**GSCHIS-A019**

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**Title:** A personal perspective on some GSC Vancouver office history

**Date of this version:** October 3, 2013

**Number of pages in document:** 5 pages

**Simplified version:**

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**Biography:** James William Heron Monger

After a B.Sc. in geology at the University of Reading, U.K., Jim Monger was awarded a Fulbright Travel Award at the University of Kansas where he obtained his M.S. He then moved to British Columbia where he completed his Ph.D. in 1966 at UBC. He joined the Vancouver office of the Geological Survey of Canada in 1965 and begun a long and distinguished career as a Research Scientist. He was instrumental in the introduction of plate tectonic ideas to Cordilleran geology and his contributions were recognized by election to the Royal Society of Canada in 1984 and the award of the Logan Medal in 2003 by the Geological Association of Canada. Following retirement from the GSC in 1995, he was an adjunct professor at Simon Fraser University and lectured at the University of Victoria.

## A personal perspective on some GSC Vancouver office history

**Some ancient history:** British Columbia came into the Canadian Confederation in 1871, and term 5 of the Terms of Union states that "Canada will assume and defray the charges for the following services…. (H) The geological survey." Field work by the GSC in B.C. started in 1871, and for the following ~110 years, the GSC was in effect the geological survey of British Columbia. Efforts of the then-BC Department of Mines and Petroleum Resources were, and still are, focussed mainly in areas of high mineral potential rather than in systematic regional mapping.

A GSC office opened in Vancouver in 1910 with one geologist. After World War II, there was a big expansion of the GSC. Graduate geologists were hired to do 1" to 4 mile (~1:250,000) scale mapping in the Cordillera, and for most this work led directly to their Ph.D. dissertations. By 1960 much of the western Cordillera had been covered on what was called "reconnaissance scale", and most of the geologists who had done the mapping in BC were hired by the GSC and moved to Vancouver in the early 1960s. This group formed the nucleus of the Vancouver office for the next 25 years, and for that period there was "first-hand" knowledge in the office of the geology of most parts of the Cordillera, ideal for a group attempting to establish the overall geological and tectonic framework of the Canadian Cordillera.

I came into the Vancouver office in as a Technical Officer in 1965 and joined permanent staff in 1966, shortly to be followed by Dirk Tempelman Kluit and Geri Eisbacher. All three of us found the group of older geologists collegial and willing to unselfishly share their knowledge, although I suspect they found us somewhat vociferous at times. We were encouraged by management to explore outside the limits of assigned projects, and funds were available to do this. It made for a superb working environment. Soon after I'd joined I can remember John Wheeler, who at that time was working on the 1960s edition of Geology and Mineral Deposits of Canada, coming into my office and asking "Do you mind me using you as a sounding board on ……?" What a great way to bring a newcomer on board!

**Geosynclines and links with industry:** In 1964, when I was still at UBC, a symposium on the Tectonic History and Mineral Deposits of the Western Cordillera was held in Vancouver. Dick Campbell once told me that it resulted from informal, coffee shop discussions between GSC personnel and those in the Vancouver mineral exploration community, many of whom worked near to the GSC office, which in those days was located right downtown near the intersection of Pender and Howe Streets. The symposium proceedings, published in 1966 as CIMM Special Volume 8, synthesized results of the new regional mapping, and also contained a paper on Cordilleran tectonics by Phillip B. King (USGS) who was the author in 1969 of the magnificent Tectonic Map of North America. The CIMM volume, with many papers couched in geosynclinal theory, provides snap-shot of then-current knowledge and ideas, and is evidence for the close links between the mineral exploration community and GSC personnel in Vancouver.

**Advent of plate tectonics:** By the 1960s, the geosynclinal "strait jacket" no longer fitted geological knowledge, although it lingered on for some time as "geological shorthand". The tectonic settings in which rocks formed became identified in such "actualistic" terms (Dietz, 1963) as continental margin deposits ("miogeoclinal rocks") and island arc and ocean floor remnants ("eugeosynclinal rocks") and later, in the 1970s and 1990s, these became divisions of the 1:5M scale Tectonic Assemblage Maps of the Canadian

Cordillera. For Cordilleran geologists, the present really was beginning to be the key to the past, thanks in large part to the systematic mapping during the 1950s and 1960s of the over 60% percent of Earth's surface covered by the oceans.

