COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES
GEOLOGY AND GEOPHYSICS.

RECORDS.

1958/23

REPORT ON VISIT TO CANADA AND U.S.A. IN 1957

by

N.J. MacKay

REPORT ON VISIT TO CANADA AND U.S.A. IN 1957

by

N. J. MacKay

RECORDS 1958/23

CONTENTS

PLATES

INTRODUCTION

As delegate for the Australian Government and the Department of National Development, I attended the Sixth Commonwealth Mining and Metallurgical Congress in Canada. The Congress opened in Vancouver, British Columbia, on 8th September, 1957 and closed at Halifax, Nova Scotia, on 10th October, 1957. At the conclusion of the Congress, I visited the establishments of the Ground Water Branch of the United States Geological Survey at Washington, Denver, and Salt Lake City. A visit was also paid to the Exploration Division of the United States Atomic Energy Commission at Grand Junction. I made a brief examination of several uranium mines on the Colorado Plateau whilst in the Grand Junction area, and inspected Bingham Canyon copper mine whilst in the Salt Lake City area.

The route of my visit to Canada and U.S.A. is shown in Plate 1.

ITINERARY

The itinerary of my visit to Canada and U.S.A. was as follows:

September 4 to 6	:	Sydney to Vancouver via Fiji, Honolulu, and San Francisco.
September 8 to 10	:	In Vancouver, B.C.; opening of 6th Commonwealth Mining and Metallurgical Congress; briefing session of the Congress; local tours; examination of mining exhibits.
September 11 to 12	:	Vancouver to Trail, B.C.
September 12	:	At Trail, B.C.; visited lead-zinc smelter and refining plants of the Consolidated Mining and Smelting Company of Canada Ltd.
September 13	:	At Kimberley, B.C.; visited Sullivan lead-zinc-silver mine.
September 14 to 15	:	At Banff, Alberta; field excursion in the Lake Louise-Banff area of the Rocky Mountains, and visit to Athabasca Glacier.
September 16 to 17	:	At Edmonton, Alberta; technical session of the Congress; visited Leduc-Woodbend and Golden Spike oilfields and the Edmonton refinery of British-American Oil Company Ltd.
September 18	:	At Saskatoon, Saskatchewan; tour of the University of Saskatchewan; brief visit to the operations of the Potash Company of America Ltd.
September 19 to 20	:	At Winnipeg, Manitoba; viewed films on mining in Canada and examined exhibits of the mining industry.
September 21	:	At Atikokan, Ontario; visited mining operations of Steep Rock Iron Mines Ltd. and Caland Ore Company Ltd.
September 23	:	At Algoma, Ontario; underground tour of Algom-Nordic uranium mine; geological field trip over part of the Blind River uranium field.

September 24	:	At Sudbury, Ontario; geological field trip across the Sudbury basin.
September 25 to 26	:	At Noranda, Quebec; geological field trip and underground tour of Noranda Mines Ltd.
September 27 to 28	:	At Toronto, Ontario; examined exhibits of Department of Mines and Hydro-electric Power Commission of Canada.
September 30 to October 1	:	At Ottawa, Ontario; tours of Mines Branch and National Research Council; discussion with officers of the Geological Survey of Canada on organisation and work of the Survey.
October 2	:	At Montreal, Quebec.
October 3	:	At Asbestos, Quebec; tour of operations of Johns-Manville Company Ltd. at Jeffrey open-pit asbestos mine and treatment mill.
October 4	:	At Quebec City, Quebec.
October 5	:	At Bathurst, New Brunswick; geological field trip and inspection of operations of Brunswick Mining and Smelting Corporation Ltd.
October 6 to 7	:	At Sydney, Nova Scotia; inspection of Princess Colliery and the coal preparation plant of Dominion Steel & Coal Corporation Ltd.
October 8 to 10	:	At Halifax, Nova Scotia; concluding technical session of the Congress; inspection of the Halifax refinery of Imperial Oil Ltd.; inspection of open-pit mine of Magnet Cove Barium Corporation Ltd.
October 10	:	Halifax to New York.
October 13	:	New York to Washington, D.C.
October 14 to 16	:	At Ground Water Branch of United States Geological Survey, Washington; discussed organization and operations with officers of the Ground Water Branch.
October 17	:	Washington to Denver, Colorado.
October 18 to 24	:	At Ground Water Branch of U.S.G.S., Denver; discussed methods of ground water investigation, engineering techniques, and systems of recording bore data; examined office and field operations of the ground water survey of the Denver Basin; inspected hydrological laboratory.
October 25	:	Denver to Grand Junction, Colorado.
October 26 to 29	:	At Exploration Division of U.S. Atomic Energy Commission, Grand Junction; discussed work of the Division and inspected the chemical and instrument laboratories; visited Big Indian Wash Area in Utah and examined several uranium mines.

October 29	:	Grand Junction to Salt Lake City, Utah.
October 30 to 31	:	At Ground Water Branch of U.S.G.S., Salt Lake City; discussed types of ground-water surveys carried out by this branch office with the chief of the office and the State Engineer.
October 31 to November 17	:	On recreation leave in U.S.A.
November 1	:	At Salt Lake City; visited operations of Kennecott Copper Corporation at Bingham Canyon open-pit mine.
November 18	:	San Francisco to Honolulu.
November 19 to 20	:	On recreation leave in Honolulu.
November 20 to 22	:	Honolulu to Sydney via Canton Islands and Fiji.

