

REPORT OF COMMITTEE 19

CHEMISTRY IN THE EARTH SCIENCES
AND RELATED FIELDS

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INTRODUCTION

Definition of the field

The earth can be logically divided into five spheres as follows – lithosphere, pedosphere, hydrosphere, atmosphere, and biosphere. The lithosphere comprises the consolidated rocks of the earth; the pedosphere is composed of the weathered products and soils of the earth including glacial materials; the hydrosphere includes the oceans, fresh water surface bodies, and ground waters; the atmosphere comprises the gases in the outer envelope of the earth and in the rocks; and the biosphere is the sphere of life and includes all living organisms on the earth as well as their fossil remains such as peat, coal, and petroleum.

The science that deals with the migration and concentration of the elements and their isotopes in the five spheres of the earth is called geochemistry, a term introduced in 1838 by C.F. Schönbein, the Swiss chemist who discovered ozone. Not until the twentieth century, however, has the science reached maturity. Most of the fundamental aspects of geochemistry have been worked out in Europe and the United States principally by V.I. Vernadsky (1863-1945), A.E. Fersman (1883-1945), V.M. Goldschmidt (1888-1947), and F.W. Clarke (1847-1931). In Canada the study of geochemical processes began with T. Sterry Hunt (1826-1892), a longtime member of the Geological Survey of Canada. Since Hunt's time various facets of the chemistry of the earth have been taken up by many agencies and academic institutions concerned with geology, mining, agriculture, forestry, fisheries, meteorology,

It need hardly be pointed out that the chemistry of the earth has an infinite number of practical applications. These of course depend essentially on the knowledge of the fundamental chemical processes taking place in the earth. The latter constitutes the basic research aspects of geochemistry and on this depends the development of ways and means of controlling and utilizing the natural chemical environment. Some of the practical aspects of the chemistry of the earth include utilization of the knowledge of the chemistry of soils for the betterment of agriculture and forestry; utilization of the knowledge of the chemistry of natural waters in water supply, fisheries, and the amelioration of the pollution problems that beset the nation as a result of industrialization; utilization of the chemistry of the atmosphere in assisting meteorology and alleviating pollution; and utilization of the knowledge of the distribution of certain elements in soil and water in combating certain endemic diseases in plants, animals, and man caused by deficiencies or excesses of these elements. In addition a knowledge of the chemistry of rocks assists in a better understanding of the nature and origin of mineral deposits, and geochemical prospecting provides a relatively cheap and efficient method of discovering new mineral deposits and accumulations of petroleum and natural gas on which Canada will depend for future supplies of raw materials for its increasing industrialization and export trade.

The number of fields on which geochemistry impinges is so diverse that a division into self contained units is necessary for any logical discussion of research and development. The committee, has, therefore chosen to accept the following subdivisions of the overall field of chemistry in the earth sciences and related fields.

1. Cosmochemistry - includes the chemistry of the cosmos and the abundance of the elements in the cosmos; also includes the chemistry of meteorites.
2. General geochemistry - includes primarily the chemistry of the various spheres of the earth and the abundance of the elements in these spheres.
3. Atmochemistry - includes the chemistry of the atmosphere and those aspects of meteorology and climatology that have a chemical basis. Also includes high altitude chemistry and air pollution.
4. Hydrogeochemistry - includes those aspects of hydrology that have a chemical basis, specifically the hydrogeochemistry of surface and ground waters excluding chemical oceanography and limnology. Includes the chemistry of hot springs.
5. Chemical oceanography and limnology - includes all chemical aspects of the oceans, major lakes, and rivers.
6. Pedochemistry - includes all chemical aspects of soils and other surficial materials. Specifically to include soil pollution.
7. Biogeochemistry - includes all chemical aspects of biogeochemistry as they affect geological processes. Also includes organic geochemistry.
8. Isotopes and geochronology - includes all chemical aspects of isotopes in geochemical processes. Also includes geochronology.
9. Geochemistry of mineral deposits - includes all chemical and isotopic research designed to elucidate the nature of the chemical processes that lead to the concentration of the elements in economic deposits.
10. Geochemical prospecting - includes research, development, and application of chemical methods as applied to the analysis of the materials of the various spheres of the earth in the search and discovery of mineral deposits, petroleum, natural gases, and other hydrocarbons.
11. Mineralogical phase geochemistry - includes high temperature - high pressure and low temperature - low pressure synthesis of minerals as well as laboratory experiments to simulate geochemical processes in nature.
12. Analytical chemistry of rocks, minerals, and fossil fuels - includes research and development of analytical

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An effort was made by the Committee members to use the statistical data compiled from the general survey of chemistry¹ R. and D. made by the C.I.C. However, the Committee found that the C.I.C. data tended to take into account much more in geological science than that part covered by geochemistry and other facets of chemistry in the earth sciences. They decided, therefore, to base their briefs on their intimate knowledge of the specific fields covered.

13. Data processing in geochemistry -- involves the selection and storage of data; the use of computers to select, compare, compute, and assess data statistically, to test hypotheses and mathematical models against stored data; the retrieval of data selectively or in computer form; and their display in standard, tabular, or graphic form.
14. Education and research in geochemistry in Canadian universities includes the teaching of all facets of geochemistry and research by professors, research fellows, undergraduates, and graduates in Canadian Universities.

Method of Collecting Information

Because of the great diversity of the field of chemistry in the earth sciences it was necessary to organize a committee of ten men, each a specialist in a particular field. Each committee member surveyed the particular field for which he was responsible and compiled a concise brief which forms part of the appendices of this report. In addition a number of briefs were solicited from individuals in Industry, Government, and the Universities on particular fields. These briefs are also included in the appendices.

The chairman interviewed numerous geologists, geochemists, and others interested in the chemistry of earth sciences at a number of universities, various government research organizations, and mining companies. The consensus of their opinions is included in the main report.

The annual reviews of "Current Research in the Geological Sciences in Canada", compiled by J. F. Henderson for the National Advisory Committee on Research in the Geological Sciences, the "Annual Reports on Support of University Research" by the National Research Council, and the report "Graduate Students at Canadian Universities in Science and Engineering" by the National Research Council were invaluable in obtaining an overall idea of the level of activity in

Research on the chemistry of the cosmos and on the abundance of the elements and isotopes in the cosmos involves spectral studies of various celestial bodies, chemical and isotopic analysis of extra-terrestrial materials such as meteorites and samples from the moon and other celestial bodies when available, and chemical and isotopic analysis of all types of earth materials. The analytical data from the above, when treated statistically, yield average abundance figures for the elements and their isotopes in the earth and in the cosmos as a whole. Combined with various nuclear data, known chemical reactions in the earth, and petrological research, the distribution of the elements in various earth and extra-terrestrial materials gives a crude idea of the chemistry of the cosmos.

Much work of the above type has been done at many institutions throughout the world, and numerous tables of abundance figures for the elements and their isotopes are available. These indicate that the general order of magnitude of the abundances of the elements and their isotopes in the crust of the earth is now well known, and further work will be concerned with details. The abundance data for the cosmos as a whole are, however, uncertain, and the orders of magnitude may be greatly in error. Similarly, while the outlines of the chemistry of the crust of the earth are relatively well established, the chemistry of the interior of the earth and of the cosmos as a whole is mainly a matter of speculation.

