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Geochemical Exploration and Metallogenic Studies, Northern Chile

Gamma-Ray Spectrometry: A Tool for Mapping Canada's North

Robert J. Chalmers: Pioneer Surficial Geologist

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Reviews

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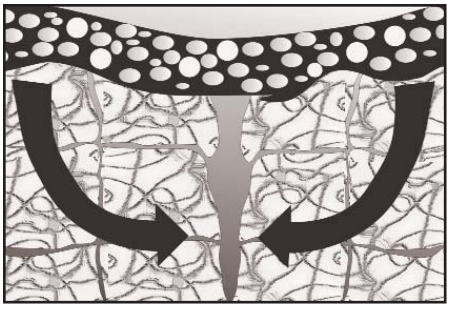
Cover. Mesoarchean volcanic rocks of the Prince Albert Group, northeastern Melville Peninsula, Nunavut. The volcanic rocks are transected by veins of white quartz. Reproduced with the permission of Natural Resources Canada 2009, courtesy of the Geological Survey of Canada (Photo 2002-560 by Lynda Dredge).

SERIES



Economic Geology Models 1. Geochemical Exploration and Metallogenic Studies, Northern Chile

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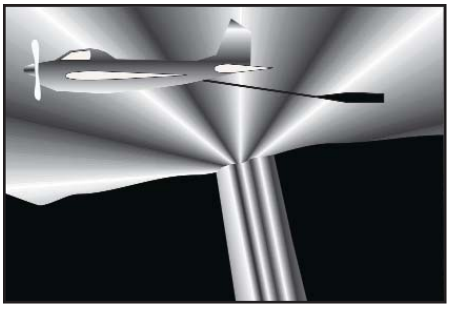
SUMMARY

Research was initiated in 1998 on geochemical methods of exploration for copper porphyry deposits buried under thick, lithified piedmont gravel cover in the Atacama Desert, Chile. Early data suggest that mineralized, saline groundwater has been episodically forced up through fracture zones to the surface during earthquakes, creating geochemical anomalies above ore deposits. Follow-up research supported by the Canadian Mining Industry Research Organization (CAMIRO) examined the composition of both groundwater and surface anomalies, confirming a link between the two. Further work suggests that the geochemical anomalies are the surface expression of a process common to the metallogenic evolution of many deposits. Porphyry intrusion and hypogene mineralization are controlled by faults, and are followed by supergene enrichment in a semi-arid climate. After burial by Miocene gravels, the climate changed to hyper-arid; estimates of the onset of hyperaridity vary from mid-Miocene (11–14 Ma) to Pliocene (~3–5 Ma). Since then, saline dewatering of the basement along long-lived faults has converted the original supergene copper oxide assemblage, formed in equilibrium with meteoric water and lacking atacamite, to one containing atacamite [$Cu_2Cl(OH)_3$], the copper mineral especially associated with northern Chile. This interpretation is supported by studies showing that the salinity of fluid inclusions in atacamite is similar to that of local groundwater and that atacamite is considerably younger than the co-existing supergene alteration.

SOMMAIRE

La recherche décrite ici et initiée en 1998 visait à mettre au point des méthodes d'exploration de gisements de porphyres cuprifères enfouis sous d'épaisses couches lithifiées de graviers dans le désert d'Atacama au Chili. Des données préliminaires indiquent que des eaux souterraines salines minéralisées ont été poussées épisodiquement jusqu'à la surface, à travers des zones de fractures, à l'occasion de séismes, créant ainsi des anomalies au-dessus de gisements minéraux. Une recherche subséquente appuyée par la *Canadian Mining Industry Research Organization* (CAMIRO) qui a porté sur la composition de l'eau souterraine et des anomalies de surface, a permis de confirmer l'existence d'un lien entre les deux. Les résultats de travaux subséquents permettent de croire que ces anomalies géochimiques sont l'expression en surface d'un processus commun à l'évolution métallogénique de nombreux gisements. L'intrusion porphyrique et la minéralisation hypogène sont tributaires de failles, auxquelles s'est ensuite ajouté un enrichissement supergène sous climat semi-aride. Après l'enfouissement au Miocène par des graviers, le climat est devenu hyperaride; selon les estimations le climat serait devenu hyperaride entre le Miocène moyen (11-14 Ma) et le Pliocène (~3-5 Ma). Depuis, l'assèchement des eaux salines du socle le long de failles persistantes a entraîné une conversion de l'assemblage original d'oxydes de cuivre supergène - lequel s'était formé en état d'équilibre en milieu d'eau météorique et qui était dépourvu d'atacamite - en un assemblage contenant de l'atacamite [$Cu_2Cl(OH)_3$], ce minéral de cuivre typique du Chili du nord. Cette interprétation est corroboré par des études montrant que la salinité des inclusions fluides dans l'atacamite est semblable à celle de l'eau souterraine locale et que l'atacamite est significativement plus jeune que l'altération supergène coexistante.

