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Mistaken Treasure – exploring Earth's oldest Lagerstätten

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Cover Image: Fossils of the Mistaken Point ‘D’ and ‘E’ surfaces, Mistaken Point Formation, Mistaken Piont Ecological Reserve, southeastern Newfoundland. See the article by Liu and Matthews in this issue for further information.

Image credit: Alexander G. Liu

SERIES

Great Canadian *Lagerstätten* 6. Mistaken Point Ecological Reserve, Southeast Newfoundland

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SUMMARY
Mistaken Point Ecological Reserve (MPER) World Heritage Site, on the southeastern coast of Newfoundland, Canada, is one of the foremost global Ediacaran fossil localities. MPER contains some of the oldest known assemblages of the soft-bodied Ediacaran macrobiota, and its fossils have contributed significantly to Ediacaran paleobiological research since their initial discovery in 1967. Preservation of multiple *in situ* benthic paleocommunities, some comprising thousands of specimens, has enabled research into Ediacaran paleoecology, ontogeny, taphonomy, taxonomy and morphology, offering insights into the possible phylogenetic positions of Ediacaran taxa within the tree of life. Meanwhile, a thick and continuous geological record enables the fossils to be placed within a well-resolved temporal and paleoenvironmental context spanning an interval of at least 10 million years. This article reviews the history of paleontological research at MPER, and highlights key discoveries that have shaped global thinking on the Ediacaran macrobiota.

RÉSUMÉ
Le site du Patrimoine mondial de la Réserve écologique de *Mistaken Point (MPER)*, sur la côte sud-est de Terre-Neuve, au Canada, est l'une des principales localités fossilifères édiacariennes de la planète. Le *MPER* renferme quelques-uns des plus anciens assemblages connus de macrobiote édicarien à parties molles, et ses fossiles ont contribué de manière significative à la recherche paléobiologique édiacarienne depuis leur découverte en 1967. La préservation de multiples paléocommunautés benthiques *in situ*, dont certaines comptant des milliers de spécimens, a permis de faire des recherches en paléoécologie, ontogenèse, taphonomie, taxonomie et morphologie de biotes édiacariens, ce qui a permis d'avoir un aperçu de différentes positions phylogénétiques possibles des taxons édiacariens dans l'arborescence biologique. Aussi, grâce à une colonne géologique épaisse et continue, on a pu placer ces fossiles dans un contexte temporel et paléoenvironnemental bien circonscrit qui s'étend sur un intervalle d'au moins 10 millions d'années. Cet article passe en revue l'histoire de la recherche paléontologique au *MPER* et souligne les découvertes majeures qui ont façonné la réflexion sur le macrobiote édiacarien.

Traduit par le Traducteur

INTRODUCTION
The barren southeastern coastline of Newfoundland, Canada, can be a wild and mysterious place. Intense post-tropical cyclones in the fall, and ferocious Atlantic winter storms that bring snow, ice, and howling gales, combine with destructive effect to shape the rugged cliffs. During the summer, the coastline is at times barely visible beneath a dense veil of fog and mist that sits atop the landscape for weeks on end. It is only in the late summer months when the fog lifts that the area's natural riches can be truly appreciated. A unique ecological biome (the Eastern Hyper-oceanic Barrens; Damman 1983; Meades 1990), coupled with spectacular rocky scenery

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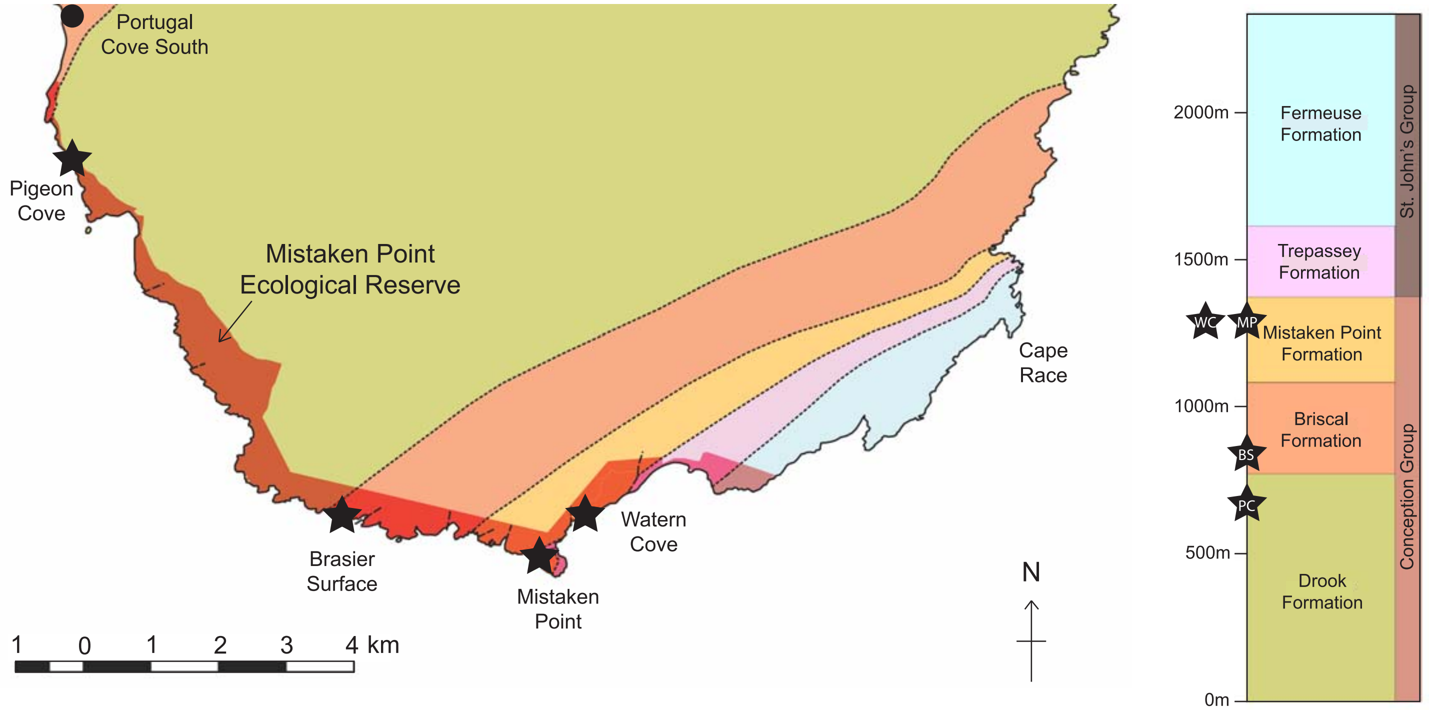

Figure 1. Geological map and stratigraphy of Mistaken Point Ecological Reserve (MPER), showing key fossil localities and their relative stratigraphic positions (black stars). Red shading indicates the areal extent of MPER.

and diverse bird and marine life, would be sufficient cause for the designation of this coastline as a provincial Ecological Reserve. However, even more remarkable, but less easy to see on the weather-worn rock surfaces, are countless impressions of soft-bodied organisms that inhabited the seafloor ~565 million years ago. These fossils, dating from the middle-late Ediacaran period, have proven amongst the most difficult to decipher in the entire geological record, but they are crucial to shaping our understanding of the early evolution of large, morphologically complex organisms (Narbonne 2005; Fedonkin et al. 2007; Attenborough 2010).

Ediacaran fossils were first discovered at the prominent headland called Mistaken Point in the summer of 1967. Shiva Balak Misra, a geology M.Sc. student at Memorial University of Newfoundland, was undertaking a mapping project (Misra 1969a) when he and his field assistant, Paul Thompson, recognized unusual and diverse impressions preserved on the bedding surfaces. Amongst the discoveries were spindle-shaped, leaf-shaped, lobate and radiating forms, which were recognized to comprise a new Canadian biota that was demonstrably Precambrian in age. Misra reported the discovery in *Nature* with Michael Anderson of Memorial University (Anderson and Misra 1968), and then documented the fossils in more detail the following year (Misra 1969b). Correspondence with Professor Martin Glaessner in Adelaide confirmed to Misra that the Mistaken Point specimens were similar to those being found in the Ediacara Hills of Australia (Glaessner and Wade 1966), and in Charnwood Forest of the UK (Ford 1958). Together with specimens from Russia and Namibia, these assemblages gave rise to the concept of a globally distributed "Ediacara biota:" an eclectic assortment of largely soft-bodied organisms that inhabited the ocean floor in the ~30 million years immediately preceding the Cambrian period.

The Mistaken Point fossils represent some of the most spectacular occurrences of soft-bodied macro-organisms in the geological record. Thousands of specimens are found on numerous natural exposures of laterally continuous bedding planes through the siliciclastic sedimentary successions of the Conception and St. John's groups (Fig. 1). These fossils include some of the oldest known records of large and complex macrofossils, metazoan trace fossils, and complex macroscopic ecosystems (Liu and Brasier 2012; Thomas et al. 2015). Ediacaran assemblages from the White Sea in Russia (e.g. Zakrevskaya 2014), and the Flinders Ranges in Australia (Droser and Gehling 2015), can be better preserved and document a wider variety of organisms than those in Newfoundland. However, the Newfoundland assemblages are several million years older than these other sites, and reflect deeper marine depositional environments (Boag et al. 2016). The Mistaken Point Ecological Reserve (MPER) fossil-bearing bedding planes are also unusual in that they occur through a considerable thickness of sediment, documenting a deep marine but broadly shallowing upwards sedimentary environment (Wood et al. 2003). Fossils, preserved as epirelief impressions and ranging from a few millimetres to over one metre in dimension, can reach densities of over 100 individuals per square metre on some surfaces (Clapham et al. 2003). They are often difficult to see due to their low topographic relief, but under low-angle sunlight they provide an unprecedented paleontological spectacle (Fig. 2a).

The MPER succession has contributed to well over 100 scientific publications to date, and has proven to be our most

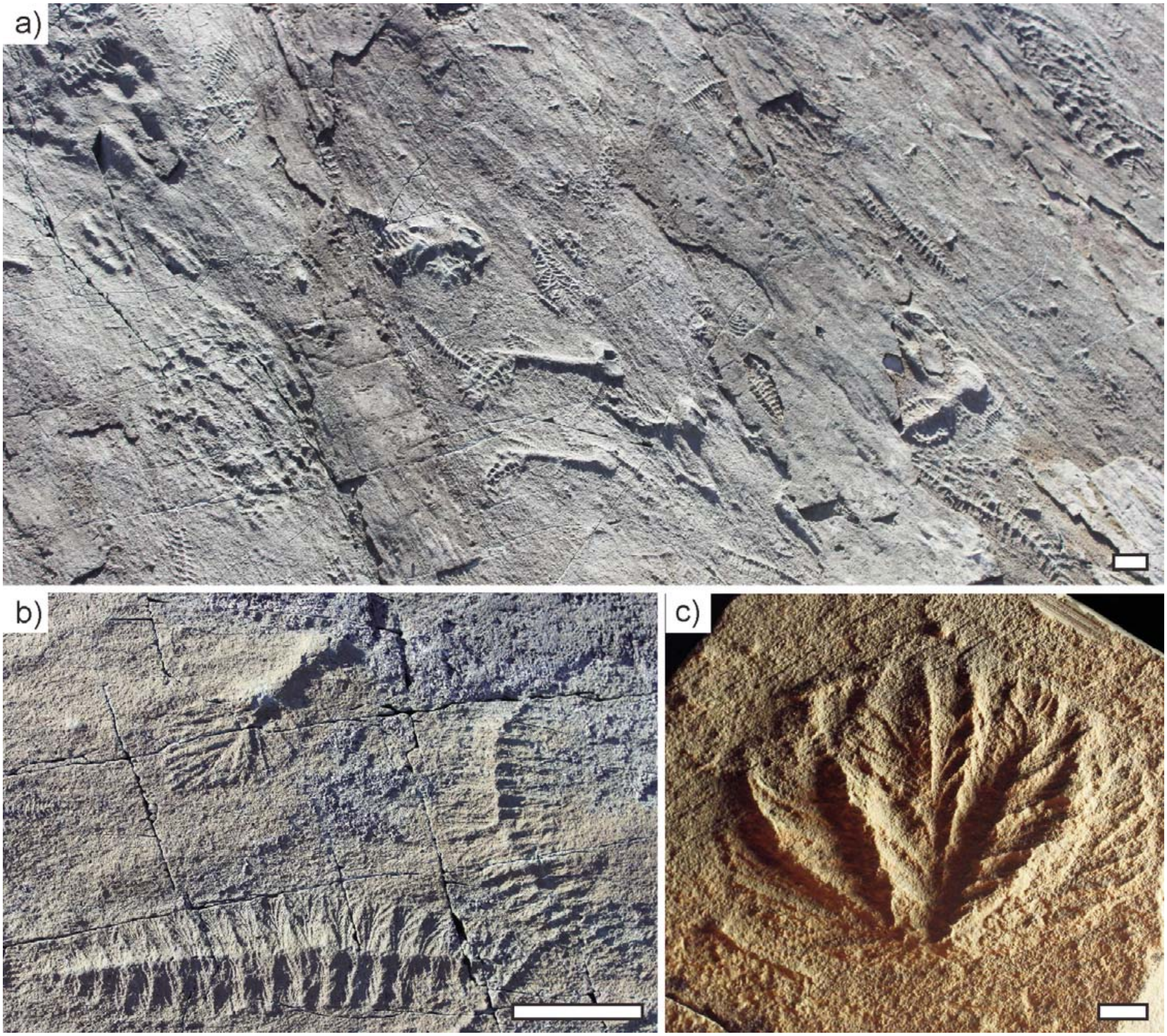

Figure 2. Fossils of the Mistaken Point 'D' and 'E' surfaces, Mistaken Point Formation. a) Dense assemblages of Ediacaran macrofossils, representing at least 8 different taxa in this image, on the 'E' Surface. b) The Ediacaran macrofossils *Plumeropriscum* (top centre) and *Fractofusus misrai* (bottom and right) on the 'E' Surface. c) *Bradgatia* from Watern Cove, clearly showing displayed 'self-similar' rangeomorph branches, ROM 36500. Scale bars a–b) = 50 mm, c) = 10 mm.

