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Résumé de l'article

Walter Andrew Bell (1889-1969) était un homme affable et réservé. Il était originaire de St-Thomas, Ontario, de parents pres-bytériens d'origine écossaise. Gradué de Queen's et de Yale, sa carrière débuta à la Commission géologique du Canada (CGC) en 1920. D'abord assistant paléo-botaniste, il gravit progressivement les échelons et en devint le directeur. Bell fut directeur de 1950 à 1953, années cruciales de modernisation pour la CGC, où il encouragea et renforça l'importance des recherches stratigraphiques et paléontologiques. Au cours d'une carrière particulièrement longue, Walter Bell fut l'auteur ou le co-auteur de 70 publications, portant surtout sur la stratigraphie du Carbonifère, la paléobotanique et la paléontologie des régions atlantiques du Canada. Il a également contribué de façon importante à l'avancement des connaissances paléobotaniques du Mésozoïque et du Cénozoïque du centre et de l'ouest du Canada.



**Walter Andrew Bell
(1889-1969)
Canadian Carboniferous
Stratigrapher,
Paleobotanist and
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par excellence**

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SUMMARY

Walter Andrew Bell (1889-1969) was a gentle, modest man of few words, born to Scottish Presbyterian parents in St. Thomas, Ontario. After graduating from Queen's and Yale universities, he began his full-time career with the Geological Survey of Canada (GSC) in 1920, progressing through the ranks from Assistant Palaeobotanist to Director. Bell was Director from 1950 to 1953, pivotal years in the emergence of the modern GSC, when he encouraged and strengthened paleontological and stratigraphic studies. Over his exceptionally long career Walter Bell authored or co-authored 70 publications, mostly concerning Carboniferous stratigraphy, paleobotany and paleontology of Atlantic Canada. He also contributed significantly to central and western Canadian Mesozoic and Cenozoic paleobotany.

RÉSUMÉ

Walter Andrew Bell (1889-1969) était un homme affable et réservé. Il était originaire de St-Thomas, Ontario, de parents presbytériens d'origine écossaise. Gradué de Queen's et de Yale, sa carrière débuta à la Commission géologique du Canada (CGC) en 1920. D'abord assistant paléobotaniste, il gravit progressivement les

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THE MAN

Walter Bell was a wiry, slim, small man whose vigor and energy, even at an advanced age, have become legend. As a personality, he was a withdrawn, quiet-humor kind of individual; partly deaf because of his World War I military service, he was a man of few words who was uncomfortable in crowds (Andrews, 1980; Zodrow, 1995). In reviewing Bell's life and accomplishments, one is left with the strong impression that he felt most at home with his fossils and microscope.

His daughter, Laura Jean Bell (hereafter abbreviated LJB, together with the date of our communication), remembers her father as:

...a rather Edwardian figure, elegant, very particular in his dress — shoes shining, always a vest with his jacket, shirts creaseless (even when we had a maid, mother ironed his shirts and pyjamas and boxer shorts!) and I can even remember canes and homburg and bowler hats, spats — and sadly, always an array of pipes. He never appeared unshaved or unkempt, even at camp, nor do I remember hearing a vulgar remark — sarcastic, yes, but crude or blasphemous, never (LJB, 1992).

Walter Bell was both private and religious. Although he had no church affiliation after he was asked to buy a pew in St. Andrews Presbyterian Church in his early days in Ottawa (something that shocked his Presbyterian sense of propriety), he had a spiritual strength that sustained him throughout his life (LJB, 1992). He also had a love and respect for nature, probably instilled in him by his father (Zodrow, 1995), long before ecological concerns came to the forefront. This aspect is remembered by his daughter:

In the summers we were always dry-tented in some field near a beach or river — whether at Pugwash, Five Islands or

on the Margaree [all in Nova Scotia] — and the nature study continued there as well. Long before the word ecology proliferated, he worried about falling and adulterated water tables, the destruction of so many species and habitats. When he and mother moved to New Glasgow in the 1960s, he raised some eyebrows...by deploring the establishment of Scott's...[paper] mills nearby... (LJB, 1992).

Walter Bell's extraordinary dedication to geology is shown by his publication record spanning 57 years (see Zodrow, 1995). Having survived the battlefields of World War I "...he labored single-mindedly and effectively with relatively few interruptions" (McLaren, 1969) through the Great Depression, World War II, and the post-war era. He persevered despite always limited personal means, illness in the family and the temptations of a higher salary south of the border; the latter he avoided in favor of having more research time (LJB, 1992). Even when he reluctantly became Director of the GSC in 1950, he continued to exercise a crystal-clear focus with regard to his research (Zodrow, 1995). Digby McLaren, later himself Director, remembers this time:

In spite of carrying out his duties as Director expeditiously and efficiently, he nevertheless continued to work on fossil plants. An afternoon visit to the Director was a memorable experience. One approached across his large office to where he sat, behind his desk, totally absorbed in his work. When he became aware of one's presence, he would turn with difficulty from his microscope to consider your problem—always with sympathetic attention. As soon as he felt that the interview was over, however, he would turn back to the microscope and that was the end of it. (McLaren, 1969).

He was much honored during his long life, receiving a variety of medals — including the Logan Medal — and honorary memberships and degrees (McLaren, 1969; Zodrow, 1995). Despite this recognition, Walter Bell was, and remained, a modest man. An anecdote told by his wife, Budda Bell, illustrates this aspect of him:

We owned a much loved cairn terrier, Brigand, that Walter used to exercise. After he died, I was walking Brigand early one morning in a nearby cemetery when an elderly man approached, obviously the caretaker. 'Are you Mrs. Bell? I recognized the dog.' Upon being assured that I was, he continued: 'You know, I often met your husband in the morning and we would stop and have a chat. Until I read about him in the newspaper, I never realized he was a great man. I thought he was just a simple man,

like myself. That was Walter. (Andrews, 1980).

EARLY YEARS

Walter Andrew Bell was born on January 4, 1889 in the town of St. Thomas in southwestern Ontario (Zodrow, 1995). Walter (Fig. 1) was the fourth of five sons born to James Anthony Bell and his wife Katherine (Kate). Walter Bell's father, a long-time and much respected surveyor and civil engineer in St. Thomas and Elgin County (*St. Thomas Times-Journal*, 1928 and October 20, 1962), was born in Lobo Township, Middlesex County, of parents who came from Paisley, Scotland in the 1830s. Mother Kate Bell (née Darrach), whose family came from Islay in the Inner Hebrides, taught school at the Wellington Street School in St. Thomas before her marriage. James Bell ran a 'tight ship'; living at the edge of town the five boys all had chores and were kept busy working in the garden and orchard and looking after animals. There was little time to play and although he participated in squash and track at Yale, Bell never learned to play. His daughter summarized her father's childhood as an "old-time Presbyterian upbringing [with] no whistling or reading on Sunday other than the Bible" (LJB, 1992).

Walter Bell attended Wellington Street School in St. Thomas before going on to

St. Thomas Collegiate Institute (LJB, 1995). He graduated in 1906 at the age of 17, entering Queen's University in Kingston, Ontario the same year (not 1909 as in McLaren, 1969 and Andrews, 1980). His undergraduate career (Fig. 2) was both diverse and lengthy; the principal

reason for this seems to have been that he switched programs several times, graduating with a B.Sc. in Geological Engineering in 1911 (Zodrow, 1995). Walter Bell's B.Sc. thesis entitled "The Birdseye and Black River formations as occurring on Wolfe Island" (Zodrow, 1995) was ap-



Figure 1 Walter Bell as a three- or four-year old (source: Laura Jean Bell).

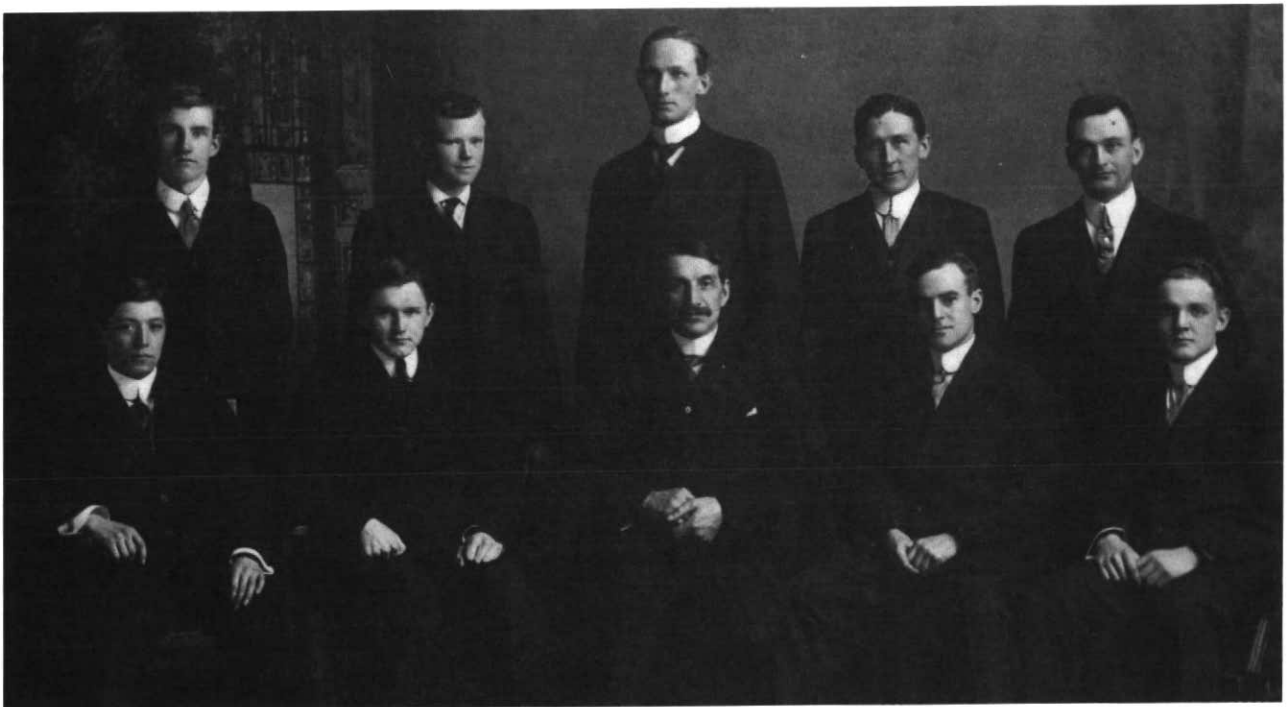


Figure 2 The executive of Queen's University Science Class of 1910, in the academic year 1909-1910. Walter Bell, the 2nd Vice President, is in the first row, far left (source: Laura Jean Bell).

parently sufficiently rigorous or intellectually promising for Bell to be awarded the "1851 Exhibition Scholarship" of 150 Pounds, tenable at the university of his choice; he chose Yale University in New Haven, Connecticut.