SIXTH COMMONWEALTH MINING AND METALLURGICAL CONGRESS

VANCOUVER B.C.

The Sixth Commonwealth Mining and Metallurgical Congress commenced in Vancouver on the 8th September, 1957. Delegates were registered, and briefing sessions were held for the tours of the various areas in Canada. A film on the history and development of the Kitimat aluminium plant was shown to the delegates.

On 9th September, the inaugural session of the Congress was opened by Dr. M. Boyer, Deputy Minister of Mines and Technical Surveys, representing the Prime Minister of Canada. The total number of countries represented by delegates was 35. The number of delegates was 479, of whom 391 were from 22 Commonwealth countries and 88 from 13 non-Commonwealth countries.

The President of the Congress, Dr. R.W. Diamond, delivered his Presidential Address at the Inaugural Session. He welcomed the delegates and pointed out that it had been decided by the Committee of the Congress not to hold formal sessions for the presentation of technical papers. He explained that numerous informal sessions had been arranged for technical discussions at opportune times and places, and that special literature of a local nature would be distributed at stops along the route of the Congress tours. The technical literature obtained during the Congress is available at the Canberra library of the Bureau.

Several alternative tours were available to delegates, and I participated in the All-Rail Tour from Vancouver to Halifax, Nova Scotia where the Congress closed on 10th October.

On 9th and 10th September, further briefing sessions were held, local tours of Vancouver industries were made, and several exhibits by mining companies and the Mines Department of the Province of British Columbia were examined. The All-Rail Tour left Vancouver on 11th September for Trail, travelling by a special train.

TRAIL AND KIMBERLEY, B.C.

The mining and metallurgical operations of the Consolidated Mining and Smelting Co. of Canada Ltd., at Kimberley and Trail, were visited on 12th and 13th September.

Kimberley. The Sullivan Mine at Kimberley is the largest lead-zinc-silver mine in the British Commonwealth. The ore deposit is considered to be a replacement body along a zone in argillaceous siltstone beds which are Proterozoic in age. The zone is up to 300 feet thick, and the deposit lies on the east limb of a broad anticline, the ore zone dipping about 30° to the north-east. Overlying the siltstone beds is massive quartzite and the footwall of the ore zone in most places is conglomerate. Only parts of the ore zone have been replaced by sulphide minerals. The sedimentary beds have been intruded by sills and other bodies of diorite in the vicinity of the mine.

The ore is well banded, the thickness of layers ranging from a fraction of an inch to several feet. The layers evidently reflect original sedimentary bedding. Individual ore bodies in the ore zone are up to 1,000 feet long and more than 200 feet thick. The vertical range of the ore zone is at least 1300 feet. Galena, sphalerite as the variety marmatite, pyrite, and pyrrhotite are the principle metallic minerals. A zone consisting mainly of pyrrhotite underlies much of the ore.

The general opinion of the local geologists is that the argillaceous siltstone was preferentially replaced by the ore minerals because (a) it was less competent than the conglomerate and quartzite, and (b) the chemical composition of the argillaceous siltstone made it favourable for replacement by metalliferous solutions. However, several of the visiting geologists considered that the possibility of a syngenetic origin of the metallic minerals should not be ignored.

Ore is produced from underground operations and an open pit. All ore is crushed underground and transported along the 3700 main haulage level to the surface and thence to a concentrator which is two miles from the mine. The average grade of the ore is approximately 3.1% lead and 3.7% zinc. At the concentrator, an average of 11,000 tons of ore are treated each operating day. A selective flotation process is used to separate lead, zinc, iron, and tin concentrates, from the fine-grained and complex ore.

Trail. The lead and zinc concentrates from the Sullivan Concentrator are trucked by rail 200 miles to the smelting and refining plants at Trail. Daily metal production at Trail is 400 tons lead, 520 tons zinc, 30,000 ounces silver, 250 ounces gold, and small amounts of cadmium, bismuth, antimony, and indium. About 2,000 tons of solid fertilizer is also produced daily at Trail.

The Company's Research and Development Laboratory at Trail was inspected. Experimental work covering a wide field is carried out at this laboratory. One major project at the present time is the investigation of the economic possibility of producing iron and steel from the pyrrhotite tailings at Sullivan Mine.

A folio of pamphlets on the activities of the company at Kimberley and Trail is available in the Canberra Library.

BANFF-LAKE LOUISE, ALBERTA.

On 14th September, the Congress party were taken on a field excursion in the Banff-Lake Louise area to see part of the stratigraphy and structure of the Eastern Ranges of the Rocky Mountains.

The Rocky Mountains form the Eastern front of the Cordilleran region and consist of a belt of north-westerly-trending mountain ranges which extends for about 900 miles in Canada. The mountains rise sharply from the flat Interior Plains on the east, through a Foothills belt, to peaks reaching elevations of over 11,000 feet. The mountain belt is 60 to 80 miles wide. The highest peak in the Banff area is Mount Assinboine which is 11,870 feet above sea level.

In the late Tertiary time, the thick succession of Precambrian, Palaeozoic, and Mesozoic sediments deposited in the Rocky Mountains geosyncline was subjected to orogenesis which, together with subsequent erosion, produced the Rocky Mountains. Folding and large-scale thrust faulting occurred. Along the fault lines, Precambrian, Palaeozoic, and Mesozoic strata were thrust upwards and eastwards over younger Palaeozoic, Mesozoic, and Tertiary sediments. The Rocky Mountains now consists of overlapping west-dipping blocks which have been thrust eastward, one on top of the other. Generally, the ranges have precipitous eastern faces and much less steep western slopes. The thrust blocks were clearly seen from the Jasper Highway which runs along the valley of the Bow River. Excellent examples of glacial topography were seen during the excursion. Colour slides and a brochure on the excursion are available in the Canberra library.