SERIES



Remote Predictive Mapping 2. Gamma-Ray Spectrometry: A Tool for Mapping Canada's North

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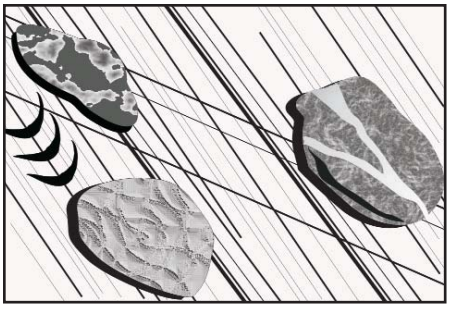
SUMMARY
This paper reviews the theory, acquisition and application of gamma-ray spectrometric data for geological mapping, especially for Canada's North. Theoretical principals are reviewed and survey parameters and data acquisition procedures are discussed. Interpretation principles are then presented and various methods, utilizing computer processing, enhancement and classification procedures are introduced using many image examples.

The ability of gamma-ray spectrometry to map the distribution of potassium, uranium, and thorium on the surface of the Earth provides powerful assistance for regional and local bedrock and surficial geological mapping. Important direct and indirect exploration guidance, in a wide variety of geological settings, is also provided, as is important information for environmental radiation monitoring and land-use planning.

SOMMAIRE
Le présent article passe en revue les fondements théoriques, l'acquisition et l'application des données spectrométriques du rayonnement gamma comme outil de cartographie géologique, particulièrement pour le Nord canadien. On y examine les principes théoriques et on y discute des paramètres de levé et des méthodes d'acquisition des données. Puis, on y présente les principes et diverses méthodes d'interprétation, utilisant le traitement de rehaussement et de classification par ordinateur, à partir de nombreux exemples d'images.

La cartographie de la distribution du potassium, de l'uranium, et du thorium à la surface de la Terre à partir de techniques de spectrométrie du rayonnement gamma est une aide précieuse pour la cartographie géologique de surface locale et régionale. Cette technique constitue aussi un important guide d'exploration direct et indirect, dans une large gamme de contextes géologiques, tout comme une importante source d'information pour le monitorage des radiations dans l'environnement et la planification de l'aménagement du territoire.

ARTICLE



Robert J. Chalmers: Pioneer Surficial Geologist

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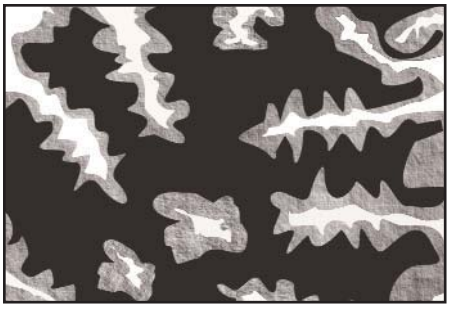
SUMMARY
Most Quaternary geologists working in Atlantic Canada view Robert J. Chalmers' investigations of the surficial geology of New Brunswick for the Geological Survey of Canada (GSC) as seminal contributions. Yet, the fullest biographical information available for Chalmers is a 7-page typescript by E.R. Faribault of the GSC, held at Natural Resources Canada Library in Ottawa. Therefore, it appeared necessary to bring Chalmers' little-known life, and the variety of his surficial geologic investigations, into the mainstream. Lists of Chalmers' published works in GSC reports and in periodicals are compiled from all available sources.

SOMMAIRE
La plupart des géologues du Quaternaire au Canada atlantique voient les études de Robert J. Chalmers sur 'la géologie en surface' de Nouveau Brunswick pour le Commission géologique du Canada comme des ouevres séminales. Mais, l'information biographique le plus pleine de Chalmers est un texte bref dactylographié par E.R. Faribault du CGC, tenue à la bibliothèque du Département des Richesses naturelles canadienne à Ottawa. Donc, il apparait nécessaire à porter au premier plan sa vie mal-connue, et le variété de ses oeuvres. Aussi, listes des oeuvres de Chalmers pour le CGC et dans les journaux scientifiques sont ici présentent des sources disponsible.

[1] Note that author citation in the Bibliography and References section is divided into "G" for Chalmers' GSC reports, "P" for Chalmers' periodical articles and abstracts, and "O" for references to other authors.

