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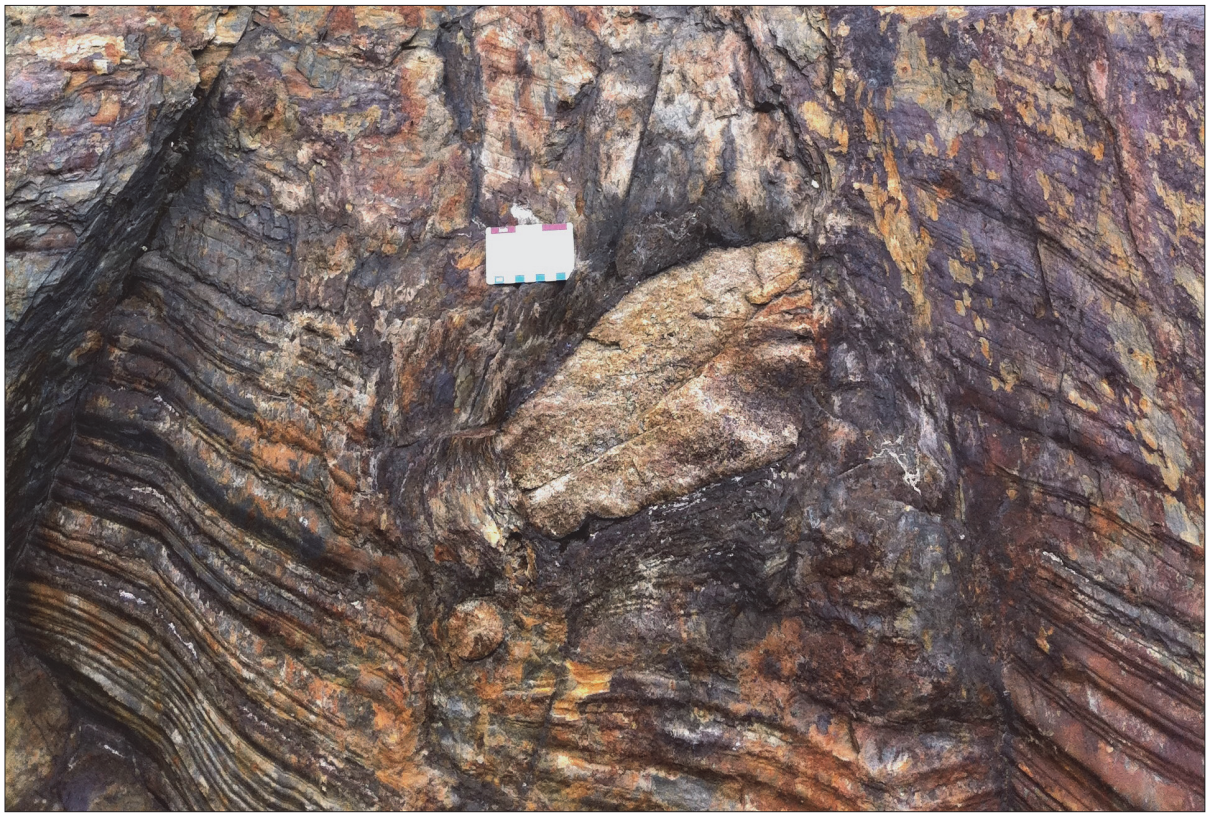

Sudbury 2023 GAC-MAC-SGA:
Discovering Ancient to Modern Earth

Tuzo Wilson: The Unlikely Revolutionary of Plate Tectonics

The Lewisian: Britain's Oldest Rocks

2023 VOLUME 50

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Cover Image: Field stop photo for an upcoming Sudbury 2023 preconference field trip showing a dropstone at the contact between the Ramsay Lake mixtite and overlying Pecors Formation rhythmites of the Paleoproterozoic Huronian Supergroup. Photo credit: Patricia Corcoran.

GAC-MAC: FIELD GUIDE SUMMARY

Sudbury 2023: GAC–MAC–SGA Joint Annual Meeting Field Trips

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SUDBURY 2023 FIELD TRIPS OVERVIEW

This year's 2023 GAC-MAC Annual Meeting returns to Sudbury after a 24 year absence, with the Society for Geology Applied to Mineral Deposits (SGA) as a partner. Sudbury's unique location at the junction between the Archean Superior Province, Proterozoic Southern and Grenville provinces, and Paleozoic–Quaternary cover sequences, offers opportunities to attend field trips in a wide variety of geological settings from Archean greenstone belts to Proterozoic glaciogenic rift-drift sequences to Paleozoic passive platformal sequences. Sudbury also sits on the world-renowned Sudbury impact structure, is the world's premiere nickel-copper mining district, and is located within three hours drive of the prolific Abitibi-Wawa greenstone belt, which is famous for its world-class gold deposits and copper-zinc volcanogenic massive sulphide deposits. All of these add up to an impressive offering of ten pre- and post-conference field trips lasting one to four days.

Pre-Conference Field Trips

To kick-start the meeting, from May 20th to 23rd, join Stéphane Perrouty and Ross Sherlock on a four-day field trip *"Discovering the Abitibi Gold Belt"* across the Timmins, Kikland Lake, Larder Lake, Malartic, and Val-d'Or gold mining districts. This is a unique opportunity to visit many famous gold deposits, such as the Kirkland Lake, Kerr-Addison, Canadian Malartic and Sigma deposits, in a single field trip. This is a must-do for anyone interested in orogenic gold deposits.

During *"Geological Traverse of the Sudbury Impact Structure and Evolution of the Impact Melt"* on May 24th, Dustin Peters, Sandra Baurier Aymat, Shirley Peloquin, and Caroline Gordon will take participants on a one-day geological traverse across the Sudbury Structure, one of the world's oldest, largest, and best-preserved impact structures. From shatter cones and pseudotachylite bodies in the target rocks, over impact-melt related breccias and intrusions, to the world-class magmatic Ni-Cu-(PGE) sulphide mineralization, participants will be able to examine a variety of geological features that bear witness to the unique origin and complex evolution of the Sudbury Structure.

Enjoy beautiful Manitoulin Island during *"Geology of Manitoulin Island"* led by Frank Brunton, Catherine Béland Otis, Katie Hahn, and Patrick Julig. During this two-day field trip on May 23rd and 24th, you will explore the Paleozoic geology of Manitoulin and adjacent islands, including an overview of indigenous uses of local bedrock geology and a guided tour of one of Canada's oldest indigenous quarry sites. This field trip will introduce participants to one of the few places in the Great Lakes Region where Upper Ordovician and Lower Silurian sedimentary strata form prominent escarpments and cuestas. Manitoulin and surrounding islands have a distinguished paleontological and geological history, where arguably some of the first fossils were formally described in Canada, and where variably rich shelly faunas and extensive patch reef and barrier reef tracts flourished at different times proximal to Proterozoic highlands.

The sedimentology of the Huronian Supergroup will be the focus of a field trip by Patricia Corcoran and Carolyn Hill-Svehla exploring the *"Paleoproterozoic Glacial, Microbially Induced, Tidal, and Seismic Deposits of the Huronian Supergroup, Elliot Lake Region, Canada"*. This two-day trip on May 23rd and 24th will provide a detailed look at outstanding examples of ancient varves with dropstones, tillite, microbially induced sedimentary structures (MISS), flaser and lenticular beds, herringbone crossbeds, slump structures, clastic dykes, and soft-sediment deformation structures. The outcrops will provide an opportunity to discuss the factors that controlled the composition of the Huronian Supergroup formations, including the Great Oxygenation Event (GOE).