informative record of deep marine Ediacaran macrofossil assemblages. The fossils are becoming increasingly appreciated outside of academia, and have featured in artwork, poetry, books, and television documentaries. The scientific importance of the fossils around Mistaken Point was recognized by the Government of Newfoundland and Labrador in 1987, with the establishment of the Mistaken Point Ecological Reserve to encompass an 8.5 km stretch of coastline spanning 5.7 km^2. The Reserve was expanded to its current 17 km extent in 2003 to include a number of newly discovered fossil surfaces. Following almost a decade of preparation, MPER was added to the UNESCO World Heritage List on July 17th 2016, joining Miguasha National Park, Joggins Fossil Cliffs, Dinosaur Provincial Park, and the Canadian Rocky Mountains Park (home to the Burgess Shale) as one of Canada's five UNESCO World Heritage Sites inscribed at least in part on the basis of their paleontological attributes.

The Ediacaran Enigma

The Ediacaran macrobiota, ~570–541 Ma, comprises the first diverse populations of large and complex organisms in the fossil record (Fedonkin et al. 2007). Determining what sort of organisms were present among the biota is important for understanding the causes and consequences of both the rise of

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macroscopic multicellularity, and potentially the origin and diversification of animals (Budd and Jensen 2017; Cunningham et al. 2017). Indeed, resolving the biological affinities of the biota and their relationship to extant eukaryotic groups such as animals and algae is a major outstanding goal in the field of paleobiology.

Considerable biotic diversity had already been achieved prior to the appearance of the Ediacaran macrobiota. Bacteria and acritarchs are abundant among Proterozoic microfossils (Vidal and Moczydlowska-Vidal 1997), while evidence for testate amoebae (Bosak et al. 2011a), ciliates (Bosak et al. 2011b), foraminifera (Bosak et al. 2012), and largely sub-centimetric algae (Butterfield 2009; Zhu et al. 2016), fungi (Butterfield 2005) and rare putative animals (Yin et al. 2015) all predates the Ediacaran period.

The precise temporal and spatial distribution of the Ediacaran macrobiota remains to be fully constrained, and is likely to have been influenced by paleogeography, facies variation, and incompleteness of the fossil record (Waggoner 2003; Grazhdankin 2004, 2014; Droser et al. 2006; Gehling and Droser 2013; Boag et al. 2016). The earliest known Ediacaran macroscopic fossils are probably the Lantian biota of China, which includes possible animals (Wan et al. 2016) alongside several macroscopic algal taxa (Yuan et al. 2011). These are followed by specimens from Newfoundland and the U.K., together referred to as the Avalon assemblage (Waggoner 2003), which were ~570–560 Ma. More diverse assemblages from the White Sea coastline of Russia, and South Australia, follow at around ~560 Ma (summarized in Fedonkin et al. 2007; Dunn and Liu 2017). After reaching their zenith ~555 million years ago (Boag et al. 2016), the Ediacaran macroorganisms appear to diminish in diversity and number, with the depauperate Nama assemblage of Namibia (Darroch et al. 2015), barring a few rare potential Cambrian survivors (e.g. Conway Morris 1993; Jensen et al. 1998), long thought to represent the last of the soft-bodied Ediacaran macrobiota. Recent research suggests that a globally abundant latest Ediacaran assemblage of fossils with tubular morphologies, some of which were capable of organic or calcium carbonate biomineralization, span the latest Ediacaran–Cambrian transition (e.g. Warren et al. 2012; Smith et al. 2016). The relationships between late Ediacaran organisms and those of the Phanerozoic remain unclear, although there is a growing belief that the Ediacaran macrobiota reflects a diverse, polyphyletic assemblage of organisms allied to a variety of eukaryotic clades (Xiao and Laflamme 2009; Laflamme et al. 2013; Liu et al. 2015).

From a geological perspective, the initial appearance and subsequent apparent decline of the Ediacaran macrobiota and associated organisms raise questions about the interplay between life and the biosphere. A variety of major geological and environmental events are documented during the late Neoproterozoic, including at least two geographically widespread and long-lived glacials (the Sturtian, ~717–660 Ma, and the Marinoan, ending ~635 Ma; Rooney et al. 2015); the breakup of the supercontinents of Rodinia and Pannotia from ~700 Ma (Li et al. 2008; Scotese 2009); significant global perturbations in carbon, sulphur and oxygen stable isotope records (Halverson et al. 2005; Bristow and Kennedy 2008; Le Guerroué 2010); a rise in atmospheric and deep marine oxygen concentrations (Fike et al. 2006; Shields-Zhou and Och 2011; Lyons et al. 2014); and increasing stability in oxic conditions from latest Ediacaran into earliest Cambrian shelf settings (Johnston et al. 2012). Each of these changes has been postulated to have potential links to the evolution of the Ediacaran macrobiota (e.g. Cloud Jr. 1968; Dalziel 1997; Narbonne and Gehling 2003; Catling et al. 2005; Canfield et al. 2007). Further questions include why the soft-bodied Ediacaran macrobiota appeared ~570 million years ago, and essentially disappear from the record at the basal Cambrian boundary? How did the inception of metazoan burrowing and biomineralization in the latest Ediacaran period (Buatois and Mángano 2011; Wood 2011), or the demise of benthic microbial communities (Seilacher and Pfluger 1994; Bottjer et al. 2000), influence global nutrient cycling (Boyle et al. 2014), or affect the preservation potential of soft tissues (Callow and Brasier 2009)? Efforts are ongoing to refine age models in order to correlate cause and effect more precisely across this interval (e.g. Pu et al. 2016).

History of Research into the Ediacaran Fossils of Newfoundland

The type sections that document the very end of the Ediacaran System, namely the Global Stratotype Section and Point for the Ediacaran–Cambrian boundary (Brasier et al. 1994), are located on the Burin Peninsula of Newfoundland. Those sections contain a small number of latest Ediacaran body fossils (e.g. *Palaeopascichnus* and vendotaenids) and trace fossils, but the majority of Newfoundland's Ediacaran macrofossils are around 20–30 million years older, and are found on the Avalon and Bonavista peninsulas.

Research into the Ediacaran fossils of Newfoundland began in 1872 with the description of the discoidal fossil *Aspidella terranovica* from Precambrian rocks in downtown St. John's (Billings 1872). The biological nature of that material was questioned for many years (summarized in Boyce and Reynolds 2008), but has been confirmed by Gehling et al. (2000), who interpreted the impressions as probable holdfasts of frondose taxa. Interestingly, it is almost certain that such discoidal fossils were observed, even if their biological interest was not recognized, by some of the first European settlers in Newfoundland, since *Aspidella* fossils can be found in the flagstones of house foundations dating to the 1600s in the town of Ferryland on the east coast of the island.

Misra's discoveries at Mistaken Point in the late 1960s precipitated considerable exploration of the region, aided in part by the mapping exploits of Williams and King (1979). Much of this exploration was led by Michael Anderson of Memorial University, who reviewed the different fossils in the region, and largely concluded that they were either of uncertain biological origin, or colonial cnidarians (Anderson 1978; Anderson and Conway Morris 1982). Meanwhile, sedimentological and stratigraphic studies (Williams and King 1979; Gardiner and Hiscott 1988; Landing et al. 1988) developed a geological and paleogeographical framework within which to interpret the fossil assemblages (summarized by Conway Morris 1989).

Throughout the 1980s and 1990s, the Newfoundland fossils were often marshalled as evidence in discussions regarding the phylogenetic position of the Ediacaran macrobiota (Conway Morris 1985). Dolf Seilacher, in particular, worked on several of the fossil assemblages at MPER, and the Vendozoa and Vendobionta concepts he and his colleagues developed drew heavily on his examination of those specimens (Seilacher 1989, 1992; Buss and Seilacher 1994). Seilacher's research has also proven highly influential in shaping how study of not only the Newfoundland taxa, but the Ediacaran macrobiota as a whole, has been approached by future generations of researchers.

Research efforts in Newfoundland increased from the late 1990s onwards, as Guy Narbonne and his group from Queen's University, Ontario, investigated the sites around Mistaken Point (Thomas et al. 2015). They discovered a host of new fossil-bearing surfaces, and set about completing formal taxonomic descriptions of the fossils (e.g. Clapham et al. 2004; Laflamme et al. 2004; Gehling and Narbonne 2007; Laflamme et al. 2007; Bamforth and Narbonne 2009; Mason and Narbonne 2016), assessing aspects of their paleoecology (Clapham and Narbonne 2002; Clapham et al. 2003; Laflamme et al. 2012b), and interpreting the paleoenvironments represented within the stratigraphic succession (Wood et al. 2003). Members of that group continue to explore paleoecological questions relating to the fossil assemblages in Newfoundland, increasingly utilizing quantitative statistical and computational techniques to assess data collected from the MPER bedding planes (Clapham 2011; Darroch et al. 2013; Ghisalberti et al. 2014).

In 2002, Martin Brasier of the University of Oxford, in collaboration with former student Duncan McIlroy at Memorial University of Newfoundland, began to study the Newfoundland Ediacaran sites in order to compare the specimens to similar fossils in the U.K. (Antcliffe and Brasier 2007). The work of Brasier and his colleagues initially focused on determining evolutionary relationships (Brasier and Antcliffe 2009) and taphonomic processes (e.g. Callow and Brasier 2009), and constraining the influence of time-averaging on fossil assemblage composition (Liu et al. 2011). It later expanded to incorporate taxonomy (Brasier et al. 2012), ichnology (Liu et al. 2010), paleoecology (Liu et al. 2012), and most recently geochronology, stratigraphy, and sedimentology.

The past decade has witnessed a period of unparalleled growth in research into the Ediacaran biota, both globally and within Newfoundland, as the enigmatic nature of the organisms has attracted public attention. Additional major Ediacaran fossil localities have been described from the Catalina Dome of the Bonavista Peninsula (O'Brien and King 2004; Hofmann et al. 2008), and Spaniard's Bay (Narbonne 2004; Narbonne et al. 2009), significantly embellishing Newfoundland's Ediacaran paleobiological riches. These new sites have revealed several additional taxa (Hofmann et al. 2008; Narbonne et al. 2009), and include probable identifiable metazoan body fossils (Liu et al. 2014a). However, the majority of studies into Ediacaran paleocommunities have continued to focus on material from Mistaken Point Ecological Reserve. These include statistical studies into reproduction and paleoecology (Mitchell et al. 2015); study of lateral heterogeneity within paleocommunities on individual bedding planes (Matthews et al. 2017); study of growth within rangeomorph taxa (e.g. Hoyal Cuthill and Conway Morris 2014); discussion of sedimentary environments (Retallack 2013) and taphonomy (Liu 2016); and preliminary attempts to resolve the phylogenetic relationships between frondose taxa (Dececchi et al. 2017).

MISTAKEN POINT ECOLOGICAL RESERVE

The following sections review some of the major contributions that MPER has made to scientific understanding of the late Ediacaran interval.

Paleobiology

Fossils are known from over 80 bedding planes within the Mistaken Point Ecological Reserve, but the vast majority of studies have focused on just a handful of bedding surfaces. Principal among these are the Pigeon Cove surfaces in the Drook Formation (Fig. 3b–e), and the 'D' and 'E' surfaces at Mistaken Point itself (Landing et al. 1988; Figs. 2, 4a). The 'D' and 'E' surfaces were the first fossil-bearing horizons to be discovered by Misra, and each possesses over 1000 individual specimens (Clapham et al. 2003). The daunting task of taxonomic description of the various taxa has largely been completed by the Queen's University group. This work has identified forms described from other global sites amongst the Mistaken Point assemblages (e.g. *Charnia*, *Charniodiscus* and *Bradgatia*; Laflamme et al. 2004, 2007; Flude and Narbonne 2008), but has also introduced several new taxa (e.g. *Thectardis* Clapham et al. 2004; *Fractofusus* Gehling and Narbonne 2007; *Pectinifrons* Bamforth et al. 2008; *Trepassia* Narbonne et al. 2009; *Hapsidophyllas* and *Frondophyllas* Bamforth and Narbonne 2009; *Culmofrons* Laflamme et al. 2012b; *Plumeropriscum* and *Broccoliforma* Mason and Narbonne 2016), many of which appear to be endemic to Newfoundland. Supplemented by forms documented by other researchers (e.g. *Primocandelabrum* Hofmann et al. 2008; *Beothukis* Brasier and Antcliffe 2009; *Vinlandia* Brasier et al. 2012), the vast majority of macrofossils found within MPER have now been formally described.