SERIES



Economic Geology Models 2. Melt Inclusions of Native Silver and Native Bismuth: A Re-examination of Possible Mechanisms for Metal Enrichment in Five-Element Deposits

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SUMMARY

This paper presents preliminary observations on veinlets and trails of native bismuth and silver melt inclusion that cross-cut silicate and carbonate vein fill and alteration minerals in the five-element veins at Cobalt, Canada. The low melting temperature of bismuth (271°C) is consistent with the current estimates of vein formation at Cobalt, and melt textures are displayed in native bismuth inclusions and trails. Native silver displays identical textures and these are also interpreted to have formed from a melt. However, native silver melts above 950°C, which is in direct conflict with current estimates of silver deposition within the Cobalt camp. In light of the similarities in textures, existing temperature evidence, the lack of experimental studies in the Co–As–Ag ternary, and recent advances in the study of melt inclusions in sulfide deposits, the native silver textures are also interpreted to have formed at temperatures as low at 350°C.

A primary three-phase fluid inclusion assemblage contained within growth-zoned quartz crystals in the granophyric phase of the Nipissing diabase was chosen as representative of the highest temperature fluids responsible for ore deposition at Cobalt. This fluid inclusion assemblage displays microthermometric behaviour similar to the hypersaline fluid inclusions previously determined as the transporting medium for the silver mineralization at Cobalt and are consistent with depositional temperatures of about 350°C. These temperatures, although sufficient to produce melt inclusions of native bismuth, are insufficient to melt silver. Petrography and solid inclusion textures are consistent with metallic silver melts, indicating that Ag–Sb–Hg ternary or more complex silver-bearing systems containing H_2O, H_2S and salts may have eutectics at temperatures below 350°C. This is interpreted as a potential mechanism for silver mobilization and enrichment, and has potential applications to other types of vein mineralization.

SOMMAIRE

L'article suivant décrit des observations préliminaires effectuées sur des filonnets minéralisés et des trainées d'inclusions vitreuses de bismuth et d'argent natifs recoupant les carbonates et les silicates de remplissage des filons ainsi que les minéraux d'altération des filons à cinq éléments à Cobalt, Canada. La basse température de fusion du bismuth (271°C) concorde avec les interprétations actuelles sur la formation des filons à Cobalt, ainsi qu'avec les textures de fusion visibles tant dans le bismuth natif que dans les trainées. L'argent natif montre aussi des textures identiques, lesquelles sont aussi comprises comme des indices de fusion. Cela dit, la température de fusion de l'argent natif dépasse 950°C, ce qui contredit carrément les estimations courantes concernant les dépôts d'argent dans le camp minier de Cobalt. Considérant la similarité des textures, les indications de température, le manque d'études expérimentales sur le comportement du sysème ternaire Co–As–Ag, et de percées récentes dans le cadre d'études d'inclusions fluides dans des gisements de sulfures, nous estimons qu'il est raisonnable de penser que les textures d'argent natifs ont pu se former à des températures aussi basse que 350°C.

Un assemblage primaire à trois phases d'inclusions fluides au sein de cristaux de quartz à zones de croissance de la phase granophyrique de la diabase de Nipissing a été retenu comme indicateur de la température maximale des fluides à l'origine de la formation du gisement de Cobalt. Cet assemblage d'inclusions fluides affiche un comportement microthermométrique semblable à celui des inclusions hypersaline dont on a montré précédemment qu'il avait été le transporteur de la minéralisation d'argent de Cobalt et qui correspond à des températures de formation d'à peu près 350°C. Bien que ces températures soient suffisantes pour expliquer la formation d'inclusions vitreuses de bismuth natif, elles ne peuvent expliquer

la fusion de l'argent. Les données pétrographiques et les textures des inclusions solides justifient l'hypothèse de fusion de l'argent métal, et permettent de croire que le système ternaire Ag–Sb–Hg ou des systèmes argentifères plus complexes renfermant de H_2O, H_2S et des sels peuvent avoir des points eutectiques à des températures inférieures à 350°C. Nous pensons qu'il pourrait s'agir de mécanismes de mobilisation et d'enrichissement de l'argent, et qu'il pourrait être considérer dans d'autres cas de minéralisation filonienne.

REVIEWS

Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup

Edited by G.D. Karner, G. Manatschal and L.M. Pinheiro
The Geological Society of London
Special Publication 282 (2007)
ISBN: 978-1-86239-228-1
Hard cover, 482 p.
Price ?100; Fellows price ?50.