Research in cosmochemistry is a long term proposition, and there are few breakthroughs such as occurred in the early part of this century with the discovery of radioactivity, nuclear fission, and nuclear

'chemical fall-out' of routine and specialized work such as astrophysical and spectroscopic studies of heavenly bodies, investigations of various natural nuclear processes, chemical investigations of meteorites and other extra-terrestrial materials such as those that presumably will soon come from the moon, and general geochemical investigations of earth materials.

In Canada routine and specialized investigations of the above types are carried out at a number of institutions including the Dominion Observatories (Astrophysical and spectral studies of heavenly bodies), the various universities (studies of nuclear processes, general geochemical studies, meteorite studies), the National Research Council (nuclear studies, meteorite studies), Atomic Energy of Canada, Limited (nuclear studies and abundance of the elements), and various other federal and provincial government institutions (general geochemical studies and meteorite studies).

Meteorite studies have always played a large part in cosmo-chemical research. Dr. J. A. V. Douglas of the Geological Survey of Canada briefly reviews Canadian research on meteorites (Appendix I). He maintains that meteorites play an important part in geochemical abundance studies of trace elements and isotopes, and remarks that chemical and mineralogical studies of meteorites may lead to a better understanding of the laws governing the distribution of the various elements in the earth's mantle and core. This could provide useful information in the future exploration of mineral deposits at great depth in the earth. Furthermore, a knowledge of the chemical and crystallographic characteristics of meteorites may have future applications to Canadian metallurgical processes since the characteristics of meteoric

The level of chemical research on meteorites in Canada appears to be adequate, and the necessary analytical facilities are available for expanded research at a number of Canadian universities and government institutions. According to Dr. Douglas financial assistance should be increased, however, to provide adequate funds for meteorite searches by the Associate Committee on Meteorites of the National Research Council of Canada. He mentions an annual sum of \$10,000 as adequate for this purpose. When the proposed network of cameras for tracking incoming fireballs is installed by the Dominion Observatories throughout a large part of Western Canada, the money required for searches will probably increase because of the greater number of sightings. In the matter of education and training Dr. Douglas emphasizes that a fuller treatment be given to the basics of meteoritics in university courses, in order to stimulate research in this aspect of cosmochemistry.

The race to the moon by the U. S. A. and U. S. S. R. has fired the imagination of man in the second half of the twentieth century, and it certainly goes without saying that the analysis of moon material will represent a great advance in cosmochemistry. A group of officers of the Geological Survey of Canada and Dominion Observations have been named by the United States National Aeronautics and Space Administration (NASA) to undertake petrological, mineralogical, geophysical, isotopic, and chemical studies of a sample of lunar crustal material to be obtained by the United States Apollo space program. The chemical and isotopic studies by this group as well as those by other groups in numerous countries will be of great interest to all concerned with cosmochemistry.

The number of personnel engaged in cosmochemical research in Canada and the amount of money actually expended on cosmochemistry in Canada cannot be estimated because of the 'by-product' nature of the

subject. THE CHAIRMAN, after consultation with numerous authorities in Canada, U.S.A. and overseas, judges that the level of activity in Canada, the money expended in the past, and that to be expended in the next five years are adequate for a country with the population of Canada. It would seem, judging from past performance in this field, that future progress is assured. He would point out, however, that certain gaps exist mainly in research in the fundamental aspects of the geochemistry of the earth's crust. These are discussed in greater detail in the section below.

2. SURVEY OF RESEARCH AND DEVELOPMENT IN GENERAL GEOCHEMISTRY

General geochemistry is concerned with the chemistry of the elements and their isotopes in the five spheres of the earth (lithosphere, pedosphere, hydrosphere, atmosphere, and biosphere) and with the abundance of the elements and their isotopes in these spheres. The subject is a comprehensive and diverse one, and the details are considered at greater length in the sections that follow on the various subdivisions of geochemistry, viz atmo-geochemistry, pedogeochemistry, etc. Here only some generalities are considered.

Research in general geochemistry is pursued in at least three ways -- (1) by chemical and isotopic analyses of rocks, soils, sediments, waters, the air, and biological materials; (2) by studies of dynamic chemical processes in the five spheres of the earth, at the interfaces of these spheres, or where one sphere impinges on one or more of the other spheres; and (3) by chemical and isotopic experiments devised to simulate the natural situations. Analyses of materials from the five

respective spheres, and these when integrated, with due regard to the quantitative aspect of each sphere, yield overall abundance figures for the earth. A knowledge of the chemical reactions in the earth yields information on the migration, concentration, or dispersion of the elements in the various spheres of the earth. All of these aspects are of vital importance in the practical use of geochemistry, especially in agriculture, in forestry, in the fishing industry, in pollution control, and in geochemical prospecting for mineral deposits. The fundamental data on abundances and on the chemistry of the elements in the earth are the foundation on which all practical work in geochemistry is based.

The data of fundamental geochemistry come from several sources, as follows: (1) Geological, mineralogical, and petrological investigations, (2) various investigations by soil scientists, (3) various investigations by oceanographers, hydrologists, and water control agencies, (4) meteorological and air chemistry studies, (5) various biochemical and biogeochemical investigations, and (6) specialized geochemical investigations.

Because of the diversity of the origin of the data it is nearly impossible to estimate the number of personnel engaged in providing fundamental geochemical data. It is also impossible to determine the money expended on the acquisition of the data since the geochemical aspect of the various investigations ranges all the way from minor to major proportions.

Since 1945 research in general geochemistry at Canadian universities and government institutions has increased yearly to a relatively high level. However, on a per capita basis, compared with the U.S.A., U.S.S.R., Britain, and France, the level of activity is still relatively low, not because of lack of funds but rather through

lack of trained specialist personnel. There are some serious gaps in the fundamental data from certain spheres of the earth in Canada mainly because of too much specialization in certain fields, particularly in those concerned with igneous rocks and igneous processes.

The state of the production of fundamental geochemical data is discussed briefly below.

1. The production of geochemical data on igneous rocks, igneous processes, metamorphic rocks, and metamorphic processes is adequate and expanding yearly. This is probably because of the traditional stress at Canadian universities and government institutions on igneous rocks and igneous processes and metamorphic rocks and metamorphic processes.

2. The production of geochemical data on sedimentary rocks and sedimentary processes is low and not expanding rapidly enough, having regard to the importance of these rocks and processes in petroleum and ore geology.

3. The production of geochemical data for all varieties of surficial materials (soils, till, glacial clay, stream and lake sediments) is adequate for agricultural needs and probably also adequate for the needs of the foresters. It is inadequate for pollution research, and certainly inadequate as far as geology is concerned, especially geochemical prospecting. Few geochemists have been addressing themselves to surficial materials research in Canada mainly because most universities have neglected to expand training and research in this field commensurate with present day needs. Most government geological institutions have, likewise, failed to expand sufficiently in this field. Research in surficial chemical processes at universities and government institutions is woefully inadequate, a state

that urgently requires correction, considering that the surface geology of Canada is largely concerned with Pleistocene deposits and soils developed on them. Further remarks about the inadequacy of surficial materials research are made in the section on geochemical prospecting.