The biological affinities of the Mistaken Point macrofossils have, as with the wider Ediacaran soft-bodied macrobiota, been much debated. Most early work on the Mistaken Point organisms considered them to belong to cnidarian clades (e.g. Misra 1969b; Anderson 1978; Anderson and Conway Morris 1982), while similar forms elsewhere in the Avalon region were considered as possible algae (Ford 1958). The subsequent suggestion that the Ediacaran macrobiota may form a discrete clade belonging to an entirely extinct kingdom or phylum, the 'Vendobionta' (Seilacher 1989, 1992, 1999, 2007), provoked consideration of a host of metazoan and non-metazoan biological affinities for members of the Mistaken Point assemblages (summarized in Narbonne 2005). Current thinking supports the view that the biota likely includes members of several diverse phyla and kingdoms, and the biology of each taxon should be assessed on a case-by-case basis (Xiao and

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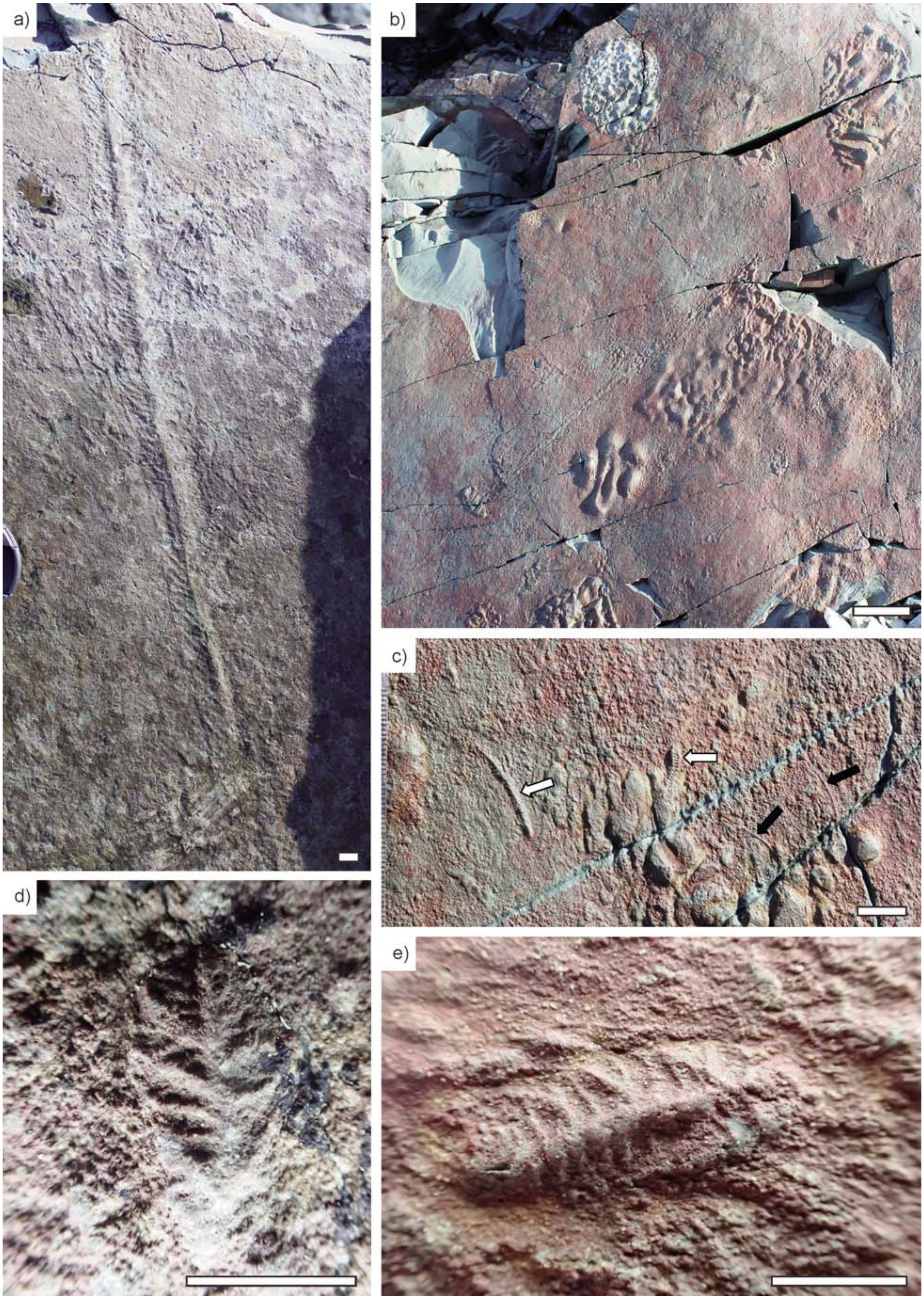

Figure 3. Notable fossils from the Drook Formation of the Mistaken Point Ecological Reserve. a) The rangeomorph *Trepassia wardae* from the Drook Formation, one of the oldest macro-fossil taxa observed in the region. b) Ivesheadiomorph fossils in the Drook Formation at Pigeon Cove. c) Small fronds (white arrows) and filamentous impressions (black arrows) on the Pigeon Cove surface. d–e) Small (rangeomorph?) fronds at Pigeon Cove. Scale bars = 10 mm, except d–e) = 5 mm.

Figure 4. Geology of Mistaken Point Ecological Reserve. a) View of the 'D' (black arrow) and 'E' (white arrow) surfaces at Mistaken Point, and additional Ediacaran bedding planes that extend along the coast. b) Tectonic ripples and fractures on the 'D' Surface. c) Prominent tuff bands (arrowed) on fossil-bearing surfaces in the Drook Formation at Pigeon Cove. Zircon crystals from such tuff layers can be used for U–Pb ID-TIMS geochronology, enabling precise dating of the associated fossil-bearing surfaces.

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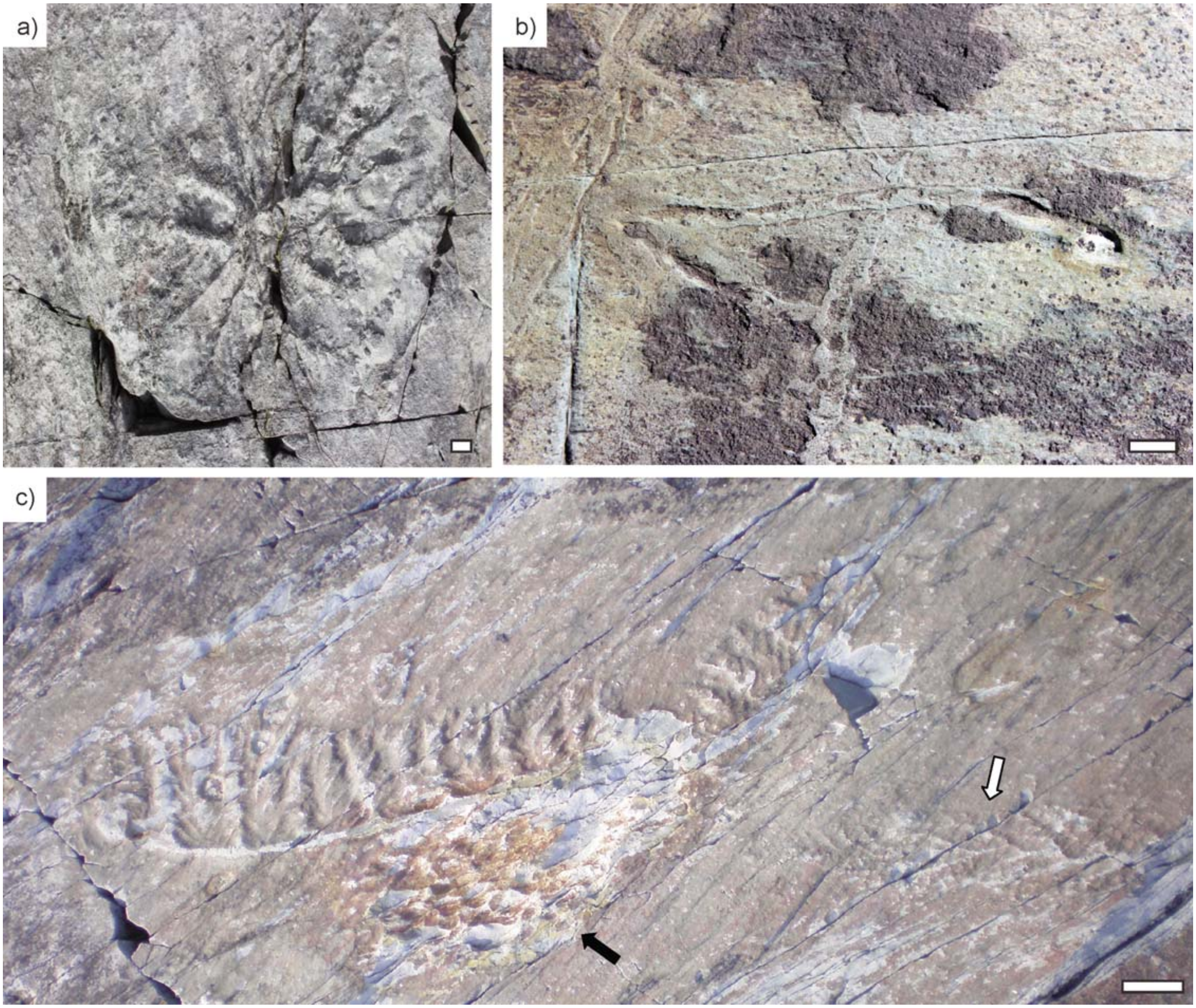

Figure 5. Additional notable fossils from the Mistaken Point Ecological Reserve. a) *Hapsidophyllas* from the 'B' Surface at Mistaken Point (cf. Landing et al. 1988). b) Horizontal surface trace fossils in the Mistaken Point Formation. c) *Pectinifrons abyssalis* (centre), *Charnia* (white arrow), and an Ivesheadiomorph (black arrow), at Mistaken Point North. Scale bars = 10 mm, except c) = 50 mm.

Laflamme 2009; Laflamme et al. 2013; Liu et al. 2015).

Rangeomorphs (Figs. 2, 3, 5; Narbonne 2004) are numerically the most common group of organisms within the Mistaken Point biota, and have received the most attention from researchers. The phylogenetic position of these frondose forms, with their characteristic branching units that repeat at finer scales in a self-similar manner, has proven difficult to constrain, and they have variously been allied to organisms of fungal grade (Peterson et al. 2003), algae (Ford 1958), stem- or crown-group animals (Narbonne 2005), or a 'failed experiment' towards the base of animal evolution (Narbonne 2004; Narbonne et al. 2007). Since morphology alone has so far been unable to confidently place the rangeomorphs within the tree of life, researchers have turned to alternative means in attempting to determine their phylogenetic position. Assuming the organisms are preserved in life position, the extensive MPER fossil assemblages can be interpreted as faithful reflections of census populations of benthic paleocommunities (e.g. Clapham et al. 2003; though see Liu et al. 2015). MPER is therefore an almost unique natural laboratory for paleoecological research, and its fossils have contributed enormously to global understanding of Ediacaran community structure and ecology. Modern ecological techniques have therefore been applied to the assemblages to investigate aspects of paleoecology such as community structure and reproductive strategies (Clapham et al. 2003; Darroch et al. 2013; Mitchell et al. 2015).

Assessment of the population structure of several rangeomorph taxa on individual bedding planes revealed that they occur as single cohorts with wide variance in the size of individuals, which was interpreted as evidence of a continuous reproductive strategy (Darroch et al. 2013). Meanwhile, the clustered spatial distribution of the rangeomorph *Fractofusus* (Fig. 2b) may suggest a complex reproductive strategy involving both stolon-like reproduction and the release of waterborne propagules for that taxon (Mitchell et al. 2015). Other paleoecological studies have suggested that rangeomorph ecosystems were structured in a similar way to those of modern benthic animals (Clapham et al. 2003; though see Liu et al. 2015). Efforts to determine the preservational history of specimens, and the impact of microbial activity on the macrobenthos, have also helped to distinguish true biological characters from taphonomic artefacts (Liu et al. 2011, 2015; Laflamme et al. 2012a; Antcliffe et al. 2015; Liu 2016).