From May 22nd to 24th, Chong Ma, Lianna Vice, Carl Nagy, and Bruno Lafrance will lead participants on a three-day field trip exploring outcrops associated with *"Orogenic and intrusion-related gold mineralization in the eastern part of the Neoarchean Wawa Subprovince, Superior Province"*. This trip will emphasize the structural geological controls on gold mineralization in the Missanabie-Renabie, Dubreuilville, and Wawa gold districts of the Michipicoten greenstone belt and the Eagle River mine of the Mishibishu greenstone belt. It will provide an excellent opportunity to learn how to apply structural geology to the study of gold deposits.

Geoscience Canada, v. 50, https://doi.org/10.12789/geocanj.2023.50.193 pages 1–3

Dropstone at the contact between the Ramsay Lake mixtite and overlying Pecors Formation rhythmites of the Paleoproterozoic Huronian Supergroup. Photograph courtesy of Patricia Corcoran.

Impact-induced Sudbury breccia with Laurentian University campus in the background. Photograph courtesy of Bruno Lafrance.

Post-Conference Field Trips

End your meeting exploring and discussing new ideas on the formation of "*Base, Critical, and Precious Metals Mineralization in the Metasomatic Iron and Alkali-Calcic Systems of the Southern Province in the Sudbury Area*". This two-day field trip on May 28th and 29th will be led by Jean-Francois Montreuil, Louise Corriveau, Wyatt Bain. Metasomatic Iron and Alkali-Calcic (MIAC) mineral systems are known to be capable of forming a large suite of polymetallic mineral deposits, including Iron Oxide Copper-Gold (IOCG) deposits. Using a selection of outcrops and drill cores from a mineral exploration project located 25 km east of Sudbury, the field trip presents examples of base, critical, and precious mineral mineralization (Ni, Cu-Ag-Au, Au, Co, and REE) from showings, prospects and historic mines, including the Scadding deposit. Alteration facies and mineralization types described during the field trip illustrates the spatial and temporal linkage in MIAC mineral systems between Fe-rich to Fe-poor alteration facies, deformation and mineralization, which can be used to develop predictive mineral exploration models.

Guided in part by recently-released LiDAR digital elevation models, *"Ice on the Rocks: Quaternary Geology of the Sudbury Region"*, which is led by Riley Mulligan, Abigail Burt, Grant

Strongly-deformed gold-bearing quartz vein at the Eagle River mine of the Mishibishu greenstone belt. Photograph courtesy of Bruno Lafrance.

Clinton Group in foreground along the Niagara escarpment on Manitoulin Island. Photograph courtesy of Frank Brunton.

More than just the Big Nickel – nested and cross-cutting glacial erosional marks surrounding Sudbury's (second-most) iconic landmark tell a story of changing ice flow dynamics and directions during deglaciation. Ice flow was away from reader. Photograph courtesy of Riley Mulligan.

Sharp-walled massive chalcopyrite veins at the Podolsky North Zone in the Whistle embayment of the Sudbury Structure. Photograph courtesy of Bruno Lafrance.

Hagedorn and Andrea Marich, explores the evolution of micro- to regional-scale subglacial processes operating on Shield bedrock terrains through stops showing part of a regional moraine system, bedrock- and till-cored subglacial bedforms, and nested bedrock erosional features ranging in scale from millimetres to hundreds of metres. The one-day field trip on May 28th also provides participants with exposure to the effects of past mining and smelting practices on local landscapes as well as the region's world-class re-greening efforts.

Discover how tectonic structures form along a major geological province boundary during *"Multiscale and polyphase deformation structures in the Grenville Front Tectonic Zone near Sudbury"* led by Dazhi Jiang and Changcheng Li. During this one-day field trip on May 28th, you will visit spectacular outcrops of deformation structures including one of the world's best exposed mylonite zones. The geometry and overprinting relationships among these structures will provide you with a clear understanding of the kinematic evolution of the Grenvillian orogeny.

Building on the results of the Metal Earth program, the largest mineralization exploration project in Canada, Harold Gibson, Thomas Gemmell, Taus Jørgensen, Evan Hastie, Rasmus Haugard, and Alan Smith will lead a four-day field trip on May 28th to 31st "*Exploring Differential Metal Endowment: A comparison of the Eastern (Rouyn-Noranda) and Western (Swayze) Abitibi Greenstone Belt"*. Crustal-scale processes and features affecting metal endowment, as defined through Metal Earth's seismic, magnetotellurics, and gravity surveys, will be linked to surface geological features and crustal-scale faults. In the Swayze and Rouyn-Noranda areas the trip will focus on key outcrops, tied to a new stratigraphy, that provides insights into the differences in the magmatic and structural evolution of the ca. 2704–2695 Ma Blake River Group in both areas, their base and precious metal metallogeny, and evolution of crustal-scale faults. The trip will include a half-day visit to IAMGOLD's Côté Gold and Gosselin deposits (> 19 Moz) and explore key differences in the setting and styles of ore deposits between the western and eastern Abitibi region.

From May 28th to 30th, Henning Seibel and Michael Lesher will lead participants on a three-day trip around the Sudbury Structure in *"Sudbury Offset Dikes and Associated Ni-Cu-PGE Mineralization"*, utilizing some of the most spectacular outcrops the area has to offer. The first day will include a traverse through shocked footwall rocks, the differentiated melt sheet, and suevitic fall-back breccias associated with the Sudbury impact (visiting many of the stops of the one-day pre-meeting field trip on Sudbury) and the concentric Hess Offset dike in the North Range. The second day highlights similarities and differences between the inclusion- and sulphide-poor and inclusion- and sulphide-rich lithologies in the Trill, Worthington, Vermillion, and Copper Cliff dikes west, southwest, and south of Sudbury. The complexity and variety of barren and mineralized breccias at the contact of the former impact melt sheet with the footwall will be the focus of the last day while visiting the Whistle embayment and Whistle and Parkin dikes to the northeast of Sudbury.

Further information and registration details can be found at the Sudbury 2023 GAC-MAC-SGA website: https://event.fourwaves.com/Sudbury2023/

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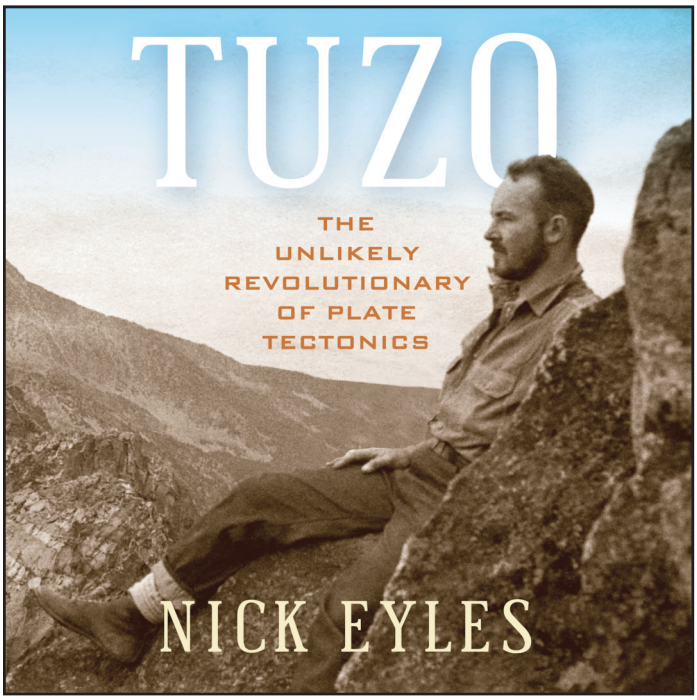
REVIEW