4. The production of geochemical data on natural waters (ocean, lake, river, stream, and ground waters) falls into two categories -- that concerned with major constituents and that concerned with trace constituents. The production of data on major constituents by various government institutions and agencies has been extensive and will probably expand in the next five years to a level commensurate with the requirements of the country. The production of data on the trace constituents of all natural waters is completely inadequate at this point in time, having regard to the fact that this data is particularly valuable in pollution control, in fisheries research, and in geochemical prospecting.

There is also a dearth of research activity concerned with the solution, migration, and precipitation of the elements in natural waters at both the universities and various governmental institutions. Furthermore there is no attempt to train students intensively in the complex chemistry of natural waters at any of the universities in Canada.

Chemical research on cold springs and hot springs has been completely neglected in Canada, this despite the fact that these phenomena are important from the viewpoint of the tourist industry and from the viewpoint that many springs may contain elements which could be extracted economically. As a measure of the neglect it should be stated that the last comprehensive chemical report on the springs of Canada appeared in 1926.

5. The production of fundamental data on the atmosphere continues at a relatively low level, insufficient for the purposes of the vital problem of pollution control.

6. The production of biogeochemical data and research on biogeochemical processes is not adequate in Canada considering the importance of the field to pollution, geochemical prospecting, the petroleum and natural gas industries, and the health of the nation. With the exception of some notable work done at one university and one federal government institution few geochemists have addressed themselves to the problems of biogeochemical processes involving plants and animals. Likewise, with the exception of one federal and one provincial government institution, where some good work has been done, there is a dearth of research on the natural hydrocarbons. This despite the fact that Canada is a major producer of petroleum and natural gas. There is also a glaring gap in geochemical research on coal.

3. SURVEY OF RESEARCH AND DEVELOPMENT IN ATMOSPHERIC CHEMISTRY, INCLUDING AIR POLLUTION AND UPPER ATMOSPHERIC STUDIES

Atmochemistry is concerned with the chemistry of the near surface atmosphere and the high atmosphere up to a level of 50 kilometres or more. Work done in the field is generally part of more extensive studies that have a physical and meteorological basis. Research in the field is particularly important in the control of pollution of the air.

Dr. J. L. Sullivan of the Department of National Health and Welfare outlines in his brief (Appendix II) the level of activity and the state of research in atmospheric chemistry, upper atmospheric studies,

in Canada, but finds that compared with the U.S.A. and some European Countries research in the chemical, as well as other aspects of air pollution, lags well behind. Furthermore, apart from work directed toward air pollution little or no research on the chemistry of the surface level atmosphere is being done in Canada, nor is there any research in atmospheric chemistry related to climatic modification.

Dr. Sullivan attributes the low level of activity in atmospheric chemistry to inadequate finance of research in this field and stresses the need for a several fold increase in research expenditure in the next few years. He also mentions a lack of co-ordination in research effort in atmospheric chemistry in Canada and finds various impediments due to jurisdictional problems between federal and provincial agencies. Universities should be given greater encouragement to develop graduate studies in air chemistry, otherwise a shortage of trained staff will present difficulties for the future.

4, 5. SURVEY OF RESEARCH AND DEVELOPMENT IN HYDROGEOCHEMISTRY, CHEMICAL OCEANOGRAPHY, AND LIMNOLOGY

Hydrogeochemistry is concerned with the chemistry of natural waters in all environments of the earth. Work done in the field is generally part of more extensive surveys involving hydrologic studies, water control studies, and pollution.

Dr. I. C. Brown outlines in his brief (Appendix III) the level of activity and the state of research and development in groundwater studies in Canada. He states that activity in hydrogeochemistry has increased greatly in the last ten years, and that all agencies which he polled agree

dollars in the next five years. Dr. Brown, himself, estimates a doubling of effort in the next five years to the point where annual expenditures for the whole of Canada could be in the order of five to ten million dollars for research and development in the groundwater field. He points out, however, that while university courses are being developed to cover the field, they are inadequate at present, as is also the supply of undergraduate and post-graduate students.

Drs. J. P. Tully and B. A. Gingras outline in their brief (Appendix IV) the state of research and development in oceanography and limnology and in the important field of pollution control in natural bodies of water. It is evident from their brief that the level of research and development in all aspects of oceanography and limnology will increase to a satisfactory level in the years ahead. They stress, however, that the training of chemists in oceanography, limnology, and anti-pollution research is inadequate at the present time, and that there are very real requirements for better training in water chemistry of graduates from technical institutes and at the B. Sc. level from universities.

Despite the favourable state of hydrogeochemistry in Canada and assurance of progress in the field in the next five years the chairman feels that there are still some gaps in research in the subject in Canada. These include the general low production of data on trace elements in all types of natural waters, and the general low level of detailed field and synthetic research on the solution, migration, and precipitation of the elements in natural waters. With respect to the last subject there is a general paucity of data on the nature of organic compounds in natural waters and their effect on the solution, transport, and precipitation of the elements. This is an important matter since many of the natural waters of Canada have a high organic (humic)

content. Finally, the chairman would stress that the chemistry of hot springs requires much more attention in the future.

6. SURVEY OF RESEARCH AND DEVELOPMENT IN PEDOCHEMISTRY

Pedochemistry is the science dealing with the chemistry of surficial materials including soils, weathered rocks, glacial till, glacial clay, and other glacial materials. The science is particularly important in agriculture and forestry and also in surficial geology and geochemical prospecting.

Dr. J.S. Clark, Soil Research Institute, Department of Agriculture, Central Experimental Farm, Ottawa, in his brief (Appendix V), reviews the state of research and development in pedochemistry and soil pollution, principally from the viewpoint of agriculture and forestry. He states that the past and present objective of agricultural pedochemistry is to make most effective use of the soil resource for food production. The virgin nutrient factor in soils is, however, not now as important as it was in the past because of the introduction of chemical fertilizers. Dr. Clark concludes from this feature that although pedochemical activity will be necessary to ensure high agricultural production, there appears to be no long term agricultural justification for a major expansion in pedochemistry. On the other hand he sees an expansion of pedochemistry in the future in the fields of forestry, in waste disposal, in soil pollution, and in geology and engineering. From the viewpoint of education in pedochemistry Dr. Clark thinks that the number of pedochemists coming from the universities is slightly below the anticipated need, but the gap is not large and can be reduced or eliminated by increasing the number of students in the field.

in the chemistry of surficial materials with a number of Pleistocene geologists and with geochemists interested in geochemical prospecting. The general consensus of opinion is that the level of activity in this field is inadequate. There have been, for instance, only a few limited and local efforts to characterize the chemistry of glacial tills and clays in Canada, and one can say truthfully that we know practically nothing about the major and trace element content of the glacial deposits in this country. Furthermore, we have no idea of the post-depositional chemical history of surficial deposits in Canada, and there have been few if any synthetic researches on the migration and concentration of the elements in glacial materials. In addition there has been only a limited amount of systematic work on the geochemistry of the extensive muskeg areas of Canada. The latter deficiency is amplified in more detail in the section on biogeochemistry below.