The new ideas on global tectonics crept into the geological community in the 1960s, through publications such as Nature, Science and the Journal of Geophysical Research, and were catalysed by discoveries made during ocean floor mapping that glued together many existing but disparate observations. The ideas started to influence geologists in the Cordillera, where the natures and metamorphism of the enigmatic Jurassic and Cretaceous eugeosynclinal Franciscan Complex in California were being unravelled by Dickinson (1964) and Ernst (1965). Two influential papers for many in the Vancouver office were by Warren Hamilton (1969), who interpreted rock units in the western US in terms of the plate tectonic settings in which they formed, and by (graduate student) Tanya Atwater (1970) who related trajectories of Pacific oceanic plates to younger on-land Cordilleran geology.

The Second Penrose Conference held in Asilomar, California in 1969 brought plate tectonic concepts to the wider geological community. The conference was attended by five members of the Vancouver Office: John Wheeler, Hu Gabrielse, Jim Roddick, Jack Souther and Bill Hutchison: their attendance subsequently encouraged discussion and wider acceptance of the new concepts in the office. I recall Hutch coming back from the Penrose and, bubbling with enthusiasm, saying we must get these ideas to the Vancouver mineral exploration community. Hutch was largely responsible for organizing a meeting (showing how much he enjoyed doing this) in February, 1970 at the Bayshore Inn in Vancouver under the aegis of the newly created Cordilleran Section of the Geological Association of Canada. Bill Dickinson and Dietrich Roeder, major players at the Penrose Conference, were invited speakers. Hutch expected about 200 to attend; 800 people came, mostly from industry. Subsequently, the Cordilleran Section of GAC organized meetings always at the same time of year on various aspects of Cordilleran geology and their relation to mineral deposits. The meetings eventually died out but their lineal descendant is the Association for Mineral Exploration British Columbia (AME BC) Annual Roundup, held at the same time of year as the 1970 GAC meeting and at the Bayshore Inn. The 2013 Roundup was attended by 7,800 participants.

**Heady days: exotic rocks and Cordilleran mountain-building:** In the 1880s, G.M. Dawson recognized that rocks of the late Paleozoic Cache Creek series (later Group, Complex and terrane) occurred along the axis of the Canadian Cordillera from southwestern British Columbia to south-central Yukon (where they originally had a different name). In 1949, Jack Armstrong noted some similarities (blueschist, bedded chert) between Cache Creek rocks in central British Columbia and Franciscan rocks in California. Before I joined the office, John Wheeler and Hu Gabrielse had proposed a future "Atlin Horst project" whose purpose was a more detailed examination of Cache Creek rocks in northern BC and south-central Yukon between Dease Lake (where Gabe had mapped) and Whitehorse (where John had worked). When I came on permanent staff in 1966, the project was dusted off, renamed "Upper Paleozoic rocks of the western Cordillera", and I started work near Dease Lake.

For my Ph.D. thesis at UBC (Bill Dickinson was my external examiner) I'd worked in the Cascade Mountains, east of Vancouver, on the late Paleozoic Chilliwack and Cultus rocks, identifying them as remnants of late Paleozoic and early Mesozoic volcanic arcs. I had a reasonably good knowledge of paleontology having done my M.S. in Kansas

University, birthplace of the stratigraphic code. In my new GSC project I was very well served by paleontologists: in particular Wayne Bamber, GSC Calgary, looked after corals and handled outside contracts, and Charles Ross of Western Washington University who was the reigning North American expert on fusulinids (large calcareous foraminifera), which are important fossils for Carboniferous and Permian biostratigraphic zonation. However, different zonation schemes existed in North America and eastern Asia because there was little commonality between Permian faunas of these regions, which lived at low latitudes on different sides of the supercontinent called Pangea.