Reviewed by Jeremy Hall
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The Geological Society has been producing Special Publications for 40 years, with the series gaining clear identity in 1981. The Society currently publishes about 20 new volumes in the series each year. The intention is to provide state-of-the-science reviews of geological topics, where the guest editors are expected to provide a balanced coverage. Based on the success of the series, this is what many geoscientists want: a collection of papers that takes the non-expert up the learning curve of background and currency of a theme of interest. Many of the publications are based on presentations made at scientific meetings, and that is true of the Special Publication under review here, which is based on a one-week workshop held in Pontresina, Switzerland in July 2004. Given that the workshop took place in 2004, the Special Publication was published in 2007 and I am reviewing it in 2008, one might ask if the content is too dated. I attended a session on *Continental Rifting andBreakup* at the European Geosciences Union meeting in Vienna in April 2008. Several authors presented papers that offered incremental enhancements to their contributions to the Special Publication, but no radically new ideas (at least so far as I could determine!). So this Special Publication, based on a workshop held four years ago, is still of great value today to those wanting to get close to the cutting edge of modern research in continental rifting processes.

The notion that rifted continental margins consist of thinned, extended continental crust abutting normal oceanic crust was dispelled years ago, nowhere more emphatically than in studies of the Iberian margin, where serpentinized peridotite was discovered intervening between extended continental crust and oceanic crust. Thus, the continent–ocean transition is more complex than previously thought, and depth-dependent stretching and/or simple shear have been invoked to explain how mantle could be exhumed during the rifting process, and lead to asymmetrical conjugate margins. Recent seismic work followed by Leg 210 of the Ocean Drilling Program on the Newfoundland margin, conjugate to Iberia, resulted in the discovery of an equally complex continent?ocean transition there, where serpentinized peridotite is again present in a zone that exhibits magnetic strip anomalies, previously interpreted as arising from normal oceanic crust. Thus many questions about the nature of the rifting process are posed by these recent studies of the Iberia–Newfoundland conjugate pair.

The Pontresina workshop was held to discuss the recent findings from the Newfoundland margin, how they relate to the conjugate margin, and the rifting processes that led to the present margin configurations. The focus of the workshop, and the Special Publication, was on this conjugate pair, including details of the structure, and models of the processes involved. In addition, a number of papers were presented, for comparative purposes, on other margins and analogues from older rifted margins now exposed on land.

A virtue of the Special Publications is that they usually start with pieces written by the guest editors that set the context and summarize the content. This is particularly valuable for the non-expert who might otherwise get lost quickly in some of the individual contributions. This book is no exception, and the editors provide an excellent summary, explaining the volume's six sections. The full list of contents of the volume can be found at [http://sp.lyellcollection.org/content/vol282/issue1/].

The first section provides geological and geophysical insights from four papers that describe the structure of the Iberia–Newfoundland conjugate pair. A comprehensive review of the Newfoundland–Iberia rift, incorporating the results from the ODP Leg 210 drilled in 2003 in the Newfoundland Basin, is provided by Tucholke et al. Other interesting papers (Hopper et al.; Sibuet et al.) address the peculiarity of the Flemish Cap (e.g. its motions and its margin) at the northern end of the Newfoundland Basin, whereas a contrast with the Iberian margin is presented by Reston. A general conclusion from these papers is that continent–ocean transition zones (made up of a complex mix of highly-extended continental crust, exhumed sub-continental mantle, and abnormal oceanic

crust) can be over 100 km wide, are found on both conjugate margins, and are subject to continuing debate as to their genesis.

The second section presents three papers on geodynamic modelling that focus on the strain response to specific stresses applied to defined rheology, with reference to the Iberia–Newfoundland conjugate pair. Huismans and Beaumont present some vividly illustrated examples of the variety of both symmetrical and asymmetrical responses to variable lithosphere rheology and rifting velocity, and transformation from one form to the other during deformation. Other papers address the role of density inversions in the rifting process (Burov), and of pre-existing weaknesses in the rifting history of the Flemish Cap–Galicia Bank conjugate margins (Harry and Grandell).

The third section includes two papers on kinematic modelling, in which the overall subsidence of basins is calculated from lithosphere stretching, optionally with depth dependence and consequent isostatic/flexural response, and including an interpreted thermal history. A Black Sea study by Egan and Meredith shows that crustal thinning, rather than fault displacements, gives a better fit to observed subsidence. Healy and Kusznir provide an example of how upward divergent flow of asthenosphere can provide admissible models of margin evolution, exemplified by the Goban Spur margin of NW Europe, a little to the north of the Iberia–Newfoundland conjugate margin.

Two comparative papers, one examining the Woodlark Basin, Papua-New Guinea (Goodliffe and Taylor), and the other the southern Australian margin (Direen et al.), are presented in the fourth section. The Woodlark Basin displays asymmetry in structure, characterized by distinctly different amounts of faulting that is interpreted as a consequence of contrasting lithospheric deformation; i.e. removal of lower crust through ductile flow on one margin, and brittle faulting of the upper crust on the other. The wide continent–ocean transition zone on the South Australian margin exhibits magnetic signatures which, like those in the Newfoundland Basin, might earlier have been interpreted as indicative of oceanic crust, but are now interpreted to have formed during exhumation of serpentinized peridotite mantle.