7. SURVEY OF RESEARCH AND DEVELOPMENT IN BIOGEOCHEMISTRY

Biogeochemistry is that branch of science which is concerned with the interaction and effects of living organisms on the natural cycle of the elements and their isotopes in geochemical processes. More specifically biogeochemistry is intimately concerned with the chemistry of all natural organic substances in the biosphere, both living and dead. Among the living are the organisms that comprise the two great kingdoms -- the Plantae and Animalia -- and those of microscopic dimensions, the typical bacteria and algae. In the category of the dead are humus, peat, coal, carbonaceous shales, petroleum, and various other hydrocarbons, all of which were derived in one form or another from once living organisms.

and the synthetic. The analytical one employs the methods of chemical and other types of analyses to trace the cycle of the elements in biological systems. The synthetic one attempts to reproduce and study the course of natural biogeochemical systems in the laboratory. An example of the latter would be a laboratory study of the role of sulphate reducing bacteria in the precipitation of sulphides under the conditions of sedimentation thought to be present in certain reducing basins in the oceans.

The data of biogeochemistry are derived from a variety of sources - from the researches of biologists, biochemists, coal and petroleum chemists and geologists, soil scientists, and biogeochemists. Since the data have such a varied derivation it is impossible to give an adequate estimate of the number of scientists actually involved in biogeochemical research in Canada and the yearly amount of money actually spent on obtaining the data. Dr. Fortescue in his brief to the Committee (Appendix VI) estimates that overall there are perhaps about a hundred scientists working on some facet of biogeochemistry in Canada. Of these probably less than ten are fully engaged in biogeochemical research. The latter are grouped mainly in four institutions, the University of British Columbia, the Alberta Research Council, the Geological Survey of Canada, and the Bedford Institute of Oceanography. The yearly cost of biogeochemical research (excluding salaries) in Canada is estimated by Dr. Fortescue to be a few tens of thousands of dollars.

To describe the present level of biogeochemistry in Canada and point out the existing gaps in research in the science, a grouping into subjects is necessary. These include: (1) general biogeochemistry and

deposits such as mires (bogs and fens) and other types of poorly consolidated organic materials, (3) research in coal chemistry, (4) research in the chemistry of petroleum and other natural hydrocarbons, (5) research in carbonaceous shales and other similar types of organic sediments, and (6) synthetic biogeochemical research.

(1) The level of activity in general biogeochemistry and in the study of biogeochemical processes is difficult to assess because these are the fields where a considerable amount of work has been done and is being done by a great variety of scientists, including biologists, biochemists, and biogeochemists. Compared with the level of activity in these fields in U. S. S. R., U. S. A., and Great Britain the level of activity in Canada seems low on a population basis, although it should be remarked that some very good work has been done and is being done in Canada which is recognized throughout the world. There are, however, many serious gaps in our knowledge of the cycle of trace and minor elements in the plants and animals in the Canadian setting which should be filled by increased research. Such knowledge is especially valuable in endemology and in geochemical prospecting.

Pollution of the biosphere, especially as it relates to the health of man, is a concern to all. The Department of National Health and Welfare, as well as various Provincial health agencies, are vitally concerned with this particular problem and carry out a large number of routine checks and analyses of food stuffs and other products used by the populace. The Department of National Health and Welfare has long been monitoring natural materials for Sr-90 and Cs-137 arising from atomic explosions. This work is continuing. In addition, this department has also initiated specialized studies in natural radioactivity and its effects on animals and man. Also recently initiated are studies of the

a moderate level at a number of institutions in Canada. At the Soil Research Institute, Department of Agriculture, Ottawa, much good work on organo-metallic compounds in soils has been done and is continuing. The chemistry of peat has also received considerable attention at the Quebec Department of Mines and at the Fuels Research Center, Mines Branch, Ottawa. Studies of mires (bogs and fens), the familiar muskeg to many people, have been pursued at McMaster University and the National Research Council for a number of years. All of this research has supplied data that are invaluable to geochemistry. Chemical research on mires has been pursued at the National Museum of Canada, at the Geological Survey of Canada, and by certain individual geochemists in mining companies. Despite all this work our knowledge of the chemical processes in humic deposits is meagre, and there remain numerous facets which are relatively uninvestigated in Canada. Foremost among these is a knowledge of the distribution, migration, and fixation of various trace elements such as copper, zinc, and uranium in mires and other humic deposits. Such knowledge is of great importance in geochemical prospecting because large parts of Canada are covered by organic terrain.

(3) Research in coal chemistry has been carried out mainly at the Fuels Research Center, Mines Branch, Ottawa and at the Alberta Research Council. Much of this work has been directed toward coal utilization, but the data are also useful in geochemical studies on the origin of coal. The distribution of trace elements in coal has received some attention at Queens University and elsewhere, but there has been relatively little work of this kind in recent years at any institution in Canada. Furthermore there have been no systematic geochemical

investigations of the Canadian coal basins and their enclosing sediments.

This is one aspect of the geochemistry of coal that requires attention in Canada.

As far as the chairman can ascertain there is no course in coal geochemistry at any university in Canada nor are there any research projects on the geochemistry of coal or coal basins now in progress at any university or government institution in the country.

(4) Research in the chemistry of petroleum and other natural hydrocarbons is carried on extensively in a number of industrial laboratories; at the Fuels Research Center, Mines Branch, Ottawa; and at the Alberta Research Council. Most of this work is directed toward petroleum and natural gas utilization but the data are in many cases useful in geochemical studies of the origin, migration, and concentration of petroleum and natural gases.

Some of the research, such as that on porphyrins, carried out in the Petroleum Division of the Alberta Research Council, is directed specifically toward the problem of the origin and migration of petroleum. Similar research on the organic constituents of marine sediments underway at the Bedford Institute of Oceanography is, likewise, of fundamental importance in deciphering the origin of the mother substance of petroleum.

Outside of these studies and a few others, some dealing with the sulphur isotopic composition of oils and minerals in their reservoir rocks, there is no concerted research attack on the geochemistry of petroleum and other hydrocarbons at Canadian institutions. There is, likewise, with the exception of only one project now completed by the Geological Survey of Canada, no effort by Industry, Universities, or

prospecting. These are rather strange and serious gaps, considering the importance of petroleum in the economy of the nation.

(5) Research in carbonaceous shales and other similar types of organic sediments has received some attention at a number of Canadian universities and government institutions. The level of activity is, however, low having regard to similar work now going on in U.S.A. and U.S.S.R. Black carbonaceous shales, bituminous shales, and other similar sedimentary rocks are often enriched in many metals such as copper, zinc, and uranium as well as in bitumin and other organic constituents. Such sediments will be low grade metal deposits and sources of hydrocarbons in the future. A knowledge of their chemistry is imperative now to provide a basis for their utilization in the years ahead.