By the time Bell had enrolled at Yale in 1911 (Bell, 1912; Zodrow, 1995) he had already established a relationship with the GSC, one that was to last the rest of his life. As has happened so commonly among Canadian geology undergraduates and graduates, Bell was offered a summer job with the GSC and spent the summer of 1909 with a field party in the Yukon led by D.D. Cairnes (Fig. 3) (McLaren, 1969) (not 1910 as in Zodrow, 1995; the summer of 1910 D.D. Cairnes worked in the Atlin District of British Columbia [GSC Summary Report for 1910, 1911]).

By the summer of 1911 Bell was doing field work for the GSC in the Carboniferous of Chignecto Bay, Nova Scotia, an area that includes the famous Joggins section (Bell, 1912). During the summer of 1912, with the support of the GSC, Bell began his Ph.D. field work on the Lower Carboniferous rocks of the Horton-Windsor district of Nova Scotia (Bell, 1929), a study suggested by Charles Schuchert of Yale University (Bell, 1921a). He continued the work late in the season of 1913 and for four months in 1914 (Bell, 1915, 1921a), probably not completing the field work until late September, 1914 (13 August 1914 letter from Bell to his mother).

Although employed by the GSC during the summers, Bell had been enrolled as a graduate student at Yale since 1911. Three years at Yale and completion of his

field work should normally have meant that Bell would spend the next year or so doing laboratory and library research and completing his dissertation. However, these were not normal times. In his 13 August 1914 letter home, Bell wrote that while he and his party were camped out at a remote spot at Bishopville (near Hantsport), Nova Scotia "...we could only secure mail there twice a week and seldom had the privilege of seeing a newspaper, so that recent international complications fell upon us like a boomerang." The complications were, of course, that World War I had been declared on 4 August 1914. The news must have been quite a shock in the midst of what should have been a carefree Nova Scotia summer. Walter Bell's reactions were a mixture of romanticism and adventurism, tinged no doubt with some apprehension. He wrote to his mother that, "It would certainly be great sport to chase a few of those burly good-natured Germans who visited us the past summer, and with whom I drank more than one siddle of beer — that is, it is nice on paper and in contemplation."

The climate in those early days of the war, particularly in coastal Nova Scotia, tended to be alarmist and Bell commented in his 13 August 1914 letter that the Halifax papers were disgustingly lurid and partisan. He could not yet have been totally convinced about the seriousness of the war, for he still treated what was happening with a degree of humor and skepticism:

Haven't there been rumors of German cruisers off the Nova Scotia coast? And only the other day wasn't a geologist friend — an American Prof. Goldthwaite [sic] [J. W. Goldthwait, the geomorphologist who studied the physiography of Nova Scotia (Goldthwait, 1924)] engaged by the Canadian Survey — while working about Hantsport, taken for a German spy by a somewhat hysterical piece of femininity? I was greatly tickled to hear about it at Hantsport last evening and must duly warn my German confrere. At least it is a pleasurable variation to be taken for something so original & awe-inspiring.

Although Walter Bell probably completed the 1914-1915 academic year at Yale, he must have decided that year to answer the call of King and Country. He spent the summer of 1915 doing further GSC field work in Nova Scotia, particularly in the Sydney coalfields (GSC Summary Report for 1915 [1916]). That fall found him in Kingston, Ontario, rather than

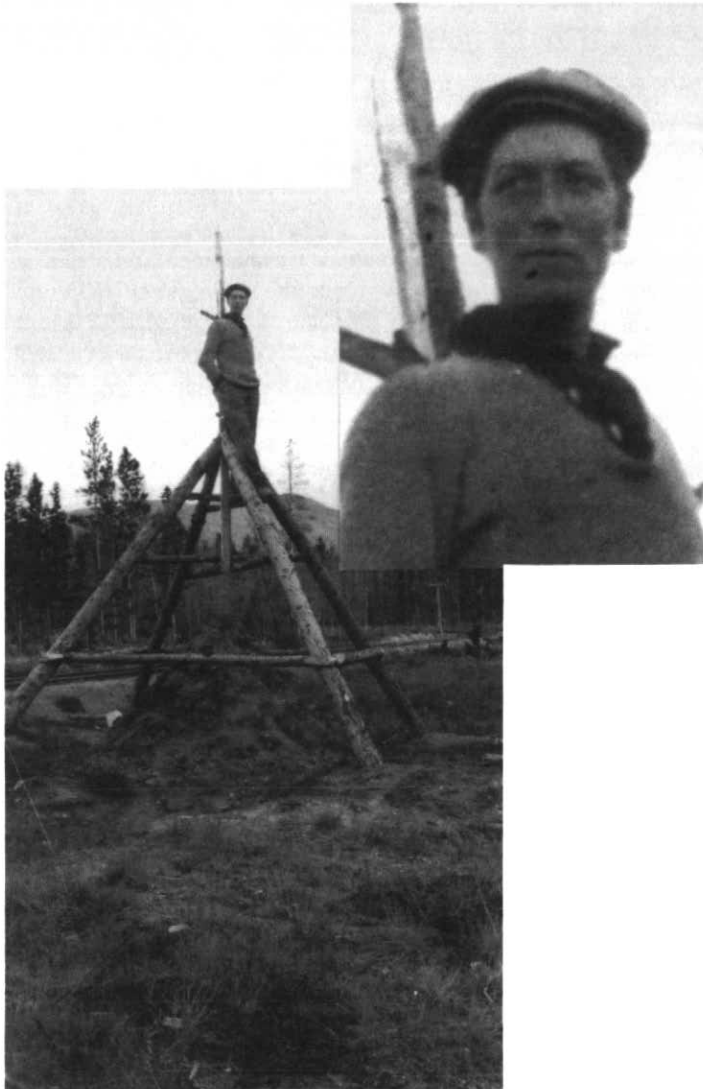


Figure 3 Walter Bell on a triangulation tower in D.D. Cairnes' 1909 Geological Survey of Canada field party in the Yukon Territory (source: Laura Jean Bell).

in New Haven, Connecticut, waiting to be inducted into the army, possibly as an officer (letter to his father dated 1 November 1915).

Bell's anticipated induction and hoped-for officer status was apparently premature. In a booklet entitled the *History of the 45th Battery of the Canadian Field Artillery of the Canadian Expeditionary Force* (Anonymous, n.d.), he is listed under the category of "Men of the 45th," with a home address of 81 Elm Street, St. Thomas, Ontario. According to this history, the 45th Battery was organized in Kingston on 24 January 1916, sailed from Saint John on 5 February, and landed in Plymouth, England on 13 February 1916. After training in England, the Battery sailed for France on 13 July 1916. That Walter Bell held the rank of bombardier (Zodrow, 1995) is confirmed by a 23 January 1919 letter from Charles Schuchert addressed to Bdr. Walter A. Bell. However, it is unknown what Bell saw and experienced in France and Belgium. Among his personal effects was a hand-written list of battles that he and his comrades engaged in, among them Ypres, Vimy Ridge and Arras, names that have become famous in Canadian history. The 45th Battery returned to Canada in the Spring of 1919, landed in Halifax on 23 March and was demobilized in Kingston on 1 April 1919.

Correspondence from Charles Schuchert (23 January 1919) encouraged Bell to leave the army and return to his studies:

If by hook or crook you can get out of the army, my advice to you would be to stay through a semester at Paris...to study the Carboniferous, both from the invertebrate standpoint and the floral as well...You should also, if possible, see some of both the Belgian and French Coal Measures sections, to study them from the stratigraphic standpoint, and to note the extent of the coal beds, the significance of the underclays and so on.

Bell must have succeeded in leaving the 45th Battery before it returned to Canada, because by the beginning of May 1919, Schuchert was writing to him care of Dr. A. Smith Woodward at the British Museum (Natural History) (7 May 1919 letter to Bell from Schuchert). Bell probably spent about a month in London and by early June 1919, he was living in Cambridge and writing enthusiastically to his father about his examination of British paleobotanical material:

The paleobotanical work has been interesting. Outside of the ordinary carbonized impressions they have a great number of microscopic slides of petri-

fied material, marvellously preserved. Imagine spores or pollen grains one five thousandth of an inch diameter with fine delicate hairs on the wall preserved to perfection from the Coal Measure period. Transverse sections of the skins of Coal Measure ferns are almost as perfect as sections cut from fresh material to-day & these measures are certainly at least 10 million years old. The material is derived from the coal seams where it is petrified in limestone balls. It shows that our ferns had a very old ancestry. None of our flowering plants go back this far so the forests of the river flats in which our coal seams were laid down would be a little too sombre for our liking today.