A brief visit was made to the Athabasca Glacier on 15th September. This valley glacier is five square miles in area, and its terminal margin is receding at the rate of 70 to 100 feet per year. Two lateral moraines and a terminal moraine have been formed. Behind the Glacier is the Columbia Icefield which is the remnant of a huge valley glacier and occupies an area of 150 square miles. It is reported to be the largest inland icefield in the world.

EDMONTON, ALBERTA.

A technical session of the Congress was held at Edmonton on 16th September to acquaint the visitors with operations on the Alberta oilfields. The following talks were given:

(a) An outline of the Canadian oil industry, by S.D. Turner.

(b) The geology of Western Canada with reference to the petroleum basins, by Professor J. Stelk.

(c) Geophysical exploration in Alberta and exploration problems in Northern Alberta, by W. Ogilvie.

(d) Oil production activities in Alberta, by C. McLaughlin.

(e) The development of natural gas in Western Canada by M. Stuart.

The Interior Plains of Western Canada are underlain by a great succession of flat-lying or gently folded sedimentary rocks of Palaeozoic, Mesozoic, and Cainozoic ages. These lie on a Precambrian erosional surface of variable relief. Geological studies in the Eastern Ranges and Foothills belt of the Rocky Mountains have yielded much valuable information to the exploration teams of oil companies. Reflection seismic surveys, and to a lesser extent, gravity surveys, are extensively employed on the Interior Plains. Productive horizons in the Upper Cretaceous, Lower Cretaceous, Jurassic, and Triassic rocks are principally sandstones, whilst Palaeozoic reservoirs are in carbonate rocks.

Two oil fields in the vicinity of Edmonton were visited by the Congress party. Both fields lie on the eastern flank of the large Alberta Syncline. All oil and gas production from these two fields is from sturctures which are depositional in character.

Leduc-Woodbend Oilfield was found in 1947 and this discovery initiated the present day expansion of the Canadian petroleum industry. At the time of my visit, oil and gas were being produced from about 1250 wells on the field. Production of oil and gas comes from dolomite of the Nisku (D2) zone and reef limestone of the Leduc (D3) zone, both Upper Devonian in age. A zone of anhydrite, 200 to 300 feet thick, lies between the D2 and D3 zones. There is a small amount of production from the Blairmore sandstone of Lower Cretaceous age.

At Golden Spike Oilfield there are only six producing wells but the field has large reserves of oil and gas. Production is limited due to lack of water under the oil and there is a drop in pressure if oil is removed from a well at a high rate. Gas produced from this field is returned to the reservoir at a daily rate of 10 million cubic feet. The producing zone (D3) is a reef limestone, 500 feet thick, of Upper Devonian age. The oilfield was discovered by seismic survey.

A series of Devonian reef fields have been developed along a trend north and south of the Leduc-Woodbend oilfields. The discovery of oil in the Cardium sand of Upper Cretaceous age in 1953 opened up the Pembina Oilfield. This field is the largest oil producer in Alberta at the present time. Apparently the volume of production from the Cretaceous sandstones is dependent on the porosity and thickness of the reservoir rocks.

There are 45 important fields producing oil or gas in Alberta. The production of crude oil in 1956 was 144 million barrels. This was 84% of the total production for Canada. The production of natural gas in Alberta was 146,113,173 million cubic feet in 1956. Canada now ranks as the 7th largest oil producer in the world.

Imperial Oil Limited's Battery and Gas Conservation Plant on the Leduc-Woodbend field were visited. At the Battery, gas is separated from crude oil and water and is piped to the Gas Conservation Plant. Water is removed from the oil and returned underground to the producing zones. The crude oil is cleaned and piped to Edmonton where it is refined for local use or sent by pipelines to Vancouver and Ontario.

A tour of the Edmonton refinery of the British-American Oil Company Ltd. was made on 17th September. This refinery processes crude oil from nearby oilfields and manufactures a full range of petroleum products, excluding lubricants. The plant handles 7,000 barrels of crude oil per day.

Reports by officers of the Federal Department of Mines on the petroleum and natural gas industries of Canada were obtained, and they are available in the Canberra Library.

SASKATOON, SASKATCHEWAN.

On 18th September, I accompanied a conducted tour of the University of Saskatchewan. Visits were made to the library and various university departments.

A brief visit was made to the operations of the Potash Company of America Ltd. at Patience Lake. This Company is bringing into production a potash deposit which was discovered four years ago during exploration drilling for petroleum. The deposit lies at the top of salt beds of Devonian age at a depth of 3,200 feet. The thickness of the deposit ranges from 30 feet to 1 inch and the average grade shown by diamond drilling is 25% potash.

The sinking of a shaft is in progress and the depth of the shaft at the time of the visit was 2,200 feet. The project has involved serious engineering difficulties as there are thick sequences of weak, water-bearing sediments in the strata overlying the deposits. The Company decided to freeze the ground to a depth of 3,000 feet by using a ring of 28 freeze holes on 4 foot centres with 7 inch casing and 3 inch tubing. This closely controlled operation took more than a year. The circular shaft is 16 feet in inside diameter and is lined with reinforced concrete. A concentrating plant is being erected, and this plant will use flotation methods to separate the sylvite (potassium chloride) ore from the salt gangue of the deposit.