In the fifth section, three examples of "non-Atlantic" extensional systems follow. Two of the papers deal with the evolution of passive margins now exposed on land. Manatschal et al. describe the similarities between the Iberia–Newfoundland margin and the Tethyan margins exposed in the Alps. Robertson discusses the roles of asthenospheric shear, inherited lithospheric weaknesses, and slab pull from a neighbouring subduction zone as causative agents for Tethyan rift sequences now exposed in Oman. These rift sequences are devoid of exhumed mantle, unlike the Iberia–Newfoundland margin. A third paper (Cochran and Karner) discusses the transition from rifting to drifting in the Red Sea, concluding that rift systems that are characterized by large rotated fault blocks rarely lead to seafloor spreading, but may be left stranded alongside adjacent margins or survive as failed rifts.

The final section revisits some fundamental concepts, in four contributions. Kusznir and Karner discuss the upward-divergent mantle flow kinematic model and apply it to the Woodlark Basin and the Iberia–Newfoundland conjugates. Christie-Blick et al. reinterpret faults in the Basin and Range Province of the western United States as having much smaller displacements than previously claimed, thus demanding more careful review of models of extreme thinning associated with low-angle normal faults. Dyksterhuis et al. investigate the effects of pre-existing weaknesses on rift architecture with numerical experiments that confirm rotation of normal faults to low angles, and stress how such weaknesses can be dominating factors in determining the mode of deformation. Moresi et al. use a yield criterion developed for incompressible viscous layers and show how it can be manipulated to produce effects similar to those of the Mohr-Coulomb criterion used in brittle failure models.

This is a book with a lot to digest, but very much worth reading for anyone interested in how the details of rifted margins may fit with theories of their genesis. There are some residual questions. Is the thoroughly-studied Iberia–Newfoundland margin the best example for learning about rifting processes that lead to seafloor spreading? The complex along-margin variations, related, in part, to the step-wise northern migration of extension, suggest that this area might not be the best place to isolate a 2D cross section to characterize the process. But then we live in a 3D world, as is confirmed by the variety of passive margin features described in this volume.

Four Centuries of Geological Travel: The Search for Knowledge on Foot, Bicycle, Sledge and Camel

Edited by P.N. Wyse Jackson
The Geological Society of London
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ISBN: 978-86239-234-2
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Most geologists are by nature a peripatetic group. Our science demands that we travel, observe, document and collect. In the last few decades most government agencies concerned with the geosciences have frowned on field work – mapping as well as rock, fossil, and mineral collecting. In Canada, recent changes in world demand for resources, global warming of the Arctic, the opening of the northern seaway through the archipelago and concerns over territoriality, provide some hope that this situation will reverse itself.

This volume consists of chapter-long vignettes that explore aspects of geologically based travel and researches conducted by many scientists. Some of the individuals described are clearly geologists, others are better known in related scientific fields, but many are not widely known for their past contributions to their field. This 415 page book is divided into 28 chapters and has a general introduction by the editor. "Global peregrinations" by Wyse Jackson provides a summary of the book and explains the background of the compilation for the 28th Symposium of the International Commission on the History of Geological Sciences, held in Dublin, Éire, in 2003.

When geological field parties go into the field today, lengthy and systematic preparation is required to ensure that they have what they need to operate. The same applied in the past, and the initial chapter describes the required "scientific instructions" for "geological travels" during the 18th and 19th centuries. The remainder of the book is divided into "regional" sections, commencing with Britain and then Europe, Greenland, Russia and the Caucasus, Africa, the Atlantic Islands, North America, South America, Australasia and Japan. A concluding chapter describes "Geophysical travellers" and concentrates not on geological travel, but on the worldwide perambulations of a group of dedicated magneticians from the Carnegie Institute in Washington who operated during the first 35 years of the twentieth century.

Within the body of the book, chapters describe the work and travels of Robert Hooke (1635–1703), who was perhaps best known for his microscope work, but also for his investigations into many other areas of science. Apparently he was a keen observer of geology, particularly of his home area on the Isle of Wight, and his observations of crystal growth were even more significant than those of his contemporary, Nicholas Steno. Mention is also made of his contributions to stratigraphy, his thoughts on fossils, and lectures that inspired others (such as Hutton) to develop the basic premises of geology. The Isle of Arran and the observations of Robert Jameson (founder of the Wernerian Society of Edinburgh) then follow. Jameson (a neptunist) contradicted many of Hutton's (plutonist) observations at the same localities.