Rangeomorph feeding strategies have been investigated from morphological, modelling, and theoretical standpoints, and have led to competing suggestions that rangeomorphs may have been filter feeders (Narbonne 2005) or osmotrophs (Laflamme et al. 2009; Ghisalberti et al. 2014). Another promising avenue of research is into the growth and development of rangeomorphs (and indeed Ediacaran organisms in general). The only previous detailed study of rangeomorph growth suggested that the genus *Charnia* possesses a growth polarity that is incompatible with that of extant pennatulacean cnidarians (to which frondose taxa had previously been compared, cf. Jenkins and Gehling 1978), thereby refuting a potential relationship to those organisms (Antcliffe and Brasier 2007). Expansion of such developmental reasoning to consider other taxa potentially offers a powerful way to distinguish between competing phylogenetic positions. Discoveries of small specimens in MPER, interpreted as 'juvenile' growth stages (Fig. 3c–e; Liu et al. 2012), ensure that the site will remain integral to research in this area as the surfaces are studied at finer and finer scales.

Stratigraphy and Paleoenvironmental Interpretation

Ediacaran fossils in Newfoundland occur largely in turbiditic facies of the ~2000 m-thick Conception and St. John's groups. These units are considered to have been deposited in axial basin and slope depositional settings, close to a volcanic island arc complex (Wood et al. 2003). Fossils are found mostly in the Drook, Briscal, Mistaken Point and Trepassey formations, which reflect a broadly shallowing-upwards marine succession (Fig. 1). The organisms are preserved as cast or mould impressions of their exterior surfaces on the tops of hemipelagite beds, and often lie beneath volcanic tuffite layers (Anderson 1978; Narbonne 2005). This sedimentary relationship is responsible for their modern exposure as extensive bedding plane assemblages, since the tuffite layers typically weather preferentially off the surfaces, uncovering the fossils beneath (Narbonne 2005). The tuffite layers were long thought to be the primary agents of fossil preservation (the Conception-type preservation of Narbonne 2005), but recent petrological studies have revealed thin veneers of pyrite on bedding surfaces (Liu 2016), suggesting that the 'death mask' taphonomic mode postulated for other global Ediacaran fossil localities (Gehling 1999; Gehling et al. 2005) may also play a key role in fossil preservation in Newfoundland. This process is considered to involve bacterial sulphate reduction of organic matter in the early stages of burial, producing hydrogen sulphide, which would have reacted with iron in the sediment to create a pyritic 'death mask' over the surface of both the organisms and the surrounding microbial mats (Gehling 1999), permitting replication of their external morphology prior to significant decay.

In the absence of evidence for shallow marine sedimentation throughout hundreds of metres of succession, the MPER depositional environments are considered to have been deep marine (Misra 1969a, 1981; Anderson 1978; Wood et al. 2003). Frondose fossils are commonly found oriented in a similar direction on individual surfaces, suggesting that they were benthic and preserved in a life position on the seafloor. They are often aligned at an angle 90° to the paleoslope direction indicated by cross-bedding directions in the surrounding turbidites (e.g. Wood et al. 2003; Flude and Narbonne 2008), leading to the suggestion that they have been aligned by contour currents, with hemipelagic siltstone interbedded with the turbidites interpreted as contourites (Wood et al. 2003; Ichaso et al. 2007). A deep marine environment, assumed to be below the photic zone, would have been inhospitable to photosynthetic organisms. Phylogenetic affinities for the Ediacaran organisms that would require photosynthesis (algae and plants) have therefore been largely rejected (e.g. Laflamme and Narbonne 2008).

In recent years, there have been persistent claims in the literature that the Mistaken Point sections include terrestrial deposits, specifically tempestites, tsunamites, and paleosols (Retallack 2010, 2011, 2013, 2016). These suggestions, made on the basis of sedimentological and geochemical investigations, would imply that the Ediacaran biota lived on land, lending support to the suggestion that many Ediacaran macro-organisms could have been lichens (Retallack 1994). This terrestrial assessment of the Conception and St. John's groups at MPER is demonstrably incorrect, due to the convincing evidence for abundant debris flows and turbidites (Fig. 4; Wood et al. 2003; Liu et al. 2014b), and a complete absence of evidence for terrestrial emergence. Prominent surface undulations on several horizons (Fig. 4b), initially discussed as possible wave ripples (Dalrymple et al. 1999), are now accepted by those and other authors to lie within deep marine sediments (cf. Wood et al. 2003), and recognized to be tectonic in origin (e.g. Matthews et al. 2017). Furthermore, several of the taxa found in the MPER succession have also been found in marine sandstone (e.g. Gehling and Droser 2013) and carbonate rocks (e.g. Grazhdankin et al. 2008) elsewhere in the world. It should be noted that demonstrably shallow marine, fluvial and subaerial Ediacaran deposits higher in the section elsewhere in Newfoundland (the St. John's and Signal Hill groups) are not known to contain macrofossils.

Geochronology and Geochemistry

Radiometric dating of zircon crystals within the volcanic tuffs that overlie many fossil-bearing bedding planes (e.g. Fig. 4c) indicates that the oldest macro-organisms in the MPER appeared ~570 Ma (Pu et al. 2016). This puts them just a few million years after the end of the Gaskiers glaciation event (Narbonne and Gehling 2003), a short and possibly regional glaciation that occurred around 581–580 Ma (Pu et al. 2016). The sheer size of some of the earliest Mistaken Point taxa – *Trepassia* specimens can be over a metre in length (Fig. 3a) – strongly suggests a greater, as yet undocumented antiquity to some Ediacaran macrofossil lineages. Ediacaran macrofossils persist until ~560 Ma in Newfoundland, giving them an older stratigraphic range than most other global Ediacaran localities (such as the Australian Flinders Ranges, or the White Sea region in Russia, both of which are considered to have been deposited ~560–550 Ma; Martin et al. 2000), but one that is broadly equivalent to sites in Charnwood Forest, U.K. (Noble et al. 2015). Zircon grains from directly above the 'E' Surface have been dated by U–Pb TIMS as 565 Ma (Benus 1988; Pu et al. 2016). Additional fossil-bearing surfaces in the MPER are in the process of being dated in order to better constrain rates of sedimentation and evolution.

Only a handful of geochemical studies have been published from the Reserve. Bulk sampling through MPER and nearby sections on the Avalon Peninsula permitted investigation of late Ediacaran redox conditions (via iron speciation techniques), and suggested that the fossil-bearing strata of the Drook to Trepassey formations were deposited in an oxygenated water column, with low total organic carbon (TOC) and sulphide concentrations (Canfield et al. 2007). Elemental data from some of the tuffs within the Reserve confirm a predominantly dacitic composition for the volcaniclastic deposits (Retallack 2014). The siliciclastic sedimentary rocks of the Conception and St. John's groups are not amenable to measuring certain proxies such as stable carbon isotopes, and the application of more recently developed geochemical proxies has largely not yet been attempted.

FUTURE DIRECTIONS AND CONCLUSIONS

The rocks and fossils of MPER have played a key role in shaping scientific understanding of the early development of Ediacaran macrofossil assemblages, but they continue to offer enormous potential for future research. This is evidenced by newly discovered surfaces such as the 'Brasier Surface' in the Briscal Formation (Fig. 6), which exhibits exceptional fossil abundance and preserved morphological detail. In addition to permitting the identification of new taxa, such preservational quality enables recognition of interactions between individual specimens, and assessment of spatial relationships between taxa. The application of new techniques and approaches to Ediacaran fossils, including spatial statistical analyses (Mitchell et al. 2015), study of growth and development, ancestral state reconstruction (Gold et al. 2015) and fluid modelling (Rahman et al. 2015), will undoubtedly continue to shed light on their original biology and ecology. Microfossil studies have not been systematically undertaken within MPER since the 1970s (and even then most samples from within the Reserve yielded no microfossils; Hofmann et al. 1979), but modern techniques may offer hope of obtaining a more detailed microfossil record. Biomarker studies have never been conducted, although the low organic carbon content of the sections (Canfield et al. 2007) suggests that obtaining biomarkers may not be possible.

Non-paleobiological disciplines also have considerable potential for further research within the Reserve. Although paleomagnetic data were collected as early as the 1970s, MPER-specific readings that could assist in constraining the paleogeographic position of the region have not yet been published (Thomas et al. 2015). Previous bulk geochemical analyses examined iron speciation, sulphur isotopes and carbon content (Canfield et al. 2007), but studies of trace elements or clay mineralogy are yet to be undertaken. The Reserve contains spectacular examples of faulting, folding, and diverse cleavage patterns (e.g. Fig. 4b), and yet the structural geology has only been studied at a coarse regional scale (Williams and King 1979). The volcanic tuffites that commonly cover the fossil surfaces also represent prime targets for future work, not only in terms of their geochemistry (Retallack 2014), but for their potential to yield high-precision radiometric dates for fossil surfaces to further constrain rates of evolution and sedimentation. The wider regional stratigraphic context also requires constraint, for example to investigate the relationship between the Conception Group and the contemporaneously deposited but non-fossil-bearing Musgravetown and Connecting Point groups situated ~100–200 km to the west (Pu et al. 2016). All of the above suggested studies would enrich our understanding of the MPER biota, and permit tighter integration into global studies of Ediacaran evolution.

In the 50 years since the discovery of Ediacaran macrofossils at Mistaken Point, MPER has revealed many often unexpected facets to Ediacaran paleobiology, and has been integral in shaping our understanding of the Ediacaran macrobiota. A literal reading of the existing data would suggest that the earliest Ediacaran macro-organisms were largely sessile communities of predominantly frondose organisms, and that they were quite different in their composition to the more diverse, motile, shallow-water assemblages of the later Ediacaran. However, rare early motile animals, evidenced by horizontal surface traces found at Mistaken Point (Liu et al. 2010), appear to represent the vanguard of a significant late Ediacaran increase in behavioural and ecological complexity that culminated in the diversification of animal life in the Cambrian. Whether the Ediacaran macrobiota really did first evolve in deep-marine habitats, and whether its component species were animals or entirely unrelated taxa, remain tantalising but currently unanswered questions. As MPER enters a new chapter in its history as a World Heritage Site, with all the challenges and opportunities that status brings, we can be confident that this truly remarkable locality will continue to yield new information, and that it will shape our thinking on Ediacaran paleobiology for many years to come.

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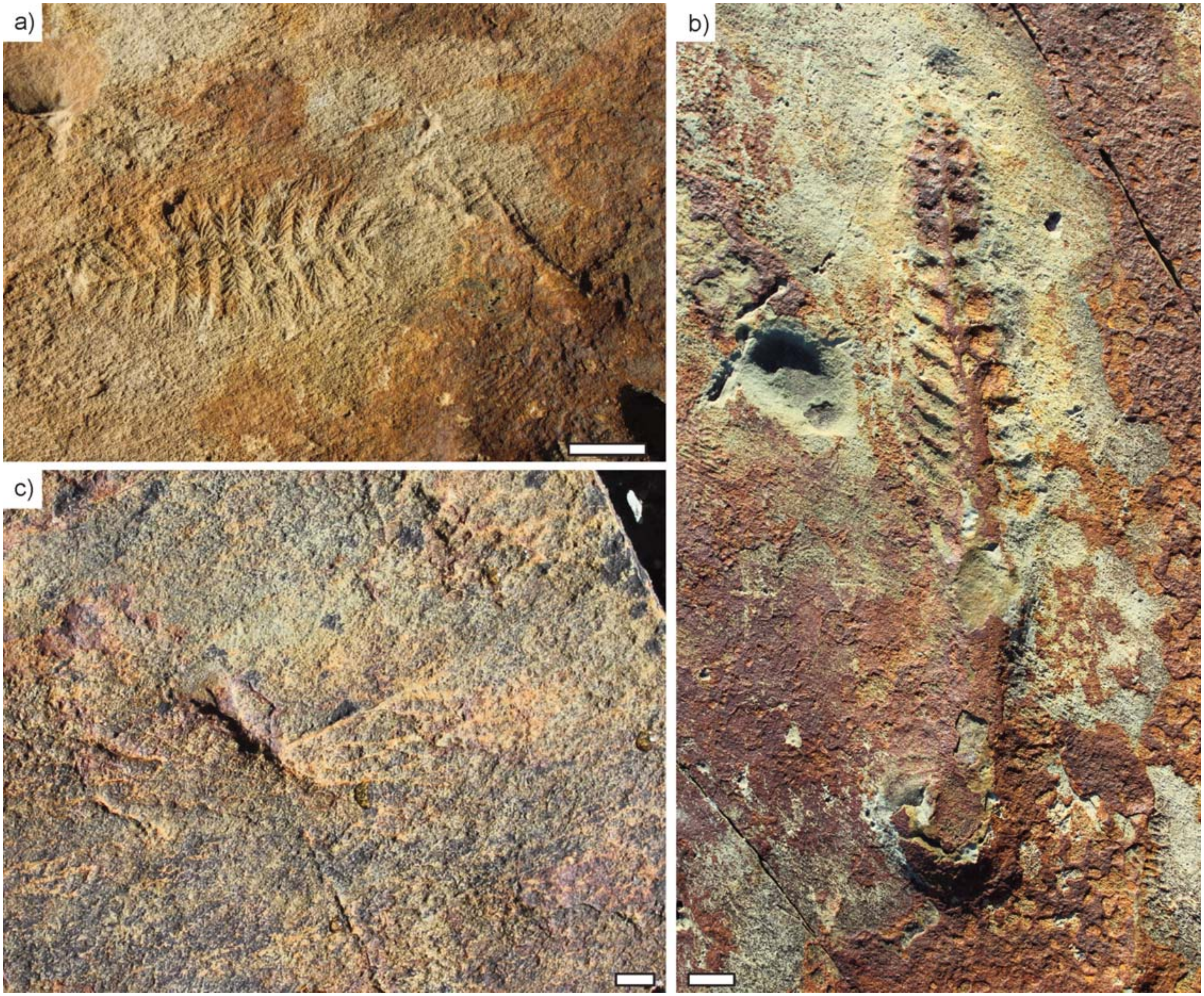

Figure 6. Ediacaran macrofossils on the recently discovered 'Brasier Surface,' Briscal Formation, Mistaken Point Ecological Reserve. This surface is remarkable for its very high fossil densities (>100 individuals/m^2), and their particularly fine preservation. a) *Fractofusus andersoni* (centre left) and *Beothukis plumosa* (centre right). b) *Charniodiscus* sp. surrounded by red and orange iron oxides, which are interpreted as the modern oxidative weathering products of an originally pyritic surface veneer (Liu 2016). c) *Primocandelabrum* sp. Scale bars = 10 mm.