(6) Synthetic biogeochemical research to simulate processes whereby organisms concentrate or disperse the elements in nature has received little, if any, attention at Canadian universities and government institutions. The reason for this is not clear but probably stems from the fact that biochemists, have not taken any interest in the subject and that geologists and geochemists in Canada are traditionally inorganically oriented as a result of the curricula at most Canadian universities. This situation persists despite the fact that it has been known for many years that bacteria and many other organisms play a part, probably a major part, in oxidation processes in ore deposits, in sedimentation processes, in the formation of petroleum, and indeed in the formation of numerous types of sedimentary ore deposits as well as those in faults, fractures, and other structures. It is time for the universities, government institutions, biochemists, and geochemists to take note of this fact and direct their attention to synthetic biogeochemical research in order to rectify this grave omission.

8. SURVEY OF RESEARCH AND DEVELOPMENT IN THE NATURAL DISTRIBUTION OF ISOTOPES AND GEOCHRONOLOGY

Studies of the natural distribution of isotopes in the materials of the spheres of the earth, in addition to providing fundamental data on the abundance of the various isotopes of the elements in nature, also, when properly applied, yield information on various geochemical processes concerned with the formation, metamorphism, and transformation of rocks and the formation of mineral deposits, petroleum, and natural gas. Studies of the abundance of those isotopes that arise through radioactive decay in the rocks of the earth provide a basis for measuring geological time, a science now known as geochronology. Both types of studies have been pursued at Canadian universities and government institutions with increasing tempo since 1945.

Most of the research on stable isotopes in Canada has been concerned with the isotopes of sulphur, lead, hydrogen, carbon, and boron, with some limited work on magnesium, and a few other elements. The geochronological laboratories in Canada have specialized in dating methods utilizing K/Ar, Rb/Sr, U/Th/Pb, and Pb/Pb isotopic systems and radiocarbon measurements. Much of the work on stable isotopes has been directed toward elucidation of the processes of formation of mineral deposits, native sulphur deposits, and petroleum accumulations. The geochronological investigations have been focused on both local and regional problems concerned with the age of intrusive rocks, stratified rocks, and mineral deposits. Radiocarbon measurements have been used widely in interpreting the age of Pleistocene deposits of till and other materials containing carbon.

Dr. R. K. Wanless of the Geological Survey of Canada, in his brief submitted to the committee on the history of geochronology, and the brief submitted to the committee (Appendix VIII) reviews the history.

level of activity, and future of isotopic research and geochronology in Canada. His estimates of present and future activity and expenditures of money appear to auger well for research in geochronology but leave much room for improvement in the study of stable isotopes in the opinion of the chairman and other geologists whose opinions were sought on the subject. Dr. Wanless also notes a general scarcity of trained professional and technical personnel, especially the latter, in the isotopic field. He points out that our technical institutes are not producing personnel with training and experience in vacuum technology and an understanding of isotopic problems.

To summarize briefly, it appears that geochronological research in Canada is adequate and assured of a good future. Stable isotopic research, especially that directed toward elucidation of the processes of formation of rocks and mineral deposits is lagging compared with the effort in U. S. A., U. S. S. R., and other countries. (See also section 9 below.)

9. SURVEY OF GEOCHEMICAL RESEARCH OF MINERAL DEPOSITS

Geochemical research of mineral deposits includes the following:

1. Analysis of the geological and structural setting of the deposits. This is essentially a geological problem and will not be discussed further.
2. Analysis of the abundance or content of the various elements (and their isotopes) in the deposits.
3. Elucidation of the source of the elements comprising the deposits.
4. Elucidation of the geochemical processes that have produced the concentration of the elements in the deposits.
5. Elucidation of the geochemical processes that disperse the elements from deposits during weathering processes.

The reader familiar with the various problems in the genesis of mineral deposits will recognize that the first is a matter of geological observation and the second a matter of chemical and isotopic analysis. The third admits of some interpretation if it is assumed that the elements were derived from rocks on the plane of observation and that can be chemically analyzed. The fourth is largely a matter of inductive and deductive reasoning as only the products of the processes remain as object of study. Synthetic studies, simulating natural conditions, are useful in the fourth problem in limiting speculative possibilities. The fifth problem generally admits of solution since the initial minerals, the solutions involved in weathering, and the final mineral products resulting from the various weathering reactions are available for study. Solutions to all of the five problems are fundamental to the application of geochemical methods of prospecting.

Research in all of the above aspects of the genesis of mineral deposits has been carried out in Canadian universities and various government institutions for many years. Most of the emphasis has been placed on items 1, 2, and 4 above. The level of activity in geochemical research in mineral deposits has, however, declined somewhat in recent years in both universities and government institutions in the opinion of the chairman, a situation that is to be deplored considering the importance of mineral deposits in the economy of the nation. There is also less emphasis on teaching the fundamentals of mineral deposits and their chemistry in the curricula of many universities, another situation that requires correction. Graduate work in the genesis of mineral deposits at our universities also appears to be declining rather than increasing when compared with the phenomenal growth of the mineral industry in Canada.

Specifically, more research should be directed to elucidating the source of the elements comprising mineral deposits. In this respect the new methods of trace element analyses and stable isotopic analyses should be used much more than they have been in the past. Finally, research on the chemical and mechanical processes that disperse the elements from deposits during weathering and glaciation requires much greater emphasis in our graduate schools and government institutions, because of the great importance of the subject in geochemical prospecting.

10. SURVEY OF RESEARCH AND DEVELOPMENT IN GEOCHEMICAL PROSPECTING

Geochemical prospecting is the applied part of geochemistry that has as its aim the discovery of mineral deposits and accumulations of hydrocarbons. The importance of the field need hardly be emphasized in the economy of the nation.

Briefly the various methods of geochemical prospecting that can be applied are based on major, minor, or trace element analyses of weathered products, soils, and glacial tills (pedogeochemical methods), on similar analyses of rocks (lithogeochemical methods), on similar analyses of water and stream sediments (hydrogeochemical methods), on similar analyses of gases (atmogeochemical methods), and on similar analyses of biological materials of all types (biogeochemical methods).

The basis of geochemical prospecting in all methods is the minor or trace element halo or dispersion train which may be either of a primary or secondary nature. The primary halo or train is formed at the time the orebodies were deposited; the secondary halo or train generally results from weathering and transport processes. These halo and train

reflect the presence of mineralization in many ways in the rocks, soils, waters, stream sediments, rock gases, atmospheric gases, and biological materials. The details of the halos are much too complicated to be dealt with here, but a general idea of their nature is discussed in some of the briefs appended to this report.

The halos and trains provide the "anomalies" for which all geochemists search.

The modern development of geochemical prospecting springs directly from the work in the nineteen thirties of the famous Russian geochemists A.E. Fersman, V.I. Vernadsky, I.I. Ginzburg, and A.P. Vinogradov, and the Scandinavians, V.M. Goldschmidt, S. Palmqvist, and N. Brundin.

