

GSCHIS-A011.pdf

Author: Gordon A. Gross

Title: Reflections on the iron project 570029: Iron Formation, Metalliferous Sediments, Volcanology and Plate Tectonics

Date of the version: February 14, 2009

Number of pages in document: 21 pages

Related documents: None

Author Biography:

Following service in the RCAF (1943-45) that included operational flights with RAF Bomber Command, Gordon Gross received a B.A. (1950) and an M.A. (1952) in Geology at Queen's University, Kingston and a Ph.D. (1955) at the University of Wisconsin. He was Assistant Professor of Mineralogy and Petrology at the University of Cincinnati (1955-56) and joined the Geology of Mineral Deposits Section of the Geological Survey of Canada in 1956. In 1957 he was assigned to what became a career long project on the Geology of Iron Deposits in Canada until his retirement in 1989 and as an Emeritus Scientist since 1993. During his career, he carried out scientific exchange work on ferrous metal resources in many parts of the world, including USSR, China, India, Europe, Africa, and North and South America, and completed a number of assignments for the United Nations, including member of the panel for the United Nations Survey of World Iron Ore Resources, 1966-67.

He was Head, Geology of Mineral Deposits Section, GSC from 1967-1972, and was appointed Commonwealth Geological Liaison Officer and Executive Secretary, Commonwealth Committee for Mineral Resources and Geology in London, UK, 1972-74. He is the author of more than 100 books and papers on the geology of ferrous metal resources, and his awards include the Leonard Medal from the Engineering Institute of Canada (1965), Public Service of Canada Merit Award (1971), and the Queen's Golden Jubilee Medal (2002).

**Reflections on the iron project 570029:
Iron Formation, Metalliferous Sediments, Volcanology and Plate Tectonics
by Gordon A. Gross
2009**

Part I - Introduction

This paper is a brief review of the history of a special continuing project assignment started in 1957 to carry out metallogenic and resource appraisal studies on Canada's iron ore resources. It outlines some of the progress and achievements in the project in an organization that has had concerns throughout its history with its mandate to do research on the metallogeny of mineral resources. It refers to some of the achievements, problems and difficulties encountered regarding the history of policy and directives for work on the geology of mineral resources found in a report "Mineral Deposit, Metallogeny and Related Studies at the Geological Survey of Canada 1984", in A Brief Submitted to the Canadian Geoscience Council Advisory Committee on Mineral Deposits Research at the Geological Survey of Canada, by Economic Geology and Mineralogy Division, August 1984.

The title chosen for this paper seems appropriate because circumstances have directed attention to these related topics throughout most of my career in geology. I was made aware of them in undergraduate courses at Queen's University and remember well the visits of Professor Tuzo Wilson from Toronto and his enthusiastic presentation of plate tectonic concepts. Professor Ed. Hawley made us aware of the existing diversity of concepts and theories for the origin of iron formation sediments, and various aspects of volcanology were introduced in courses in petrology, stratigraphy, historical and economic geology. Nearly four years of graduate work at the University of Wisconsin with Professor Tyler were focused on research on metalliferous sediments. Few people at the time expected that concepts from these topics would one day be integrated in a genetic model for iron formation and stratafer metaliferous sediments, the source rocks for major resources of iron, manganese, rare earth elements, copper, zinc, lead, gold, silver and other elements required by industries throughout the modern world.

As an undergraduate student I did not expect to become involved in a project in which the understanding of the origin of metalliferous sediments would be of special interest in research throughout my professional career. After service in Bomber Command in World War II I did not anticipate training that would lead to long term involvement in Economic Geology and an opportunity to contribute to the exploration for and evaluation of a major part of the iron ore resources of Canada and the world, and other mineral resources essential for modern industry and our way of life.

I was pleased to be able to return to Canada and join the Mineral Deposits Division in the Geological Survey of Canada in June of 1956. In previous years I had spent five field seasons with mining companies in Quebec and Labrador in the exploration and evaluation of iron formation resources, a year with International Nickel Company supervising deep diamond drilling in exploration of the Sudbury Basin rocks, and three semesters teaching mineralogy and petrology at the University of Cincinnati, after receiving my Ph.D. degree at the University of Wisconsin in 1955.

My first assignment with the Geological Survey of Canada in 1956 was to examine the uranium deposits in the Maritime Provinces that had been reported by prospectors as required by

Government Regulations. On returning to Ottawa in September I was directed to report on my field work and because of a change in policy further research work on uranium deposits was to be cancelled or restricted. This of course was disappointing as the opportunity to do research on mineral deposits had provided special incentive for joining The Geological Survey of Canada.

I was assured that I would be given a new assignment as soon as program objectives for the next year were approved. It was evident that major work on the geology of nickel, iron and other mineral deposits was being considered and since I had more experience with the geology of nickel deposits than others in the Mineral Deposits Section I was an obvious candidate to lead a project on the nickel resources in Canada. I was more interested in doing research on the iron formations than on nickel deposits because there was interesting territory to be explored and probably the mining companies were more interested in having government sponsored research on the iron ore resources of Canada than on nickel or other metals.

During my first winter in Ottawa I spent time at home compiling a map showing data that I had assembled on the distribution of iron formation throughout the belt of folded and metamorphosed rocks being referred to as the Labrador Trough. When I finally received confirmation that I was being assigned to a new special project on iron deposits in Canada I was able to present this map showing the general distribution of iron formation in the Labrador-Quebec fold belt which the Survey published as Special Paper 60-30. This region in Canada was receiving special attention as the iron ore companies were anxious to find and develop iron ore resources within the continent and they remembered the sinking of many ore carriers by enemy action during World War II.

Major changes were in progress in the iron ore industry in North America in the years following World War II. The naturally enriched high grade iron ore deposits in the Mesabi Iron Range in Minnesota were essentially mined out, having provided iron for the steel industries during the war. The steel industries were converting to the use of ore concentrates produced in the beneficiation or concentration of the iron oxide minerals in the low grade iron formations or taconite beds. Canada had exceptionally large resources of iron formation to be evaluated as taconite ore, not only iron formations comparable to that available in the iron ranges in the United States, but most of the iron formation or metataconite in Canada was metamorphosed and coarsely crystalline with larger mineral grain size that provided specific advantages for concentration and beneficiation of the Canadian resources. It was a time of change that could provide important opportunity for Canada in developing a large new iron mining industry and all the industrial and transportation facilities associated with it. The Geological Survey of Canada could make an important contribution in locating iron ranges, classification and defining the properties of iron ore that were important in their processing and assessment. .

I believe that this kind of contribution by the Geological Survey of Canada was anticipated when I received instructions in mid April which stated:

“Your field work for the summer of 1957 will be to begin a study of the geology of iron deposits of Canada. Although this study should be as comprehensive as practicable, and is expected to require several field seasons, the large number of known iron occurrences require that a selection be made of those that seem of greatest economic importance at the present, those that may provide large reserves for the future, and others that represent additional geological types or that promise to elucidate pertinent geological problems.

Particular attention should be paid to the economic geology and mode of origin of the deposits, with a view to providing data useful in prospecting for, and evaluating and exploring, iron deposits.