Bell was, of course, describing the exquisitely preserved plants in British Carboniferous coal balls. The date of "at least 10 million years" for the Carboniferous Coal Measures suggests that Bell was conservative about then changing ideas of geological time (Boltwood, 1907; Holmes, 1911).

Fossil collections at the Sedgwick Museum at Cambridge include brachiopods and corals from the Avon Gorge, Bristol, that were used by Vaughan (1905) to establish his important Lower Carboniferous faunal zonation. As Bell's Ph.D. collections included similar Lower Carboniferous faunas from the Windsor Group of Nova Scotia, he must have been keen to examine the British material. Bell briefly referred to what is likely Vaughan's material in his 30 June 1919 letter to his father:

...I shall probably stay over to the first or second week of August in order to have a good squint at some fine collections from the Lower Carboniferous—mostly corals. They have a pretty neat lot showing the evolution of some varieties of cup corals.

Vaughan's work was extended and tested by E.J. Garwood of University College, London. Garwood met Bell and took him into the field to examine Lower Carboniferous strata in Yorkshire and Westmoreland (Bell, 1921a, 1929). The relationship between Bell and Garwood seems to have been cordial and the application of the biostratigraphic techniques that had worked so well for Vaughan, Garwood and others in the Lower Carboniferous of Britain to the Windsor Group of Nova Scotia (Bell, 1921a, 1929) was probably influenced by this contact. Bell's zonation, based on the distribution and evolution of fossil corals and brachiopods, is, with modification, still used in Atlantic Canada (Moore, 1967; Moore and Ryan, 1976).

Although it has been claimed (McLaren, 1969; Andrews, 1980; Zodrow, 1995) that Bell was influenced by A.C. Seward while he was at Cambridge, the only evidence for this of which the writer knows is a letter to Bell from Schuchert dated 11 June 1919 in which the latter expressed his delight that Seward was looking after him and that this would assure that Bell would "get a great deal of paleobotany and the proper methods of studying it." Subsequent to Bell's three-month stay at Cambridge, he thanked Professor J.E. Marr of that University for the many courtesies shown, without mention of Seward (Bell, 1921a, 1929). Similarly, although Charles Schuchert had been keen to expose Bell to the ideas and work of Belgian and French Carboniferous workers and specifically recommended that Bell meet Dr. P. Pruvost and Professor C. Barrois at the Musée d'Histoire Naturelle in Lille, France (11 June 1919 letter to Bell from Schuchert), I am unaware of evidence that Bell visited French or Belgian geologists or that he spent any time at the École des Mines in Paris (Nowlan, 1970; Zodrow, 1995).

Charles Schuchert was keen to have Bell back at Yale, writing to him on 23 January 1919 that "if you should also be here next fall, the place would take on some of its former color..." Bell was probably back at Yale in the Fall of 1919 and the following Spring finished up and defended his dissertation (Bell, 1920). Charles Schuchert wrote:

Bell is by all odds the best man I ever had, and now with the training in Europe, in the field of honor, and in a temple of learning (Cambridge) he, I prophesy, to be not only a worthy follower of Sir William Dawson in unearthing the geology of the Maritime Provinces, but, let us hope, as great a promoter of the earth sciences in general. He is not only a paleontologist and paleobotanist, but an equally good geologist. (letter to R.G. McConnell, Director, GSC, dated May 3, 1920; previously cited by McLaren, 1969, Nowlan, 1970 and Zodrow, 1995).

Although Walter Bell's studies at Yale University between 1911 and 1920 were interrupted by his war service, he had the good fortune while at Yale to be associated with some of the most famous American geologists of the early part of this century, as faculty and fellow students (Fig. 4). Until 1920, when amalgamation occurred, Yale geology faculty were located in three separate settings: Yale College, the Sheffield Scientific School, and the Graduate School (Skinner and Narendra, 1985). Faculty members from these

settings included the brilliant and demanding tectonics specialist, Joseph Barrell, who was also the originator of formal graduate courses in geology at Yale; William E. Ford, a famous mineralogist who revised Dana's Textbook of Mineralogy; the well-known petrologist Louis V. Pirsson, one of the founders of normative calculations in igneous rocks; John D. Irving, a petrologist and economic geologist who was the first editor of the journal *Economic Geology*; and the geomorphologists and geographers Isaiah Bowman, Herbert E. Gregory, and Ellsworth Huntington. On the sedimentary side, undoubtedly the person who had the most influence on the young Walter Bell was Charles Schuchert, a largely self-taught stratigrapher and paleontologist of formidable ability (Skinner and Narendra, 1985), who was Bell's Ph.D. dissertation

supervisor. Others who may have influenced Bell were the vertebrate paleontologist Richard S. Lull, an enormously stimulating and gifted lecturer on evolution and paleontology, and George R. Wieland who lectured in paleobotany (Fig. 4).

Bell's fellow graduate students at Yale included Alan M. Bateman, later famous as an economic geologist and author of the classic text, *Economic Mineral Deposits*. Like Bell, Bateman was a Canadian who had also been an undergraduate at Queen's University in Kingston. Bateman's Ph.D. studies on the Bridge River area of British Columbia were also supported by the GSC; he completed his Ph.D. in 1913 and joined the Yale faculty in 1916 when John Irving left to join the United States Army. (Irving did not return to Yale, for he died at the Flanders front in 1918 from influenza) (Skinner and Narendra, 1985).

Other Canadian fellow graduate students of Walter Bell's at Yale between 1911 and 1920 included C.W. Drysdale, J.J. O'Neill, M.Y. Williams, M.E. Wilson, B. Rose, F.J. Alcock, W.J. Wright, J.S. Stewart, F.H. MacLearn, G.S. Hume and W.S. McCann (Brian Skinner and Barbara Narendra, pers. comm. to Roger Macqueen, 12 February 1997). Many of these students were supported and/or hired by the GSC and went on to make notable contributions to Canadian geology. Other Yale graduate students from Bell's time, later to become famous, included the structural geologist Chester Longwell, and the stratigrapher and historical geologist Carl Dunbar, who completed his Ph.D. dissertation under Charles Schuchert in 1917 and was appointed to the Yale Faculty in 1920 (Skinner and Narendra, 1985).

We do not know how much influence

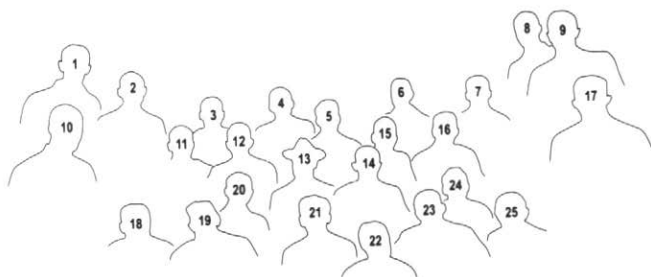


Figure 4 Yale University faculty and students on the steps of the old Peabody Museum of Natural History (demolished in 1917). Names of faculty members are in Roman type; graduate students' names are italicized with year of award of Ph.D. (if known) in parentheses. 1) Bruce Rose (1913); 2) Ellsworth Huntington; 3) Isaiah Bowman; 4) Charles W. Drysdale (1912); 5) William E. Ford; 7) Edward S. Dana; 10) Alan M. Bateman (1913); 11) Freeman Ward; 12) Joseph Barrell; 13) Herbert E. Gregory; 16) Richard S. Lull; 18) John D. Irving; 19) Louis V. Pirsson; 20) M.Y. Williams (1912); 21) Charles Schuchert; 22) Henry G. Ferguson; 23) J.J. O'Neill (1912); 24) Walter Bell (1920). Unidentified are 6, 8, 9, 14, 15, 17 and 25. The photograph is likely to have been taken in 1912 since C.W. Drysdale (4) and J.J. O'Neill graduated in that year. A similar photograph showing faculty and graduate students was taken in 1911 (see Skinner and Narendra, 1985, fig. 8, p. 363).

these men had on Bell, but it is reasonable to assume that it was considerable, playing a major role in developing his enthusiasm, devotion and dedication to excellence in his Carboniferous and other studies.

GEOLOGICAL SURVEY OF CANADA YEARS

By the summer of 1920 Bell was back in the Maritimes studying the Carboniferous strata of the Sydney district (Bell, 1921b). His status as a field assistant was finally changed to permanent staff when he was appointed Assistant Palaeobotanist of the GSC in December 1920 (Zaslow, 1975). Unlike so many young men of his generation he had survived the war, had belatedly completed his education, and had a job.

Bell's publications (Zodrow, 1995) suggest that after 1920 he established a pattern of spending summers doing field work in the Carboniferous of Nova Scotia and New Brunswick and winters in Ottawa researching and writing up his previous summer's findings. Of the summers, that of 1922, when he was working in the Pictou Coalfield of Nova Scotia (Bell, 1923), was especially significant.

After the fateful encounter in the potato patch — in actuality a field on my grandparents' farm at Bear Brook on the outskirts of Westville in Pictou County — Walter Bell's private life centered around Sarah Campbell, known by all as Budda... (LJB, 1993).

Walter Bell and Sarah Campbell married on 7 September 1923 in the Campbell home; their daughter, Laura Jean, was born on 7 August 1924 (LJB, 1995). Subsequently, Bell had female company in the field each summer:

Summers, mother and I went out in the field with the survey party — an incipient ulcer made Daddy unable to cope with a hired camp cook. Anything but handy around the house, Daddy was an able camper. (LJB, 1992).

After living in a number of places in Ottawa, Walter and Budda Bell eventually settled at 18 Torrington Place, "a Swiss chalet inspired duplex" (Fig. 5). Describing her family's circumstances during the late 1920s and 1930s, his daughter commented:

They doubtless would earlier have bought a home in the Glebe [a comfortable middle-class part of Ottawa] but serious illness in the late 1920s (mother was pregnant, caught pneumonia and pleurisy) ate up their savings and ended hopes of a house and larger family (she lost that

baby). It was a bitter blow. (LJB, 1992).