The concept of prospecting by geochemical methods was introduced into Canada by H. Lundberg in 1940, but it was not until 1945 when Drs. H.V. Warren and R.E. Delavault and their co-workers at the University of British Columbia began their research that geochemical prospecting methods began to be taken seriously. Other early workers included J.E. Riddell at McGill University and H. Hawkes, H. Bloom, J.E. Riddell, and J.S. Webb who conducted the first large scale geochemical reconnaissance survey in northern New Brunswick in 1954.

Research in geochemical prospecting by the Geological Survey of Canada began in 1949 when a study of primary halos associated with gold deposits in the Yellowknife area was undertaken. This has been followed by work on waters and soils in the Yukon; reconnaissance surveys of waters and stream sediments in Nova Scotia and New Brunswick; biogeochemical surveys in a number of metalliferous belts in Canada; bedrock surveys in Northern Ontario and in carbonate rocks in Western

Canada; and hydrocarbon analyses of soils over known oil fields in Eastern and Western Canada. In addition, a number of other projects have been carried out both in the field and laboratory, concerned with the development and improvement of geochemical methods and techniques.

Geochemical methods of prospecting have been adopted by industry on an ever increasing scale. From the initial efforts of E. O. Chisholm in 1949, geochemical prospecting methods have grown to be one of the major tools in mineral exploration. Several of the provincial governments have recently carried out regional geochemical studies as an aid to prospecting within their boundaries.

Because of the importance of geochemical prospecting to the mining and petroleum industry briefs were requested from a number of individuals in mining exploration, consulting services, and universities. In addition a number of interviews were held with geologists carrying out exploration programs in various parts of Canada. The general consensus of those submitting briefs (Appendices VIII to XII) and those interviewed is:

1. The expenditures on geochemical prospecting by the mining industry is considerable; in 1967 Dr. Clews (Appendix XI) estimates that the expenditure was 2.5 million dollars; in five years this expenditure will increase to 5 million dollars.
2. The expenditures on geochemical prospecting by the petroleum industry is negligible.
3. A serious shortage of experienced geochemists capable of carrying out geochemical surveys and interpreting the results from such surveys exists in Canada.
4. While some good research in geochemical prospecting has been done at two universities and two government institutions in Canada the

level of activity in geochemical prospecting research is far below that required in the subject and on a comparative basis far below that in U.S.S.R., U.S.A., and Great Britain.

The reason for the low level of activity in government institutions has been primarily the recruitment and retention of qualified geochemists at salaries equivalent to those in industry. In the past there has also been a failure of government executives at all levels to appreciate the importance of geochemical prospecting research to the mining and petroleum industry of Canada.

The reasons for the low level of activity in geochemical prospecting research at our universities is difficult to assess accurately but seems to stem from the fact that many geological faculties and faculty heads view problems in mineral deposits and prospecting for mineral deposits as being not scientific - this despite the fact that the 'bread and butter' of geological science is mineral and petroleum deposits. The comments by Drs. Warren and Delavault, two of the pioneers in geochemical prospecting research in Canada seem particularly pertinent in this matter (Appendix VIII): "When an attempt was made to introduce geochemistry into one Canadian university, with special emphasis on problems involved in mine finding, the attempt was vetoed on the ground that this type of work was not of high enough quality to be considered as a university subject, in spite of the examples provided by London University, and California; surely centres of academic quality and competence", and "Nor do the universities do much to raise the status of the minefinding geochemist. Two of Canada's most important universities do have Institutes of Earth Science, and 'under this umbrella' one might reasonably expect to find

subsurface geology and to geochemistry as applied to mine finding. Such is not the case. Excellent and challenging work is being done in other geochemical fields, such as age dating, but a student enlisting in an Institute of Earth Science in Canada finds little, if anything of substance offered in the fields of geobotany, biogeochemistry, and only a modest initiation to the various aspects of hydrogeochemistry, pedogeochemistry, and lithogeochemistry."

It seems hardly necessary to point out that these circumstances at our universities has led to the state where geochemists, trained in geochemical prospecting techniques and the interpretation of geochemical data, are in short supply.

5. Research in the primary dispersion pattern of metals associated with mineral deposits continues at a low level in all institutions in Canada. This is a subject that requires immediate attention if deeply buried mineral deposits are to be discovered in the future. Research in the secondary dispersion patterns of metals in surficial materials, likewise, requires much more attention than it has received in the past. This aspect of geochemistry has been repeatedly emphasized in other sections of this Committee report. The comment by Dr. Hansuld seems particularly appropriate in this matter (Appendix IV). "R and D in the field of geochemical exploration is, with a few exceptions, just starting. Our understanding of the chemical processes taking place in surficial materials at or near the earth's surface is pathetic compared to what we know or think we know about the chemistry within the earth's crust. This situation is indeed ironic when one considers we can actually see and sample materials at the surface and yet know so little about them."

6. A systematic long term approach to research in geochemical prospecting for petroleum and other hydrocarbons should be started to *into the role of geochemistry in petroleum industry.*

7. Numerous exploration geologists and geochemists have pointed out the necessity of establishing an institute for teaching and research in applied geochemistry at one of the universities in Canada. Various opinions on this matter are given by Dr. Clews (Appendix XI), Dr. Gleeson (Appendix X), and Dr. Coope (Appendix XII). It is the considered opinion of all who were interviewed that such an institute should draw its funds from three sources - the mining industry, the petroleum industry, and government. The direction and teaching in this institute must be by adequately trained applied geochemists, and fundamental research should be mainly by thesis work leading to advanced degrees.

11. SURVEY OF RESEARCH AND DEVELOPMENT IN MINERALOGICAL PHASE GEOCHEMISTRY

This field includes high temperature - high pressure and low temperature - low pressure synthesis of minerals as well as laboratory experiments of various types to simulate geochemical processes in nature.

The field is important in two respects:

(1) The data obtained are exact and limit speculation on the possible geochemical processes responsible for the migration and concentration of the elements in the spheres of the earth. Syntheses cannot be said, however, to solve the problems inherent in natural geochemical processes because of the multicomponent nature of natural systems, their constant change with time, and their very slow reaction rates. The time dependence factor cannot be duplicated in the laboratory.

(2) The data obtained are frequently useful in technology, e. g. silicate systems in ceramics.

Notable advances in mineralogical phase chemistry in Canada have been made in recent years in a number of silicate systems, in sulphide and oxide systems, and in computer techniques for predicting phase boundaries in salt and silicate systems.

Dr. L. J. Cabri reviews the status of the field of mineralogical phase chemistry in his brief (Appendix XIII) and draws the following conclusions:

1. Mineralogical phase chemistry research is in its infancy, having only really started growing in the 1960's.
2. Most of the research in the field is done at universities with limited amounts at a few government institutions. There is apparently no, or very little, research in mineralogical phase chemistry being carried out in industry.
3. The training facilities have developed to a certain extent and are expanding to look after future needs, if continued support is given to the university departments concerned.
4. Government organizations should participate more fully in research in mineralogical phase chemistry. One way to do this would be to establish a non-profit Materials Research Institute which would bring together individuals of numerous disciplines who would work as teams or in direct consultation with one another.
5. The wisdom of having up to ten universities in Canada, each with a relatively small staff engaged in mineralogical phase chemistry should be examined.