Because of the current interest in deposits in New Quebec and Labrador, most of the 1957 season should be devoted to deposits in these areas, but the relatively short season there will permit some time to be devoted to deposits in other parts of Eastern Canada. Signed by C.S. Lord, Chief Geologist. ”

I was surprised and delighted with the assignment and terms of reference for this new project. The scope of work set forth for federal geologists in the work on uranium deposits left no doubt that mineral deposit geology was no longer considered to be an exclusive provincial task, and the terms of reference for this new project on the geology of iron deposits was assurance that the Geological Survey of Canada was ready to sponsor work in a national context in mineral deposit geology and metallogeny, or what was widely referred to at the time as economic geology. Having spent five field seasons in exploration and evaluation of iron deposits with industry I was excited about this project assignment and the possibility of being able to contribute to fundamental questions about the origin and tectonic setting of iron formation sediments through time and also to the development of a major part of the mineral industry in Canada. The assignment opened the door for research on the iron formations, their metallogeny, the iron ore that could be recovered from them, and regional assessments of potential ore and resources. The assignment had broad economic implications for Canada and a comprehensive data base on the geology of the iron deposits was essential for making significant contributions in the project to an important part of the geology of Canada.

Obviously the first years of the iron project would enable the development of a data base for project research and resource appraisal. It included data from the literature with locations of iron occurrences, reports of previous work on the iron resources with brief descriptions of their geology, but data available on the iron formation rocks were very limited. The first three field seasons spent in the iron project were oriented to building a data base of information necessary for the broad range of work required in the project and included an overview from field work in eastern Canada, Central Canada mainly in Quebec and Ontario, and in Western Canada in the coastal and southern parts of British Columbia and in parts of Alberta. This overview work would provide data for classification of the types of iron deposits, the locations of iron ranges, data essential for resource appraisals and where work on deposit genesis would be most helpful.

An important part of the data base required for carrying out resource assessment in the assigned project included systematic petrographic study of samples from all of the deposits types, particularly the iron formation lithofacies, but also from the contact metasomatic, skarn, and magnetite deposits hosted in anorthosite and ultramafic rocks in the Grenville Province.

The iron ore industry in North America was being forced to turn to beneficiation and processing of iron formations and taconite resources, and large deposits of iron formation that had a coarse granular texture were being explored in Labrador and Northern Quebec. Other iron ranges were being evaluated in Eastern, Central and Arctic Canada. Specific knowledge of the mineralogy, textures and the development of grain size enlargement during metamorphism in the iron formation deposits was essential for determining their physical properties, amenability to beneficiation and economic evaluation. The systematic study of the petrography of the iron formations initiated in the iron project provided this kind of data and was an essential step

toward recognizing and evaluating iron resources for the future. A paper that demonstrated the significance of metamorphism in the beneficiation of Quebec Iron Ores was acknowledged as a major contribution and step forward in understanding the extensive potential iron ore resources in Canada and the world. The author of this paper, G.A.Gross, was recognized by the Engineering Institute of Canada and awarded the Leonard Medal in 1966.

The new project on the geology of iron deposits was received enthusiastically by the exploration and mining industry and their assistance and advice with field work and data gathering was offered with an interest and frankness beyond expectations. They did not hesitate to provide data from previous exploration work, to share their map data, to discuss ore genesis and I felt a special sense of responsibility in being assigned to such a timely project. It took a lot of time and effort to develop a data base on the iron deposits in Canada that would enable a suitable contribution to mineral resource assessment and evaluation and that would be useful for answering basic questions on iron and manganese resources in Canada of interest to the mining industry, in the Geological Survey and The Department.

The initial stages of developing a data base in the project and research on selected topics in the Iron Project were progressing well and field reconnaissance of deposits in the Yukon, Alberta, Axel Heiberg Island and other sites in the Arctic were included in my annual instructions for 1963. On returning from work on the ironstone sediments in the Peace River area of Alberta in mid August I was badly injured in a head-on collision on a dusty section of road north of Fairview, which terminated my field work for the season. It was a devastating experience but thanks to skilled surgery in reconstructing my broken feet I was able after a few weeks to resume work at my office in Ottawa and to accept an assignment in Asia in Sri Lanka with United Nations starting in April, 1964.

As research and the development of a data base on the iron deposits progressed the scope and magnitude of the project assignment became better understood and a lot of concern developed about adequate facility for managing the collection of representative specimens from hundreds of properties, the files with maps and records of the deposit geology provided by the exploration and mining companies, and facilities for study and synthesis of data. Obviously projects presenting similar requirements for storage and working space had not been attempted previously in the GSC and I had little reason to believe that my seniors and managers in the GSC understood what I was trying to do or appreciated what needed to be done to respond properly and with professional competence to the tasks assigned. Others in the mineral deposit section joined in the request and demands for appropriate laboratory facilities for providing thin sections of rocks, polished sections for the study of opaque and ore minerals and for modern microscope equipment for the study of the mineralogy of the ores of metals. The need for these laboratory facilities did not seem to be understood by all of the senior geologists in the GSC and progress in the development of the work of the mineral deposit geology group was seriously delayed, neglected or even ignored.

Part II - Project and Section Responsibilities

Unexpectedly one morning in 1967 my Division Chief walked into the office and informed me that I had been named Head of the Mineral Deposits Section, effective immediately. I felt uncertain about how I should react to this assignment and the confidence that senior management placed in my work or in my ability to do the Section Head job as well. My predecessor as Head

of The Section, Duncan Whitmore, had often remarked that the Section Head duties should be avoided if at all possible as the management expected that you could look after them on your way to the washroom, and I held great respect for his judgment and realism. If the GSC management didn't want to bother with any suggestions for change or direction then I had to doubt whether they were convinced that reference files and my efforts to build a data base for a part of mineral deposit geology was really necessary for the research work required for the reporting on the geology of mineral deposits and mineral resource potential. The new assignment was not expected to bring any advance in salary and would divert a lot of time from project work, but this seemed to be of little concern and was not being considered by the establishment. I accepted the assignment realizing that some changes were needed in the best interest of all concerned.

Evidently the senior management was expecting to expand the work in economic geology and the Mineral Deposit Section. Retirements of a few of the staff were imminent, and I was expected to provide a plan or proposal for a future program that would provide a database and essential data on mineral resources for Government needs and purposes. Policy guidelines for work on mineral resources were not clearly defined and it was a time to be realistic and try to provide good foresight and sound professional judgment. I was very much aware of the time required to build a database on the geology of the various mineral commodities, and more importantly the need for developing specialists with knowledge of the different kinds of mineral deposits and the geology of each mineral commodity and groups of related elements. To provide the geological work and understanding of the principal mineral commodities produced in Canada would require a minimum of about 20 specially qualified staff members. I tried to outline all this in a realistic, enthusiastic and logical manner for consideration by the Survey management.