I think that two things of importance for tectonic models of the Cordillera came out of the Cache Creek study. First, it became clear that Cache Creek rocks had formed in an "oceanic" tectonic setting (the big, shallow water, fossiliferous limestone bodies in the Cache Creek were the remains of atolls that capped seamounts or oceanic plateaus) whereas most other late Paleozoic volcanic-sedimentary packages in the western Cordillera evidently formed in arc settings. Second, it had long been known that Permian fusulinids in the Cache Creek were like those found in eastern and southeastern Asia and in the Paleotethys Ocean (whose remnants extend through central Asia to the Mediterranean) but these fossils were thought to be very late in the North American Permian biostratigraphy. Serendipity struck in 1967 when we stumbled across an outcrop of massive limestone southwest of Atlin, BC that contained "Asian" fusulinids and ammonoids. I could only collect fragments of the latter with a hammer, but knew that Walter Nassichuk, GSC Calgary, was the expert on Permian ammonoids. The following summer Walter and I staggered up the ridge carrying a rock drill and water, and drilled out better material. This turned out to be a key discovery, because the same ammonoids also occur in the standard Middle Permian sections of West Texas (Wordian; Ross and Nassichuk, 1970). We now knew the age of these rocks in terms of North American biostratigraphy and that they were older than they were formerly thought to be.

South of the Atlin locality in arc-related deposits of the Stikine River region, typical "North American" Middle Permian (Wordian) fusulinids had been described (Pitcher, 1958) so that we knew there were different faunas of the same age close together in the Canadian Cordillera. This raised the question of how did "home-grown" Stikinian fossils come to be oceanward of the "exotic" fossils in the Cache Creek. Furthermore, reports showed "North American" fusulinids also to occur east of the Cache Creek. In the light of the new permissiveness on mobility, Monger and Ross (1971) combined ideas on Permian tectonic settings and fossils and proposed that the oceanic rocks containing exotic "Asian" fusulinids became sandwiched between arc rocks containing the "North American" faunas by northward displacement of Stikine rocks oceanward (west) of the Cache Creek.

In the fall of 1971 a symposium on Plate Tectonics was held at the Annual Meeting of the Geological Society of America in Washington, DC, with invited papers from those who had attended the Asilomar Penrose Conference. Partly because Jack Souther, who I think would have been lead author but was in Japan at the time, and partly because of the Cache Creek discoveries, the resulting paper on a plate tectonic model of the Canadian Cordillera was by Monger, Souther and Gabrielse (1972). That paper noted differences between the western Cordillera of Canada and that of the conterminous United States because rocks west of the Cache Creek rocks (in the Stikine region and on Vancouver Island) are absent west of rocks correlative with the Cache Creek in California. The "time-space" figure on p. 492 of Zaslow's "Reading the Rocks" taken from that paper shows the "actualistic settings" of rock units, gaps between columns indicating the uncertain paleogeographic relationships between age-equivalent rocks, and the links between columns provided by clastic detritus that was eroded from one column and deposited on another. Since then, considerable efforts have been expended by geologists, paleontologists and paleomagneticians, trying to learn just where the rocks separated by gaps were at the time they formed, and the routes they followed to arrive in their present positions within the Cordillera.

Since the early 1970s, enormous advances have been made in both isotopic and paleontological dating, and in paleobiogeographic studies. In the case of the Cache Creek, newer work (e.g. Orchard et al., 2001) shows that not only the fusulinids, but radiolarians, corals and conodonts in are like those in eastern Asia and Paleo-Tethys. The former late Paleozoic Cache Creek Group is now known to range in age from Early Carboniferous through Early Jurassic (~345-180 Ma). The Cache Creek represents remnants of the floor of the global ocean called Panthalassa accreted during the early Mesozoic subduction that generated widespread early Mesozoic magmatic arcs to east and (?) west of the Cache Creek.