Tuzo: The Unlikely Revolutionary of Plate Tectonics

Nick Eyles

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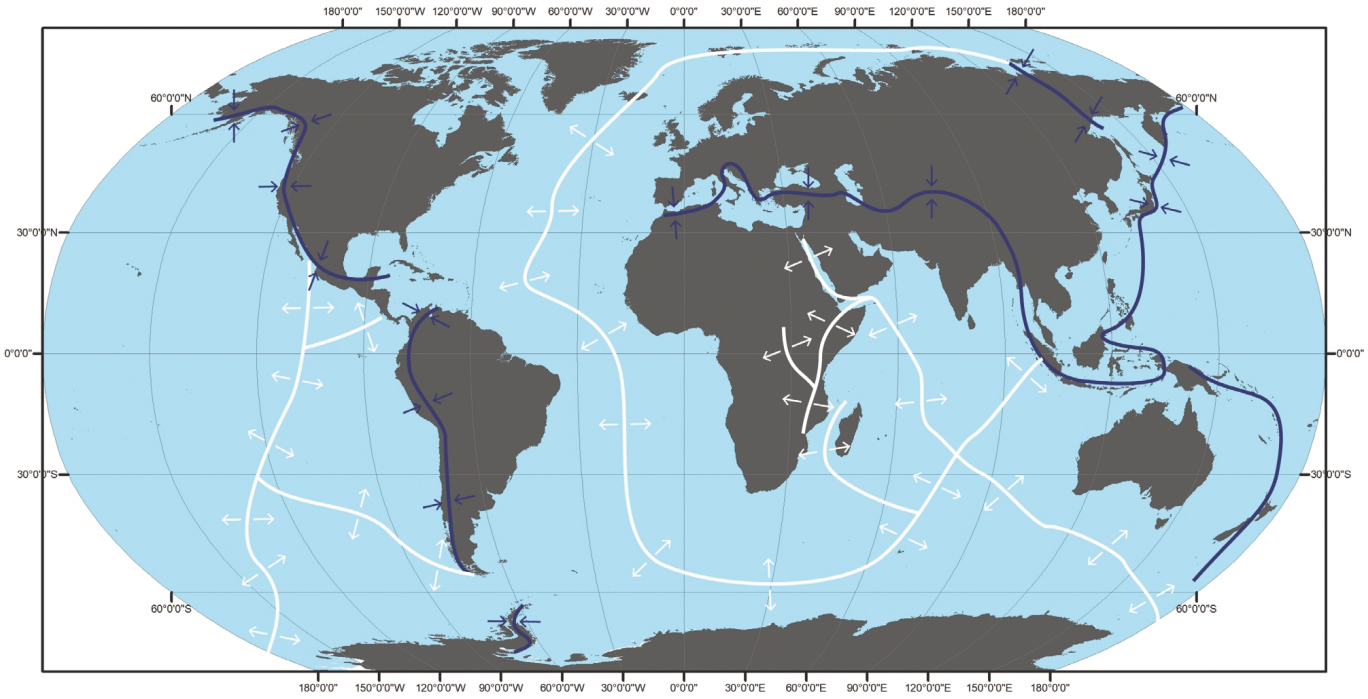
This book presents a long overdue appreciation of the geologist J. Tuzo Wilson and his profound contributions to the development of our understanding of plate tectonics. It describes how, as a teenager, Tuzo worked as a junior geological assistant one summer doing field mapping north of Lake Superior. He enrolled at the University of Toronto to study physics and mathematics. His continuing summers of fieldwork, with the Geological Survey of Canada, however, stimulated his interest in geology and he managed to arrange to take a combined Physics and Geology program, thereby instituting a program that persists to this day. After graduation, he obtained an MA from Cambridge University and a PhD from Princeton, carrying out a fairly conventional field-based study of an area in the Beartooth Mountains of Montana. On returning to Canada he joined the Geological Survey of Canada as an assistant geologist, conducting field-based mapping studies over three seasons in Nova Scotia, northern Quebec and the Barren Lands of the Northwest Territories.

At the outbreak of war in 1939 he enlisted in the Royal Canadian Engineers. Tuzo spent much of the war based in Britain and later Sicily, making use of his geological expertise to train soldiers in the drilling, tunnelling and explosives techniques that would be useful in the war effort, and in the analysis of aerial photographs to identify enemy positions and develop maps of battle fronts. Although he wished to become actively involved in the war effort in Europe, he was transferred back to Canada in 1943 to take up a position as director of Army Operational Research, in which position, among other things, he launched a spirited program to prepare the Canadian Armed Forces for high-latitude combat. This program gained added impetus when the war with Germany was replaced by the Cold War. Tuzo remained with this program until 1946, when he took up an academic position in the Department of Physics at the University of Toronto. Over the next 15 years, Tuzo conducted research in the Canadian Shield, concentrating both on the application of the newly developed radiometric dating techniques and on the application of aerial photography to the elucidation of structural divisions and glacial history. Throughout this period, Tuzo remained a confirmed 'fixist'; i.e. an opponent of the 'mobilist' theory of continental drift first proposed in detail by Wegener in the early part of the twentieth century but largely rejected by most of both the geological and geophysical communities.

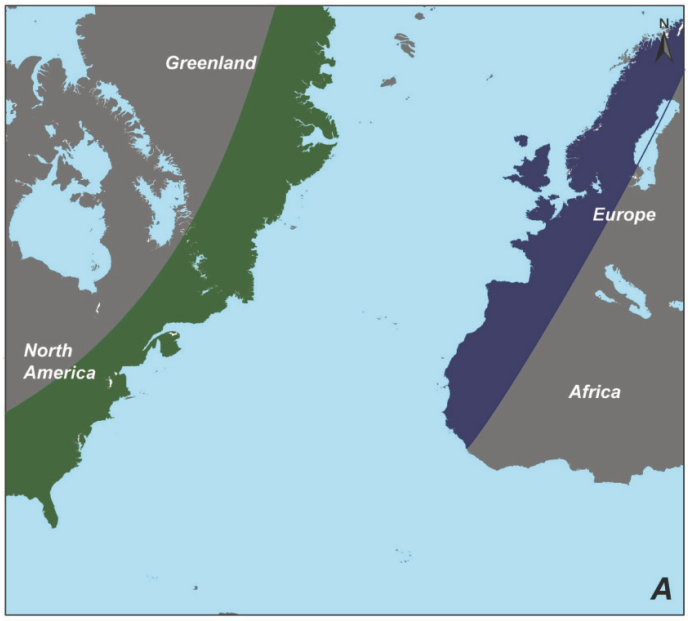
Tuzo's conversion to mobilism appears to have occurred on a visit to Hawaii in 1961 when, after hearing a talk by Robert Dietz on sea-floor spreading at mid-oceanic ridges, he went to the Hawaiian peak Mauna Loa. While there he realized that the northwestward increase in

Lieutenant John Tuzo Wilson's photo taken in Ottawa in the Fall of 1939 shortly after he enlisted with the Royal Canadian Engineers. Photo credit: Yousuf Karsh.

J. Tuzo Wilson, Professor of Geophysics, University of Toronto, visiting the Ticlio Pass at the highest part of the Cordillera Central in the Peruvian Andes.

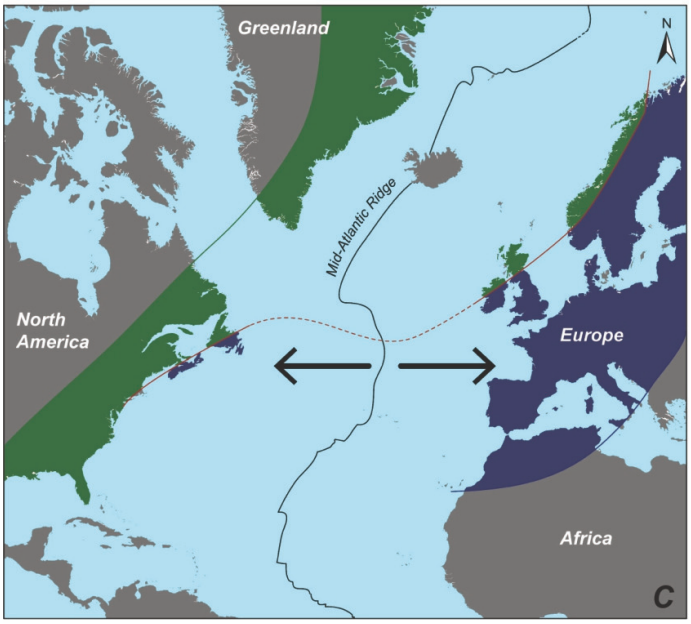


Tuzo Wilson's map, published in Scientific American in 1963, (v. 208, p. 86–100), identified a moving Earth's surface with mid-ocean spreading centres (white lines) at the site of mantle upwelling and deep blue lines where these mantle convection currents descended.