Qualified and well trained geologists were essential for an expanded mineral deposit section but storage facilities, access to and curatorship of the reference specimens for mineral deposits was essential for future research, and of course systematic reference files for the literature, maps and reports on the mineral deposits had to be developed and maintained for future reference. Research on mineral deposits had to be treated in a progressive context for the development of new data and revision of geological concepts. The reference by some to my bibliophile approach was not helpful and provided little insight as to what was needed for a research program on mineral deposit genesis and how it might differ from the mapping projects in the Geological Survey.

Some negative reaction to new proposals was expected but I did not anticipate some of the comment, ridicule and inferences about my professional competence which followed. However I was ready to defend my proposal for commodity specialists and working groups and by the time new staff members were hired and a few small working groups organized the attitude of senior management seemed to have changed somewhat, and I heard less and less ridicule about my proposals for organizing and assigning work on the geology of mineral commodities and resources, and applied geology in general. We can now look back with respect and give credit for the fine achievements of the staff of the Mineral Deposit Geology Section that followed in the past half century.

In retrospect it is worth noting that some years passed before we were informed by new arrivals in the earth science forums that applied geology was not really creditable research science. Whatever viewpoint one chooses it is necessary to recognize professional integrity and to judge accomplishment on the basis of what was assigned and expected of the geologists on staff and how they responded to the challenges set before them by the organization that hired

them. Some of the reviewers and reporters on science policy in the Geological Survey of Canada have failed in their understanding of what a government organization is expected to do and how it differs from what is expected from academics.

There was no question that the Geological Survey's Economic Geology Series publications would be most appropriate for reporting on the initial work of the iron project. At least four volumes were planned at this early stage in the project, Volume 1 - The Geology and Evaluation of the Iron Deposits in Canada, Volume II - Iron Deposits in the Appalachian and Grenville Regions of Canada, Volume III – Iron Deposits of the Labrador Geosyncline, and Volume IV – Iron Deposits of Central and Western Canada.

Manuscripts for the first three volumes were submitted in 1962 before I went on loan for two to three months on my first assignment with the United Nations Technical Assistance Board to report on possible iron ore potential in the laterite rocks in Guyana. This assignment not only provided an opportunity to study tropical weathering processes and types of mineral deposits that were not known in Canada but at the end of the assignment I was able to muster finances, with some assistance from the Survey in Canada, to make brief visits to principle iron ranges in Brazil, Peru and Venezuela. This short excursion to iron ranges in South America proved to be a most valuable experience for me in the study of iron formations and in identifying various genetic features for special research. These included the association of iron formation and volcanic rocks, the tectonic environments in which iron formation sediments formed or had formed, their distribution through time and evidence of biogenic activity in their deposition and sedimentation.

Assignments with the United Nations brought a new dimension in my career work on iron deposits, and an opportunity for study of iron deposits in Asia came in an assignment in Sri Lanka (Ceylon) in 1964. This was followed by visits at my own expense to the iron ranges in the states of Orissa and Bihar in India. In 1968 I accepted a United Nations assignment to an area north of the Congo River in the People's Republic of Congo to advise on geological work being carried out by geologists from Europe, and on work by the local government on their appraisal of the Zanaga iron formation as a source of iron ore for a proposed local steel industry. Then to my great surprise I was appointed to the United Nations Panel of eight experts to update and revise their survey of World Iron Ore Resources. This appointment came as a major challenge as I didn't think that anyone was paying much attention to my work on iron ore resources.

The assignment to the United Nations Panel came at a critical time for the development of future work and research in the iron project. I was having to deal with a major disappointment in the project work on iron deposits when the Ph.D. thesis work on The Algoma Type iron formations in Central Canada assigned to Paul Wilton and sponsored in the iron project was rejected at the University of Minnesota. No reason for the rejection of this research was given except that it was considered inappropriate. On receiving word of this rejection I was not only disappointed but angry; however, Paul returned his field notes from excellent work in his first field season and accepted the fact that his thesis advisor Professor Preston Cloud did not want to recognize these Archean metalliferous sediments as iron formation. I had no idea that some geologists held such firm convictions about the origin of iron formation that they would reject further research on the subject. Under these circumstances the appointment to the United Nations world panel would provide an extra challenge not only to provide substantive data on iron resources in iron formation in Canada but I would have the benefit and opinions of the panel members on the concepts in geology that I would present in my report for Canada and the West

Indies.

The publication of Volume I of Economic Geology Report 22 on the Geology and Evaluation of Iron Deposits in Canada provided a reference for terminology in use, quality standards for iron ore accepted by industry, a classification of deposit types, and a review of theories held for the origin of iron formation with summary information on their regional geological settings and other general information. Volume I was a useful reference for anyone interested in iron resources and was received well by industry, most specialists in the geology of iron deposits, academics and the general public. I was able to present copies of Volume I to the United Nations panel members at our first meeting in New York. They received the volume enthusiastically and decided immediately that I should write the chapter on the nature and occurrence of iron deposits for the World Report, as well as the section on the iron ore resources of Canada and the West Indies.

My report on the iron ore resources in Canada for the United Nations Survey presented a very different picture to that in previous reports and obviously caused some deep concern for some of the panelists. I was able to present current data on iron resources in the deposits of naturally enriched iron formation but my report also provided one of the first attempts to tabulate the taconite and meta taconite resources in Canada's vast iron ranges. I was called to a special meeting of some of the panelists who were somewhat hostile to what seemed like an extravagant assessment of potential ore that differed greatly from previous reports that had not considered the low grade deposits that could be beneficiated. In dealing with questions and doubts about my data I showed them work sheets showing our tabulation of data for each iron range and assured them that I had done field work on many of these deposits and could provide more data in support of my assessments of iron resources and potential resources. I challenged the panel members to provide similar supporting data for their reports and the meeting ended on a complimentary note. I left the meeting feeling assured that we were doing the right things in our resource assessment work in the Geological Survey of Canada.

Part III More International Involvement

The response to the publication of Volume I in Economic Geology Report 22 was beyond expectation, not only from a personal viewpoint but it was widely accepted and became a popular reference internationally. Translations of Volume I in at least four languages became available in other countries. I had an opportunity to visit the Soviet Union in 1966 in the exchange program for scientists sponsored by the National Research Council in Canada and the Academy of Sciences of the U.S.S.R. I was pleased to present a copy of my newly published Volume I on iron deposits in Canada when I arrived in Moscow. It was accepted enthusiastically and I was informed that they had already translated this volume and that it would be published in Russian within a few months.

I had a most encouraging experience in the Soviet Union interviewing a large number of geologists who had done extensive research on iron formation and was able to visit iron mining operations in the Kursk and Krivoy Rog iron ranges, as well as Institutes in Novosibirsk, to learn of their research work and the development of iron ore resources in the Ural Mountain region. It was exciting for me to find that Russian and Ukrainian Geologists held many of the same concepts and conclusions on the origin of iron formation that I held and had considerable literature, data and documentation that supported their ideas. They also were interested in the

United Nations World Survey of Iron Ore Resources in which I was involved. I mentioned their interest to United Nations associates when I returned to Ottawa and it was no surprise to me that when our United Nations panel met in Geneva in 1968 to finalize our World Survey Report that Professor G. Sokolov from Moscow was able to attend and provide a report on iron resources in the Soviet Union. I believe his report was one of the first contributions from the Soviet Union to any United Nations project.