Laura Jean Bell, in describing her early life, refers to her family's "always limited means" (LJB, 1992) a situation not helped by the Great Depression that Canadians found themselves in the 1930s; however, despite these concerns, she remembers that:

...as a family we were surrounded by books, music, friends, good food and good times — and there were those wonderful summers in the field. (LJB, 1992).

McLaren (1969) remembered the Bell home as a happy and fulfilling one:

To know Walter and Budda at home was a privilege and a delight. They took joy in each other, and allowed one to share in it. In spite of his extreme commitment to research and long hours of work, Walter Bell, nevertheless, enjoyed, modestly but intensely, good conversation and good living, and these could always be found in his home...

Professionally, Walter Bell and E.R. Faribault did most of the work for the GSC in Nova Scotia between the two World Wars (Zaslow, 1975). Walter Bell's publication record (Zodrow, 1995) shows that he devoted himself almost exclusively to the Upper Carboniferous of Nova Scotia and New Brunswick during his first 25 years with the GSC. Departures from this generalization include his publications on the (mostly) Lower Carboniferous Horton and Windsor groups that were the result of, or related to, his Ph.D. dissertation (Bell, 1920, 1921a, 1929, 1930). The eval-

uation of Tertiary plants from the Mackenzie Basin (Bell, 1922) may have been the origin of his interest in Mesozoic and Cenozoic floras.

Between 1920 and 1949, Walter Bell rose steadily in the GSC, from assistant paleobotanist (1920) to chief paleontologist (1938), to senior geologist (1946). In 1950 (Zaslow, 1975) Bell was appointed Director of the GSC, the first paleontologist to achieve this rank (Zaslow, 1975) (Fig. 6). Despite Bell's reluctance to take on the position, he was Director at a critical time:

Bell's years as director saw the beginning of all the major advances that were to characterize the Survey over the next two decades. ... As director, Bell gave long-overdue attention to the stratigraphic and paleontological aspects of Canadian geology, an area that had been neglected by his predecessors... The result was a considerable expansion of staff for paleontological laboratory and other work. Field operations were extended to the limit of procurable staff, especially in keeping with the needs of the oil and gas industries... in the Western Plains region... In sum, W.A. Bell presided over the early stages of a revolution in Survey activities, perhaps without having any clear idea where it was leading, as indeed no one had. (Zaslow, 1975).

RETIREMENT YEARS

Bell must have been anxious to escape his administrative duties and return to his scientific work for he stepped down as



Figure 5 Budda and Walter Bell in front of their home at 18 Torrington Place, Ottawa (source: Laura Jean Bell).

Director of the GSC in 1953 (McLaren, 1969; Zaslow, 1975). He was subsequently given a transition research position with the title of Chief Geological Consultant (McLaren, 1969) or Chief Geologist Consultant (Zaslow, 1975; Zodrow, 1995). Bell's actual retirement date is slightly confusing: 1954 (Zaslow, 1975; Zodrow, 1995), 1956 (McLaren, 1969) and 1957 (Nowlan, 1970). The 1954 date is

probably correct since 4 January 1954 would have been Bell's 65th birthday; 1956 and 1957 were probably dates until which Bell worked under contract for the GSC.

Upon retiring from the GSC, Walter and Budda Bell moved to New Glasgow, Nova Scotia (Nowlan, 1970), the area with which he was so familiar professionally and also the one from which his wife had come. Bell did everything but retire, how-



Figure 6 Walter Bell ca. 1950. An official(?) photograph taken when Bell became Director of the GSC (source: Laura Jean Bell, but based on GSC negative 201114; previously utilized by McLaren, 1969; Zaslow, 1975; Zodrow, 1995). Republished with permission of the GSC.



Figure 7 Walter Bell in his retirement examining fossil plants (source: Laura Jean Bell).

ever, consulting for the GSC (McLaren, 1969), the Nova Scotia government (McLaren, 1969; Nowlan, 1970), and industry (Nowlan, 1970). At least twice a year he would make study trips to Ottawa to examine new paleobotanical collections, generally with manuscript in hand (McLaren, 1969) (Fig. 7). Subsequent to 1954 Bell published 13 papers, including three major memoirs and bulletins on Upper Cretaceous floras of western Canada (Bell, 1956, 1957, 1963). He returned as well to interests of many years before with a memoir on the Horton Group of the type Windsor-Horton district (Bell, 1960a) and a bulletin on the flora of the Pictou Group (Bell, 1962a). During this time, he also established, or re-established, a relationship with the Nova Scotia Department of Mines; this resulted in a report on petroleum possibilities in Nova Scotia (Bell, 1958) as well as published comments on the Pictou Coalfield (Bell, 1960b).

In Walter Bell's final years, he conscientiously and methodically tied up loose ends, completed manuscripts, curated collections and popularized paleobotany. That he completed all of these admirably is due to a combination of vision, drive and good genes, as illustrated below:

His mind stayed sound to the end. In his 80th year, mother recalls a young geologist coming to question him about a problem he had in the section he was working. Daddy stayed silent, jingling coins in his pocket nervously, his face blank. Had he heard the question, mother wondered, or had he suffered a memory lapse? Then Daddy spoke. He identified the anomaly, then went on to theorize about its probable cause in detail, a subject he had not dealt with for some four decades! (LJB, 1992).

The result of his curatorial labors were two catalogues of all the type and figured specimens of fossil plants in GSC collections (Bell, 1962b; 1969 [posthumous]). Bell's three volumes illustrating Canadian fossil plants (1965a,b; 1966) are monuments to his efforts to popularize the subject in an interesting and informative way.

Walter Bell died of lung cancer at New Glasgow, Nova Scotia on January 28, 1969 at 80 years of age (Nowlan, 1970); he is buried at Heatherdale Memorial Gardens at Alma, Pictou County, Nova Scotia (LJB, 1992) on the Carboniferous that he spent his life studying. McLaren (1969) summarized Walter Bell's life best in these words:

He worked to the end of his long life, and died, as he had lived, a deeply respected and much loved human being.

ACKNOWLEDGMENTS

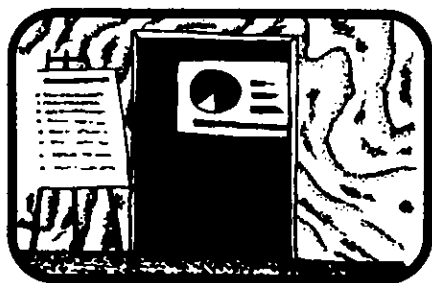
The name and publications of Walter Bell first became known to me some 35 years ago, as a student at Acadia University working with R.G. Moore on the Lower Carboniferous Windsor Group of Nova Scotia. Thus, my direct knowledge of Bell's work is limited to his earlier research on the (mostly) Lower Carboniferous Horton and Windsor groups and to his later work on the correlative Anguille and Codroy groups of western Newfoundland. Walter Bell and I corresponded briefly in the mid-1960s and the late Bud Cumming introduced me to him in Ottawa in 1967.

This sketch of Walter Bell's life and accomplishments would not be as satisfying and complete had Laura Jean Bell not shared personal family information. I gratefully acknowledge her generosity and openness; I also thank Wayne Bamber, Desmond Collins, Peter Hacquebard, Digby McLaren, Brian Norford and Erwin Zodrow for information, discussion and clarification. Brian Skinner and Barbara Narendra of Yale University suggested the likely date (1912) for the photograph in Figure 4; they also provided the years of Ph.D. awards and confirmation of most identifications of Yale Geology Department faculty and graduate students shown in that figure. Roger Macqueen, *Geoscience Canada* editor, also helped with identifications for Figure 4. Joan Burke of the Royal Ontario Museum, as always, assisted immeasurably.

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Conference Report



New Mineral Deposit Models of the Cordillera

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A two day short course on "New Mineral Deposit Models of the Cordillera" was presented first in Vancouver prior to the 1996 Cordilleran Roundup and then in December of the same year in Spokane in conjunction with the Northwest Mining Association meeting. The objective was to provide industry participants with new ideas and models to assist them with exploration. A spectrum of ore deposit models was discussed, from deposit types with proven economic potential to styles of mineralization that remain to be evaluated. Both sessions were well attended by geologists from Canada and the United States. The first course was organized by the British Columbia Geological Survey (BCGS) in collaboration with the Mineral Deposit Research Unit (MDRU) of The University of British Columbia and the Geological Survey of Canada (GSC), while the second was a joint venture between the BCGS and the Northwest Mining Association. Most speakers participated in both workshops.

SHORT COURSE NOTES AND ABSTRACTS

The Northwest Mining Association is selling the notes for the second short course for \$85 US plus \$12.50 handling charges. Northwest Mining Association
10 N. Post Street, Suite 414
Spokane, Washington 99201-0772
Tel: (509) 624-1158 FAX: (509) 623-1241
E-mail: nwma@on-ramp.ior.com

The abstracts for the first short course in Vancouver are posted on the BCGS's web site:

<http://natural.gov.bc.ca/geosmin/metalmin/depmodel/rdup-abs.htm>

INTRODUCTION

The short course began with a presentation by Michael Etheridge of Etheridge, Henley and Williams on "Making Models Matter." He pointed out that exploration geologists increasingly are being asked by non-technical people to explain what

"Even the most 'pragmatic' of explorers use models to help justify their decisions."

they do, why they do it that way, and how to measure program effectiveness. The answers often involve deposit models because even the most "pragmatic" of explorers use them to help justify their decisions and to argue that their approach is effective (*i.e.*, lower risk). The principal deficiency in many models is that they do not incorporate an understanding of the critical geological process responsible for forming a deposit. For example, the critical process in forming a porphyry copper deposit may well be the dilatant deformation that gave rise to the stockwork vein system, rather than the petrogenesis of the intrusive host rock, or even the associated alteration. Effective exploration models should maintain relevance by continual modification, and be presentable in map form to focus

effort on the most favorable areas.