The book's narratives then move to Europe. The first section deals with three 18th century "mineralogical" authors who recount their travel experiences in the Carpathian Mountains, and this is followed by von Goethe's and Sternberg's geological observations and differing philosophies in the Habsburg region. Chapters follow on "Geological Travellers in Auvergne" (with a fine foldout reproduction of a 1771 map of the Clermont region), and on "J.D. Forbes and Naples" (with Forbes's visits and observations of Vesuvius, Pompeii and other areas of the Bay of Naples).

Many readers will be aware that Charles Lyell and Roderick Impey Murchison and his wife Charlotte travelled to France and northern Italy together in 1828, and a succeeding chapter describes this trip in some detail. It explains the different working styles (and some differing geological interpretations) of these men, and the invaluable assistance provided by Charlotte in translation, observation, recording and collecting. Another chapter describes the work of Nery Delgado (Portuguese Geological Survey) in Spain in 1878, and his attempts to rationalise the mapping of transborder geological contacts between Spain and southern Portugal. Grenville Cole, a geologic educator from Ireland, is featured in "Grenville Cole (1859–1924): Cycling Geologist". This chapter describes his exploits in Europe and Ireland, where he tried to educate students in the geology of that country by taking them on cycling fieldtrips. Karl Ludwig Giesecke (later also known as Sir Charles Lewis Giesecke) has a chapter devoted to his early career in the theatre in Germany and then on his later life as a geologist and explorer in Greenland before his appointment to the Geology Chair of the Royal Dublin Society in 1813. He was (perhaps) responsible for large parts of the libretto, "The Magic Flute", but he also discovered many new mineral species including sodallite, allanite, and gieseckite, was responsible for exploring both eastern and western Greenland, and provided assistance in the planning of several arctic voyages to the Northwest Passage.

Alexander von Humboldt is the subject of another chapter. Although perhaps best known for his work in the New World as a naturalist and scientist, a chapter is devoted to his expedition into Siberia in 1829. On this journey he averaged an amazing (even by modern standards) 300 km a day by coach and horseback whilst still making observations of the geology, geomorphology and mining sites! The Eurasian content is completed with a chapter on Herman Abich and his travels, over 30 years, in the Caucasus and Armenian highlands.

Moving on to Africa, the next chapter describes a fascinating montage of four French geological explorers of the Sahara Desert who literally travelled thousands of kilometres on foot and by camel. This is followed by

another very readable chapter that deals with Théodore Monod and the on and off, three-quarters of a century-long search for the lost *Fer de Dieu* meteorite of Mauritania.

Two related chapters cover the travels and geological observations of Charles Lyell on the Canary Islands and Madeira and Georg Hartnung on Madeira and the Azores. Continuing with an island theme, the following chapter covers Charles Darwin's visit to the Cape Verde Islands and more specifically examines his (then) catastrophist views and his "conversion" to the more gradualist views of landscape modification expressed by Charles Lyell.

Work in the Americas is highlighted by several chapters including "Naturalists from Neuchâtel", which refers to the Swiss scientists that accompanied Louis Agassiz to America. Also discussed are Clarence Dutton's work on western North American volcanic activity, isostasy, and the geology of the Utah Plateau, and the journeys of J.B. Tyrrell (of Royal Tyrrell Museum of Palaeontology fame) and J.W. Tyrrell across the "Barren Lands" of Canada in 1893 and 1894. This chapter describes the Tyrrells' observations on an epic journey from Edmonton to Lake Athabasca, Baker Lake, Chesterfield Inlet, Churchill and, eventually, Winnipeg, and would be of interest to many Canadian geologists.

A tour of several continents takes the readers first to South America, with two chapters that describe, respectively, native geological travellers in the Portuguese Empire of the late 1700 and early 1800s, and the travels of Charles Darwin (and others) in Patagonia. In Australasia, a chapter is devoted to the search for limestone in colonial New South Wales; another to the works of Thomas Mitchell, a soldier and a geologist who compiled perhaps the first geological maps of southeastern Australia in 1834; and lastly to nineteenth century observations of the Mt. Dun (of Dunite fame) Ophiolite belt of South Island, New Zealand. One other chapter describes the work of Franz Hilgendorf who introduced evolutionary theory to Japan around 1873.

Anyone interested in additional information on any of these topics would be well-served by the comprehensive bibliographic references that accompany each chapter.

Is the book of general interest? Certainly some sections are, and different readers will find items that will attract and keep their attention. The editor is to be congratulated in pulling together a very diverse set of contributions in a logical pattern. However, some topics will appear more "academic" and of less general interest — albeit still providing material that should broaden knowledge of some areas geographically far removed from North America and Europe. The book is not easy to read, as it contains a large amount of information in a visually condensed format; although the text is clear (no problem with the chosen fonts) there is a problem with the point size and especially with the quotations of abstracted text that appear to be in 5 or 6 point. All illustrations are clear, within the limitations of the original diagrams, maps and photographs.