But the interest of our Soviet Union colleagues extended much further. When I was preparing to leave after a stimulating exchange visit of six to seven weeks I was informed that they had been contemplating the need for an international working group on the origin and geology of iron ore resources for some time. They considered that Canada was an obvious place for leading and organizing such international cooperative work. I could not help but be surprised and flattered with this proposal but was compelled to explain that it was most unlikely that I could muster adequate support for involvement in such a working group but promised to do whatever I could. When I returned to Canada and reported on my visit to the USSR the idea of sponsoring international cooperative work on the geology of iron deposits was not treated negatively but the timing for starting another international venture was not good. Canadian geologists were committed to hosting the International Geological Congress in 1972 and there was no funding available for other international projects; however, I was not discouraged from trying to organize international interest in a working group on the geology of iron deposits. I was pleasantly surprised with the response I received from colleagues in other countries and had a good program in view for a meeting in 1970 but there was no hope of raising funds for holding a meeting in Canada or for attending such meetings in the future. On explaining the situation an Institute in Kiev offered to host a meeting in 1970 and went on to develop a program similar to what I had proposed, and to organize field excursions to the Kursk and Krivoy Rog iron ranges. The geologists in the Soviet Union made every effort possible to provide an outstanding scientific program and presented the visiting scientists with maps of the geology of the iron ranges visited, an unprecedented act of good will and cooperation in their country at that time. These field excursions attended by an enthusiastic international group set a precedent for international scientific cooperation in geology, and especially for research on the origin of iron formations and metalliferous sediments.

The year 1972 was eventful for me and for the history of the project work on iron deposits in Canada. My contribution as a panelist for the United Nations Survey of World Iron Resources was recognized in Canada with a Public Service of Canada Merit Award. I organized and led a field excursion to the iron ranges in Quebec and Labrador for the International Geological Congress hosted in Canada; with the help of two Geological Survey staff, Roy McLeod and Terry Ganton, a report on the iron ore resources of Canada was submitted as part of the Operation September Report on mineral resources completed in the Mineral Deposit Geology Section at the request of the Department. I prepared a major paper on iron ranges marginal to the Superior-Ungava Craton for presentation at an International Conference on Iron Formation hosted in Minnesota in October. This paper brought attention to the distribution of iron formation on the margins of the Superior-Ungava craton or continental plate that were related to the major fault and fracture zones on the plate margins. This paper was presented by Steve Zajac, a co-author who had been sponsored in the iron project for his Ph.D. thesis work at the University of Michigan on the naturally enriched iron ore resources in the Schefferville area of Quebec and Labrador.

After an extremely busy and eventful year in Canada and the completion of my four year term as Head of the Geology of Mineral Deposits Section I departed with my family for London, England in the middle of September, to start a two year appointment as Commonwealth Geological Liaison Officer and Secretary of the Commonwealth Committee for Mineral Resources and Geology. It was Canada's turn to provide a candidate for this assignment and I was approached by my Division Chief earlier in the year and informed that they wanted to present my name as a candidate. I was reluctant to accept a diversion from research in the iron project at this time but I was assured by the Deputy Minister that they wanted to present my name as a candidate. There are times when one doesn't argue and this was one of them. But confirmation of acceptance of the appointment was not forthcoming until early in September and we spent a summer of suspense as arrangements for schools in London for our early teenage children could not be confirmed. As it happened after arrival in London in late September and finding a suitable residence we were informed that there was no room in the local council schools and that we could make arrangements for our children in private schools. This was not an easy task but we were successful although arrangements were not entirely to our satisfaction.

We learned after arriving in London that the London Management Committee had recommended discontinuing the Commonwealth Geological Liaison Office and their proposal could not be considered until the meeting in Montreal scheduled in late August or Early September. But the African countries wanted the Liaison Office continued and as it turned out I was assigned in early 1973 to visit Commonwealth countries in Africa to confirm what they expected from their Liaison Officer in London.

I had mixed feelings about accepting the diversion to the Commonwealth Office for two years. Work in the Iron Project was at a high point in the acceptance and cooperation by the Canadian Mineral Industry, we had a lot of scientific data and concepts from the research on iron formation to present in publication and there were special opportunities for further liaison work with the world community and especially in the study of metalliferous sediments on the seafloor. For some reason metallogeny, the branch of geology that deals with the origin of ore deposits, was finally being given special emphasis by the Division Chief and some of the Senior Geologists in the Mineral Deposit Section. It came as some kind of an enigma for the staff in the Mineral Deposit Section as a previous chief of the Mineral Deposit Section, Arthur Lang, had emphasized metallogeny and the publication of a series of Metallogenic Maps on a national scale for major mineral resources in Canada.

I was not able to accept an invitation in 1972 by Gene Talbert, a leading geologist with the United States Steel Company exploration group in Brazil and previously a colleague in their exploration work in northern Quebec, to visit the Caracas iron range which he had discovered, and he wanted to have the opinion of other geologists about its geology and whether it should be classified as Algoma Type iron formation even though it was decidedly larger than the iron ranges of this type known in Canada. It was unfortunate for me that I could not accept this timely invitation, and there has been no opportunity or funding offered since that time for field study and comparison of the geology of this now famous iron range with smaller iron ranges in Canada of similar geological age and setting.

The assignment in London was presented to me as a sabbatical which probably was not a bad idea as I had had a very active schedule in the previous years with more than enough warning about health concerns and there was a case to be made for a change of pace. The two year term spent in London as Commonwealth Geological Liaison Officer was an interesting experience and

I learned a lot about the work and what was expected from Geological Survey organizations. I had an opportunity to learn more about some of the iron formations in Africa during the two months spent visiting ten of the Commonwealth countries there. Before returning to Canada at the end of my term as CGLO in October of 1974 I made a short visit to the Geological Survey organization in Hanover, Germany, and had an opportunity to examine some of the cores of metalliferous sediment from deposits in the Red Sea before they were returned to Egypt. My time in London had diverted my participation in research on iron formation during a critical period in the iron project. I was delighted when I returned to Ottawa to find that during my absence Roy McLeod had carried out important work in the iron project and liaison with the iron ore industries and had visited occurrences of Paleozoic iron formation in New Brunswick that provided important new information for the project data base and research on the iron formations.

The two years in London interrupted other activities that I had established in support of the work in the iron project. I had attended annual meetings of a group of Wisconsin Alumni and International Associates working on marine geology known as The Underwater Mining Institute who were actively interested or involved in the exploration of mineral deposits on the ocean floor. The papers presented at the Institute meetings provided excellent reviews and current reports on exploration being carried out on the seafloor and provided vital and most useful information for my work in the Department in Ottawa on the Department Committee on Ocean Minerals on which I served and the advisory reports this committee provided for the development of National Policies relating to possible ocean mineral resources. But of greatest interest to me and for the iron project were the candid reports presented by leading European and North American Geologists on the origin and genetic processes involved in the deposition of minerals on the seafloor, their significance in documenting processes relating to the volcanogenic origin of iron formation and metalliferous sediments. Although the Underwater Mining Institute eventually gave most of its attention to the origin of sulphide mineral deposition and the deposition of manganese nodules on the seafloor there was considerable data presented on the genesis of metalliferous sediments in general. My absence from Ottawa negated any possibilities of participating in this exploration and of obtaining samples of Recent age for comparison with ancient lithofacies of iron formation.