David Lefebure (BCGS) discussed **British Columbia deposit profiles** that are being developed for Cordilleran-type settings. More than 140 metal, coal and industrial mineral deposit models are relevant to British Columbia. The deposit profiles are two- to five-page descriptions used to classify known deposits and occurrences, to estimate undiscovered mineral resources, and to group deposits to allow compilation of representative grade and tonnage data.

GOLD SKARNS AND CARLIN DEPOSITS

During a comprehensive review of **gold skarns**, Gerry Ray of the BCGS highlighted the need to assay all mineral assemblages in skarns because micron-sized gold may be associated with barren sulphides or even sulphide-poor assemblages. Most gold skarns have low metal ratios (Cu/Au <2000; Cu/Ag <1000; Zn/Au <100, Ag/Au <1) compared to other types of skarns. The oxidation state of the hydrothermal fluids and the oxidizing or reducing capacity of the hostrocks influences the skarn mineralogy and metal chemistry.

"New ore in Carlin trend has come largely from the discovery of high-grade (>6 g.t⁻¹) refractory deposits."

"Reduced" gold skarns are marked by low garnet/pyroxene and pyrite/pyrrhotite ratios and the presence of hedenbergitic pyroxene and Fe-rich biotite. Associated intrusions have low Fe₂O₃/FeO ratios and the ore bodies

are developed distal to plutons, in the outer parts of pyroxene-rich exoskarn envelopes (Fig. 1). Examples include Nickel Plate (BC), Fortitude (Nevada) and Buckhorn Mountain (Washington State). Oxidized gold skarns are characterized by

high garnet/pyroxene and pyrite/pyrrhotite ratios, and by the presence of diopside pyroxene, pyrite, magnetite and hematite. Ore bodies tend to form proximal to intrusions. Examples include Nambija (Ecuador) and McCoy (Nevada).

Newmont Exploration Limited geologists David Groves and Mac Jackson provided updates on the **Carlin trend**, a 60-kilometre long belt of sedimentary-hosted gold deposits in Nevada with a total current resource of 3100 tonnes of gold. Near-surface oxidation has rendered many of the deposits amenable to bulk tonnage mining and heap-leach processing, which has led to the mistaken impression that all deposits in this class are large tonnage and low grade. In recent years new ore has come largely from the discovery of high-grade ($>6 \text{ g}\cdot\text{t}^{-1}$) refractory deposits. The Hardie Footwall deposit is a stratigraphically controlled, downdip extension of the original Carlin oxide-gold deposit. The deposit contains a drill-indicated, geologic resource of 1,315,000 tonnes grading $16 \text{ g}\cdot\text{t}^{-1}$ Au. The West Leeville deposit is another stratigraphically controlled deposit located 2 km north of the Carlin mine with drill-indicated reserves of 5.4 million tonnes grading $14.7 \text{ g}\cdot\text{t}^{-1}$ Au. As well, there are breccia bodies, such as Deep Star, Deep Post and Purple Vein, that are located close to the Goldstrike intrusion at the northern end of the Carlin trend. Deep Star has a drill-indicated, geologic resource of 797,000 tonnes at a grade of $32 \text{ g}\cdot\text{t}^{-1}$ Au. The deposit is located between steeply dipping strands of the Genesis fault zone at depths of 350 m to 500 m and, in plan, measures only 75 m by 100 m. These new deposits show significant variations from the original "Carlin-type" model, which exploration geologists should keep in mind.

The potential to find **Carlin-type deposits in Canada** was addressed by Howard Poulsen (GSC, Ottawa). He noted that the geological and genetic models for Carlin-type deposits (Fig. 2) continue to evolve, in part because for many of the deposits the primary features of hypogene ores are obscured by oxidation. The hypogene aspects of these deposits are the most relevant to Canadian exploration. Western Canada is one area that has exploration potential because of some of the obvious geological similarities with central Nevada. For example, the Paleozoic stratigraphy of the Roberts Mountains Allochthon of Nevada is correlative with that of the Kootenay Arc and Selwyn Basin in Canada, and that of the Golconda

Allochthon is correlative with Slide Mountain rocks. Important metallogenetic similarities to the Carlin trend are the presence of sedex barite deposits (Selwyn Basin) and of vein and manto-type Ag-Pb-Zn mineralization (East Kootenay, Cassiar, Keno Hill).

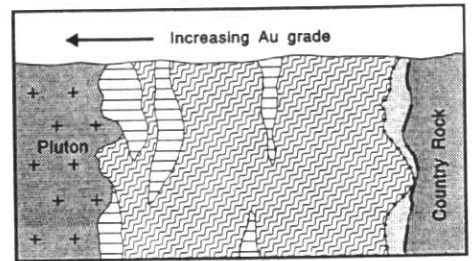
Odin Christensen of Newmont Exploration Ltd. reviewed examples of **Carlin-type deposits from the western Pacific region**, including the Mesel deposit, Indonesia, deposits in southwestern China, and the Bau District in Malaysia. The Mesel and Bau deposits are located in sedimentary sequences within volcanic arcs, clearly a different environment than Nevada. At Mesel, the gold mineralization is hosted by a Middle Miocene limestone immediately beneath and adjacent to an andesitic intrusion. The mineralization, limestone and intrusion all formed between 13-11 Ma. Mesel has mineable reserves of 8.77 million tonnes at an average grade of $7.10 \text{ g}\cdot\text{t}^{-1}$ Au. The Chinese deposits include Banqi, Getang, Lannigou and others hosted by Permian to Triassic rocks. There are no known igneous rocks in the districts. Orebodies occur as stratabound deposits within carbonates, along faults, and along contacts between carbonate and siliciclastic units.

INTRUSION-RELATED GOLD

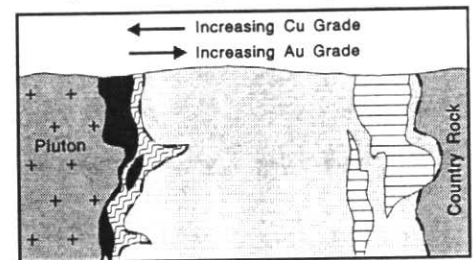
Jacob Margolis of Home-stake Mining Company reviewed the gold and copper deposits of the northern **Sulphurets district**, located 60 km northwest of Stew-

art, British Columbia. These deposits span a spectrum from porphyry to epithermal environments. During the emplacement of the initial porphyry Cu-Au mineralization, quartz stockworks with chalcopyrite containing electrum, such as the Mitchell deposit (~ 200 million tonnes grading 0.2% Cu and $0.857 \text{ g}\cdot\text{t}^{-1}$ Au), developed at higher levels within the volcanic and intrusive rocks. An initial stage of phyllic alteration

Garnet-rich ("oxidized") Au Skarns



Pyroxene-rich ("reduced") Au Skarns



Legend for Figure 1:
 Garnet-rich skarn (wavy pattern)
 Pyroxene-rich skarn (dotted pattern)
 Copper-rich mineralization (solid black)
 Gold-rich mineralization (hatched pattern)

Figure 1 Schematic sections comparing the main features of "oxidized" and "reduced" gold skarns (from Gerry Ray).

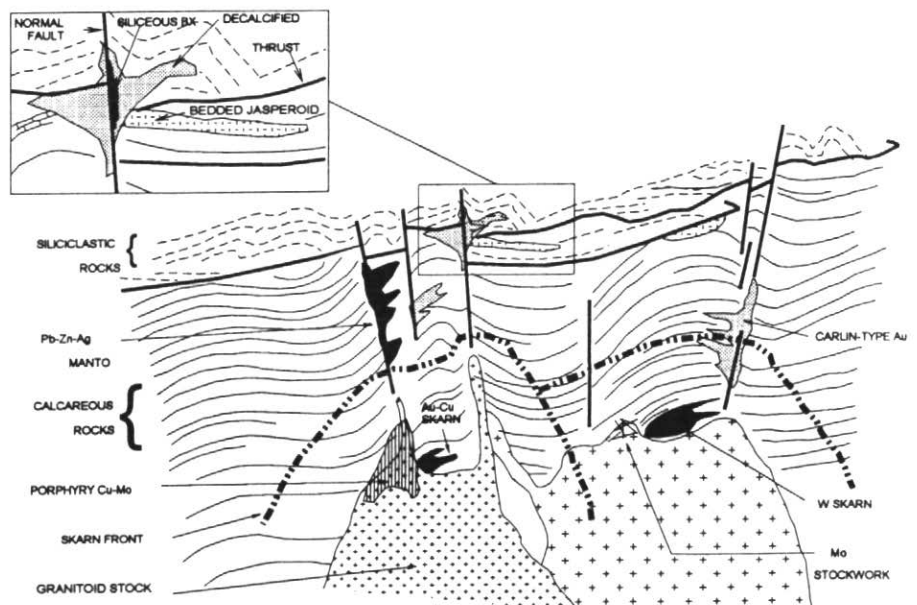


Figure 2 Occurrence model for Carlin-type deposits (from Howard Poulsen). Adapted from Sillitoe and Bonham (1990, *Geology*, v. 18, p. 157-161), and Berger and Bagby (1991, in Foster, R.P., ed., *Gold Metallogeny and Exploration*: Blackie, Glasgow and London, UK, p. 210-248).

hosting quartz–molybdenite veins was followed by argillic alteration and a final stage of precious metal-rich epithermal systems developed in the volcanic rocks. These epithermal systems consist of quartz–barite veins containing galena–sphalerite–tetrahedrite–pyrargyrite–gold–acanthite (West Zone) and a low-grade,

"Porphyry molybdenum systems can have associated gold."

disseminated auriferous pyrite zone (Snowfield deposit, >8 million tonnes grading 2.7 g·t⁻¹ Au). Margolis concluded by pointing out that porphyry molybdenum systems can have associated gold mineralization and that calc-alkaline intrusives are as prospective for the yellow metal as alkaline suites.