ATIKOKAN, ONTARIO.

The mining operations of two companies working large deposits of high grade iron ore at Steep Rock Lake were examined on 21st September. Direct underground mining of the ore deposits which lie under the lake is impossible. The workings cannot be supported under the weight of silt and water in the lake, and the pervious nature of the iron ore would permit such free flow of water into the workings to be beyond any pumping capacity. The only choice was to remove both the water and silt until the top of the ore was exposed, and then enter the mining area by open-pit or underground methods, or both. The successful accomplishment of this operation is one of the major achievements of the Canadian mining industry in recent years.

The ore zones consist of massive geothite, brecciated and recemented by botryoidal and vuggy hematite, together with narrow bands of cherty silica. The zones contain ore of high grade, averaging 60% iron or better, and very low in silica, sulphur, and phosphorus. The ore bodies are considered to be replacement deposits in brecciated, siliceous limestone which forms the footwall of the ore zones. The rocks on the hangingwall of the ore zones are volcanic ash rocks which belong to the Steep Rock Group of Precambrian age. I feel that the deposits could be sedimentary ones formed by lateritic processes on the limestone surface prior to the deposition of the cover of ash rocks.

Several pamphlets on mining operations at Steep Rock are available in the Canberra library.

Steep Rock Iron Mines Limited

In 1943, this Company commenced operations in the area and diverted Seine River in order to drain the water from sections of Steep Rock Lake. Deposits of clay-silt and boulder clay were removed by use of high-pressure hydraulic jets and suction dredges.

Three ore bodies are being mined and developed at the present time: the Errington, Hogarth, and "G" ore bodies. Production procedure consists essentially of (a) mining, open-pit and underground; (b) transporting ore to the crusher by truck, ship or conveyor belt; and (c) crushing, grading, and shipping. The Errington open-pit has been worked out, and ore is now being extracted underground using block-caving methods. Production from the Hogarth open-pit commenced in 1953, and now preparations are under way for underground extraction of ore from the Hogarth ore body. Removal of clay-silt overburden from the "G" ore body by dredging is in progress.

Production of iron ore by the Company in 1957 amounted to 3½ million tons valued at 38 million dollars. This will be raised to 5 million tons per year by 1959. The three ore-bearing zones have a combined length of approximately 15,000 feet and a width ranging from 400 to 100 feet. Ore is known to exist at depths of 2100 feet and is expected to persist to much greater depth. Ore reserves have been estimated at 184 million tons per 1,000 feet of depth.

Caland Ore Company Limited

This Company commenced operations in 1953 on property in the Falls Bay section of Steep Rock Lake; the property is leased on a royalty basis from the Steep Rock Iron Mines Limited.

At the present time dredging of clay-silt at the bottom of the lake water at Falls Bay is being carried out to remove 180 million cubic yards of clay-silt which overlies the "C" and "D" iron ore bodies. The thickness of the clay-silt ranges from 50 to 400 feet, and the dredging project should be finished by late 1960. Some details of this large operation are of interest. Two electric dredges, each weighing 2,000 tons, were constructed at Falls Bay. A cutter head operates at a maximum of 52 feet below the surface of the water and agitates the clay-silt into a slurry. The slurry is drawn through a 36 inch pipeline from the dredge to a floating booster station which in turn pumps the material through a 42 inch pipeline for four miles to settling basins in Marmion Lake. Each dredge is capable of removing 4,000 cubic yards of slurry per hour under good operating conditions.

A shaft is being sunk at Falls Bay to permit underground extraction of ore as well as the open-pit operation. Three main drives at the 800, 1,000 and 1,200 foot levels will be used to extract the ore by block-caving methods. The Company's plans call for production and shipment of 750,000 tons of ore in 1960 and this figure will gradually increase to 3 million tons annually in 1969. Ore reserves to a depth of 1,000 feet for the "C" and "D" ore bodies are estimated by the Company to be 104 million tons.

ALGOMA, ONTARIO.

On 23rd September, the Congress Party visited Blind River uranium field at Algoma. Delegates were separated into three groups - mining, metallurgical, and geological - according to their interests. An excellent brochure, "Mining, Metallurgy and Geology in the Algoma Area", was presented to each delegate. This comprehensive story of the development of the uranium field was prepared for the Congress by the co-operation of all the companies on the field. It is available in the Canberra Library.

The most striking feature of the Blind River field, apart from the continuity and uniform grade of the uranium deposits, was the speed at which the mines have been brought into large-scale production since the initial discovery. In April, 1953, F.R. Joubin first proved the presence in the area of uranium ore of economic grade. Production of uranium oxide started at Pronto Mine in October, 1955. At the time of my visit there were 11 operating mines, 4 of which were producing uranium oxide. All 11 mines will be producing uranium oxide by early 1958, when the milling capacity of the field will be 34,300 tons of ore per day. Contracts, worth 1,108 million dollars, have been made with the Canadian Government and provide for the sale of uranium oxide concentrates to be delivered before March, 1963. The available tonnage of uranium ore at the operating mines has been estimated to be 500 million tons, ranging in grade from 2.0 to 2.5 pounds U_3O_8 per ton.