Newfoundland and Labrador Natural Areas Section, Land Management Division permit only. Permit application information and forms are available here: http://www.flr.gov.nl.ca/natural_areas/wer/r_mpe/permits.html. M. Laflamme, R. Thomas, and one anonymous reviewer are thanked for helpful comments on this manuscript.

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The Development of Canada's Competency Profile for Professional Geoscientists at Entry-to-Practice

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SUMMARY

Competency-based assessment approaches to professional registration reflect the move by professions, both in Canada and around the world, away from traditional credentials-based assessments centred on a combination of academic achievements and supervised practice time. Entry-to-practice competencies describe the abilities required to enable effective and safe entry-level practice in a profession.

In 2012, Geoscientists Canada received funding from the Government of Canada's Foreign Credentials Recognition Program. A central component of the funding involved the development of a competency profile to assist in assessment for licensing in the geoscience profession. Work concluded with the approval of the *Competency Profile for Professional Geoscientists at Entry to Practice* by Geoscientists Canada in November 2014.

The Competency Profile comprises concise statements in plain language, setting out the skills and abilities that are required to be able to work as a geoscientist, in an effective and safe manner, independent of direct supervision. It covers competencies common to all geoscientists; competencies for the primary subdisciplines of geoscience (geology, environmental geoscience and geophysics); and a generic set of high level competences that can apply in any specific work context in geoscience.

The paper is in two parts. Part 1 puts the concept of competencies in context and describes the approach taken to develop the profile, including: input from Subject Matter Experts (practising geoscientists representing a diverse sampling of the profession); extensive national consultation and refinement; and a validation procedure, including a survey of practising Canadian geoscientists. Part 2 introduces the profile, explains its structure, and provides examples of some of the competencies. The full competency profile can be obtained from the Geoscientists Canada website, www.geoscientistscanada.ca.

Future work will identify specific indicators of proficiency related to each competency and suggest appropriate methodologies to assess such competencies. It will also involve mapping the profile to the existing Canadian reference standard, *Geoscience Knowledge and Experience Requirements for Professional Registration in Canada*.

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RÉSUMÉ
Les approches d'évaluation basées sur les compétences en vue de l'inscription professionnelle reflètent l'abandon par les professions, tant au Canada que partout dans le monde, des évaluations classiques basées sur les titres de compétences et axées sur une combinaison de réalisations académiques et de temps de pratique supervisée. Les compétences au niveau débutant sont les capacités requises pour une pratique efficace et en toute sécurité audit niveau dans une profession.

En 2012, Géoscientifiques Canada a reçu un financement du Programme de reconnaissance des titres de compétences étrangers du gouvernement du Canada. Une composante centrale du financement incluait l'élaboration d'un profil des compétences pour faciliter l'évaluation de la délivrance de permis dans la profession de géoscience. Ce travail a été conclu en novembre 2014 avec l'approbation par Géoscientifiques Canada du *Profil des compétences pour les géoscientifiques professionnels au niveau débutant*.

Le profil des compétences comprend des déclarations concises dans un langage clair, définissant les compétences et les capacités requises pour exercer efficacement, en toute sécurité et indépendamment de toute supervision directe, en tant que géoscientifique. Il couvre les compétences communes à tous les géoscientifiques; les compétences pour les sous-disciplines primaires de la géoscience (géologie, géoscience environnementale et géophysique); et un ensemble générique de compétences de haut niveau pouvant s'appliquer dans tout contexte de travail spécifique en géoscience.

Le document comporte deux parties. La 1ère partie met en contexte le concept de compétences et décrit l'approche adoptée pour élaborer le profil, y compris: les contributions d'experts dans le domaine (géoscientifiques professionnels représentant un échantillonnage diversifié de la profession); de vastes consultations et perfectionnements à l'échelle nationale; et une procédure de validation, incluant une enquête auprès des géoscientifiques professionnels canadiens. La 2ème partie présente le profil, explique sa structure et fournit des exemples pour certaines des compétences. Le profil des compétences complet est disponible sur le site web de Géoscientifiques Canada www.geoscientistscanada.ca.

Les travaux futurs identifieront des indicateurs spécifiques d'aptitude liés à chaque compétence et suggèreront des méthodologies appropriées pour leur évaluation. Ils comprendront également la mise en correspondance du profil avec la norme de référence canadienne existante et les exigences en matière de *Connaissances et expérience des géosciences requises pour l'inscription à titre professionnel au Canada*.

INTRODUCTION
In September 2012, Geoscientists Canada received funding from the Government of Canada's Foreign Credentials Recognition Program for a 30-month project to conduct four interrelated initiatives on behalf of its members, namely, the provincial/territorial professional bodies that regulate geoscience practice and professional licensing in Canada. The central and largest initiative involved the development of a competency profile to assist member associations in assessment for licensing a geoscientist as a professional, details of which were announced in a Government of Canada press release, with backgrounder, on 19 February 2013 (Government of Canada 2013). In November 2014, Geoscientists Canada approved its *Competency Profile for Professional Geoscientists at Entry to Practice,* (Geoscientists Canada 2014).

The paper is based on a talk given by the first author at the 35th International Geology Congress, in Cape Town, South Africa, on 30 August, 2016. The talk built on previous interim presentations on this project as the work progressed, given by several of the authors.

PART 1: CONTEXT
Canada sits at the midpoint of the spectrum of models for the regulation/self-regulation of professions in the classification scheme set out by the Council on Licensure, Enforcement and Regulation (CLEAR 2006), interpreted in the context of geoscience (Tepel 2010). The provinces and territories follow the Semi-Privatized Self-Regulatory Model where licensing associations are enabled by their own legislative act. The acts provide statutory powers so that each association operates independently, i.e. they are self-administered and self-financed by the member practitioners, and not by government. This is in contrast to the Government Agency Model used by individual states in the United States, at one extreme, and the Voluntary Self-Regulatory Model commonly used in the United Kingdom and other commonwealth countries, where there is little or no connection with government, at the other. There are 10 professional geoscience associations in Canada. The Northwest Territories and Nunavut are served by one association which administers two separate acts and there are no associations in either Prince Edward Island or Yukon.

Requirements for registration in Canada generally require: a four-year Bachelor of Science (B.Sc.) degree in one of the Earth Sciences; 48 months of geoscience work experience (at least 12 months of which is in a Canadian or equivalent work setting); three or more professional references; good character and conduct; and writing and passing a specific law and ethics examination.

These requirements are summarized in *Geoscience Knowledge and Experience Requirements for Professional Registration in Canada*, commonly referred to as 'the GKE.' The GKE was originally approved and published by Geoscientists Canada in 2008, revised and reprinted in 2011, and reprinted again in 2014 (Geoscientists Canada 2008). The GKE details the academic university coursework requirements to become registered and sets guiding principles for obtaining, and for assessing, practice experience in geoscience needed to be eligible for the Professional Geologist (P.Geo.) designation. It should be noted that each association has its own specific legal requirements and the requirements differ slightly between associations.

The GKE is generally accepted as the national document of reference on requirements for entry to the geoscience profession in Canada and most, but not all, associations have adopted it completely. In addition to the professional associations, the GKE is used extensively by students, faculty and advisors at universities; it is used by geoscientists migrating to

Canada, as well as global practitioners undertaking geoscientific work in the country. The GKE serves as an important reference for policy makers and other regulators, employers, users of geoscience services, and the general public. This document alone serves as the single most important benchmark for admissions to the profession in Canada.

However, the GKE is not specific to workplace activities, which is the primary purpose of the self-regulation of a profession. The GKE is not expressed in terms of academic outcomes from university study courses; nor is it appropriate for all types of applicants. Because it is credentials-based and not competency-based, the GKE is dependent on past achievements, rather than measuring current abilities. Competence, or current abilities, for workplace activities are the focus and the purview of the licensing associations.

WHAT ARE COMPETENCIES *AND* WHAT IS A COMPETENCY PROFILE?

The concept of competencies is not new in professional affairs and the admission of individuals to professional organizations; nor is it new to science or geoscience. For example, in 2004 the National Association of State Boards of Geology in the Unites States published *Tasks of the Professional Geologist* (ASBOG 2004). The Science Council in the United Kingdom (Science Council 2010) sets out the competencies that an applicant must demonstrate in order to be eligible for the Chartered Scientist (CSci) designation. The Science Council divides competence into five broad areas. In area A, entitled *Application of Knowledge & Understanding*, one of the specified skills is to be able to "*Demonstrate critical evaluation of relevant scientific information and concepts to propose solutions to problems;*" another is to "*Exercise sound judgement in the absence of complete information and in complex or unpredictable situations*" (Science Council 2010).

One of the earliest definitions of an occupational competency was "*a measurable pattern of knowledge, skills, abilities, behaviors, and other characteristics that an individual needs to perform work roles or occupational functions successfully*" which was introduced by the Office of Personnel Management in 1992, where it is still used today (Office of Personnel Management 2017). Since 1992, there have been many variations on the understanding of competencies, including some which have considered competencies to be the knowledge, skills, and attributes required to perform in the workplace, while others have considered competencies to be the workplace outcomes that result from the application of knowledge, skills and attributes.

More recent attention has focused on competencies as abilities. Kaslow et al. (2007) noted "*It is essential that competencies be conceptualized as generic, wholistic* (sic) *and developmental abilities.*" The Canadian physician competency framework defines a competency as "*An observable ability of a health care professional that develops through stages of expertise from novice to master clinician*" (Royal College of Physicians and Surgeons of Canada 2015)

From a regulatory perspective, we suggest that a competency profile is most useful when it refers to actual workplace abilities rather than only to the underlying knowledge, skills, and attributes. Workplace abilities are directly in the public interest; articulating desired workplace outcomes engenders professional accountability.

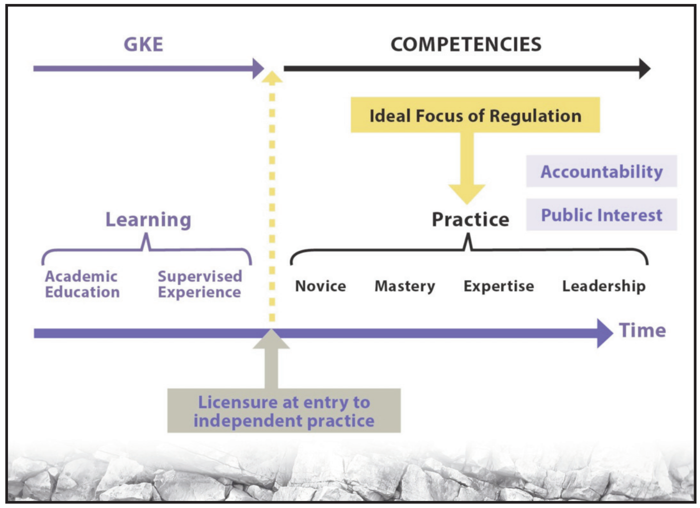

Figure 1. The focus of competencies in a regulated profession is towards practice, accountability and the public interest; while the focus of the *Geoscience Knowledge and Experience Requirements for Professional Registration in Canada* (GKE) is towards education and learning. The profile describes competencies expected at entry to independent practice; the point an individual geoscientist commences work as a standalone scientist at the novice level.