Dani Alldrick and Trygve Höy (BCGS) described a newly differentiated deposit type, **intrusion-related gold-bearing pyrrhotite veins**. The veins are commonly emplaced in an echelon fracture sets around the periphery of subvolcanic plutons in a transitional setting between porphyry and epithermal systems (Fig. 3). These veins are composed of massive fine-grained pyrrhotite and pyrite and/or massive bull quartz with minor calcite. They are attractive exploration targets because of their high grades, continuity due to strong structural controls, and predictable relationships to intrusions and genetically related deposits. Examples include

the Scottie Gold, Snip, Johnny Mountain, Le Roi, War Eagle and Centre Star mines in British Columbia and some of the main veins (Copper Rand, Portage, Merrill, Main and Chib-Kayrand mines) in the Chibougamau Camp, Quebec. The Snip and Johnny Mountain deposits were described in a presentation by David Rhys, consulting geologist. High-grade gold–silver mineralization occurs in thick, semi-tabular pyrite+pyrrhotite stockworks with intense sericitic alteration.

Rhys also described the **Red Mountain** precious metal deposit, located 15 kilometres east of Stewart, British Columbia, which occurs within several zones within a folded sequence of Mesozoic sedimentary rocks, volcanoclastic and intrusive rocks. Several shallow-dipping alteration zones are developed sequentially above a propylitic zone with a quartz stockwork

"High-grade gold-silver mineralization occurs in thick, semi-tabular pyrite±pyrrhotite stockworks with intense sericitic alteration."

carrying molybdenum. These include sericite–quartz–pyrite alteration, chlorite–K–feldspar–sericite–titanite alteration with disseminated and vein pyrrhotite and brown to black tourmaline veins and K–feldspar–pyrite–titanite–actinolite alteration. Anomalous gold (>0.3 g·t⁻¹) mineralization is developed at the transition from pyrite to

pyrrhotite dominant alteration over a >1 km² area. Within this anomalous zone, high-grade gold–silver mineralization (3–20 g·t⁻¹ Au) occurs in 5–29 m thick, semi-tabular pyrite+pyrrhotite stockworks (1992 resource of 2.5 million tonnes grading 12.8 g·t⁻¹ Au and 38.1 g·t⁻¹ Ag) with intense sericitic alteration and surrounding disseminated sphalerite+pyrrhotite. The alteration zoning, molybdenum–copper quartz stockworks, extensive K–silicate and tourmaline alteration, and the relationship with a hypabyssal porphyritic intrusion show similarities to many porphyry systems.

FORT KNOX-TYPE GOLD MINERALIZATION

Jim Mortensen of The University of British Columbia described the host **Tombstone Plutonic Suite**, a lithologically diverse belt of mid-Cretaceous plutons that intrude miogeoclinal strata. The belt has been offset along the Tintina Fault and extends west to the Fairbanks mining district in Alaska. Mineralization spatially associated with Tombstone Plutonic Suite ranges from intrusion-hosted porphyry Au–(Bi–W–Mo) deposits (e.g., Fort Knox, Dublin Gulch, Emerald Lake, Pukelman), to intrusion- and wallrock-hosted Au-bearing quartz–arsenopyrite veins and breccias (e.g., Ryan Lode, Dublin Gulch), to proximal W–(Au) skarns (e.g., Mar/Ray Gulch, Scheelite Dome, Rhosgobel, Tungsten Hill), to distal (?) Au- and/or Sb-rich replacement/manto deposits (e.g., Scraf-ford, Wayne). Relatively late, lower-temperature, Ag- and base metal-rich veins locally both overprint the intrusion-centred systems (e.g., Dublin Gulch) and occur distal to the intrusion (e.g., Keno Hill, Peso, Rex, Wayne). Intrusion- and country rock-hosted, possibly Carlin-like, disseminated/stockwork Au–As–Sb mineralization is also developed in several areas (e.g., Brewery Creek, Neve/Brick, True North).

The **Dublin Gulch deposit**, located near Mayo in the Yukon Territory, was discussed by Hans Smit of New Millennium Mining Limited. The deposit area is underlain by Late Proterozoic to Early Cambrian Hyland Group clastic rocks of the Selwyn Basin. These rocks have been deformed by Early Cretaceous thrusting and later regional scale gentle folding. Subsequent to this deformation, the clastic rocks were intruded by Cretaceous Tombstone Suite intrusions, including the Dublin Gulch stock. Fort Knox-type mineralization within the stock consists of sheeted, low-sulphide gold quartz veins with very limited wallrock alteration. Ore

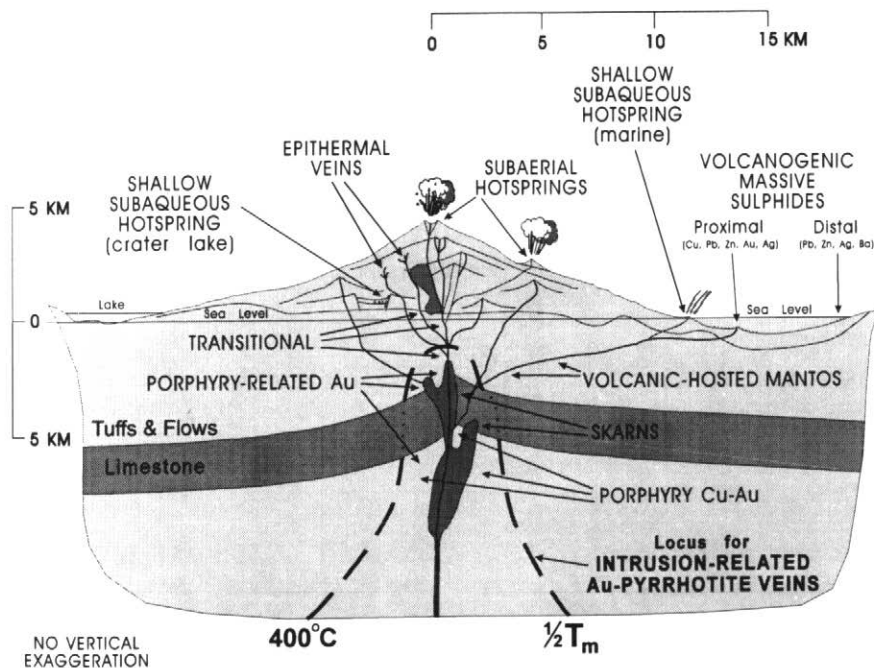


Figure 3 Island arc model for intrusion-related gold-bearing pyrrhotite veins (from Dani Alldrick and Trygve Höy).

veins grade into veins possessing distinct sericite selvages, lower gold and bismuth contents, and minor arsenopyrite, pyrite and pyrrhotite. Gold occurs as native gold, associated with bismuth minerals or less commonly encapsulated in arsenopyrite. Individual veins are thin and grade in the range of 10-30 g·t⁻¹ Au. However, the ore zone, encompassing both the vein and granodiorite host material, typically grades between 0.8 to 2.0 g·t⁻¹. In 1995, drilling defined a mineable reserve of 36 million tonnes grading 0.92 g·t⁻¹ Au.

"Dublin Gulch ore typically grades between 0.8 to 2.0 g·t⁻¹ gold."

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OPHIOLITE-HOSTED MESOTHERMAL GOLD-QUARTZ VEINS

A tectonic model describing the origin of **mesothermal gold-quartz veins** associated with ophiolitic sequences was presented by Chris Ash (BCGS). He pointed out that the deposits are hosted within, or marginal to, collisional suture zones where large volumes of CO₂-rich fluids have been channeled to produce carbonate-altered ultramafic rocks or "listwanites." These veins appear to form during periods of metamorphism and partial melting due to tectonic crustal thickening in response to arc-continent collision. They are typically associated with late syn-collisional intermediate to felsic magmatism. Mineralizing hydrothermal fluids are interpreted to be derived, at least in part, from tectonically thickened, hydrated oceanic lithosphere that undergoes metamorphic dehydration and partial melting during and after faulting.

TRANSITIONS FROM PORPHYRY TO EPITHERMAL ENVIRONMENTS

Andre Panteleyev (BCGS) pointed out that porphyry and epithermal characteristics may blend in volcano-plutonic arcs with "telescoped" hydrothermal systems. This commonly occurs as an overprinting of earlier mineralization by lower temperature, more oxidized, advanced argillic alteration assemblages. The telescoping may be due to rapid erosion of volcanic edifices by tropical weathering or glacial erosion, swift degradation of hydrothermally damaged volcanic structures, or cataclysmic decompressional events such as gravitational sector collapse. Transitional mineralization is a closely related variant of high-sulphidation deposits as the hydrothermal fluids involved are de-

derived from the same, or similar intrusions. The **transitional deposits** can have similar advanced argillic or acid sulphate alteration and mineralization (covellite and tennantite-tetrahedrite, enargite-luzonite), but these minerals are generally subordinate and restricted to late, localized acidic fluid flow. For transitional deposits, the dominant alteration is quartz-sericite-pyrite derived from relatively high temperature and pressure and highly saline solutions that are more akin to those that form porphyry deposits. Pyrite is the dominant sulphide mineral; chalcopyrite, tetrahedrite/tennantite are common; and enargite is rare or absent. The Kori Kollo mine, Bolivia and Equity Silver mine, British Columbia exemplify this deposit type.