Only part of the uranium field was seen during the short one-day visit of the Congress. The geological party's visit was restricted to an underground tour of Algom-Nordic Mine, followed by a boat trip around Quirke Lake to examine the stratigraphy of the north limb of the Quirke Lake syncline. An informal discussion was then held at the geological office of Consolidated Denison Mine.

The uranium deposits occur in the Lower Mississagi Formation which is the basal member of the Huronian Group of Precambrian Age. The Huronian sediments have been gently folded into a Z-shaped structure, trending east and overlying strongly folded Pre-Huronian greenstones and granitic rocks. The northern part of the structure is the Quirke Lake syncline which plunges gently to the west.

The ore-bearing beds are close to the base of the Lower Mississagi Formation and consist of intercalated quartz-pebble conglomerate and quartzite lenses. The matrix of the material cementing the pebbles consists of angular quartz and feldspar together with white micas and varying amounts of pyrite. The ore beds range from 10 feet to 30 feet in width. Narrow individual conglomerate beds may assay as high as 20 pounds U_3O_8 per ton or more, but, over mining widths of 12 to 30 feet, the average grade is 2.0 to 3.0 pounds U_3O_8 per ton.

Brannerite and uraninite, with minor amounts of sooty pitchblende, are the principal uranium minerals. They occur as scattered microscopic grains, together with considerable amounts of granular pyrite, in the matrix of the pebble conglomerate. Pyrite is the most abundant accessory mineral and it occurs as granular disseminations through the matrix. Two factors are used visually in the mines to determine high-grade ore: (a) abundant pyrite in the matrix of the conglomerate, and (b) close packing of the pebbles of the conglomerate due to re-working and sorting of the material during sedimentation.

The footwall of the ore is sharp and well-defined at the base of the conglomerate bed, but the hangingwall is gradual and depends on the ratio of relatively-barren quartzite beds to conglomerate beds. The ore beds dip gently at 10° to 30°, and some of the mines are working beds down dip from other mines. The deepest workings will be 3,500 feet deep. All the mines except Pronto Mine are situated on the north or south limbs of the Quirke Lake syncline.

The uranium deposits of Blind River are considered by many geologists to be syngenetic deposits of alluvial origin. The underground tour of Algom-Nordic mine and discussions with local geologists were sufficient to convince me that much more work must be done before this controversial issue of genesis is solved. The detrital theory is mainly based on the following features of the uranium deposits:

(a) restriction of most of the uranium mineralization to the pebble conglomerate beds.

(b) localisation of uranium minerals in low parts of the basement surface and in areas of close packing of the pebbles of the conglomerate.

(c) the strongest uranium mineralization is at the footwall of the ore zone.

(d) the uniformity of grade and continuity of mineralization within the pebble conglomerate bed.

(e) the presence of heavy minerals such as monazite, cassiterite, rutile, chromite, and magnetite. However, apparently no ilmenite is present.

(f) lack of any fissure-type deposits in the large area of mineralization.

Personally I do not favour the detrital theory as I cannot visualize the possibility of the uranium minerals being deposited in coarse clastic sediments and lying unaltered for millions of years. I prefer to consider the uranium as being precipitated by chemical or biochemical means during deposition of the sediments. Subsequent solution of the uranium minerals, followed by migration to the permeable conglomerate at the base of the sedimentary succession, could have resulted in the formation of the uranium ore bodies.

SUDBURY, ONTARIO

The Congress Party was divided into five groups during the visit to the Sudbury nickel-copper district on 24th September. The geological group spent the day on a field tour of the north and south rims of the Sudbury Basin. Unfortunately, the group did not visit any of the producing mines of the area.

For many years, Canada has been the principal nickel-producing country and today contributes about 70% of the total production of the world. The chief source of the metal in Canada is the nickel-copper-iron sulphide ore of the Sudbury Basin.

The International Nickel Co. of Canada Ltd. operates five mines, an open pit, two concentrators, two smelters, and a copper refinery at Sudbury Falconbridge Nickel Mines Ltd. is the other important producer in the district, and this company operates five mines, three concentrators, and a smelter.

The chief ore minerals are pentlandite, chalcopyrite, and pyrrhotite, occurring as disseminations in the host rock, as stringers, or as massive sulphides with varying percentages of rock inclusions. Typical orebodies are large irregularly-shaped masses containing massive and disseminated sulphides. Expansion in underground operations in recent years, using blast-hole and block-caving methods, has allowed low-grade ore to be extracted. The average grade of ore extracted by the International Nickel Co. of Canada Ltd. is reported (verbally) to be about 1% nickel and 1¼% copper.

The Sudbury Nickel deposits are geologically unique in their occurrence, structure, and genesis; and much literature, especially with regard to genesis, has been published on the subject. The orebodies occur at or near the base of an intrusive body called the "nickel intrusive". This body is in the form of a large basin-shaped mass, 37 miles long and 17 miles wide. It consists of an upper more acid layer of micropegmatite (or granophyre) separated by a transition rock from a more basic layer of norite. The Whitewater Series of volcanic and sedimentary rock lies inside the oval ring of the nickel intrusive as a basin conforming in shape with the underlying nickel intrusive.

At the north rim of the Sudbury Basin, the known orebodies are restricted to a breccia zone which is the contact between the norite and underlying pre-nickel granite and granite-gneiss. Most of the known orebodies at Sudbury occur at the south rim of the basin where they lie either at the bottom contact of the norite or in dyke-like masses of quartz diorite. This quartz diorite is closely related to the norite but the exact age relationship is still controversial. Exploration of favourable areas around the rim of the nickel intrusive is still very active; new prospects are being developed and brought into production at the present time.