Whereas, in principle, competencies can be articulated for any specific workplace and for any stage of career development of a professional, entry-to-practice competencies are of particular importance to regulators since they speak to the requirements for admission to the profession. In this paper, we define an entry-to-practice competency profile as "*the integrated array of abilities that the newly-qualified professional brings to the workplace to enable effective and safe independent entry-level practice in common practice settings.*"

Competency profiles are seminal documents for any profession, with multiple uses. The profile can be used to explain the work of the profession and, in our case the work of the geoscientist, the profile enables competency-based assessment of candidates for registration, it creates a direct and strong link between education and practice, and it informs decision-making on continuing competence, practice guidance, and disciplinary matters.

Figure 1 sets the frame for competencies in a regulated profession. Competencies relate directly to practice which is the ideal focus of regulation, as it is where the public interest is served, and where accountability on the part of the individual geoscientist occurs. With time, as with other professions, geoscientists progress in their career, moving through different phases of increasing ability from novice to mastery and then on, perhaps, to expertise and/or a leadership role. The focus of competencies is not education. The GKE, on the other hand, is a description of a model-learning process. It describes the course work which must be completed at an academic institution and it sets out the duration of supervised experience that must be obtained. The purpose of a competency profile is not to describe a learning process, but to document the workplace-based outcomes of that learning, without reference as to where, when or how it occurred.

APPROACH AND METHODOLOGY

Construction of the profile involved three phases: Phase 1, research and development of a draft profile; Phase 2, consultation and validation; and Phase 3, refinement and completion (Fig. 2). While the three phases followed each other in a linear fashion, there was much iteration with back-checking, adjustments and improvements as work progressed. For example, the expert team whose primary work was mostly in Phase 1 also assisted in phases 2 and 3.

Phase 1 – Research and Development of a Draft Profile

To lead the development of the profile, Geoscientists Canada engaged the services of consultant David Cane of Catalysis Consulting (a co-author), a specialist in occupational competencies for regulated professions. Nine geoscientists from across Canada were chosen as Subject Matter Experts (SMEs) to work as a group directly with the consultant. The SMEs included: two geologists with backgrounds in mineral resources and/or 'hard rock' settings and methodologies; two geologists with backgrounds in energy resources and/or 'soft rock' settings and methodologies; three environmental geoscientists working in hydrogeology, subsurface contamination and geohazards; and two geophysicists – one practising in energy and the other in mineral exploration and mining.

The SME team worked closely with the consultant over a 14-month period building the occupational profile in full draft form, from the bottom up. The key question examined was, "*What are the job tasks that we would expect, as a minimum, all geoscientists to be able to perform at entry to independent practice?*" The SMEs were tasked to focus specifically on that point in time (Fig. 1) when an individual geoscientist commences work as an independent standalone scientist at the novice level.

Guidance on the structure and phraseology for the profile was provided by referencing occupational profiles for other professions and occupations, such as physicians (Royal College of Physicians and Surgeons of Canada 2015), counselling therapists (Federation of Associations for Counselling Therapists in British Columbia 2007) and dietitians (Partnership for Dietetic Education and Practice 2013). Examples of resource material on occupational competencies specific to science in general and the geosciences in particular include: *The Tasks of A Professional Geologist* (ASBOG 2004); *A Competency Concept Study* (Geoscientists Canada 2007); *Guidance Note for Validation as a Chartered Geologist or Chartered Scientist, The Geological Society*, (Science Council 2011); *Qualification Framework and Accreditation Criteria for Geology Study-Programmes in Europe* described in part by Rieck (2010); and *Initial Competencies Compendium for Geologists from Quebec* (Ordre des géologues du Québec 2012, unpublished). The GKE was also frequently used for back-checking purposes. However, these sources were used more for subsequent cross-checking purposes than as initial primary sources to ensure the profile was developed by the group independently and 'from the bottom up.' Initial drafting took eight months and involved face-to-face meetings, distance-based communication, and document sharing. The work drew directly on the geoscientific knowledge and workplace experience of the SMEs.

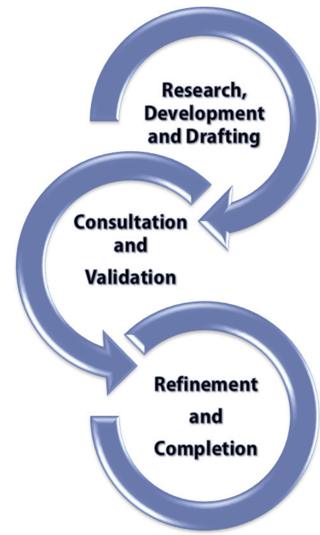

Figure 2. Three-phase iterative process of Competency Profile Development.

Phase 2 – Consultation and Validation

A period of consultation and validation followed completion of an initial draft competency profile. Each of the regulatory bodies, the constituent associations of Geoscientists Canada, was introduced to the draft document through participation in an association-specific orientation session. Also, geoscience-related technical and learned societies in Canada and a range of professional geoscience organizations in other countries were sent copies for comment. The period of consultation concluded after receipt of feedback, further changes incorporated into a revised draft profile, and a revision process further involving the SME group.

The revised draft profile comprising 122 competency statements was then the subject of a national survey (in both English and French), whereby all registered Professional Geoscientists across Canada were invited to view and comment on the draft profile in its entirety. With respect to each competency statement, geoscientists were asked three questions: How important is this task in your practice of geoscience?; How frequently do you personally perform this task?; In your opinion should proficiency in this task be an expectation of a P.Geo. at entry to practice?

A total of 1,042 geoscientists responded to the survey – representing approximately 10% of the P.Geo. population nationally. This sample size provides a margin of error on any numerical conclusions drawn from survey data of better than ± 3% (at a 95% confidence level). From the survey response data, each proposed competency was ranked as receiving a High (H), Medium (M) or Low (L) level of support for each of importance, and entry-to-practice expectation. In terms of importance, 109 of the 122 proposed competencies were ranked as high, 11 as medium, and only 2 as low. In terms of entry-to-practice expectation, 114 were ranked as high and only 8 as medium. None of the proposed competencies were ranked as low in terms of expectation.

The SME team discussed in depth every competency that received a ranking of Medium or Low. Two competencies were removed; others were modified or left unchanged. As expected, rankings for frequency of use were variable, being highly dependent upon the nature of the competency. Other than verifying that Medium and Low rankings were as anticipated, such rankings did not generate further discussion.

Phase 3 – Refinement and Completion

The revised profile was then the subject of a two-day facilitated workshop whose participants, from almost all of the regulatory bodies and represented by geoscientist members and senior admission staff, were those most involved in admissions decision-making across Canada. The purpose was to allow time for careful consideration of, and suggested refinements to, the revised profile. The workshop resulted in several minor adjustments to competency statements and some combination of competencies in order to simplify and shorten the profile. Final changes were incorporated to the satisfaction of the workshop participants.

Shortly thereafter, at a full meeting of the Canadian Geoscience Standards Board (CGSB) in June 2014, a few minor adjustments were made and the final competency profile was approved. The CGSB-approved document was put forward in turn to Geoscientists Canada for consideration of formal acceptance. This took place in November 2014, with Geoscientists Canada adopting the profile as its reference document describing entry-to-practice competencies.

PART 2: THE COMPETENCY PROFILE

The competency profile, which can be obtained in full from the Geoscientists Canada website (www.geoscientists-canada.ca), contains five sections (see Table 1). The following is a summary, with examples of competencies from each section. Sections 1 and 5 apply to all geoscientists. Sections 2, 3 and 4 are parallel sections, one applying to each of the three main subdisciplines of geoscience: geology, environmental geoscience and geophysics.

Section 1 emphasizes competencies applicable to all geoscientists. The 68 competencies in Section 1 are organized under eight headings: 1) Scientific method; 2) General geoscience, 3) Communication and reporting, 4) Information technology, 5) Organization and management, 6) Professionalism, 7) Professional development, and 8) Ethics. These competencies apply to all geoscientists irrespective of subdiscipline and area of practice.

Section 2 emphasizes competencies applicable to geoscientists working in the discipline of geology. There are 16 competencies specific to geology set out under four headings: 1) Planning; 2) Acquisition; 3) Interpretation; and 4) Integration.

Section 3 emphasizes competencies applicable to geoscientists working in the discipline of environmental geoscience. The 19 competencies specific to environmental geoscience fall under the same four headings: 1) Planning; 2) Acquisition; 3) Interpretation; and 4) Integration.

Section 4 emphasizes competencies applicable to geoscientists working in the discipline of geophysics. There are 14 competencies specific to geophysics. These fall under five headings: 1) Planning; 2) Acquisition; 3) Processing; 4) Interpretation; and 5) Integration.

Table 1. Sections of Competency Profile.

1. Generic competencies applicable to all geoscientists
2. Competencies applicable to geoscientists working within the discipline of geology
3. Competencies applicable to geoscientists working within the discipline of environmental geoscience
4. Competencies applicable to geoscientists working within the discipline of geophysics
5. Specialized competencies applicable to all geoscientists but referring to a specific area of practice'Area of practice' = an established area of practice within a discipline (e.g. survey mapping; mineral exploration; groundwater assessment; oil and gas exploration geophysics)

Section 5 emphasizes competencies applicable to the geoscientist's area of practice. At point of commencement of independent work, geoscientists will normally be engaged in a particular area of geoscience activity or geoscience specialty, such that they are fully familiar with that particular area of practice. In other words, they demonstrate competence at a professional level in that area of practice. There are numerous areas of practice within the geosciences. Some common examples within geology are: mineral exploration, petroleum geology, survey mapping; within environmental geosciences are: groundwater assessment, geohazards investigation; within geophysics: oil and gas exploration geophysics, mineral exploration geophysics.

Section 5 takes a generic approach to accommodate this diversity. It addresses any area of practice or geoscientific endeavour, from common examples such as those above, to less frequent specialties such as geochronology, palynology, or forensic geology. There are five competencies in Section 5 and they are demanding and they reflect the expectation that, at entry to practice, a geoscientist should have advanced abilities in the particular area of practice in which they are active, in addition to their general geoscientist abilities.

Tables 2, 3 and 4 are sample pages from the profile, to illustrate its structure and the composition of individual competency statements. A key element of every statement is the verb or action word used to dictate the level of proficiency implied. Furthermore, each is a statement describing ability. Statements do not specify what indicators might be sought to illustrate that a person possesses the ability or how such indicators might be assessed. The development of indicators has yet to be undertaken.

In Section 1.1 Scientific method (Table 2), the action word 'apply' is used in 1.1.1 "Apply scientific methodologies" and in 1.1.6 "Apply principles of quality assurance and quality control (QA/QC)." These imply a geoscientist, individually, can actively utilize these specified skills effectively and safely in a real work situation. This can be compared to the verb 'recognize,' as in 1.1.5 "Recognize uncertainty, ambiguity and limits of knowledge," which is a more passive, but no less important action.

In Section 2.2 Acquisition (Table 3) for geologists, we see the verbs 'implement' and 'select' as in 2.2.3 "Implement sam-

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Table 2. Extract from Competency Profile – Section 1. Competencies applicable to all geoscientists.

1. Competencies applicable to all geoscientists
1.1 Scientific method
1.1.1 Apply scientific methodologies.
1.1.2 Apply concepts and principles of mathematics and statistics.
1.1.3 Apply concepts and principles of physics and chemistry.
1.1.4 Access and search scientific literature.
1.1.5 Recognize uncertainty, ambiguity and limits to knowledge.
1.1.6 Apply principles of quality assurance and quality control (QA/QC).
1.1.7 Undertake reasonable investigation and due diligence.
1.1.8 Use peer review processes.

Table 3. Extract from Competency Profile – Section 2. Competencies applicable to geoscientists working in the discipline of geology.

2. Competencies applicable to geoscientists working in the discipline of geology
2.1 Planning
2.1.1 Compile and incorporate existing geoscience information.
2.1.2 Design field programs applicable to purpose of investigation and site conditions.
2.2 Acquisition
2.2.1 Implement mapping programs.
2.2.2 Incorporate geophysical and remote sensing methods.
2.2.3 Implement sampling programs.
2.2.4 Incorporate drilling programs.
2.2.5 Implement logging programs.
2.2.6 Select appropriate laboratory analyses.
2.2.7 Address uncertainties and limitations in data.

pling programs” and 2.2.6 “Select appropriate laboratory analyses.” These imply that a geologist can design and undertake a sampling program. However, beyond determining the appropriate laboratory and analytical method to use, the geologist may not be doing the laboratory analysis.

Table 4 indicates all of the practice-specific competencies in Section 5. As mentioned above, these are demanding competencies, but they are written in general terms so they can be utilized across the full range of practice areas that comprise geoscience. Competencies such as 5.1 “Apply a comprehensive and systematic understanding of current knowledge to practice activities,” or 5.3 “Critically evaluate models,” could apply equally to an oil and gas exploration geophysicist or to a groundwater hydrogeologist.

Figure 3 illustrates the relationship between the sections of the profile and the breadth of work and activity that all of geoscience entails. The individual profile of every geoscientist who has achieved competency is going to plot as a different radius somewhere around this large circle, and no two individuals will necessarily plot the same.

Table 4. Extract from Competency Profile -– Section 5. Competencies applicable to the geoscientist’s area of practice.