The time in London certainly was a diversion from work in the Geological Survey of Canada and in retrospect it is interesting to ponder what might have happened if I had not accepted the CGLO assignment.. I had been in London about two weeks when I received a letter from the Public Service Commission in Canada informing me that I was on the short list for appointment as Director General of the Geological Survey of Canada and they needed confirmation of my willingness to let my name stand. I had to take another serious look at my career aspirations. I had to consider some health factors including warnings about hypertension and the everlasting nagging of my hearing impairment after service in Bomber Command during World War II. Besides I felt that I was making a positive research and professional contribution in my assigned project work, and I replied that I did not wish to have my name stand as a candidate. In retrospect and all things considered I believe that the right choices were made but life has its high times along with disappointments.

Considerable progress was made in the first decade of the iron project in the development of a data base that included information about the tectonic settings and distribution of the different kinds of lithofacies in the various iron ranges, the contents of major elements in them, and a greater appreciation of their metallogenic significance. I was convinced that hydrothermal effusive discharge in and around volcanic centers located in the major deep fracture zones in the ocean floor was the main source of the iron and silica in the iron formations and related metalliferous sediments. These basic concepts for the origin of iron formation were proposed in the past century for the Lahn-Dill iron formation in Germany, visited in 1968, which was now considered to be of Algoma Type in the classification of iron formation sediments in use.

In retrospect I realize that I should have been more active in presenting the data in support of a volcanogenic model for the origin of metalliferous sediments in the initial stages of the iron project but unequivocal modern data supporting these concepts was needed. At the close of a graduate seminar at the University of Wisconsin in 1954, in which we had reviewed various theories for the origin of iron formation, most of the graduate group were convinced that volcanic processes provided the best possible answers for the source of iron in the iron formations. Professor Tyler stated in his concluding remarks at the seminar that when the day comes when we can observe and study volcanic processes on the deep sea floor we will find thermal springs in the fracture and rift zones on the ocean floor, in areas where faults and fracture zones pass through areas of high thermal gradient in the earth's crust, and we will be able to observe the deposition of iron formation and metalliferous sediments. This was a prophetic statement and ten years later in 1964 thin bedded metalliferous sediments were discovered in the deep basins over rift zones and graben structures on the floor of the Red Sea, and deposition was still taking place in some of the basins.

The metalliferous sediment found in the basins on the floor of the Red Sea was thinly banded and its bulk composition was similar to that of the ancient Precambrian iron formations. Some of these recent sediments contained contents of copper, lead, zinc and gold that were nearly high enough for economical recovery.

The discovery of metalliferous sediment in the Red Sea that had been deposited in recent time as well as the wide distribution of metalliferous sediment at many sites along the ocean ridges has convinced many that iron formation and associated metalliferous sediments were formed by volcanogenic processes. But Hal James, an outstanding authority on the geology of iron formation and iron deposits, and others, were not convinced that the Red Sea metalliferous sediments were truly modern analogues of the ancient iron formations because their mineralogical make up was different to that of the ancient iron formations. Later comparisons of the bulk compositions and correlation coefficient data for the contents of major and minor elements demonstrated remarkable similarities in element distribution in the Red Sea sediments and oxide lithofacies of both Lake Superior and Algoma type iron formations.

Research on the polymetallic sulphide deposits associated with the iron formations, that were referred to by many as volcanogenic massive sulphide deposits, was initiated in the iron project and later continued or pursued by others in the Mineral Deposits Section. The sulphide deposits were commonly associated with carbonate and silicate lithofacies of iron formation. Research on the sulphide deposits greatly influenced the development and acceptance of a volcanogenic model for iron formation and associated stratafer sediments.

Many research workers did not accept volcanogenic processes in their models for the genesis of iron formation through geological time and believed that in some way the deposition

of metalliferous sediments was related to the changes in the content of oxygen in the atmosphere through time, and they had difficulty accepting the fact that common lithofacies of iron formation occur with Early Archean, Paleozoic, Mesozoic and Recent sediments as well as in abundance with Proterozoic sediments.

Many depositional sites for metalliferous sediments have been explored along the major fracture and tectonically active zones on the ocean floor since the discovery of the metalliferous sediments in the deep basins of the Red Sea in 1964. A world map showing the location of many of these sites was prepared while serving with the Department Committee on Ocean Minerals and was published in 1987 by the Geological Survey of Canada as Paper 86-21, by G.A. Gross and C.R. McLeod.

Metalliferous sediment, located along deep fracture zones and associated with volcanic activity on the modern seafloor, has been documented since 1964, along the Atlantic Ridge and The Pacific Ring of Fire, in Indonesia, in the Red Sea and in various parts of the Mediterranean Sea. Relatively little information is available about the mineral composition of these metalliferous sediments, their thickness and distribution, the time required for their deposition, the development of various kinds of lithofacies and other features in them. The exceptional work of Evigny Gurvich, first published in Russian in 1998 and later in English in 2005, has provided data from extensive exploration of the sea floor, special insight in and appreciation of the genetic processes leading to the widespread distribution of modern metalliferous sediments in the ocean.

The special project work in the Geological Survey of Canada has provided evidence of a genetic model for iron formation sediments that has convinced many geologists of the volcanogenic processes involved in their origin, and a wealth of data on geological environments for their deposition and metallogenetic significance and the history of volcanism associated with them was assembled in the project work. Research on the iron ranges and associated metalliferous sediments constantly involves interpretation of the history of volcanic activity associated with the fracture and fold structures in which they occur, and of their location on the margins of ancient cratons and shield areas that are now considered to have been tectonic plates.

Development of a data base on iron formations and iron deposits in the initial stages of the iron project had brought important perspective on the depositional environments and origin of iron formation and stratafer sediments, particularly to the association of volcanic rocks in the stratigraphic sections hosting them and to the different tectonic settings for Algoma and Lake Superior types of iron formation. The relevance of the title chosen for this paper, Metalliferous Sediments, Volcanology and Plate Tectonics is obvious.

Research on the metallogenetic significance of iron formation and stratafer sediments required the development of a data base that included data on the content of minor elements as well as the data for the major elements in addition to that available from records of exploration for iron ore. Information on the chemical composition of the iron formations published in the early years of the project consisted mainly of data required for the evaluation of iron deposits as resources of iron and manganese. When analytical methods became available, that enabled more accurate determination of the contents of minor elements in the 1970's, special effort was made to acquire samples and to develop a modern reference file for the iron formation sediments. Some of the analytical data for minor elements in iron formation has been included in the manuscript for an open file report on iron formation geology and geochemistry for 40 iron ranges in Canada submitted in 2005 and awaiting publication.