A brochure on the field tour and several booklets on the Sudbury area are available in the Canberra Library.

NORANDA, QUEBEC

I participated in an underground tour of the Horne Mine at Noranda and in a short geological field trip around the nearby country on 26th September.

In the Noranda area, a succession of andesitic and rhyolitic flows and pyroclastic rocks have been highly folded and intruded by masses of granite and diorite and diabase dykes. Major faulting has caused large-scale disruption of the rocks. During the field tour, excellent exposures of pillow lavas and brecciated flow tops were seen. These outcrops clearly demonstrated how the strike, dip, and top of a volcanic flow can be determined in the field.

The Horne Mine is the oldest mine in the Noranda district. It has been operating since 1927 and annual production is about 20,000 tons of copper and 160,000 ounces of gold, as well as considerable amounts of silver and pyrite. Ore reserves are reported to average $2\frac{1}{4}$% copper and 0.18 ounces of gold per ton.

Most of the 36 known orebodies at the Horne Mine are large irregular masses of sulphides which have replaced rhyolitic agglomerates, tuffs, and flows shattered by folding and faulting. The ore consists of pyrite, pyrrhotite, and chalcopyrite in varying proportions, together with important amounts of gold. The massive ore usually grades rather rapidly into rock spotted with sulphides and then into rock with little or no sulphide present. Some of the very low-grade ore is mined because its high silica content makes it valuable for use as a flux in smelting operations.

The mine is unusual in that the most important orebodies have been found below the upper levels of the mine. All the orebodies occur in a structurally favourable block of volcanic rocks between two major faults which were active at the time of mineralization and served as channelways for the rising mineral-bearing solutions. Minor faults branching out between the two major faults have shattered the volcanic rocks.

OTTAWA, ONTARIO

At Ottawa, the capital of Canada, the programme for the Congress visit on 30th September and 1st October consisted of tours of various Government establishments and participation in a number of official receptions and dinners.

During a brief tour of the National Research Council of Canada, some of the laboratories of the chemical, physical, and radio engineering research groups were inspected. About 500 scientists are working under post-graduate (350) and post-doctorate (150) scholarships at the Council.

At the Federal Mines Branch, I attended the opening ceremony of the new Mines Branch building and accompanied a tour of inspection of the laboratories of the following sections:

Physical Metallurgy Division
Fuels Division
Mineral Dressing and Process Metallurgy Division
Industrial Minerals Division
Radioactive Division
Mineral Resources Division

The Mines Branch is mainly concerned with research on methods of treating ore, fuels, etc., and on new or improved uses for metals, alloys, and mineral products. The Branch also publishes information on resources, markets, prices, and uses of minerals produced in Canada.

The Geological Survey of Canada is divided into six main sections which are as follows:

Precambrian Division
Post-Precambrian Division
Fuels and Stratigraphic Division (includes Engineering Geology and Ground Water Sections)
Mineralogy Division
Mineral Deposits Division
Geophysics Division

It was not possible to visit all the Divisions in the limited time available as they are scattered through various Government buildings in different parts of Ottawa. This disadvantage will be rectified in early 1960 when a new building to house all sections of the survey will be completed.

The organization and functions of the Survey were discussed with the Director, Dr. J.M. Harrison, and some of his senior officers. Dr. Harrison was also a member of the Congress party on the All-Rail Tour and was always available to answer my queries about the work of the Survey. The geological staff of the Survey consists of about 105 geologists (Ph.D.) and 40 technical officers (B.Sc.). The Survey is much more fortunate than our Bureau of Mineral Resources with regard to the use of University students. The field season in the Canadian summer coincides with the long vacation of University students, and the students are able to work in Survey field parties. Full use is made of this by the Survey to augment the staff of field parties and to enable future officers of the Survey to gain practical field experience. The usual type of field party consists of one or two geologists of the survey and four, five, or six students.

A major part of the Survey's work is reconnaissance geological mapping at a scale of 4 miles to the inch. Other projects are detailed surveys in areas of importance to the mineral or petroleum industries and airborne magnetic surveys over extensive areas of Canada. The airborne results are published on maps at a scale of 1 mile to the inch. Both the aeromagnetic maps and regional geological maps are in great demand by the public.

A booklet showing the 1956 activities of the Department of Mines and Technical Surveys, of which the Mines Branch and Geological Survey are part, is available in the Canberra library.

Extensive use of helicopters to assist field parties has been made by the Survey in the last few years. A report analysing the results of three different types of helicopter-assisted surveys carried out in recent years is available in our library and should prove interesting reading to those Bureau officers who have been connected with helicopter work.

An excellent coloured map of Canada showing the principal mineral areas has been published by the Survey and is brought up-to-date each year. The map shows broad geological divisions of the rocks, statistics of mineral production for the previous year, and indices and locations of the principal producing mines and the principal oil and gas fields. The scale of the map is 120 miles to the inch, the same scale as used for the geological map of Canada.

Four types of publications are produced by the Survey. They are Memoirs, Economic Geology Series, Bulletins, and Paper Series. Memoirs consist of printed reports embodying the full results of an investigation. The Economic Geology Series consists of reports on a particular economic topic covered in a country-wide way. Bulletins are printed reports on special investigations that warrant publication. The Paper Series consists of preliminary maps and reports often issued before a field project is completed. Sometimes a Paper Series only consists of a map and marginal notes, produced quickly to provide the highlights of a survey for the public. Coloured and uncoloured geological maps at various scales are also available to the public. Some of these maps carry marginal notes on the geology and resources of the areas mapped.