In summary, this rather expensive book (US$180.00) book is likely of more interest to the academic reader than to a casual reader of geological information.

Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera

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This volume represents the culmination of several years of systematic mapping of large areas of the Canadian Cordillera and adjacent Alaska, with a focus on those regions that have traditionally been assigned to the Yukon–Tanana and other pericratonic terranes. Most of the papers represent contributions under the umbrella of the 1999-2003 Pacific Margin NATMAP program, in which provincial and territorial surveys combined with the Geological Survey of Canada to focus mapping efforts on terranes related to the Paleozoic and Mesozoic margins of the Laurentian plate. Additional contributions on Alaska were supported by the United States Geological Survey. The volume represents the culmination of that five-year effort, and provides documentation of the major conclusions of those programs.

This volume contains a huge amount of information, which partly accounts for the length of time it has taken to complete this review. In addition to 18 papers, and two fold-out maps and charts, a CD-Rom (provided in a pocket inside the back cover) contains, in its 345 Mb of data, a prodigious amount of additional information.

The volume can be divided into two somewhat unequal parts. The first twelve papers deal mainly with

areas that have, at one time or another, been associated with the Yukon–Tanana terrane in Alaska, Yukon, and northern British Columbia. These papers present a tightly integrated view of tectonic relationships in the newly mapped areas. An introduction by Colpron et al. attempts to clarify the rather convoluted history of nomenclature in the Yukon–Tanana terrane, and introduces the two fold-out plates contained in the back pocket: a synthesis map of the pericratonic domain of the northern Cordillera, and a stratigraphic chart displaying and correlating numerous successions documented by the research program. The succeeding papers with first authors Dusel-Bacon, Murphy, Devine, Colpron, Roots, and Mihalynuk deal with specific regions. The editors are to be congratulated in achieving some uniformity of legend and colour schemes in the stratigraphic columns, throughout these more localized studies. As a result, it is possible to use the stratigraphic diagrams in all these papers, in conjunction with Plate 2, making it easier for the reader to digest the huge amount of information presented. Efforts have also clearly been made to coordinate colour schemes and legends in the maps, although these are, perhaps, less successful; yellow, for example, is consistently used for clastic units, but it is used for clastic units of many different ages and affinities. Also, many units are filled with black-and-white shadings without colour. More use might have been made of shadings superimposed on colour to provide a scheme in which each major unit had its own pattern. The addition of more cross-sections and field photographs would have helped readers to visualize the structures being described. Nonetheless, these are nit-picking complaints that result from an effort to read these papers in succession. There is far more uniformity in the presentation than would have been possible if, for example, the papers had been presented as diverse journal publications.

Through this sequence of papers, a convincing case is built for a view of the Yukon–Tanana terrane as a portion of Laurentia that became separated in the mid-late Paleozoic but never drifted far from its place of origin. Also clarified is the relationship between the 'real' Yukon?Tanana terrane and regions of Alaska formerly classified as 'Yukon?Tanana' but which are now clearly demonstrated never to have left Laurentia. There are still some cracks in the façade of agreement, however. A careful look at the map in Plate 1 reveals a perfectly straight, N–S boundary, coinciding with the Alaska–Yukon border, between the Lake George assemblage, part of the Laurentian margin, and the Klondike assemblage, interpreted to be part of the more travelled Yukon–Tanana block. Clearly there is more work to be done in achieving a synthesis that extends seamlessly across the international boundary.

Both, the introduction by Colpron et al. and a paper by Gunning et al., attempt to extend the analysis southward into parts of British Columbia included in the Stikine terrane. Although useful new data are presented, a link between Yukon–Tanana and Stikinia seems to be assumed by the authors, without strong justification, and without discussion of the supposedly intervening Cache Creek oceanic terrane. One gets the impression from the limited data in the paper that the history of Stikinia is perhaps being shoe-horned into the framework established for Yukon–Tanana. This link comes over as more tenuous than the others established in the first section of the book, and reveals that much more work remains to be done to determine where Stikinia fits in the Cordilleran collage.

Also included in the first section of the book are 'topical' syntheses, by subject area. Papers by Orchard and Mortensen et al. deal, respectively, with conodont paleontology and with lead-isotope geochemistry. While the conodont paper is necessarily a data-intensive systematic compilation, and therefore not intended as an easy read, I found the lead-isotope paper a useful and informative introduction to a subject about which I was previously quite unfamiliar. I came out of the paper feeling I had learned a lot. The same was true of the compilation of results from igneous rocks by Piercey et al. The various techniques and isotopic arguments for the sources of magmas are well explained and the conclusions are convincing. The last paper in the section is a synthesis of the tectonic and metallogenic evolution of the pericratonic domain by Nelson et al., which rounds off the first part of the book well. There is a significant overlap between the material covered in the Piercey and Nelson papers, which probably reflects the fact that five of the six authors on each paper are the same. Both are excellent syntheses, but is it necessary to repeat the same series of maps with only very minor changes? If these papers had been published in separate journals then both would clearly have had to contain overlapping introductory material and regional analysis. Reading them back-to-back, one is left with the feeling that some condensation could have been achieved.