A: Iapetus Ocean 500 million years ago

B: Iapetus Ocean closes to form Pangea 350 million years ago



C: Atlantic Ocean today

Pacific marine organisms

Atlantic

Adapted from Tuzo Wilson's 1966 Nature paper *Did the Atlantic close and then re-open?* the panels, A and B, show the progressive closing of a proto-Atlantic (Iapetus Ocean) and then the opening to form the present-day Atlantic Ocean, thus explaining the presence of contrasting shallow marine fauna of Lower Paleozoic time, Pacific- and Atlantic-faunal realms, adjacent to each other on either side of the ocean basin.

ages along the Hawaiian-island chain, suggested by James Dana as long ago as 1840, would be perfectly explained by movement of a Pacific plate over a hotspot. He later developed this suggestion by dating the volcanic rocks all along the chain, leading to a 1963 paper on mantle plumes and hotspots that is one of his three most important contributions to our understanding of global tectonics. From this time onwards, Tuzo was a committed mobilist and he went on to publish a paper in 1966 based on faunal distributions in eastern North America and northwestern Europe, in which he argued that opening of the present Atlantic Ocean had been preceded by closure of an earlier ocean. This argument, now widely accepted, gave rise to the term 'Wilson cycle'. As Eyles points out in his book, this idea was first promoted by Amadeus Grabau who, while a professor at Columbia University, had been a spirited proponent of Wegener's ideas but lost his position at Columbia in 1919 and moved to Peking University. Grabau published

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his idea for a pre-Atlantic Ocean in 1940 but it was ignored at the time due perhaps to the prevailing wisdom that continents did not move. Tuzo's third very significant contribution was to explain how transform faults work, which he published in 1965. The stage was then set for the appreciation of how lithospheric plates move around Earth, bounded by oceanic spreading centres, transform faults and Wadati-Benioff zones. The full picture was put together in several different papers published in 1967.

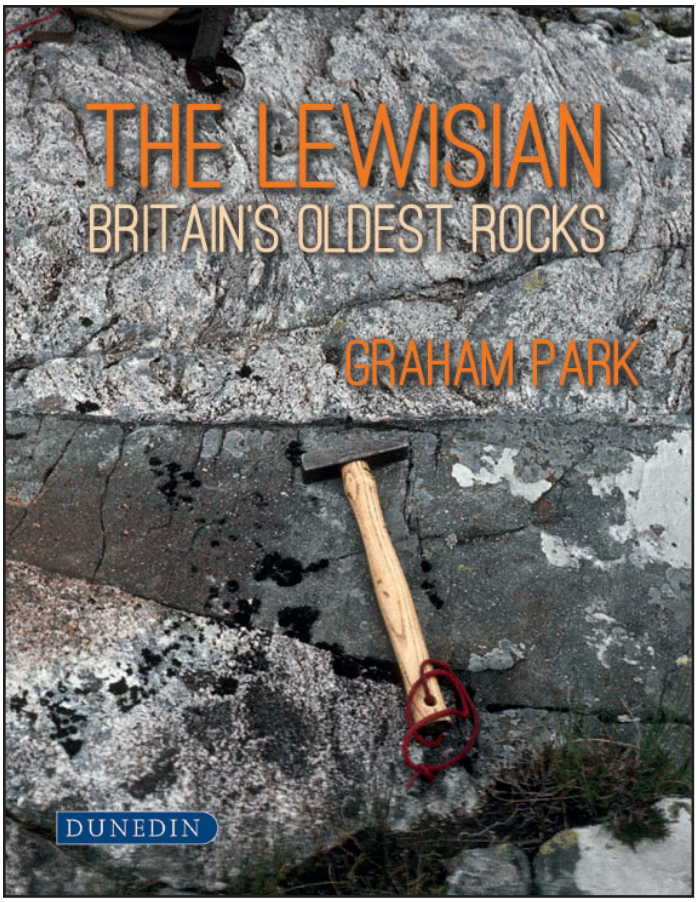
Eyles' book provides a compelling description of the long controversy surrounding the possibility of continental drift, with interesting characterizations of the main players both before and after Wegener, but particularly of the fixists who dominated the discussion, especially in North America, and to whose teachings Tuzo adhered until his Eureka moment in 1961. The book makes very clear how the positions held by well-established Earth scientists successfully suppressed mobilist ideas, perhaps driven by the fact that much of the work that had dominated their careers was in some sense discredited by the new ideas. It also argues that the success of their suppression may have been helped by the generally less-established status of proponents of mobilism.

The book interweaves the development of discussion over global tectonics with the details of Tuzo's life experiences. It shows exceptionally well how the techniques that Tuzo had gained in mineral exploration and mapping prior to the war made invaluable contributions to his ability to assist in the war effort, and also how many of the geophysical techniques that were developed to assist the war effort, by people such as Teddy Bullard and Maurice Ewing, were key to the postwar acquisition of data about the hitherto largely unknown features of the ocean floors in the years immediately after the war. Throughout the book, Tuzo's slightly quirky personality is captured very well, making use of both his own quotes and the reminiscences of his daughters and many people who worked with him at various stages in his career.

The book is very well written, delightful to read and superbly illustrated. Towards its end the book does perhaps get a little carried away, in using our understanding of plate tectonics to suggest we can make firm predictions about how the next supercontinent will form, and in arguing that plate tectonics was essential to the development of life on Earth. I might also have wished that the author had been a little more careful to ensure throughout the book that his non-geological readers understood that the lithospheric plates consist of both crust and a significant part of the uppermost mantle, and that he had avoided characterizing the crust as 'floating' on the mantle when he was explaining the isostatic principle using the iceberg analogy. I would, however, very happily recommend this book, albeit with the equivalent of a minor health warning to non-geologists.

All figures come directly from Nick Eyles' book, *Tuzo: The Unlikely Revolutionary of Plate Tectonics*, with permission from University Toronto Press.

REVIEW



The Lewisian: Britain's Oldest Rocks

Graham Park

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THE BOOK – A GENERAL OVERVIEW

I must begin this commentary on Dr. Graham Park's splendid historical and geological tome "*The Lewisian: Britain's Oldest Rocks*" by confessing that I have had limited first-hand exposure to the rocks about which he writes so passionately and with such deep insight. I am certainly not 'learned' about the Lewisian when compared to Dr. Park, so I must deflect any specific critiques of his opinions and observations to those more intellectually well-equipped to do so. Nevertheless, I have seen and walked over some of these Precambrian rocks during several field trips in Scotland associated with thematic conferences, in one case in the company of Dr. Park. Furthermore, one such excursion, when I was a graduate student in the mid-1970s, was led by the much-admired Janet Watson, whose name is inextricably linked to these rocks. I have maintained a peripheral interest in Lewisian research for a half-century and amassed a fair collection of Lewisian-related serial literature.