OLYMPIC DAM-TYPE DEPOSITS

Olympic Dam-type iron oxide deposits form from volatile-rich igneous-hydrothermal systems. Olympic Dam-type iron oxide deposits currently attract exploration attention for their associated copper, gold, uranium and LREE.

"Olympic Dam-type iron oxide deposits form from volatile-rich igneous-hydrothermal systems."

Murray Hitzman of the Colorado School of Mines pointed out they constitute a distinct class of ore deposits characterized by iron-rich, low-titanium rocks formed in extensional tectonic environments. They form primarily in cratonic or continental margin environments and are expressions of deeper-seated, volatile-rich igneous-hydrothermal systems, tapped by deep crustal structures. The majority of known deposits, particularly the larger examples, are found within Early to mid-Proterozoic host rocks (1.1-1.8 Ga). Most districts occur along major structural zones and many of the deposits are elongated parallel to local structural trends. The ores are generally dominated by iron oxides, either magnetite or hematite. The host rocks are generally intensely altered with a general trend from sodic alteration at deep levels, to potassic alteration at intermediate to shallow levels, to sericitic alteration and silicification at very shallow levels. Locally, the host rocks are intensely Fe-metasomatized. Individual deposits occur both as strongly discordant veins or breccias and massive concordant bodies. Current exploration interest is focused on copper- and gold-bearing occurrences in Australia and the Yukon.

Michael Etheridge provided a descrip-

tion of an Olympic Dam-type deposit, the **Ernest Henry** that is located within early Proterozoic rocks of the eastern Mount Isa Inlier, Australia. The deposit contains 167 million tonnes at 1.1% Cu and 0.54 g·t⁻¹ Au. Osborne (~15 million tonnes at 3.0% Cu+1.3 g·t⁻¹ Au), Selwyn (~5 million tonnes at 1.0% Cu+5.0 g·t⁻¹ Au), Eloise (~3 million tonnes at 5.8% Cu+1.5 g·t⁻¹ Au), and Elliot (~2 million tonnes at 3.0% Cu and 1.3 g·t⁻¹ Au) are other deposits that are being mined in the region. Most of the deposits are associated with "ironstones" and coincide with moderate-to-large amplitude magnetic anomalies. Etheridge pointed out that the key factors in developing exploration models for this type of deposit are the granitoid and structural associations. A genetic link between the Cu-Au deposits and the I-type granitoids (dominantly granodiorite) of the Williams Batholith is well established. As well, strong structural control is evident in most deposits of this type. The most common structural association is with dilational breccias on ductile to brittle shear/fault zones of a range of orientations.

SEDIMENT-HOSTED DEPOSITS

Sediment-hosted stratiform copper deposits include some of the richest and largest copper deposits in the world. Rod Kirkham (GSC, Vancouver) explained that they are also an important source of silver and cobalt. Most sediment-hosted stratiform copper deposits form during diagenesis of sediments deposited in low-

latitude arid and semi-arid areas. A variety of processes are involved in different districts, but metals are characteristically deposited at redox boundaries where oxic, evaporite-derived brines containing metals extracted from redbed aquifers encounter reducing conditions. The reducing environments are either those with stratigraphically controlled fixed reductants (Kupferschiefer) or those with mobile reductants, such as H₂S-bearing waters and hydrocarbons (Dzhezkazgan). Occurrences are known in Proterozoic sequences (e.g., Grinnell Formation, Montana and Redstone River area, Mackenzie mountains) in the eastern Cordillera. Possible occurrences also are found in Triassic and Early Jurassic sequences in the western Cordillera. Kirkham pointed out that these occurrences offer signifi-

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cant exploration potential in British Columbia and the Yukon.

The alteration, and its relationship to host lithologies of **sedex Pb-Zn deposits** was described by Bob Turner (GSC, Vancouver). Deposits in siliceous rocks tend to have poorly developed alteration zones; silicification is dominant and ferroan carbonate alteration (Fig. 4) can be important (e.g., Tom-Jason, Yukon; Cirque and Driftpile, BC). Calcareous sediment-hosted deposits tend to have more extensive alteration which includes silicification, dolomite or ferroan carbonate alteration (e.g., Sheep Creek, Montana; Isa and Century, Australia). Feldspathic sediment-hosted deposits display the best developed alteration zones and most diverse alteration assemblages. These include potassic (muscovite, k-spar), tourmalinite, chloritic and albitic assemblages (e.g., Sullivan, BC; Broken Hill and Can-

nington, Australia; Zincgruven, Sweden). These alteration assemblages are similar to alteration associated with feldspathic sediment-hosted Besshi deposits and modern sedimented rift-hosted deposits. Since host lithologies reflect tectonic controls on the sedimentation, the style of alteration typically varies between the syn-rift and rift sag phases. Syn-rift stratiform deposits occur in feldspathic clastic rocks associated with high heat flow and magmatism (e.g., Sullivan, Broken Hill, Cannington, Aggenays-Gamsberg), while rift-sag stratiform deposits typically occur in siliceous or calcareous strata and are associated with lower heat flow extensional basins (e.g., Mt. Isa, Hilton, Century, McArthur River, Tom-Jason, Cirque, Rammelsberg, Meggen).

Wayne Goodfellow (GSC, Ottawa) described unusual **NI-Mo-PGE sulphide occurrences**, stratiform mineralization

hosted by carbonaceous shale and chert within Phanerozoic sedimentary basins. The two most important districts occur in Middle Devonian and earliest Cambrian

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basinal facies in the Yukon and southern China, respectively. The deposits are typically thin (<20 cm) but extend over distances of hundreds of kilometres. The sulphides consist of combinations of pyrite, marcasite, vaesite, gersdorffite, millerite, sphalerite, wurtzite,

molybdenite, chalcopyrite, and tennantite. These deposits have high metal grades, including up to 10% Ni, 2% Zn, 4% Mo, 50 g·t⁻¹ Ag, and 0.7 g·t⁻¹ Au, but no accumulations that are thick enough to mine in a free market economy have been found. Goodfellow advocated that this unusual mineral assemblage formed following the impact and volatilization of a major chondritic meteorite. This led to the raining of Ni-PGE-rich quenched droplets to the sea floor of an anoxic ocean. The association of Ni-PGE mineralization with high organic-matter contents and related carbonate concretions could reflect higher rates of organic matter sedimentation following a related mass extinction event. In Spokane, Raymond Coveney Jr. of the University of Missouri at Kansas City summarized some of the characteristics of the Chinese deposits (marine platform depositional setting, polymictic textures, fluid inclusions) that support a hydrothermal origin for these deposits. Certainly if economic deposits are to be found, a hydrothermal genesis seems more likely to produce thicker local accumulations.

Godfrey Walton of Hemlo Gold Mines Inc. discussed **Irish-style carbonate-hosted Pb-Zn deposits**. He pointed out that strong structural controls are documented in the deposits, mineralization is stratabound with some local sections that cross cut stratigraphy, and replacement and breccia mineralization textures are common. Isotopes indicate two fluids were involved in the process, one hydrothermal and the other Carboniferous sea water. Walton argued that the deposits formed primarily below the sea floor and are diagenetic to epigenetic in origin. There is evidence that an early portion of the min-

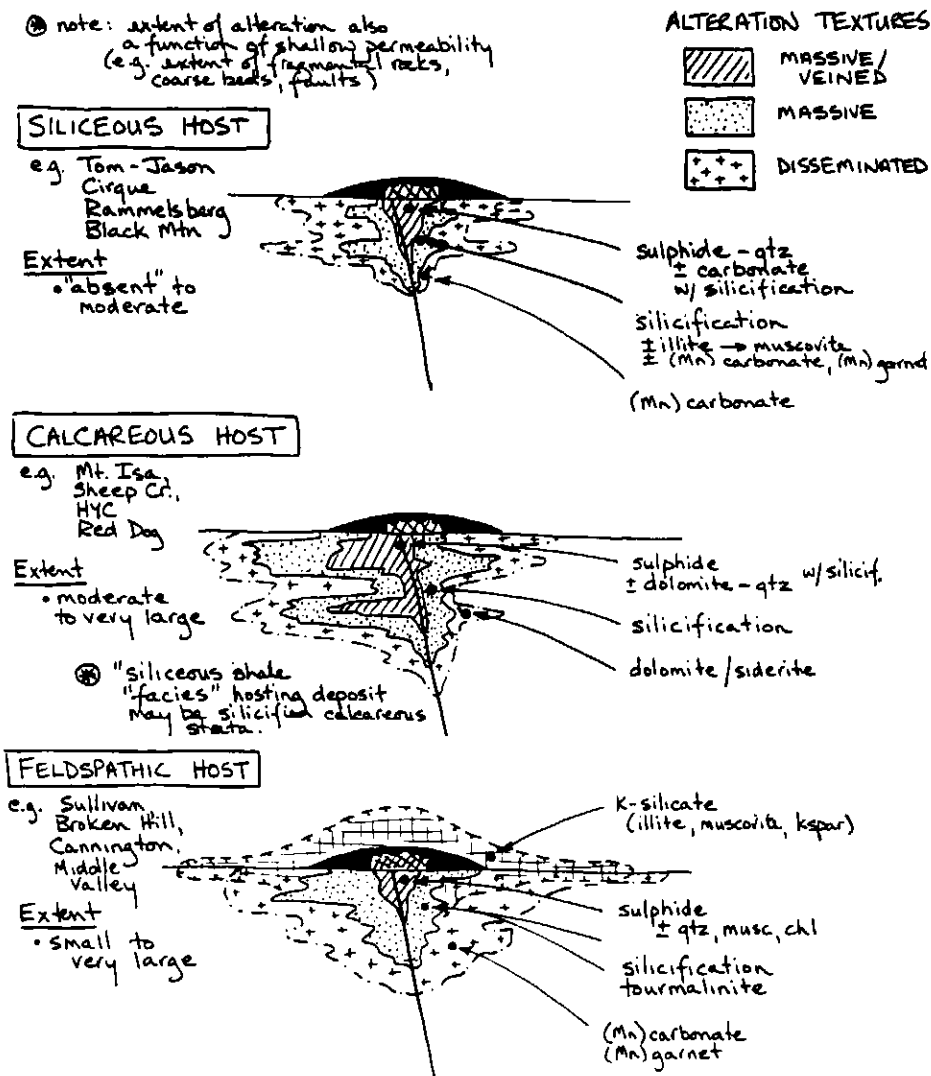


Figure 4 Alteration styles associated with sedex deposits and their relationship to host lithologies (from Bob Turner).

eralization formed on the sea floor, while the bulk of the mineralization is later. Therefore, Irish deposits have some characteristics in common with both sedex and MVT deposit types. He closed by endorsing the Cordillera as a prospective region to explore for Irish-type carbonate-hosted Pb-Zn deposits.