With respect to the latter item, the chairman interviewed a number of individuals across a fairly broad spectrum in petrology, mineralogy, geochemistry, and mineral deposits. The consensus of

opinion was that probably three university centres of excellence in training and research in synthetic geochemistry were justified in Canada because of the high cost of the equipment to carry out the work. There is a notion held by a number of university geological faculties that unless synthetic work is being done, that they are not in the research vanguard in geochemistry. Such a notion is of course nonsense. If an analogy can be drawn from biochemistry, it is apparent that analysis of the natural systems, rather than synthesis, will provide the breakthroughs to unravelling the complexities of the systems.

Finally, the chairman would like to point out that there is a predilection in Canada for high temperature - high pressure synthesis to the virtual exclusion of synthetic studies of the natural systems in soils, unconsolidated sediments, and surface waters, most of which operate under low temperature - low pressure conditions. This attitude stems from the traditional training of Canadian geologists whose ^{w/}minds have been ^{trained} brainwashed to think ^{only} in terms of magmas, hot waters, and other high temperature phenomena. It is time for at least one or two university faculties and some government organizations to consider synthetic work in low temperature - low pressure processes as they apply to Canadian conditions.

12. SURVEY OF RESEARCH AND DEVELOPMENT IN THE ANALYTICAL CHEMISTRY OF ROCKS, MINERALS, AND FOSSIL FUELS

The data of geochemistry and indeed the bulk of geochemical research and the applied aspects of geochemistry depend essentially on analysis of earth materials of all kinds. This essential aspect has long been recognized in Canada, and laboratories of outstanding merit have

been established to support geochemical work since its beginnings in the Geological Survey of Canada in 1844. Since that time numerous laboratories specializing in the analysis of earth materials have been established in all universities, research councils, and government organizations doing geochemical work.

The history of development, present status, and future of research and development in the analytical chemistry of rocks, minerals, and fossil fuels are reviewed by Dr. J. A. Maxwell in his brief to the Committee (Appendix XIV). He finds that the level of research and development in techniques is adequate to support present geochemical research in Canada, and that adequate financial support has been provided in the past. The level of activity for the next five years will not change significantly from that which prevailed during the last five.

Dr. Maxwell makes the point that rock and mineral analysis, because of its specialized nature, should be associated with geoscience studies in order to be provided with the stimuli necessary to encourage further research and method development. This latter is probably best done in university geology departments, and support should be given for this purpose. On the other hand the stimulus for developing more rapid methods of analysis that results from increasing demands for increasing numbers of rock and mineral analyses is often lacking in university work, and support should be given for such development work by the government laboratories associated with geological surveys. The only factor limiting research and development in the analytical chemistry of rocks, minerals, and fossil fuels is the lack of trained personnel, a condition shared with the larger field of analytical chemistry.

13. SURVEY OF RESEARCH AND DEVELOPMENT ON DATA
PROCESSING IN GEOCHEMISTRY

Data processing in geochemistry involves the selection and storage of data; the use of computers to select, compare, compute, and assess data statistically, to test hypotheses and mathematical models against stored data; the retrieval of data selectively or in computed form; and their display in standard, tabular, or graphic forms.

Dr. S. C. Robinson in his brief to the Committee (Appendix XV) reviews the history, present status, and future of data processing in geochemistry in Canada. He points out the necessity of using data processing in handling the vast accumulation of geochemical data in all fields of geochemistry and the need for statistical treatment of geochemical data in understanding geochemical processes and in testing mathematical models.

Dr. Robinson states that data processing in geochemistry is just beginning in Canada and estimates that in the next five years there is likely to be very rapid development with tripling of staffs and quadrupling of costs particularly in the mining and government fields. He further emphasises the necessity of geochemists to be trained in statistics and computer science at the undergraduate and graduate levels. Technical institutes should develop courses in computer science to train support staff, and vocational and technical schools should be encouraged to train key punch operators, digitizer operators, etc.

14. SURVEY OF EDUCATION AND RESEARCH IN GEOCHEMISTRY
IN CANADIAN UNIVERSITIES

Teaching and research training in geochemistry in our universities is essential to ensure a continuous supply of trained graduates for

industry, government research organizations, and the professorial ranks. Without a sustained effort in teaching and research in our universities there cannot possibly be any progress in geochemistry in Canada.

Professor J.H. Crocket, Department of Geology, McMaster University in his brief to the Committee (Appendix XVI) outlines the status of education and research in Canadian universities. He notes that 16 universities offer introductory courses in inorganic geochemistry, 6 offer courses in isotope geochemistry and geochronology, 8 in mineral synthesis and stability, 5 in analytical geochemistry, 8 in the geochemistry of soils, and 4 in chemical oceanography. There are obvious deficiencies in university instruction in the fields of organic geochemistry, cosmochemistry, the chemistry of fresh waters, in atmospheric chemistry, and in geochemical prospecting.

As regards research in geochemistry in Canadian universities, Professor Crocket finds considerable activity in the geochemistry of igneous and metamorphic rocks, the geochemistry of ore deposits, soil geochemistry, mineral synthesis and stability, and geochronology. Areas in which research is particularly weak follow the same pattern as those in teaching and include organic geochemistry, sedimentary geochemistry, cosmochemistry, fresh water chemistry, biogeochemistry, stable isotope geochemistry, atmogeochemistry, and geochemical prospecting. The entire field of low temperature geochemistry applicable to aqueous systems and dealing basically with mineral stability and reaction kinetics under temperatures and oxidation conditions prevailing at the earth's surface is very poorly covered by university teaching and current research. This particular feature, as well as that of low research activity in organic geochemistry particularly as regards petroleum, and

the general low research activity in geochemical prospecting has been noticed by others and is commented upon in previous sections.

Professor Crocket further notes that much of the instrumentation required for geochemical research, such as electron microprobes, mass spectrometers, etc., is very costly but must be provided if top research scholars are to be attracted and retained by universities. Technician help is also important if professors are to devote their time to the training and supervision of graduate students.

Professor Crocket also notes that there is no department of geochemistry in any Canadian university at either the graduate or undergraduate level. This seems to be a serious omission in our training facilities in Canada, considering that in the sister science, biochemistry, there are several departments in Canadian universities. The requirement for a teaching and research institute or department in geochemical prospecting is discussed in section 10.

SUMMARY AND RECOMMENDATIONS

1. The level of research activity in cosmochemistry in Canada is satisfactory, but teaching in the subject, especially in the details of meteorites is weak at most universities.

2. Research activity in some aspects of general geochemistry is adequate, particularly in the field of igneous and metamorphic rocks. There are serious gaps and a general low level of activity in the production of fundamental geochemical data on sedimentary rocks and sedimentary processes, on the chemical composition of most surficial materials, on the trace element content of natural waters, on biogeochemical processes, and in organic geochemistry, especially on the natural hydrocarbons and

3. Research activity in atmospheric chemistry, upper atmosphere chemistry, and air pollution continues at a moderate level in Canada. There is need for considerable increase in these fields to cope with the mounting problems of air pollution. Greater stimuli in the form of increased finance, coordination of research projects between federal and provincial agencies, and increased emphasis in the graduate schools of the universities on research in air chemistry are highly desirable.