I consider that an inter-change of Bureau officers with officers of the Canadian Survey for a period of a year or so would be beneficial to both surveys. The matter was discussed with Dr. Harrison who favoured this interchange of officers. He is willing to discuss the matter further with the Bureau if the Bureau is interested in it.

ASBESTOS, QUEBEC

On 3rd October, the geological group of the Congress made a tour of the operations of Johns-Manville Company Ltd. The Jeffrey open pit and the new treatment mill were inspected in the course of a brief half-day visit.

The Jeffrey Mine is the largest asbestos mine in the world and consists of both open-pit and underground workings. Approximately 72% of the mine's production comes from underground operations. Block-caving methods of mining are used underground from two levels, 750 feet and 1150 feet below the collar of the main shaft.

The asbestos is chrysotile, a fibrous variety of serpentine, which has been formed by serpentinization of peridotite. The peridotite, with associated dunite and pyroxenite, forms a sill-like mass, 4800 feet thick, intruding metamorphic and volcanic rocks of early Palaeozoic age. The ultrabasic intrusion is part of a narrow interrupted zone called the "Serpentine Belt"; the zone runs north-east across southern Quebec. The age of the intrusion is considered to be late Ordovician, whilst the subsequent serpentinization and formation of chrysotile was probably associated with small granitic intrusions in late Devonian time.

The asbestos-bearing peridotite at Jeffrey Mine averages 3000 feet long and 2000 feet wide. The higher-grade asbestos is confined to the more massive peridotite, although distribution of chrysotile within the ore body is very irregular. The chrysotile is of two types, cross fibre and slip fibre. The cross-fibre type accounts for most of the production and occurs in veins with sharp walls, tightly packed fibres lying at a high angle to the walls of the veins. Most veins are less than $\frac{1}{4}$ inch wide and less than 5 feet long. The walls of the veins consist of serpentine that grades away from the veins into partly serpentinized peridotite.

The slip-fibre type of chrysotile occurs in highly sheared serpentine, the fibres being matted and lying lengthwise along the shear planes. Fibrous brucite (hydrated MgO) is commonly associated with this type of chrysotile.

The daily production of peridotite ore at Jeffrey Mine is about 21,000 tons, and the average chrysotile content of the ore is 12%. Ore reserves are estimated by the company to be sufficient to last for more than 100 years at the present rate of production. I found that visual estimation of the quantity of chrysotile in the peridotite was very deceptive; peridotite, which appeared to carry very little chrysotile, was actually good-grade ore.

The new treatment mill was opened in 1954; it consists of 14 levels and has a yearly production capacity of 625,000 tons of chrysotile fibre. The peridotite is crushed, beaten, and screened. At various stages in the crushing, as fibre is released from the rock, the fibre is separated by overhead suction.

A report on the geology of the Jeffrey Mine is available in the Canberra Library.

BATHURST, NEW BRUNSWICK

Part of the Congress party visited the Bathurst area in Northern New Brunswick on 5th October. The geological group examined the mining properties of Brunswick Mining & Smelting Corporation Ltd. In 1952, the presence of lead and zinc sulphides near a deposit of magnetite, worked intermittently for iron since 1902, was first reported. The company carried out a geophysical survey along the strike of the known sulphide zone and pattern drilled an anomalous area, 3000 feet north of the old open pit. The work proved the existence of the first major base-metal orebody in the province of New Brunswick, and started widespread exploration in the district.

The deposit, known as Brunswick No. 6, is a massive sulphide body consisting of pyrite predominantly, with sphalerite, galena, and chalcopyrite. At the surface, the orebody is 1000 feet long and 270 feet wide. It dips at 50° to the west and has been extensively drilled to a depth of 1000 feet. Ore reserves are estimated to be 25,000 tons per vertical foot. Mining plans for the orebody favour an open-pit method initially, designed to operate on a ratio of 0.26 cubic yards of ore to 0.32 cubic yards of waste.

In 1953 a second ore deposit was found by the company, 6 miles north-west of No. 6; it was named Brunswick No. 12. This is also a massive sulphide body similar to No. 6, and it has been drilled to a depth of 1400 feet. The ore body is widening at depth and is estimated to contain about 35,000 tons of ore per vertical foot. No. 12 deposit will be worked by underground mining, and initial plans call for a daily production rate of 2000 tons of ore.

Both No. 6 and No.12 ore deposits are localised within favourable drag-fold structures related to the primary regional folding of the Bathurst area. Both ore deposits are on the same stratigraphic horizon. The major structural feature of the Bathurst area is a large domal structure. The rocks consist of a volcanic complex with associated sedimentary beds. All the important ore deposits, except for two occurrences in volcanic rocks, occur in "green schists" beds, at the contact of these beds and underlying quartz-feldspar porphyry. Drag folds along this favourable contact have, at some of the deposits, localised the sulphide minerals. The porphyry is considered to have originated as a "glowing cloud" type of eruptive rock. The stratigraphic control of ore deposits over a wide area indicates the possibility that the sulphide minerals were syngenetic in origin and subsequently migrated into favourable structural features.