5. Competencies applicable to the geoscientist’s area of practice
5.1 Apply a comprehensive and systematic understanding of current knowledge to practice activities.
5.2 Apply a comprehensive knowledge of current methods used to undertake investigation.
5.3 Critically evaluate models.
5.4 Seek and apply knowledge to address multifaceted problems in familiar and unfamiliar contexts.
5.5 Recognize the complexity of knowledge, as well as contributions from other geoscience areas of practice and other professions.

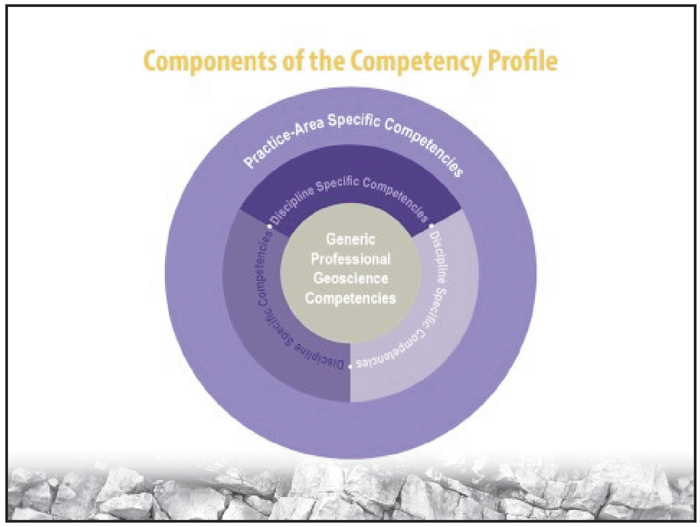

Figure 3. The relationships between the components of the competency profile and breadth of work and activity of geoscience. Every geoscientist who has achieved competency is going to plot as a different radius somewhere around this large circle, and no two individuals will necessarily plot the same.

DISCUSSION

The primary reason for developing the competency profile was to create a current and comprehensive reference that would serve as the foundation for a move to competency-based assessment for admission to the profession. Developing a competency profile is a complex process for any occupation and is a valuable standalone, reflective exercise, separate from any direct admissions considerations.

An entry-to-practice competency profile can serve many needs because it states, in plain language, the abilities that are required to be able to work independent of direct supervision in an effective and safe manner. As such, it is valuable for employers around realistic expectations for entry-level professional employees and it provides a launch point for further development across the geoscientist’s career.

Although each competency appears as a standalone statement, they should be viewed as an interdependent, integrated array; each one informing and qualifying the others. This form of construction avoids the need to use conditional language or circumstantial cross-referencing. The competencies are a set of abilities and must be applied by the geoscientist when relevant, and in context. Geoscientists will not use all of the competencies all of the time; in fact, most geoscientists will likely only use their own particular subsets of competencies frequently, while other competencies may be drawn upon less frequently, seldom, or hardly ever. However, possession of the entire profile of competencies for one of the three subdisciplines is envisaged for registration at entry to practice, so as to adequately serve the public interest and to enable the geoscientist to undertake safe and effective entry-level practice in common work settings and also that geoscientists will know their own limitations.

NEXT STEPS

As far as Geoscientists Canada is concerned, the next step in utilizing the competency profile to facilitate competency-based admissions is to determine appropriate indicators through which each competency can be assessed. Indicators are the evidence factors that one would seek, within chosen assessment vehicles, to demonstrate that the competency is possessed. Once indicators are developed for each individual competency or a combination of competencies, it will be appropriate to assign appropriate assessment approaches that should apply. For example, directly designing and implementing a QA/QC control protocol for a sampling program (under supervision), might be chosen as a suitable indicator for the competency "Apply principles of quality assurance and quality control (QA/QC)" (Table 2). An assessment process for that indicator might be for the individual to provide a summary account describing the protocol they designed and implemented, so that it can be validated by the supervisor who was in charge and then can be examined to the satisfaction of a designated assessor.

Geoscientists Canada intends to start indicator development and associated assessment approaches shortly, on behalf of, and in close collaboration with, its member organizations. Work is planned to map the profile to the *Geoscience Knowledge and Experience Requirements for Professional Registration in Canada* – the existing Canadian reference standard

CONCLUSION

The development of the Competency Profile is a significant achievement for geoscience in Canada. The profile states, in plain language, the workplace abilities that are required to undertake entry-level work as a geoscientist, independent of direct supervision, and in an effective and safe manner.

The profile is a seminal document that can be used to explain the work of geoscientists. It will enable competency-based assessment of candidates for registration. It creates a direct and strong link between education and practice, and it facilitates decision-making on continuing competence, practice guidance and disciplinary matters.

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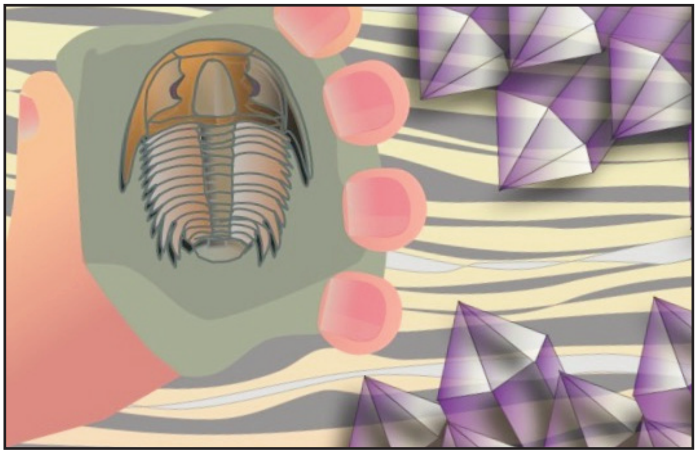
* For access to Geoscientists Canada 2007 report, please visit GAC's open source GC Data Repository Professional Affairs link at https://www.gac.ca/wp/?page_id=306.

EDUCATION MATTERS



The 'Rock 'n' Fossil Road Show:' An Enduring Earth Science Educational Outreach Initiative in Calgary, Alberta

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SUMMARY
Since 2004, the Calgary office of the Geological Survey of Canada has been holding 'Rock 'n' Fossil Road shows' at Calgary Public Library branches, in partnership with the Alberta Science Network and the Alberta Palaeontological Society. These now-annual earth science education outreach events have given more than 3700 people of all ages the opportunity to view, examine, and learn about GSC-Calgary's collection of rocks, minerals, and fossils (including many museum quality pieces), have their own samples and collections identified by experts, and gain a better understanding of local and regional geology. This article describes what goes into organizing these events, reviews their evolution, and discusses reasons for their enduring success. The 'Road Show' approach can be viable in a range of settings and may be a good educational outreach option for research institutes with collections of interesting geological specimens and a critical mass of interested staff.

RÉSUMÉ
Depuis 2004, le bureau de Calgary de la Commission géologique du Canada tient des représentations de son spectacle itinérant « Roche et fossiles » dans les succursales de la bibliothèque publique de Calgary, en partenariat avec l'*Alberta Science Network* et l'*Alberta Palaeontological Society*. Ces activités de rayonnement en sciences de la Terre, maintenant annuels, ont déjà offert à plus de 3700 personnes de tous âges la possibilité de voir, d'examiner et d'apprendre à partir de la collection de roches, de minéraux et de fossiles de la CGC-Calgary (certaines pièces de qualité muséale), et de voir leurs propres échantillons et collections identifiés par des experts, et ainsi obtenir une meilleure compréhension de la géologie locale et régionale. Le présent article décrit les détails de l'organisation de ces événements, retrace leur évolution et revoit les raisons de leur succès durable. L'approche du « spectacle itinérant » peut être viable dans différents contextes et peut être une bonne option de sensibilisation éducative pour les instituts de recherche disposant de collections de spécimens géologiques intéressants et d'une masse critique d'employés intéressés.

Traduit par le Traducteur

INTRODUCTION
For thirteen years, the Calgary office of the Geological Survey of Canada (GSC-Calgary) has been taking science to the public by means of the 'Rock 'n' Fossil Road Show.' Each year, scientists and staff visit a branch of the Calgary Public Library (CPL) on a Saturday in mid-October with a display of more than one hundred high-quality mineral, rock, and fossil specimens, as well as maps and posters on local and regional geology. Members of the public can interact with GSC volunteers to learn about the displays, and they also can bring their own favourite geological specimens to be identified and explained. These events, held in partnership with the Alberta Science Network <http://albertasciencenetwork.ca>, the Calgary Public Library system <https://calgarylibrary.ca>, and the Alberta Palaeontological Society <http://www.albertapaleo.org>, annually give hundreds of people hands-on experience with minerals, rocks, and fossils, as well as face-to-face interactions with working earth scientists (Fig. 1). These events are aimed at increasing public awareness of the earth sciences, encouraging earth science literacy, and sowing the seeds of interest that may attract a future generation of earth scientists. This article is a brief account of this long term educational outreach initiative, its history, and how we make it happen. Our experience suggests that the 'Road Show' approach can be

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Figure 1. Interactions with earth scientists, focused on discussions of actual geological specimens, are key elements to the success of the Rock 'n' Fossil Road Show.

adapted by other research institutions interested in fun and effective public educational outreach programs.

BACKGROUND

GSC-Calgary has a long history of public educational outreach, including playing a key role in the establishment and success of the Calgary Science Network (Nowlan and Neale 2000), which is now part of the province-wide Alberta Science Network (ASN). The present Rock 'n' Fossil Road Show has its origins in the 'Pet Rock and Fossil Clinic,' an earlier collaboration of GSC-Calgary, the Calgary Science Network, and National Science and Technology Week. Beginning in 1991, the lobby of the GSC-Calgary building was opened to the public on a Saturday in October. GSC scientists (sometimes with assistance from staff of the Royal Tyrrell Museum of Palaeontology) were on hand as collectors of all ages came with their favourite pet rock and fossil specimens. As recounted by Nowlan and Neale (2000, p. 26), the 'rock docs' ensured that the clients "…*were told something of the composition, age and history of their pets and, more important, shown the simple tests that would enable them to name and classify their treasures*". Attendance peaked with 800 visitors in 1995 but fell rapidly thereafter for reasons that were never determined. The event was abandoned after attendance in 1997 barely surpassed 100 people. By 2000, however, there were "…*calls for a post-mortem and possible resurrection or metamorphism*" (Nowlan and Neale 2000, p. 26).

In the early 2000s, GSC-Calgary scientists participated in a Rock and Fossil Clinic at the Calgary Science Centre, and at least twice had an outreach presence at a family fun day called "Hullabaloo," held at Calgary's Olympic Oval. In August, 2004, planning began for a Pet Rock and Fossil Clinic, to be held at CPL's Crowfoot Library in October of that year. Although the event was promoted as a Pet Rock and Fossil Clinic, and like the earlier clinics was staffed by volunteers from GSC-Calgary and the Royal Tyrrell Museum, it also was attended by staff from SciQ, a television production company, who were filming an educational program that put a geological twist on the popular *Antiques Roadshow*. *Rock 'n' Fossil Road Show* featured earth scientists examining and explaining geological specimens that had been brought in by the public. Only one episode was produced (it aired on Access TV the following February), but the event was successful enough to suggest a new name and approach to geoscience education outreach, particularly since CPL was keen to continue hosting the event. The Pet Rock and Fossil Clinic was resurrected and metamorphosed as the Rock 'n' Fossil Road Show.

HOW IT WORKS

The Rock 'n' Fossil Road Show is organized each year by a committee of two or three people, generally with one person taking the lead and the others assisting. Early each spring, the organizers scout a library branch in Calgary to host that fall's event. We have tried to hold the events throughout the city, at as many different branches as we can. By visiting the candidate library, we can ensure that staff members at the branch are keen to host the Road Show and that the venue offers adequate space, light, and access. Choosing a venue in early spring gives plenty of time for CPL to approve the event and include it in their event listings.

Promotions for the event are handled mainly by ASN, with help from Natural Resources Canada communications staff for some events. ASN ensures that the Road Show is announced in their own newsletter and via community bulletin boards and flyers. They also publicize it to schools near the host library, and in the past have put up posters in local grocery stores, community centres, and other meeting places. CPL contributes to publicity by announcing the event in its online and printed event schedules. To further advertise the event, CPL allows us to place a glass display case full of museum-quality geological specimens in a prominent spot in the host branch, three weeks prior to the event. The event is promoted as being for all ages, and the libraries do not restrict the number of participants or require advance registration.

On the Saturday morning of the event, we arrive at the library an hour before the scheduled starting time, to ensure adequate time for setup. In addition to a wide range of high-quality minerals, rocks, and fossils (Fig. 1), we also take a binocular microscope and a commercially produced 'find a fossil' kit, as well as reference books to help in identifying minerals and fossils. We take a portable backdrop on which we mount geoscience maps and outreach posters, such as Geoscape Calgary (Poulton et al. 2002; see also Turner 2013), and a large simple poster of the geologic time scale (Fig. 2). The event runs from 11:00–15:00. Afterwards, it can require up to an hour to dismantle and pack up the displays.