Hugh Abercrombie (GSC, Calgary) spoke about the discovery of **microscopic disseminated Au-Ag-Cu** (Prairie-type gold) in basement and sedimentary rocks of the Western Canada Sedimentary Basin. These recently recognized occurrences consist of low-temperature, native and intergrown or alloyed Au-Ag-Cu and associated alteration, including native S and pyrite. The metals and alteration are inferred to be related to metal transport in oxygenated brines originating in halite evaporites. Downward, density-driven flow of these brines into red bed-evaporite sequences and fractured Precambrian basement, followed by up-dip migration and eventual discharge at the eastern margin of the basin provides the mechanism for mobilization and transport of metals. Microbially mediated redox reactions involving coupled oxidation of organic material and hydrocarbons and reduction of sulphate has produced widespread occurrences of native sulphur and may have localized deposition of gold and other metals by controlling redox conditions. Although no economic grades have been reported, these occurrences could ultimately lead to the identification of a new deposit type.

George Simandl of the BCGS described a number of strata-bound, sparry magnesite deposits hosted by sedimentary rocks of Precambrian to Cambrian age from southeastern British Columbia, including the Mount Brussilof mine. The mineralogy is primarily sparry, pinolitic and zebra-textured magnesite with quartz/chert and dolomite impurities. These deposits form either by replacement of dolomitized, permeable carbonates due to interaction with a metasomatic fluid, or by diagenetic recrystallization of a magnesia-rich protolith of chemical, possibly evaporitic, origin.

SHALLOW SUBMARINE VOLCANOGENIC DEPOSITS

Mark Hannington (GSC, Ottawa) reviewed modern, **shallow submarine hot springs** and their similarities with older volcanogenic gold deposits. Pacific island arc volcanoes host extensive hot spring and fumarolic activity and locally have pro-

duced large porphyry copper and epithermal gold deposits (e.g., 40 million ounces gold deposit at Lihir). Within these arcs the submarine volcanoes forming at water depths of less than 1500 m also host mineralization, including gold-rich polymetallic massive sulfides, gold-barite deposits, epithermal vein- and disseminated-stockwork mineralization, and pyritiferous muds and pyrite replacement deposits in volcanoclastic sediments. These occurrences constitute a new type of submarine mineral deposit that resembles deep-sea metalliferous deposits but also has distinctive epithermal characteristics.

These deposits occur in a volcano-tectonic setting that is relatively under-explored in older volcanic sequences, although the Eskay Creek and Selbaie mines have highlighted the potential.

Tina Roth of Homestake Canada Ltd. described the high-grade **Eskay Creek deposit** located in northwest British Columbia. The bulk of the sulphide and sulphosalt ore is hosted in the stratiform 21B zone. Production commenced in January 1995 with a proven and probable mining reserve of 1.08 million tonnes grad-

ing 65.5 g·t⁻¹ Au and 2 931 g·t⁻¹ Ag. The 21B zone exhibits many characteristics analogous to Kuroko-type volcanogenic massive sulphide (VMS) deposits, but has a suite of elements and high precious metal content more characteristic of epithermal systems.

John Thompson (MDRU) discussed **high-sulphidation VMS deposits** that formed from hydrothermal systems dominated by magmatic water that were active in submarine settings (Fig. 5). High-sulphidation VMS deposits contain abundant pyrite and several of the following: enargite, chalcocite (hypogene), covellite, bornite, tennantite and tetrahedrite. Alteration associated with high-sulphidation VMS deposits is characterized by the presence of quartz and alunite with important barite, sulphur, kaolinite, pyrophyllite and diaspore. These mineralogical characteristics are similar to epithermal high-sulphidation deposits; however, the sea-floor setting for the VMS type influences the geometry of the deposits, the outer and upper alteration mineralogy (reflecting the involvement of seawater), and the stratigraphic control on deposits. The gold-rich polymetallic massive sulphides on the Palinuro seamount and gold-rich barite-silica-sulphide precipitates at the Hine Hina hydrothermal field in the Lau Basin are two possible modern examples. Older Phanerozoic examples occur in the Green Tuff belt of Japan, on Wetar Island

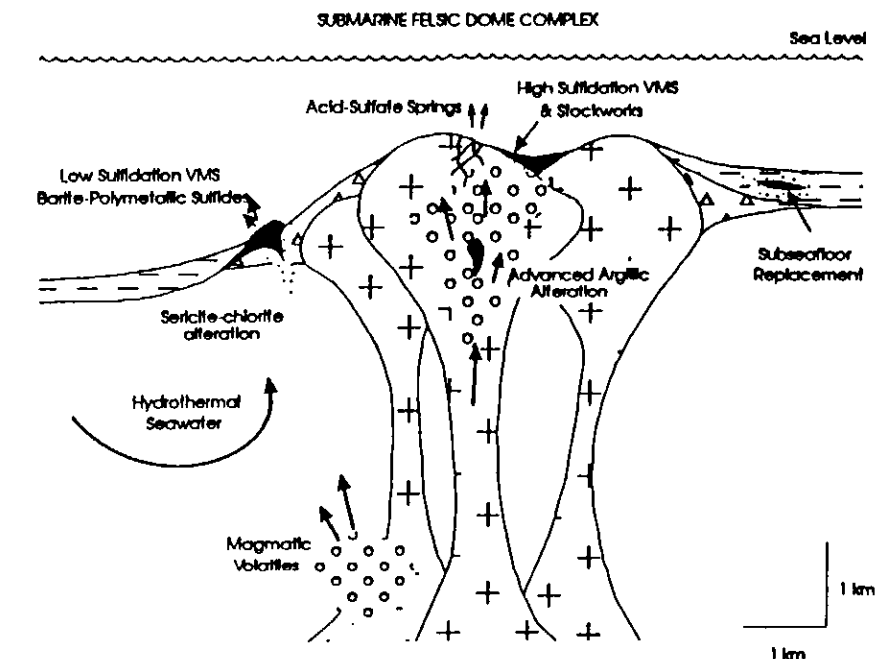


Figure 5 Schematic section of a high-sulphidation VMS environment in relation to a felsic dome complex, from John Thompson's presentation. Now published in Sillitoe, R.H., Hannington, M.D. and Thompson, J.F.H., *Economic Geology*, 1996, v. 91, p. 204-212.

in Indonesia, and in the Pontid belt of northeastern Turkey. Precambrian high-sulphidation VMS deposits may also exist, although deformation and metamorphism hinder the interpretation of their mineralogy and geometry.

Mike Rasmussen of Echo Bay Minerals Company described the **Lamefoot gold mine** located in the Republic Graben of northeastern Washington. The crudely stratiform, magnetite-pyrite-chalcopyrite-pyrrhotite ore body occurs at a major turbidite/limestone contact, immediately above felsic tuffaceous sediments, within the Permian Attwood Formation. The magnetite occurs with variably banded assemblages of magnetite and ferruginous quartz and siderite. The massive sulphides occur mostly at the northern end of the deposit and are volumetrically minor. Gold is also recovered from sulphide-quartz veinlets in the volcanoclastic footwall and a quartz breccia with a matrix of dark silica, calcite, chlorite and sulphides at the base of the magnetite-sulphide lens. The magnetite-sulphide lens is similar to some Besshi-type VMS deposits and also exhibits some replacement textures that might be similar to the Tynagh deposit in Ireland. Rasmussen suggested the veinlets and breccia are related to a younger mesothermal vein event (Jurassic?).

WRANGELLIA: A POTENTIALLY IMPORTANT NI-CU-PGE METALLOGENIC TERRANE

Larry Hulbert (GSC, Ottawa) described Triassic mafic-ultramafic intrusive complexes on the eastern margin of Wrangellia that can be traced along strike for at least 600 km from east-central Alaska to northwestern British Columbia. These sill-like intrusive centres acted as subvolcanic magma chambers that fed the thick oceanic plateau basalts of the Nikolai Group. The intrusions host numerous **NI-CU-PGE** occurrences and the Wellgreen mine. Although the parental magmas that gave rise to these intrusive and extrusive rocks are clearly of a tholeiitic origin, the intrusive complexes have striking similarities to Archean and Proterozoic komatiitic ultra-mafic bodies that host world-class nickel sulphide deposits.

CONCLUDING REMARKS

Both workshops attracted large audiences of industry geologists who were looking for updates on deposit models to apply in their exploration programs. Collectively, the presentations emphasized the impor-

tant fact that mines continue to be found in new geological or geographic settings. Another short course titled "**Metallogeny of Volcanic Arcs**" is being organized by the BCGS and will be held in Vancouver in conjunction with the 1998 Cordilleran Roundup and Pathways '98. For more information on mineral deposit models, readers may wish to consult some of the references listed below.

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