Dr. Park's book is, in my opinion, an excellent review of the impressive, two-hundred-plus-year history of study of the Lewisian rocks (Fig. 1). Researchers and students know that it is customary to review 'Previous Work' in any publication, and this superb monograph is a particularly complete and detailed example of such an overview for an influential collection of puzzling Precambrian rocks. For anyone with a bent towards historical geological treatises, this book should give many hours of pleasurable reading. The back cover summary states that it has been compiled in a "user-friendly form" for the geological fraternity and for "academics" desirous of broadening their knowledge of noteworthy "advances in earth science". As such, it will not appeal to a universal audience and would challenge geologists who lack any background in Precambrian geology, structure and metamorphism. The inclusion of a glossary aids, to some extent, to clarify terminology, but even some specialists may have their capacity to absorb details stymied by discussions of geochemical and isotopic data presented in the latter part of the book (chapters 16 to 18, see below). Nonetheless, for well-informed readers or subject-focused researchers the book is an enlightening traverse across the Lewisian gneisses and through time (both geological and historical), related by a scientist who has had an intimate research connection to these rocks for over six decades. It is impossible in a general appraisal of this book to fully encapsulate the many facets of these rocks, or to address every geologically significant site or event described in it. Therefore, a broad chapter-by-chapter précis is offered in this review.

The book is partitioned into three main sections: *The Pioneers* (chapters 2 to 5), *Gathering the Data* (chapters 6 to 13), and *Models and Hypotheses* (chapters 14 to 19). These three parts are prefaced by a general introduction (Chapter 1) that provides the geographical and geological context of the Lewisian.

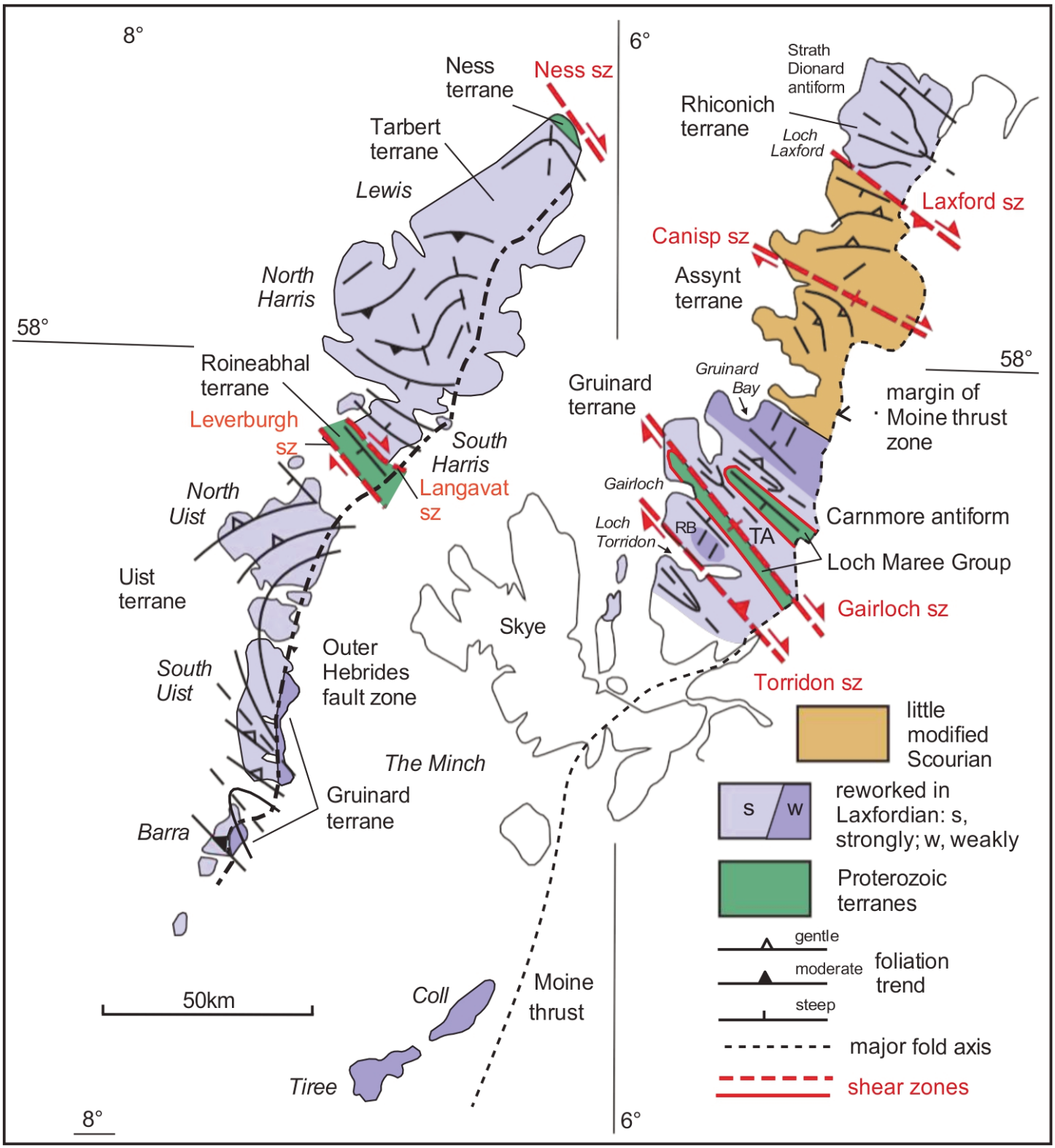

Figure 1. Distribution of Lewisian rocks in northwest Scotland. Depicted are some of the notable geological features and geographical locations described in the book.

The Pioneers

Part 1 of *The Lewisian* presents a thorough, yet succinct, history of study of the Lewisian rocks. Chapter 2 introduces the reader to the earliest geological walkabouts on the rocks. Beginning with an account of the seminal work of John MacCulloch from the early 1800s, Dr. Park proceeds to chronicle 19th century studies up to those of the British Geological Survey in the late 1800s. It is here that readers are introduced to the "Fundamental Complex", the collective term Sir Roderick Murchison coined for the ancient rocks of northwestern Scotland.

Chapter 3 is devoted to a "famous" Geological Survey memoir from 1907, "*The Geological Structure of the North-west Highlands of Scotland*", a comprehensive report prepared under the editorship of Sir Archibald Geikie. It was in this report that "the foundation stones of Scotland" were given the name Lewisian Gneiss, and mafic intrusions subsequently referred to as the Scourie dykes (Fig. 2) were first documented and used as markers to separate discrete episodes of deformation. Dr. Park highlights the part of the memoir dealing with John Horne's colourful descriptions of the Lewisian and the lithological subdivisions and structural features that he recognized among the rocks.

Chapter 4 examines the seminal work of Janet Watson and John Sutton, the results of which culminated in a landmark paper in 1951. This paper, lengthy but so elegantly written, was required reading for students of Precambrian geology and structural geology during my university days. It was in part a foundational account of how basic intrusions, the aforementioned Scourie dykes, could be utilized to unravel relative ages and superposed structural events in polydeformed high-grade gneiss terranes. The paper demarcated the "Scourian" (pre-dyke) and "Laxfordian" (post-dyke) history of the Lewisian. This fundamental approach to 'reading the story in the rocks' was later applied to Archean gneisses in western Greenland, by Vic McGregor, and in many other Precambrian Shield areas.

The final chapter of *The Pioneers* takes the reader from the Scottish mainland to the Outer Hebrides. It initially highlights the work (maps and reports) carried out on these islands by T.J. Jehu and R.M. Craig in the 1920s and 1930s, and then jumps ahead to review the studies of C.F. Davidson, M. Kursten, and R. Dearnley. There is an interesting tidbit of information associated with the Martin Kursten section, viz., the influence of D.B. McIntyre and L. Weiss on his approach to tackling the structural complexities apparent in the Lewisian of the Outer Hebrides. Ray Dearnley's 1963 account of the South Harris anorthosite and associated rocks was one of the first papers on these Precambrian basic rocks that I encountered as an undergraduate student, leading me to cultivate a further interest in Archean anorthosites in Greenland and India.