Development of the Iron Formation Chemistry File, IFCHEM, was necessary for research on the metallogenetic significance and origin of iron formation and stratafer sediments. Samples were collected from the major iron ranges in the late 1970's and early 1980's to provide a minimum of suitable material consisting of at least 10 selected samples for analyses and comparison of minor element contents in the iron formation from about 40 major iron ranges.

Work on the metallogenetic significance of iron formations was focused on five principal themes;

- 1/ Identification of iron formation that had a mineral composition and content of elements that met the standards for iron ore required by the iron and steel industries, and had textures and grain size developed during their metamorphism that would enable processing and beneficiation of the crude ore,
- 2/ Location of lithofacies that had a content and distribution of manganese that met standards for manganese ore,
- 3/ The content and association of polymetallic sulphide lithofacies,
- 4/ The distribution of gold in the iron formations and its geological environments, and
- 5/ The content and distribution of rare earth elements.

The assessment and survey of iron ore resources has been a major part of project work which started with the definition of quality and composition standards for iron ore as required by industries and was presented in various reports and papers, in Volumes I to iii of the Geological Survey of Canada Economic Geology Report 22, in the United Nations Survey of World Iron Ore Resources, The Operation September Report for Department Interest in 1972, in A Summary View of Canadian Reserves and Additional Resources of Iron Ore, MR 170 (1977), and many reports on the nature and distribution of iron resources in Canada and in particular regions that have been prepared over the years as requested.

Iron ore resources in the Appalachian and Grenville Regions of Canada were described in Volume II, of Economic Geology Report 22 on the Iron Deposits of Canada. The metallogeny of titaniferous magnetite and contact metasomatic magnetite deposits in The Grenville Province were reviewed in some detail in this report.

The highly metamorphosed and coarsely crystalline iron formations in the Labrador-Quebec fold belt west of Ungava Bay described in GSC Bulletin no.82, published in 1962, and the highly metamorphosed iron formations that extend southward into the Grenville Province in Northeastern Quebec and Labrador were described in Volumes II (1967) and III (1968) of EG Report 22.

The distribution of Algoma Type iron formation in Ontario and Southern Quebec was shown on eight map sheets (1963) on a scale of 1 inch to 16 miles to provide regional orientation for research on their metallogeny and for review in Volume IV of EG Report 22, and for use in further compilation of regional geological data and for resource appraisals, but the purpose, preparation and presentation of these maps seemed to be misunderstood in my Division and I was left discouraged in preparing the text and further map data for Volume IV which was not completed, for various reasons.

Identification and assessment of manganese resources was carried out as a part of the assessment of iron formation lithofacies and the naturally enriched iron ore deposits developed in them. Iron ore that has a high content of manganese is usually placed in separate categories and provides a separate ore product. A report that summarized information on manganese resources in iron formation in various parts of the world was prepared in the course of project research

work and published in the proceedings of an international working group in the Cameron Volume on Unconventional Mineral Deposits, 1983.

Manganese is widely distributed on the ocean floor in nodules, usually from 1 cm. to 3 cm. in diameter, that have a significant content of nickel, cobalt and other ferride elements. The known distribution of manganese nodules on the seafloor was shown on a map of the world, Metallic Minerals on the Deep Seabed, GSC Paper 86-21, published in 1987. The principal source of the manganese in the nodules evidently comes from thermal springs located along fracture and fault zones on the sea floor where vast amounts of iron and other metals are discharged in the ocean. Because manganese is more soluble than iron it is transported farther from its source and deposited separately from metalliferous sediments rich in iron.

The association of polymetallic sulphide deposits associated with iron formation was recognized in the initial stages of the development of the project data base for iron formations. Because of the wide scope of research being attempted in the iron project, most of the research on sulphide lithofacies and their metallogeny was assigned to and carried out in other projects in the Mineral Deposits Section.

Iron formation hosting significant quantities of gold has been reported world wide in all of the continents except Antarctica. It is not clear whether the gold is of syngenetic origin in the iron formation host rocks or whether the brittle iron formations provided favorable host structures for its deposition. Analyses for the content of gold were carried out on a selection of samples collected for the IFCHEM file in an effort to determine if iron formations and stratafer sediments might have a consistent syngenetic content of gold or whether it was introduced at a later time in their history. This research indicated that any significant amount of gold found in the iron formations and associated stratafer sediments probably was introduced by epigenetic processes and that only a very small amount of the gold found in the stratafer lithofacies was of syngenetic origin. (See GSC Paper 86-19, 1988, Gold Content and Geochemistry of Iron-Formation in Canada)

Data on the contents of rare earth elements in iron formations was determined in the specimens analysed for the IFCHEM file. The small quantities consistently found in iron formation ranging in age from Early Archean to Mesozoic and in Recent metalliferous sediments all have similar patterns in their distribution. Evidently the content and distribution of the rare earth elements in the iron formations was controlled by primary processes in their genesis. Experience in China led to further study of the distribution of rare earth elements in iron formation sediments.

In 1984 in the course of an exchange visit to China I was taken to the Bayan Obo iron mine in Inner Mongolia, China, from which about 15 percent of the world supply of rare earth elements are recovered in the processing of the iron ore. The questions referred to me related to whether this was iron formation and whether it was similar to other iron formations that I had studied, and whether I thought that the rare earth content was primary syngenetic in its origin or introduced later in the history of the deposit. I found no reason for not accepting this as an oxide lithofacies iron formation with a moderate amount of grain enlargement developed during a later stage of metamorphism. The group of geologists and engineers from the Potou Steel plant who looked after the processing of the iron ore and recovery of the rare earth elements wanted to hear my thoughts about the genesis of iron formation. They seemed to be favorably impressed with concepts of volcanogenesis that I suggested, and they indicated that the rare earth elements were distributed uniformly throughout the iron formation and that all of the iron ore received at the

steel plant was processed for their recovery.

On returning to Ottawa and further examination of the samples collected I found that the Bayan Obo specimens had textures and mineral composition similar to many other iron formations that I had studied. The specimens showed considerable recrystallization in their textures but evidence of primary micro ovoid forms were still discernible in them that were similar to what I had examined in other iron formations. I had a second visit to Bayan Obo in 1988 when I discovered that most of the iron formation that I had examined near the margin of the open pit mine had been mined. I was impressed when examining sections of iron formation in the mine that there was extensive distribution of fluorite in fracture zones in some of the iron formation, especially near the north side of the pit. Obviously there had been some redistribution of elements in the iron formation. The mine geologists again assured me that the content of rare earth elements, about 5 percent, and their distribution throughout the iron formation did not vary significantly. Subsequently I learned that a United States Geological Survey Geologist, Wang, 1993, who has done considerable work on the mineralogy of the Bayan Obo deposit does not recognize the host rock as metamorphosed iron formation, or accept a syngenetic origin for the rare earth elements in it. I have no doubt that the iron ore zone at Bayan Obo consists of metamorphosed oxide lithofacies of iron formation with grain size enlargement related to a later stage of metamorphism and that there has been remobilization and possibly some introduction of elements related to a later metamorphic event as suggested by the distribution of fluorite in fracture zones. But I have no incentive to change my views on the syngenetic origin of at least some of the rare earth elements in the iron formation at Bayan Obo.