Two other non-GSC contributions made in the heady early 1970s led us to a better understanding of Cordilleran mountain-building processes. Roy Hyndman (GSC Pacific; then at Dalhousie University) in a note to Nature (1972) proposed that along the eastern Pacific margin, the over-riding continental plates advance more rapidly than the subducting oceanic plates retreat (or sink back into the mantle) so that there, in effect, continent-ocean collision occurs and mountains are raised. Conversely, in the western Pacific, as arcs advance towards the retreating oceanic plates, upwelling behind the arcs result in back-arc basins. Also in 1972, Peter Coney (University of Arizona) suggested that the onset of Cordilleran mountain building closely coincides with initial North Atlantic opening and spreading. Although some early “continental drifters” had hinted at this (e.g. Daly, 1926) they lacked supporting evidence. It appears that during late Paleozoic time the pre-Cordilleran region resembled the present western Pacific basin; mountain building started in the Middle Jurassic, about 170 million years ago, when the North Atlantic first started to open widely.

**Canadian-American communication and collaboration in the Cordillera**

The Canadian Cordillera is the bridge that links conterminous United States Cordillera geology with that of Alaska, and thus is of interest to American geologists. Furthermore, mapping along national boundaries leads to exchanges between those working on opposite sides. For these reasons there has long been collaboration between GSC and USGS geologists, collaboration that more recently includes academic and provincial survey geologists (in the Ancient Pacific Margin and Edges projects). Finally, plate tectonics demands a “big picture” and ideally a global perspective; NIMBY-ism is not very productive!

In the Prince Rupert area in the early 1960s, Jim Roddick and Hutch discussed geology across the BC-southeastern Alaska boundary with Henry Berg, USGS. During the 1970s, Dick Campbell worked with USGS geologists Ed McKevitt, Don Richter and George Plafker when mapping the St. Elias Mountains. In 1968, at the Alaskan Science Conference in Whitehorse, I met Dave Brew, and through him was able to examine rocks in southeastern Alaska, which stood out as the “older eugeosynclinal deposits” on King’s Tectonic Map of North America.

In 1972, I attended the Penrose Conference on ophiolites and met Greg Davis (University of Southern California). We decided to organize an informal meeting on "Pre-Franciscan eugeosynclinal rocks of the Cordillera". This was held in 1973 when Davy Jones (USGS) offered the library of the USGS in Menlo Park for the venue. We invited a limited number of mostly younger geologists who were working from Alaska to California, including five from GSC Vancouver. At least partly as a result of this meeting, informal discussions of Cordilleran geology were held over the next decade or so mostly during Geological Society of America Cordilleran Section meetings, and travel money was available for informal field trips. All of this led to familiarity with different parts of the Cordillera by more-and-more people. It is encouraging to see that the recent Ancient Pacific Margin and Edges projects in the Cordillera cross international boundaries and involve participants from GSC, USGS, provincial surveys and universities.

**Terranes:** The terrane concept has a long history. Some proponents of continental drift recognized that rock packages originating far from one another could be brought together by tectonic processes (e.g. Argand in 1924 suggested that disparate Siberian, Sino-Korean, Tarim "massifs" came together in central Asia). In a seminal plate tectonic paper, Tuzo Wilson (1968) showed "fragments of Asia" (not Cache Creek, but later named Stikine, Alexander and Sonoma terranes) within the Cordillera. The term "terrane" was applied in 1972 to entities within the Cordillera by Porter Irwin (USGS) for fault-bound, partly coeval but different assemblages in the Klamath Mountains of northwestern California and southwestern Oregon, and by Henry Berg (USGS) for the distinctive rocks of the Alexander Archipelago, southeastern Alaska that formed "Alexander terrane. In 1977, Davy Jones (USGS) gave the name Wrangellia to rocks with similar stratigraphic records found in southern Alaska, Haida Gwaii, Vancouver Island and (erroneously) eastern Oregon. Earlier, in 1972, Ted Irving (GSC Pacific) and Ray Yole (Carleton University) had found that paleomagnetic inclinations from Triassic lavas on Vancouver Island did not match up with those from cratonal North America, and similar results were obtained in 1977 by USGS workers in southern Alaska. The term "suspect terrane" (the qualifier implies an uncertain paleogeographic setting with respect to North America) was used in a paper in Nature by Coney, Jones and Monger (1980) that combined information on the Cordillera from Alaska to Mexico. Subsequently the term "terrane" and its implications have been globally adopted as a useful tool for analysing the complex geologies of orogenic belts.