Gathering the Data

In Part 2 of the book the reader is taken on a more focused, eight-chapter tour of the Lewisian. This is the 'meat in the sandwich' of the volume, and it is peppered with names that will be well remembered by students from geology courses in the 1970s. The complexities of Lewisian structure and stratigraphy are brought out in much detail. This may make it a challenge for readers to keep all the tectonic and compositional nomenclature in mind between one chapter and the next. The text is supported by illustrations and photographs mainly reproduced from important papers that now provide the essential descriptive foundation.

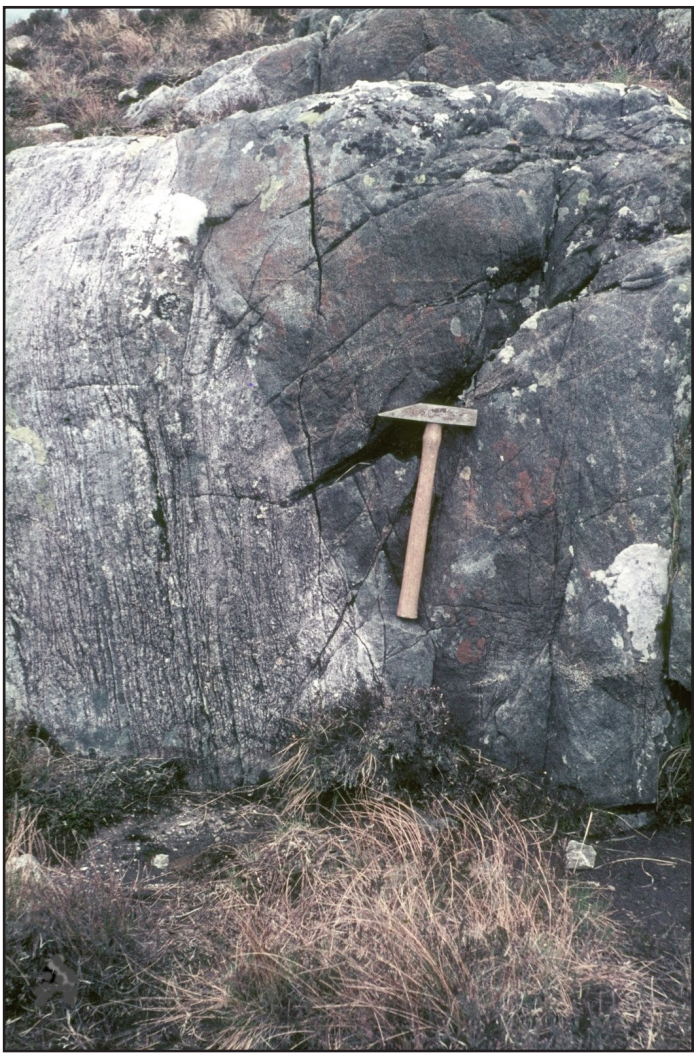

Figure 2. Sharp discordant contact between a Scourie metadolerite (metadiabase) dyke and a gneissic foliation.

Chapter 6 informs the reader of the challenges the book's author tackled as he embarked on his late 1950s and early 1960s investigations aimed at unravelling the Gairloch area. It begins with a short discussion of "granitization" and "migmatization", and from there it reviews the geological aspects of the region, incorporating a treatment of local stratigraphic nomenclature and a chronology of deformation episodes using the numbered F and D modifiers in vogue at that time. Dr. Park tells of a professional disagreement by John Sutton in 1963 of his Gairloch study, one which led him to subsequently re-evaluate his Gairloch work. He relates how Sutton's commentary prompted him to examine an adjacent area and, as a consequence, "revise my interpretation of the Gairloch area". Such stories will no doubt be familiar to other readers involved in research.

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Work undertaken as part of a re-mapping program of the Lewisian on the Scottish mainland by university researchers and their students in the 1960s is given a thorough review in Chapter 7, with much detail illustrated by original field sketches and maps. Of particular note is the study by David Cresswell, who postulated that the notable layer-parallel versus layer-discordant differences between Scourie dykes and gneissic structures at Loch Torridon reflected primary emplacement features; a reproduction of Cresswell's map for the Diabaig area gives a clear picture of dyke density and relation to gneissic foliation (Fig. 3). Dr. Park ends the chapter by commenting on the perils of correlating structural chronologies of gneisses between disparate areas, and returns to it in Chapter 8 under the title "*Problems of Correlation and Nomenclature*". He highlights some interpretative disagreements between contemporary workers, and he supplies examples of differing terminology that sometimes proved to be obstacles in assessing Lewisian structural continuity. This excellent chapter discusses many problems that compilers of regional geological maps elsewhere encounter, and illustrates the frustrations in attempting to correlate geological events documented in a multitude of independent and isolated small studies.

The first attempts to apply the then-new insights from isotope geochronology are reviewed in Chapter 9. The focus here is on the application of K–Ar and Rb–Sr methods, chiefly in the 1960s, but U–Pb studies by Stephen Moorbath and colleagues are also reviewed. A wide variety of ages came from this work. The text rightly includes caveats from the original researchers and Dr. Park pertaining to the interpretation of isotopic results in a time when complications such as Ar loss and Rb migration were not fully appreciated.

Chapter 10 is devoted to understanding the pre-deformation character of the "Fundamental Complex" (i.e. gneisses predating intrusion of the Scourie dykes) and begins with a summary of John Myers' meticulous mapping on the island of Harris. Following its summary of the gneissic subdivisions advanced by Myers, the chapter discusses efforts to characterize the gneisses on the basis of geochemistry. The work of John Sheraton, Don Bowes, Mike O'Hara and several other investigators is highlighted, reviewing the use of specific geochemical signatures to determine protoliths. An informative section addresses the attributes of basic and ultrabasic rocks of the Lewisian, the concluding pages of which outline consideration of these rocks in terms of their origins, including suggestions that they might be slices of oceanic crust tectonically intercalated with older continental crust or be layered intrusions emplaced into the crust.

Chapter 11, "*Re-mapping of the Hebrides*" was, for me, a real delight to read. The accounts of fieldwork addressed here, especially the original papers by Janet Watson, John Myers, Mike Coward, Peter Francis and Rod Graham, were required requisites for my 1970s petrology and structural courses. This chapter also brought back memories of my sense of awe upon seeing, in 1975, the impressive Lewisian slabs used in the construction of the standing stones of Callanish on the Isle of Lewis. For the casual reader this chapter may be a bit of a maze to navigate, but for those involved in structural and metamorphic geology it is a wonderful account of the problems encountered and the astute observers who partly resolved them. Peter Francis' and Mike Coward's observations of relative dyke rheology in relation to metamorphic grade were catalysts for my additional undergraduate reading of Juan Watterson's report on deformed dykes of the Ketilidian of Greenland. Dr. Park again returns to the process of "granitization" by reviewing John Myers' study of the granite-migmatite complex of Harris, before dwelling on some of the mapping undertaken on the Inner Hebridean islands. The last part of the chapter deals with geochemical attributes and element migration in granitic intrusions and granulite-facies gneisses from the inner isles reported, respectively, by Graham Westbrook and Steve Drury.