Another special experience for me in the iron project was an invitation in 1964 from the Crest Exploration Company in Calgary to visit their newly discovered iron range in the Mackenzie Mountains in the border area of the Yukon and Northwest Territories. With the benefit of the company helicopter I was able to visit many sites on the iron range located high in the mountains and to obtain data of critical interest. The oxide lithofacies of iron formation was about 400 feet thick, it was part of a stratigraphic sequence of Late Protozoic or Early Cambrian age, the iron content in it of about 40 percent was exclusively in grey hematite, drop stones of dolomitic composition nearly a foot in diameter were found in thick beds of iron formation, and there was evidence that mud flows with boulders about a foot in diameter had disturbed the soft unconsolidated sediment beds in some of their border zones. This remarkable discovery of iron formation was of special interest as it left no doubt that major iron formation lithofacies were formed after Early Proterozoic time. It was the first and only iron formation of Rapitan type reported in North America, and the term Rapitan type originated with this discovery near the Rapitan River. Discovery of the Rapitan iron formation brought a whole new dimension to understanding the origin and genesis of iron formations and the depositional environments in which they formed.

In 1964 I was invited by a veteran prospector, Murray Watts, to visit the Mary River iron range that he had discovered near the north coast of Baffin Island. This iron range was of special scientific as well as economic interest as a large part of it was composed mainly of magnetite with some specular hematite. I had seen a similar high grade zone in iron formation in Venezuela but at that time had not recognized any iron formation in Canada that did not have a significant content of silica. There was evidence in the Mary River deposit of the destruction of primary banding in the iron formation and possible enrichment in the content of magnetite which could be attributed to a later stage of hydrothermal alteration of the deposit. Explanation of the origin

of this high grade deposit presented a major challenge.

Other high grade lithofacies of iron formation of limited extent were found in the Mary River area in the following year. They consisted of thin banded specular hematite in which the banding was conformable with that in the thin banded quartz and hematite iron formation hosting them. Similar thin banded lithofacies consisting only of magnetite that were transitional into thin banded magnetite and quartz lithofacies were also present in the area. Little or no evidence was found to suggest that these zones composed principally of iron oxide were not metamorphosed primary lithofacies in the iron formation. It was concluded that the Mary River iron deposit of high grade was indeed a primary zone of iron formation composed mainly of iron oxide minerals that was altered during metamorphism in the area, and later by hydrothermal solutions that were introduced along the fault structure that intersects the Mary River high grade zone.

Banded oxide lithofacies of iron formation composed of iron oxide minerals with little or no silica are not unique to the Mary River iron range. A lenticular zone about 5 metres thick of thinly banded magnetite in metamorphosed oxide lithofacies of iron formation was found in the iron formation range west of Roche Bay near Hall Beach on the Melville Peninsula in Arctic Canada. Another similar occurrence of thinly banded magnetite in iron formation was examined near Capreol in Northern Ontario at the site of the Moose Mountain Iron Mine. Some of the pioneer work on the beneficiation of iron formation ore was carried out in the early 1900's at this mine site. No doubt other occurrences of iron formation composed of iron oxide minerals will be found when the stratigraphy of many of the iron ranges is better known.

Part V - More about International Involvement

The years from 1972 to 1974 in London, England while serving as Canada's appointee as Commonwealth Geological Liaison Officer were an interesting diversion from work in Ottawa and research on the iron resources of Canada. Providing a monthly newsletter with reports of research and activities of interest in the earth sciences as well as attending meetings at UNESCO in Paris as a representative for earth science organization in the Commonwealth was a challenging task. The interest and responses from the Commonwealth Geological organizations and others in Europe brought a sense of purpose and satisfaction in the work of the CGLO office that was not often recognized. The two years in London passed very quickly but I was anxious to return to Ottawa in October of 1974 with renewed perspectives on the geology of iron formation and iron resources.

There were many changes at the Geological Survey of Canada during my two year absence and I regretted the time lost from research and responsibilities in the special project on iron and on the Department Committee on Ocean Minerals where I had served for some time. It was hard to believe that I would have to go through official appeal procedure to recover normal salary increments for the years spent in London and my appraisal as a scientist was neglected. If I had seen the Geological Survey of Canada from a somewhat different perspective while serving in London I now had less confidence than ever in its ability to continue the scientific work that was needed in Canada. All of this was discouraging but I had reached a stage in my career when I did not want to change the course of my professional work. There was important work to pursue in the iron project, specimens to collect and data to process for the IFCHEM file, update files and data for further appraisal of iron resources in Canada and for Ocean Mineral Resources. But little funding was available for this work and program development for the Mineral Deposit Geology

Section seemed to be at a standstill. I was given to understand that I might have a place in the foreign relations work of the GSC.

I was asked to accompany the Director General, Digby McLaren, on a trip to Moscow to advise and proceed with the negotiation of a protocol for scientific exchange work with the Soviet Union. As the representative for Canada I was expected to assist with the development of an exchange program, but with rapid changes in relations with the Soviet Union and the easing of travel restrictions there was little need for this formal protocol for exchange visits of scientists in the following years. I made two trips to Moscow with Ministerial Missions as part of the Mixed Commission for Trade and Exchange Work with the Soviet Union but we had very little exchange work in geology to consider. In retrospect I can appreciate the significance of all this contact with the Soviet Union representatives in Ottawa and in Moscow as the cold war attitudes changed and normal relationships with the Soviet Union were developed.

In 1977 I was assigned the task of arranging a program, itinerary and conduct visits to mines in Ontario, Quebec and Labrador for a delegation of geologists and engineers from China who were interested in the geology, mining and processing of iron ore in Canada. This was a major assignment and I was grateful for the assistance of Roy McLeod in managing the travel arrangements and tours to the mines. This delegation visit was a new step in scientific exchange work with China and we were complimented on having set a worthy precedent in conducting all aspects of the visit.

On the return visit to China in 1978 I was accompanied by three geologists representing industry and academia and an official interpreter. The visit to China coincided with times of significant change in the country at the end of the Cultural Revolution and the influence of the Gang of Four, and although a sincere effort was made for us to meet geologists interested in iron resources and to visit a major iron mining area, our tour rated more highly for its cultural and tourist interests and some idea of what might be anticipated in future visits.

I have referred above to the visit to the Bayan Obo iron and rare earth deposit in Mongolia during the 1984 visit to China. Other iron mines were visited in north-east China near Tianjin as well as manganese deposits in the south near Wuhan. After departing China on this visit I was able to renew contacts and visit a colleague in Japan, Professor Nishiwaki, who had participated in the United Nations survey of iron ore resources.

In 1979 I was assigned the task of arranging programs and conducting Mr. Sun Dagan, Minister of The Department of Metallurgical Industries in China, and a delegation of about 25 senior engineers and scientists on their visit to Canada of about a month's time. Their work was conducted mainly in Ottawa, Toronto and in Vancouver. .

