.

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