4. Research activity in hydrogeochemistry, chemical oceanography, and limnology has increased greatly in the last few years in Canada and will reach a satisfactory level in the next five years. Increased attention is required in studies of trace elements in all natural waters, in the humic constituents of surface waters, and in the chemistry of hot springs. Increased efforts at universities and technical institutes in the training of chemists and technicians in oceanography, limnology, and anti-pollution research is prerequisite for future progress in all of these fields.

5. The survey of research and development in pedochemistry indicates that the level of activity in agriculture is satisfactory and that an expansion of the field will take place in the future in the fields of forestry, in waste disposal, in soil pollution, and in geology and engineering. The number of pedochemists coming from the universities is slightly below the anticipated need, but the gap is not large and can be reduced or eliminated with existing facilities and staff.

There is a need for increased research in the chemistry of glacial tills and clays in Canada, particularly for the proper interpretation of geochemical prospecting surveys.

6. Certain aspects of biogeochemical research have received some attention in Canada, but there are large gaps in our knowledge that

require increased attention. These include trace element studies of mires (bogs and muskegs), geochemical studies of coal and coal basins, chemical studies to elucidate the origin of petroleum and the manner of its migration into economic concentrations, and increased emphasis on the chemical constitution of carbonaceous shales and other similar types of organic sediments. In addition there is need for research in synthetic biogeochemical research to control and guide speculation on ideas relating to the migration, concentration, and dispersion of the elements as a result of bacterial and other biochemical agencies.

7. The survey of research and development in the natural distribution of isotopes and geochronology indicates that the level of activity in geochronology is satisfactory and that the future augers well for this science. There is room for improvement in all aspects of stable isotope research, particularly as it applies to the processes of formation of rocks, mineral deposits, and petroleum accumulations.

8. Research in the chemistry and origin of mineral deposits continues at a relatively high level in Canadian universities and government institutions. The research effort has, however, not kept pace with the expanding mineral production of the country, and certain signs indicate that less emphasis is being placed on the teaching of the fundamentals of mineral deposits and on research in these fundamentals in Canadian universities. This is a situation to be deplored and one that requires immediate correction by the geological faculties of all universities. Specifically, increased research at universities and government institutions should be directed to elucidating the source of the elements comprising mineral deposits and to the mechanisms whereby the various elements are concentrated. In this matter, greatly increased research activity in

both field and synthetic studies using all of the available chemical and isotopic techniques are required. Finally, research on the chemical and mechanical processes that disperse the elements from deposits during weathering and glaciation require greater emphasis in our graduate schools and government institutions, because of the great importance of the subject in geochemical prospecting.

9. Geochemical prospecting is used widely by the mining industry in the search for mineral deposits, and it is estimated that its use will double in the next five years. On the other hand the use of geochemical prospecting techniques by petroleum prospecting companies is negligible.

Teaching in geochemical prospecting and basic research in the subject at Canadian universities has not kept pace with increased use of geochemical prospecting by industry. This has resulted in a very low production of Canadian geochemical prospecting specialists. Fortunately a "brain drain" from overseas has partly filled the gap in the demand for geochemists, skilled in the techniques of geochemical prospecting.

A plea is made for increased efforts in teaching and research in all aspects of geochemical prospecting, and it is suggested that an institute for teaching and research in applied geochemistry be set up at some university in Canada - this institute to draw its funds and grants from the mining industry, the petroleum industry, and government.

10. The survey of research and development in mineralogical phase chemistry indicates that an increase in high temperature - high pressure work is taking place and will increase in the next five years. Most of the work is done in the universities and a few government institutions. There is practically no research in low temperature - low pressure processes, an omission that requires correction.

The wisdom of having up to ten universities in Canada, each with a relatively small staff engaged in mineralogical phase chemistry is questioned. It would be better to have three centres of excellence each with the required staff and instrumentation.

The suggestion is made that government organizations should participate more fully in research in mineralogical phase chemistry by establishing a Materials Research Institute which would bring together individuals from numerous disciplines.

11. The level of research and development in analytical chemistry of earth materials is adequate to support present geochemical research in Canada. The lack of sufficient trained personnel remains a problem, a condition that is shared with the larger field of analytical chemistry.

12. Data processing in geochemistry is just beginning, and there will be a rapid development in the next five years with tripling of staffs and quadrupling of costs particularly in the mining and government fields. There is a real requirement that geochemists be trained in statistics and computer science at the undergraduate and graduate levels. Technical institutes and vocational schools should develop courses in computer science to train support staff.

13. The survey of education and research in geochemistry in Canadian Universities indicates considerable activity in teaching and research in inorganic geochemistry, geochronology, mineral synthesis and stability, analytical geochemistry, geochemistry of soils, and chemical oceanography. There are obvious deficiencies in university instruction and research in the fields of organic geochemistry (petroleum and coal), cosmochemistry, the chemistry of fresh waters, atmospheric chemistry, and geochemical prospecting. Most of these deficiencies have been commented on previously.

14. A number of suggestions have been made to the chairman that a National Institute of Geochemistry be established in Canada, combining the features of the Geophysical Laboratory of the Carnegie Institute in Washington and the Vernadsky Institute of Geochemistry and Analytical Chemistry in Moscow. In this respect it should be pointed out that one of the Divisions of the Geological Survey of Canada has for many years been vitally concerned with geochemistry in all of its aspects. The establishment of an Institute of Geochemistry in Canada would seem to be best carried out by the expansion of this Division of the Survey into an institute, adequately staffed and given sufficient funds to carry out all types of research in fundamental geochemistry.

15. In the transactions of the Royal Society of Canada, Fourth Series, Volume II, 1964 -- Towards a National Science Policy -- two aims are specifically outlined for Canada's National Science Policy. These are:

1. To improve greatly our technical competence, especially in areas that relate to our natural resources.
2. To develop and support our scientific talent to the limit of its potential achievement.

The first of these is imperative for the well being of the nation.

Geochemistry has much to offer in the discovery and development of new mineral deposits and petroleum accumulations. In this respect strong support from all sectors must be given to research in the chemistry of mineral deposits, petroleum, and geochemical prospecting. In addition increased support must be forthcoming to maintain a high level of research in the chemistry of our soils and natural waters. We must also be continually aware of the problems of pollution as industrialization proceeds, and money and research personnel must be made available to keep our air, natural waters, and soils clean for the benefit of all Canadians.

16. One final point requires emphasis as regards chemistry in the earth sciences in Canada. It is possible to utilize world-wide chemical knowledge, especially that relating to industrial chemical processes, with a minimum of research and development. Such is, however, not the case in earth sciences. The Canadian natural environment is unique in many respects, and the chemistry of this environment can only be elucidated by sustained research in situ, so to speak.