My last visit to China was in 1988 when I attended a number of scientific meetings, visited iron ranges in Northeast China near the border with North Korea and met with some of the members of the previous Chinese delegations to Canada. By this time I was contemplating possible continuation of research on iron resources during official retirement from the Public Service in the following year, 1989, and further work in China was not anticipated. I had been able to visit some of the iron ranges in China but had not been able to obtain an overall assessment of the nature and distribution of the iron ranges that were of interest in a global study of iron formation types and distribution. By this time I was contemplating possible continuation of research on iron resources during official retirement from the Public Service in the following year, 1989, and further work in China was not anticipated.

But I still had a lot of reporting to do after thirty years' work on the iron resources of Canada and the world. There was a mass of data in the IFCHEM files on the iron ranges of Canada to be interpreted and reported and more research on the iron ranges in the Arctic would be helpful before their mine development and mining anticipated in the near future. The appointment as the first Emeritus Research Scientist in the Geological Survey in 1993 came as a surprise and I was greatly encouraged by the citation and recognition of my career work in the iron project that was submitted with the nomination for this status. I would be able to publish more of my work and to prepare an open file for publication on a CD-Rom presenting data on the iron ranges and from the IFCHEM file. The Manuscript for an Open File Report on Iron Formations in Canada: Geology and Geochemistry providing a brief summary of data and work in the iron project on 40 iron ranges in Canada was submitted for publication in 2005.

At least six post doctorate fellows from the U.S.A., India, Japan and China had been assigned to the Iron Project over the years. Two of them published papers based on their research in the project and in GSC, one spent most of his time on research based in other countries, and one of them from China had no aspirations to do scientific research but was interested in our methods of study, exploration and development of iron ore resources.

In the later years of the project work on iron deposit geology I was able to attend and present papers at the International Geological Congress meetings held in Washington, U.S.A. in 1984, in Moscow, U.S.S.R. and participate in the field excursion to Siberia in 1988, and in the Congress meetings held in Kyoto, Japan in 1992.

I proposed and contributed four sections to the volume on the Geology of Canadian Mineral Deposit Types, published in 1995 as one of the series of eight volumes on the Geology of North America that presented the knowledge of geology and geophysics in the 1980s, for celebration of the Centennial of The Geological Society of America.

Some of the papers published in the later years of the iron project were:

---The metallogenetic significance of Iron-Formation and related stratafer rocks, in the Journal of the Geological Society of India, Vol.28, 1986,

---- Tectonic systems and the deposition of iron-formation, in Precambrian Research 20, (1983) ,

----- Gold content and Geochemistry of Iron-Formation in Canada, Geological Survey of Canada Paper 86-19 (1988),

---- Comparison of Metalliferous Sediments, Precambrian to Recent ; Krystalinikum 19, (1988), (presented at the Int. Geol. Congress held in Moscow, 1988),

---- Iron-formation metallogeny and facies relationships in stratafer sediments, (presented at the meeting in Ottawa in 1990), and published in the proceedings of the Eighth Quadrennial IAGOD Symposium (1992),

---- The distribution of rare earth elements in iron-formations; in Global Tectonics and Metallogeny, vol.5, nos. 1&2, (1995) .

---- Industrial and Genetic Models for Iron Ore in Iron-Formations, in Mineral Deposit Modelling: Geological Association of Canada Special Paper 40, 1993.

---- Element Distribution Patterns as Metallogenic Indicators in Siliceous Metalliferous Sediments, Resource Geology Special Issue, No.17, p. 96-17, 1993. (Presented at the International Geological Congress, in Kyoto, 1992)

-----A co-author for -----A review of the microbial geochemistry of banded iron-formations, by D. Ann Brown, Gordon A. Gross and Jerzy A. Sawicki , Canadian Mineralogist, v.33 (1995) .

With the summary of research activity and data reported in the open file manuscript for

publication on a CDROM disk submitted in 2005, and requests from industry for data stored in the IFCHEM File, along with an increasing amount of time diverted from the Iron Project by the writer for medical reasons there has been less progress to report on the iron project. In retrospect the project has been a fascinating and challenging experience for which I make no apology and retire from it with a great sense of satisfaction and reward in past accomplishments. The Project has provided a profound experience with metalliferous sediments, volcanology and plate tectonics and a greater appreciation of the Mineral Resources of Canada.

Part VI -----A Brief Summary Statement of major contributions from Research on Iron Formations in The Iron Project 570029 .from 1957 to the year 2000.

Development of an appropriate data base for use in the recognition and appraisal of iron ore resources for the future was a major challenge but it provided a special opportunity for the evaluation of existing concepts and information on the genesis of iron formation.

The literature and reports on iron formation and ferruginous metalliferous sediments available in 1957 provided a wide range of concepts and theories on the genesis of iron formation and stratafer sediments but data for confirming and documenting these genetic concepts were limited. The concepts for the origin of iron formation and ironstone sediments presented in the literature could not be ignored or rejected until better data relating to them became available.

Initial work on the classification and distribution of ferruginous sediments in Canada focused attention on the following:

1. Cherty iron formation sediments were mapped in terrain from coast to coast to coast.
2. It was recognized that iron formations in Canada ranged in age from Early Archean, Proterozoic, Paleozoic, Mesozoic to the Recent metalliferous sediments offshore in the Coastal areas of Canada.
5. The association of Iron formation sediments with volcanic rocks in stratigraphic sequences ranging in age from Early Archean to Recent as mapped was considered to be evidence that the deposition of the ferruginous sediments was related to if not dependent on volcanogenic processes and probably similar to those reported in the deposition of the iron and manganese metalliferous sediment being explored at various sites on the modern seafloor.
6. In the classification for iron formation proposed in the early stages of the project it was recognized that the Lake Superior Type iron formation stratigraphy was deposited in the tectonic systems located on the margins of major tectonic plates and evidence of the volcanic centers that provided the iron and silica for the iron formations was lost in the subduction zones at the margins of the tectonic plates, while the Algoma type iron formations developed along less extensive fault systems such as transverse faults and localized in fracture systems in the crust.
7. Iron formation lithofacies of all ages from Early Archean to Recent ferruginous sediments on the seafloor have ovoid micro features composed of iron oxide minerals that are attributed to micro organisms.
8. Early work in the iron project on the petrography of the various iron formation lithofacies was directed to recognition of primary sedimentary features, mineralogy and evidence of recrystallization, grain size enlargement and textural features developed

during metamorphism of the lithofacies, all of which were critical factors in the beneficiation and evaluation of iron formations as iron ore resources.

9. Data on the content of minor elements in iron formations from about 40 iron ranges in Canada became available from project research and the development of the IFCHEM file (Iron formation chemistry file) for iron formation.
10. The data for the minor element contents in iron formations of all ages are considered to be persuasive evidence for similar metallogenetic models for the ancient and recent metalliferous sediments, and provide useful metallogenetic indicators in the iron formation lithofacies.
11. Iron formations of Ancient to Recent age showed element correlation coefficient patterns similar to those found in the Recent metalliferous sediments from basins in the Red Sea grabens,