Chapter 12 reviews an important conference held at Keele University in 1971, steered by Dr. Park and John Tarney, at which a couple of papers delved into potential connections between Scotland and Greenland. The chapter provides an

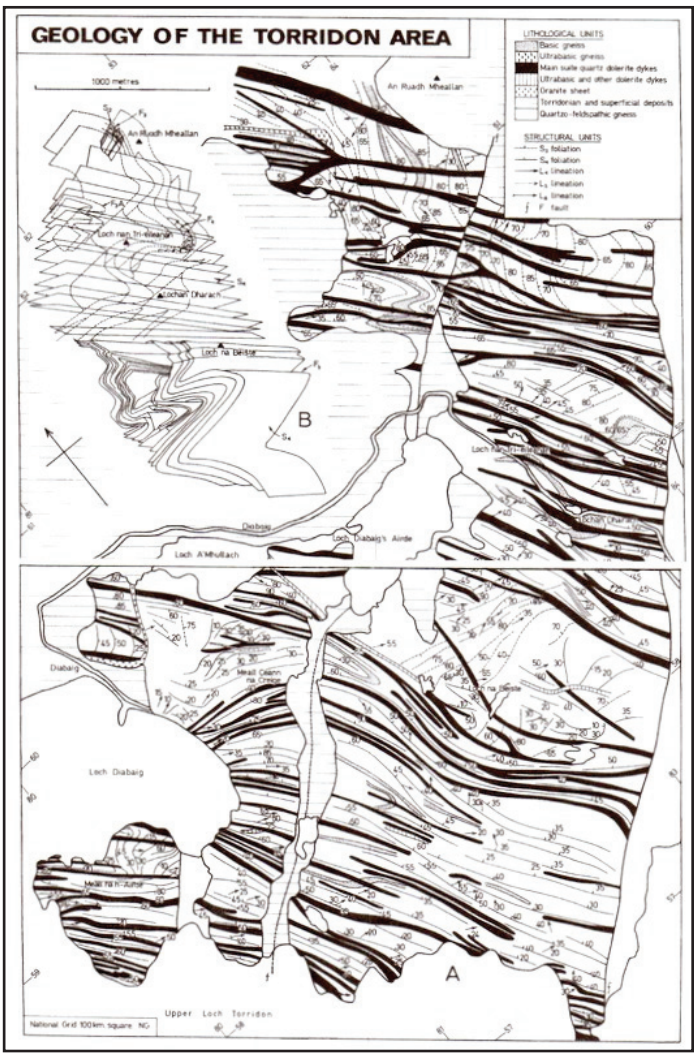

Figure 3. Reproduction of David Cresswell's map published in the Scottish Journal of Geology, (v. 8, p. 293–308; figure 2), illustrating the relationship between Scourie dykes (solid black; vertical line pattern), gneissic foliations and lithological subdivisions in the Diabaig area.

overview of the conference, recounting contemporary interpretations that were applied to selected features of the Lewisian, but Dr. Park also includes a few supplementary references to subsequent (post-1971) re-interpretations. A particularly interesting section of this chapter is devoted to the Scourie dykes and discussions about their emplacement into a hot crust and the exact relationships between morphology and deformation. The last pages of the chapter give a review of the papers presented at the Keele meeting in which provisional comparisons were advanced between the Precambrian of Greenland and the Lewisian. A dog-eared and pencil-annotated copy of the proceedings of the conference, entitled "*The Early Precambrian of Scotland and Related Rocks of Greenland*", still holds a treasured place on my library bookshelf!

Chapter 13, the final one in Part 2, returns the reader to the 'boots on the ground' field studies, discussing investigations on the Scottish mainland in the 1970s. The opening section of the summary brings to the forefront the work of Mike Coward, Rod Graham and Alistair Beach, and Dr. Park passes comment on their differing interpretations of facets of the Scourie dykes in comparison to his earlier publications with David Cresswell. An impressive and detailed illustration of Scourie dykes in a 12 km^2 area near the Gruinard River, based on mapping by Alan Crane, shows the level of detailed study and the level of geological complexity. References to multiple episodes of deformation (D), folding (F) and metamorphism (M) and their possible regional correlations may not be of particular importance to the general reader but Table 13.1 provides one useful summary for those with a penchant for such things.

Models and Hypotheses

In Part 3 of the book, the reader passes into the 'arm-waving' and 'big-picture' analyses of the Lewisian. The six chapters here deal with subjects such as shear zones and kinematic models of deformation (chapters 14 and 15, respectively), the petrogenesis of Scourian and Proterozoic parts of the Lewisian (chapters 16 and 17, respectively), an absolute chronology of events (Chapter 18), and finally an evaluation of the Lewisian in the context of Precambrian plate tectonics (Chapter 19). This last part of the book took me back to my undergraduate and graduate student days with its many references to individuals and papers that influenced our thinking on many topics.

Chapter 14 begins with a discussion of an influential 1962 structural geology paper by Derek Flinn, one which approached deformation through a three-dimensional lens. This paper was required reading for aspiring structural geologists during my student days. Flinn's work influenced Juan Watterson's subsequent research on gneisses in Greenland, a study also given prominence in the chapter. This work in turn brought new ideas to Scotland by showing how prolonged polyphase ductile deformation could produce deceptively simple sedimentary-like layering. Dr. Park then proceeds to a discussion of another classic paper, one on shear zones by John Ramsay and Rod Graham, and subsequently highlights examples from the Lewisian, such as South Harris and Gairloch. Lewisian shear zones also underpin much of the discussion in Chapter 15, which is related to the "third Lewisian conference" held in 1985 in Leicester. This chapter focuses on some of the most prominent Lewisian shears and evaluates them within the context of crustal deformation processes.

Two chapters on petrogenesis follow, Chapter 16 dedicated to the ancient rocks of the Scourian Complex and Chapter 17 to younger Proterozoic components. The Scourian is approached by a review of conclusions advanced in the mid-1970s to late-1980s, including work by Bryan Davies, Janet Watson, Steve Drury, John Tarney and collaborators. Drury was the first to apply rare-earth element (REE) data and theoretical modelling to ascertain the original character of the Scourian gneisses. This chapter provides a comprehensive summary of several geochemical studies of the rocks, and how inferences from geochemical signatures pointed to plutonic parents likely of variable nature and tectonic setting. The last part of Chapter 16 is dedicated to an overview of the metamorphic evolution of the Scourian, including derivation of P-T conditions and also the new and compelling evidence of multiple thermal events revealed by U–Pb zircon geochronology. Chapter 17 addresses the Proterozoic rocks, including those derived from sedimentary and volcanic precursors. The Loch Maree succession of supracrustal rocks is addressed in detail, Dr. Park having spent many years investigating it, including hypotheses regarding the genesis of its various components. The petrogenesis of the Scourie dykes is approached using work on trace element and isotopic patterns, which suggested derivation from partial melting of the mantle during crustal extension; the "main" dyke set was emplaced ca. 2.4 Ga. Felsic plutonic rocks of the Laxfordian episode, representing crust of ca. 1.9 Ga to ca. 1.7 Ga age, are discussed near the end of the chapter, and ascribed to volcanic arc magmatism and partial melting of older rocks. The final section of the chapter gives an overview of metamorphism imposed on the rocks, including early ultra-high temperature (UHT) and later greenschist-facies events.

Chapter 18 is a review of many geochronological investigations conducted between the late 1960s and mid-2010s, using a wide variety of specialized methods. Trying to keep in mind the multitude of results could bring on giddiness, but general readers and geochronologists will appreciate the protracted geological history. The oldest rocks in the "Fundamental Complex" were formed some 3 billion years ago whereas the youngest isotopic ages record events that occurred some 2 billion years later. The intervening events encompass plutonism, sedimentation and metamorphism, all of which were repeated. A crust-forming event prior to 2.9 Ga produced the precursor igneous rocks, and significant metamorphic imprints occurred ca. 2.7 Ga (termed Badcallian), ca. 2.5 Ga (termed Inverian) and across a temporal span from ca. 1.9 Ga to ca. 1.7 Ga (termed Laxfordian). Dr. Park highlights differing interpretations of diverse data, pointing out how modern laser-based, spot analyses of individual mineral grains (e.g. zircon, titanite, monazite) provide better constraints and detail compared to the previously employed 'whole mineral' and 'whole rock' methods.