The last part of the book deals with a series of six studies extending into the southern Cordillera. These papers contrast with the first part of the book in that they are much less integrated. Papers by Logan and Colpron, and Ferri and Schiarizza deal with stratigraphic and structural relationships in the Kootenay terrane. Interestingly, cross-sections are much more in evidence here than in the first part of the book, and they help the reader significantly in grasping the map relationships. A substantial paper by Paradis et al. examines magmatism and massive sulphide deposits in the Eagle Bay assemblage of the Kootenay terrane. While providing excellent data and interpretations on these topics, the stratigraphic framework of these units is particularly convoluted; the reader's grasp of the stratigraphy is not helped by the fact that many units are referred to only by their map acronyms (e.g. unit EBAF), which are never spelled out in full. While this language may be common to participants in the Pacific Margin NATMAP program, it is not particularly accessible for outsiders who wish to learn their way around Cordilleran geology. The largestlongest and probably most controversial paper in the second part of the volume, is by Thompson et al., and presents a discussion of a large swath of southern British Columbia, much of which has been included in the Quesnel terrane. The authors present a strong critique of previous syntheses, including an unusual number of quotations from

previous literature, which they use both to underscore the contradictions of previous interpretations and to support their thesis that stratigraphic units can be traced from the Laurentian margin well out into the area mapped as Quesnellia. Interestingly, many of their section headings and interpretations are stated as questions; they raise the possibility that, at the latitude of their study, there was never a Slide Mountain oceanic domain separating Quesnellia from the continental margin, and that previous cross-sections and palinspastic reconstructions showing the Kootenay terrane originating outboard of the Monashee complex are incorrect. The final two papers in the volume present additional data that have a bearing on the status of Quesnellia, from stratigraphic and isotopic perspectives, respectively. The short paper on the Trail Gneiss by Simony et al. shows that at least some basement rocks in Quesnellia appear to be juvenile, and do not represent fragments of North America as would be suggested by the Thompson et al. hypothesis.

It is clear from the overall structure of the volume that these topics are controversial, and that the broad consensus achieved in the northern Cordillera does not extend to southern British Columbia. The cover picture, for example, shows a reconstruction from the Nelson et al. synthesis in which Quesnellia is located well away from Laurentia, in contrast to the Thompson et al. model for a Quesnellia which remains attached to the continent. These controversies will undoubtedly be thrashed out in the coming years; unfortunately, the GAC special volume format means that there is no opportunity for 'discussion and reply' debates as would be possible in a journal.

The volume also raises a broader question in Cordilleran tectonics. When the terrane concept was originally proposed in the Cordillera in the 1970s and 80s, terranes were defined as fault-bounded regions between which there were no known stratigraphic links. A division into terranes became standard in presenting the geology of the Cordillera. The work stimulated by the terrane concept, including that presented in the current volume, has led to the discovery of stratigraphic links between some of these regions. For example, in the present volume, mafic rocks described as 'oceanic' and labelled 'Slide Mountain Terrane' are shown in stratigraphic contact withthe authors and editors of this volume have chosen (perhaps wisely) not to open this Pandora's box just yet, preferring instead to use the traditional terrane terminology. In the meantime, those learning Cordilleran geology have to be prepared to deal with some contradictions.

Physically this is a well-produced volume. There are occasional grammatical errors that the editors missed, as well as some instances where east and west are mixed up in locations, but these are minor irritations. The CD contains complete copies of all 18 papers in pdf formats at both low and high resolution, together with supplementary information in the form of data tables and no less than 30 complete open file maps at 50 000 and 100 000 scales. Although most of these maps are available on the BC and Yukon government websites, it takes time to search out and download them; having all 30 maps in the same place is a tremendous benefit. It is unfortunate that it was not possible to include pdf maps in the contributions on Alaska, which would have made this a truly international resource. Nonetheless, the data that are provided represent significant added value for researchers.

Despite the minor misgivings expressed above, this volume is a major achievement and is a tremendously useful resource for Cordilleran geology. The editors are to be congratulated in bringing together a huge number of authors in a volume that has a much more integrated feel than a typical conference-derived special publication. The degree of coordination is impressive, particularly over the first twelve papers. This volume should stand for many years as a milestone, and as a basis for discussion and further work, in the understanding of the Canadian Cordillera.

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