To aid those who may consider staging a similar event, we offer the following summary of time requirements. For keen volunteers, the Road Show event itself is a day-long commitment. Some also participate in the packing (2–3 hours the day before the event) and unpacking of samples (generally about 2 hours). The lead organizers expend roughly another 14 hours, spread among 2 or 3 people, for scouting the location, dealing with paperwork and promotions, delivering the display case, and doing wrap-up reporting after the event.

Figure 2. General interest posters, such as Geoscape Calgary (Poulton et al. 2002; Turner 2013), are an important part of the displays at each Rock 'n' Fossil Road Show.

EVOLUTION OF THE ROCK 'N' FOSSIL ROAD SHOW

Since the first event in 2004, the Rock 'n' Fossil Road Show has evolved in response to both challenges and opportunities. A major change is that the Road Show initially was held twice a year but from 2010 onward became an annual event, in response to the excessive demands that biannual Road shows had come to make on organizers and volunteers. A fall show made sense because of the event's longstanding association with National Science and Technology Week (NSTW), and also because it avoided any scheduling conflict with the Calgary Rock and Lapidary Club's annual show, which is held in the spring. In 2016, NSTW was renamed "Science Odyssey" and moved to the spring. Although we valued our role as part of NSTW, we decided to continue holding our event in the fall—not least because spring is a busy time of year for earth scientists who are preparing for summer field work.

The make-up of our volunteer contingent also has changed. After the first Road Show, early events were staffed almost entirely by Research Scientists from GSC-Calgary. As GSC research staff numbers have shrunk, we have come to rely increasingly on retirees, students, technical staff, and postdoctoral fellows to run the event. We also have been joined on occasion by administrative staff, whose lack of earth-science expertise was more than offset by their ability to interact enthusiastically with the public. A welcome addition to our volunteer ranks came during the first two years of the Road Show's history, when we began an informal partnership with the Alberta Palaeontological Society (APS). APS members have been a small and enthusiastic volunteer contingent at some events, particularly "Dino Dan" Quinsey, a fossil collector with a passion for public outreach, who has attended most events. Dan continues to bring unique, engaging, high-quality displays to virtually every Road Show. From 2011–2014, we also were joined by staff from the CanmetMATERIALS Pipelines group (another branch of Natural Resources Canada), who brought displays about their research on pipeline safety.

Figure 3. Holding events in high traffic, public areas of the host library branch helps to ensure that each Rock 'n' Fossil Road Show is visited by as many library patrons as possible. It also helps to ensure that the volunteers are seldom idle. Note the drill core of Athabasca oil sand at lower right in foreground, an example of an Alberta-focused display specimen.

Early Road shows were held in program rooms at the hosting library branches. These were essentially multi-purpose rooms set off from the main area of the library. While this was all right for people who already knew about the event and had come expressly to attend it, we found that being away from the main part of the library reduced our visibility and opportunities to interact with library patrons. Many program rooms had only one door or lacked natural light, which made them uninviting and problematic for people moving in and out. As a result, we now request (gently insist) that our program be held in a public area of the library with as much natural light as possible. We have found the library branches to be very willing to let us operate in this way, and some staffers have happily commented that events like ours show that their branch is actively serving the community. The result has been a more pleasant working environment for us and, we think, more interactions with the public (Fig. 3).

SIGNS OF SUCCESS

Since the key goal of the Rock 'n' Fossil Road Show is to increase public awareness of the earth sciences, the number of interactions with members of the public is an important outward measure of our success. Although we did not track the number of visitors to our first four events, we have since tried to estimate attendance (Table 1). Based on our estimates, we have interacted with more than 3700 individuals, of all ages, since we began tracking. Unsurprisingly, our largest turn-outs have been at larger library branches, which tend to have more patrons than smaller, neighbourhood branches. Our record turnout is 500 people, which has happened twice, both times at the Crowfoot Library, which is the largest branch in Calgary's NW quadrant. Our smallest turnouts have been roughly

Table 1. Dates and locations of Rock 'n' Fossil Road shows with the estimated attendance for events from autumn, 2006, onward.

DATE	LIBRARY BRANCH	ATTENDANCE
2004-10-23	Crowfoot	*not recorded*
2005-04-09	Shawnessy	*not recorded*
2005-10-15	Thornhill	*not recorded*
2006-04-01	Signal Hill	*not recorded*
2006-10-14	Village Square	100
2007-03-31	Fish Creek	250–300
2007-10-13	Country Hills	350–400
2008-04-05	Forest Lawn	100–125
2008-10-18	Crowfoot	400–500
2009-04-04	Fish Creek	350–400
2009-10-17	Nose Hill	250–300
2010-10-23	Country Hills	300–350
2011-10-22	Signal Hill	300–350
2012-10-20	Saddletowne	250
2013-10-19	Bowness	250
2014-10-18	Thornhill	250
2015-10-17	Alexander Calhoun	200
2016-10-15	Crowfoot	450–500

100 people, which happened twice at smaller libraries where, for reasons that were unclear, there was little interest in the event. As a rule, even the small venues see turnouts of 200–250 people, and the attendees are just as engaged and enthusiastic as patrons of larger branches. We do think it is important to cover both the big libraries and the smaller, neighbourhood branches.

Although we do not actively survey attendees for their views of how successful we are at communicating our science, we have received consistent and strongly positive feedback from attendees and from library staff, including numerous instances of people asking where and when the next event will take place. Staff members at smaller branches have commented that hosting the Road Show meant they had a busier-than-usual Saturday, and librarians at all branches commonly express the hope that we will come back again.

It is important to comment on an inward measure of success as well. Despite the changing demographics of our group of volunteers, we have been running Rock 'n' Fossil Road shows successfully for more than a decade. This history includes two major transitions in the leadership of the event, pointing to the importance of intentional 'succession planning' for ensuring the ongoing success of outreach activities such as this.

We have reason to think that the Road Show model can be applied in a wide range of community settings. In 2015, two of us (KMF and RBM) were conducting field work based out of the small northern community of Colville Lake, NWT. During the field season, we made a point of collecting representative samples of the main types of rocks and fossils that local people might encounter on the land. On our last evening in Colville Lake, we displayed the samples on a picnic table at the community barbeque pit. The event had been promoted by the community leadership and, despite many people being away at a reunion in a neighbouring community, we had a good turnout. Some community members brought rocks that they had collected and were curious about, and many people stopped by to look at our display. Interactions ranged from watching small children use the samples as stacking blocks to hearing a community elder share her memories of traditional Dene uses of rocks. In this smaller community setting, we were able to operate a successful event with two research scientists and one summer student. Afterwards, we donated the specimens to the community for use in their school.

REASONS FOR SUCCESS

The Rock 'n' Fossil Road Show has benefited from several demographic, logistic, and pedagogic advantages. Public interest in the events may reflect the prominent place of energy resources in the Alberta economy, and the resultant large number of geoscientists living in Calgary. GSC-Calgary is well positioned to run this kind of event, being blessed with a critical mass of keen scientists, technicians, and students who are encouraged by local management that has consistently recognized the value of public outreach. Our long-standing partnership with Alberta Science Network is important for ensuring publicity and also gives us credibility with library staff, who are more likely to be aware of ASN than of GSC. Partnership with the Alberta Palaeontological Society has helped to ensure that we have sufficient volunteers present for each Road Show, while also adding to the diversity of our displays.

By providing a venue for the Road Show, the branches of the CPL play an obvious role in ensuring success. Most branches have responded enthusiastically when approached about hosting an event. Holding the Road Show in libraries lets us take science into the community in a location already associated both with learning and enjoyment. For some events, library staff has set up a display of earth science books from the branch's collection, so that interested patrons can follow up by reading about minerals, rocks, or fossils. Using libraries as venues lets us engage with passers-by as well as dedicated rock and fossil collectors, and also lets us visit different parts of the city from year to year, giving us an ever changing 'market'—a market now into its second generation of new attendees.

A key pedagogical advantage derives from the excellent outreach collection of high-quality mineral, rock, and fossil specimens to which we have access at GSC-Calgary. These are the backbone of our Road Show displays and include Alberta-focused materials such as ammolite (gem-quality ammonite shell) or drill core from the Athabasca oil sands (Fig. 3). In a discussion of best practices in urban earth-science outreach, Harnick and Ross (2004, p. 426) identified access to authentic materials as a key element for success, noting that "[h]*ands-on experiences with real fossils can engage students . . . by drawing upon their interests and by entrusting them to handle materials of scientific and cultural value. In addition, a hands-on approach provides opportunities for students of different learning styles, including those with limited English proficiency, to actively engage in scientific processes and content.*" The

Alberta third grade curriculum includes a major unit on rocks and minerals, meaning that many of the young people who visit our events have already been introduced to basic principles of geology, and our events help reinforce what they already know. (It is especially gratifying to watch knowledgeable children explaining our specimens to their parents and grandparents.)

The Rock 'n' Fossil Road Show shares an advantage with the original Pet Rock and Fossil Clinic. As Nowlan and Neale (2000, p. 26) noted in their discussion of that initiative, "[t]*he strength of this type of event is that the scientific discussion is based on an object of considerable mutual interest*." The fact that the items under discussion may have been collected by the visitor, or perhaps have a strong family connection, contributes to this. Harnick and Ross (2004) similarly noted that when urban outreach efforts were focused on specimens that students had collected personally, or that came from the local neighbourhood, it led to students displaying increased investment and interest during learning activities. "*Incorporating local examples into classroom activities increases student confidence as it draws upon student experiences and background knowledge while demonstrating the connection between classroom curricula and student experience*" (Harnick and Ross 2004, p. 426).

The Rock 'n' Fossil Road Show originated in an effort to develop an earth science variant on the pop culture phenomenon of the long-running *Antiques Roadshow*. This was reflected in the format of the first event, which focused on identifying specimens brought in by members of the public and filming interactions between earth scientists and the public for broadcast. However, the Rock 'n' Fossil Road Show quickly developed in directions distinct from its inspiration. A key difference is that from the beginning we have emphasized the scientific stories told by specimens and downplayed their commercial value. We lack the expertise to pronounce on such matters, and we also have found that commercial value is of interest only to a minority of attendees at our events. This is in contrast to the *Antiques Roadshow*, where the value of the antiques is a strong driver for attendance (Bishop 2001) and arguably the biggest focus of the resulting broadcasts (Clouse 2008).

The Road Show and its inspiration also are radically different in scale. A single *Antiques Roadshow* event in the United States will be attended by 6,000 people, who will wait through a complex series of pre-assessments, with many of the attendees never actually having their antiques looked at by a specialist (Bishop 2001; Hix 2014). Our process is much more straightforward. Anyone can walk up to the display tables and be sure that their specimens will be 'appraised' by experts (Fig. 3). This includes even the 'mystery' specimens that we cannot identify. One segment of the original TV episode included a scientist offering multiple hypotheses for the origin of an odd structure in a rock, and then concluding that it was not possible to make a confident interpretation. It seems unlikely that an antique that could not be definitively appraised would ever make it to camera on the *Antiques Roadshow*.

Over time, the Rock 'n' Fossil Road Show has evolved to focus on the display and explanation of GSC specimens, although the opportunity to have specimens identified is still strongly promoted and people still bring in their rocks and fossils. For those who do, we suspect that the strongest driver is the same one that Bishop (2001, p. 199) identified in an ethnographic study of the *Antiques Roadshow* (at a 1999 filming of the program in Baltimore): "*For many of the attendees, curiosity—about their items and the items brought by others—was the primary motivation for coming* …" We suspect that curiosity also is the main reason that casual passers-by stop to take in the displays at the Rock 'n' Fossil Road Show.

There may be additional reasons for attending the event. Some attendees appear to be seeking validation regarding the interest value of their specimens, or may even have a desire to show them off. Other attendees already are sure of the identity of their samples but want to 'stump the experts' at the event. Such interactions are uncommon but, when done with mutual good humour, can be enjoyable. It also is fun and educational for the public to see specialists scratching their heads and conferring with each other while struggling to identify a specimen. Some of the more bemusing interactions at Road Shows have involved a whale's ear bone, small children and their gravel collections, or people with collections of polished pebbles, colourized agates, or 'mystical' crystals.

CONCLUSIONS

The Rock 'n' Fossil Road Show grew out of GSC-Calgary's earlier educational outreach efforts, especially the Pet Rock and Fossil clinics of the 1990s. Beginning with a 'one-off' outreach opportunity inspired by the pop culture phenomenon of the *Antiques Roadshow*, it has evolved into GSC-Calgary's major annual science outreach event. Our collaboration with the Calgary Public Library system has given us access to numerous venues, although similar events could be held in shopping malls, sports facilities, community halls, or museums. Our experience suggests that the Road Show model is a good educational outreach option for any earth-science research institute with a critical mass of knowledgeable volunteers and access to a collection of specimens that have scientific interest and visual impact. This approach also lends itself to modification as circumstances demand. After more than a decade, we believe that the most important reason for the success of the Rock 'n' Fossil Road Show is its focus on taking science to the public, via events that are both engaging and informative.

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