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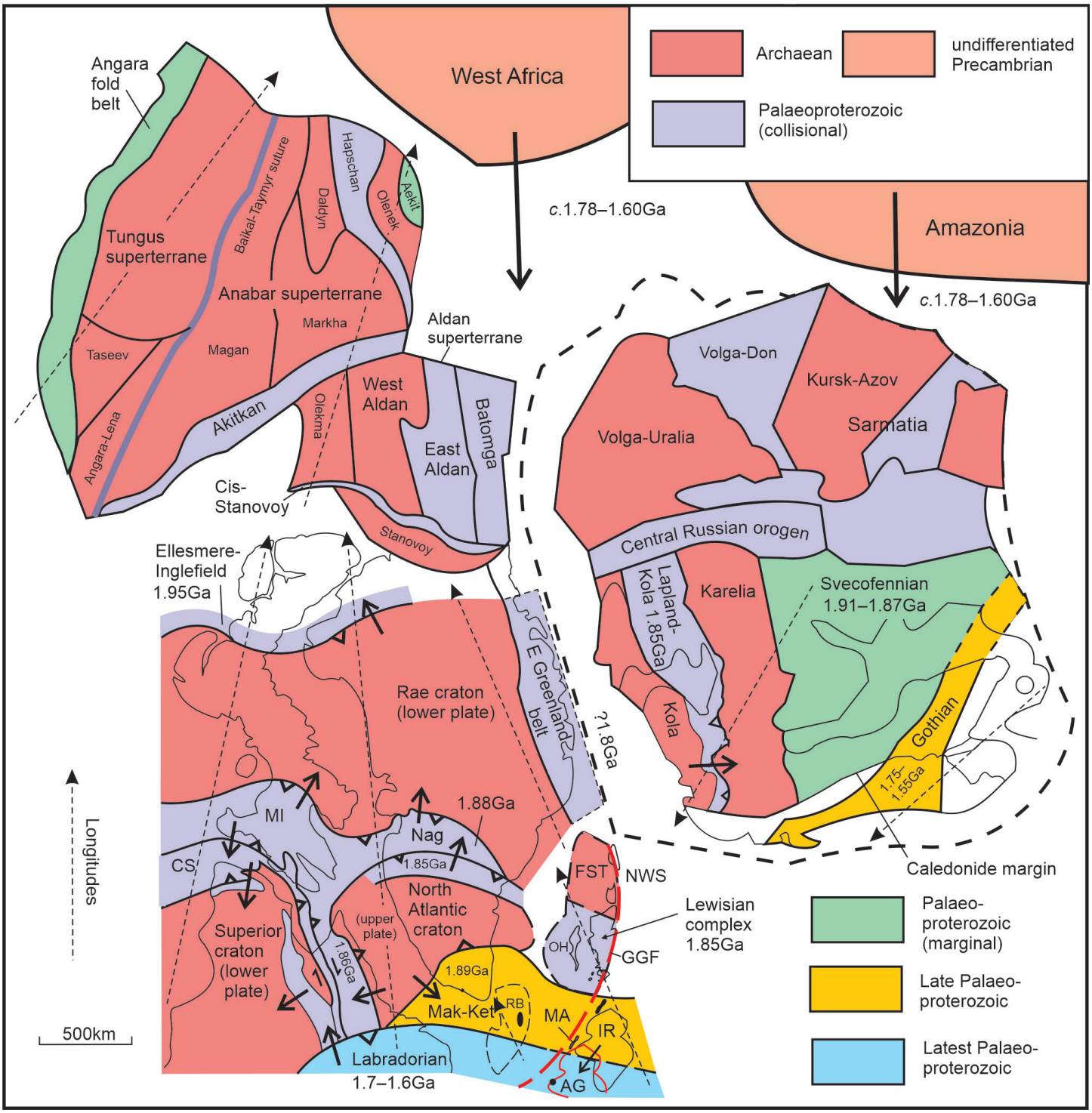

Figure 4. Distribution of several hypothesized continents in the Proterozoic, showing the possible location of the Lewisian gneiss complex within the tectonic framework. This illustration in the book is complemented by additional interpretative drawings of continental migration and interactions between 1.9 Ga and 1.5 Ga.

Chapter 19 wanders into global geodynamics and is aptly entitled "*The Wider Picture*". It visualizes the Lewisian in the light of global-scale processes – continent assembly and continent sundering – and is rich in colourful interpretative illustrations (Fig. 4). The chapter includes geographic reconstructions of the Lewisian and the other Precambrian rocks in terms of plate tectonic processes, with emphasis on correlations with east Greenland, Canada and Scandinavia. The application of the "Terrane Concept" to the Lewisian is introduced as the third section of this chapter. There is particular reference to "controversial" proposals by Clarke Friend and Peter Kinney, who suggested that the Lewisian comprised multiple

welded terranes, having disparate crustal histories. The alternative view, advanced by Dr. Park, is that there are fewer 'terranes' and the regional patterns reflect the collisional stacking of two slabs of continental crust. Paleoproterozoic plate interactions are suggested to govern assembly of wandering continental fragments into Earth's first supercontinent, and the Lewisian tells one part of that story. Dr. Park ends his book with a section that could be summed up by *Where do we go from here?*, a query that not only applies to the Lewisian but also to a further understanding of the evolution of the early Earth.

SOME CLOSING REMARKS

I have not scrutinized *The Lewisian* with an eye to editorial shortcomings but some, such as the fuzziness of line diagrams reproduced from other sources, are readily apparent. Additionally, a few 'gremlins' have crept into figure captions. None of the foregoing poses an impediment to the pleasure of reading this book, and they are expected from the very nature of the publication. The photographs supporting the text are crisp, but some are not very informative and others lack scale references; several photographs are duplicated. I detected a couple of spelling inconsistencies and errors, but anyone who has written detailed scientific reviews will know that such things are inevitable. The use of the past tense in describing existing features of rocks or units as outlined in historical literature irritated me at times, but I acknowledge my own preference for using the present tense for all descriptive uses. A book of such depth, length and breadth would challenge any writer or editor in terms of imposing consistency and clarity to each and every paragraph.

The writing in this encyclopedia of Lewisian research is not all dry and technical. Dr. Park has incorporated numerous informative 'aside' comments throughout the book and has recounted differences in geological interpretations between himself and other workers. Professional divergences are not surprising in the geoscience world and they are inevitable in our efforts to understand such cryptic and challenging rocks. Comparative discourse allows differing approaches to ultimately arrive at an acceptable level of uniformity. The history of research on the Lewisian is very much a testament to how field-related geoscience works and progresses.

I would like to end this review with a couple of personal anecdotes and a prediction. My first visit to the Lewisian, in 1975, was a bit disappointing. Having spent several years walking the ice-scoured and barren shorelines of Labrador, features in the coastal outcrops of the Scottish Highlands were harder for me to discern because of the moss and lichen cover. It took me some time to appreciate the details discussed by the excursion leaders. A routine aspect of field work in northern Canada involves tearing back the blanket of vegetation to seek critical features and relationships. On a field trip in the 1980s I attempted this technique on a poorly exposed rock surface – near Gairloch, I believe. Dr. Park cautioned me – in a whispered, friendly manner – that such drastic action was not a regular practice among Scottish geologists and might not receive their blessing! Regardless of whether the Lewisian is stripped bare or hidden beneath a cloak of vegetation, it represents one of the most fascinating and influential regions for our understanding of the Precambrian. Dr. Park has revealed in his book a personal chronicle of historical, geological and interpretative details that will be an invaluable reference for many future generations of geoscientists. I wholeheartedly recommend this volume to students of Precambrian geology, to geologists who love to absorb historical studies of classic regions, and to anyone having an interest in structurally complex metamorphic rocks. Any geoscientist who is curious as to how a reasonable – but invariably debatable – story can be extracted from such rocks will admire the huge effort involved in writing this book, and appreciate the immense contribution that it makes. Like many of the classic studies that it draws upon for details, it will truly stand the test of time.

All figures come directly from Graham Park's book, *The Lewisian: Britain's Oldest Rocks*, with permission from Dunedin Academic Press Ltd.

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