For the last four years, the Bathurst area has been the scene of extensive prospecting and diamond drilling. Seventeen important sulphide ore deposits have been found scattered over an area of 1200 square miles since the original discovery in 1952. Much of the area is covered by glacial overburden and heavy timber. Exploration techniques used include airborne electromagnetic and magnetic surveys; ground magnetic, electromagnetic, and self-potential surveys; detailed geological mapping and geochemical surveys. The usual technique is to select an area which general geology indicates as favourable and to carry out an airborne electromagnetic survey. Ground electromagnetic or self-potential surveys are then done over areas of interesting airborne anomalies, together with detailed geological mapping and geochemical sampling. A ground magnetic survey is used if the sulphide body is suspected to contain pyrrhotite. Most of the methods are used before any drilling is commenced.

A report by C.P. Penney on exploration in New Brunswick 1932/1957 is available in the Canberra Library. He estimates known ore reserves of the Bathurst area, shown by drilling results, to be of the order of 128 million tons to a depth of 1000 feet. He considers the overall grade of the known ore bodies in the district to be 0.52% copper, 2.28% lead, 5.61% zinc, and 1.93 oz. silver per ton.

The sulphide bodies are banded and consist of two types -

(1) Very fine grained pyrite with sphalerite, galena, minor chalcopyrite and appreciable amounts of silver.

(2) A pyrrhotite-chalcopyrite type with minor amounts of sphalerite, galena, silver and some gold.

Serious metallurgical difficulties have retarded exploitation of the ore bodies. Early flotation tests indicated that the ore would be difficult to treat because of the intimate associations of minerals in the fine-grained massive sulphide bodies. Metallurgical research is still in progress, and the Brunswick Mining & Smelting Corporation Ltd. have been operating a flotation laboratory and a 150 ton per day pilot mill at one of their properties for the last three years to determine the best treatment for the ore.

SYDNEY, NOVA SCOTIA

On 7th October, I took part in a tour of some of the operations of the Dominion Steel & Coal Corporation Ltd. at Sydney where Princess Colliery and the new coal preparation plant were inspected.

The Sydney Coalfield covers a land area of about 57 square miles as well as a large submarine area. The richest part of the field is beneath Sydney Harbour. There are over 40 coal seams in the field, and they form part of the Morien Group of Pennsylvanian age. The coal seams dip seawards at 5 to 15° to the north-east, and those that have been worked range from 4 to 7½ feet in thickness. Some of the workings extend for more than 5 miles under the sea, and the coal-bearing measures are believed to extend seawards for another 30 miles.

Princess Colliery produces coal from the submarine areas of a coal seam 5 to 7 feet thick, the main working being almost 4 miles offshore and at 1850 feet below sea level. Longwall methods of coal extraction, using the mechanical "Dosco Miner", average about 600 tons of coal per shift from a 500 foot face. The coal is hauled about 19,000 feet from the working sections and transferred to a 42 inch cable belt conveyor which is designed to handle 4000 tons daily. The cable belt hauls the coal through a 20% inclined tunnel, 3445 feet long, from the pit bottom to the surface, from where the coal goes direct to the preparation plant, which is designed to handle 350 tons per hour.

Several brochures on coal mining practice at Sydney are available in the Canberra Library.

HALIFAX, NOVA SCOTIA

The Halifax refinery of Imperial Oil Ltd. was inspected on 8th October. This refinery has the capacity to process 42,000 barrels of crude oil per day, producing petrol, diesel fuel, heating oils, propane gas, and various special products. Processing methods include atmospheric and vacuum crude distillation, fluid catalytic cracking, and catalytic polymerization, all regulated from a central control room. The storage capacity of the refinery is 4 million barrels.

A visit was made to the mining operations of Magnet Cove Barium Corporation Ltd. in the Walton district on 9th October. The barite deposit lies within a limestone-conglomerate zone 200 feet thick, that forms the basal beds of the Windsor Group of Mississipian age. The barite is considered to have replaced the sediments along a brecciated zone on the flank of a synclinal fold. Production has been from an open pit now worked to a depth of 350 feet; underground mining from a shaft 1000 feet deep, will commence in 1958. The output of 250,000 tons per year is processed by grinding and washing to minus 2¼ inch size. It is then bulk-shipped or is reground to a fineness of 98% through 325 mesh and shipped in sacks.

The concluding technical session of the Congress was held on 9th October. An overall resume of mining and metallurgical practices in Nova Scotia was given to the delegates. This completed the Sixth Commonwealth Mining and Metallurgical Congress, and delegates departed Halifax on 10th October.

UNITED STATES GEOLOGICAL SURVEY

My visit to the Geological Survey was restricted to the Ground Water Branch. I gratefully acknowledge the generous assistance of Dr. A.N. Sayre (Chief of the Branch) and his staff at Washington, Denver, and Salt Lake City offices of the Ground Water Branch.

WASHINGTON, D.C.

The headquarters of the Ground Water Branch of the U.S.G.S. are at Washington. Recently, it became necessary to decentralize administrative work due to the large increase in the size of the Branch since 1945. The U.S.A. was divided into four areas, and branch offices (one yet to be established) were provided for each area. These branch offices will ease a considerable part of the administrative work from Washington headquarters. They are:

Area	Branch Office
Atlantic Coast	Arlington
Mid Continent	To be established
Rocky Mountain	Denver
Pacific Coast	Menlo Park

Under the control of these branch offices are the various district offices and field offices in each of the four areas. The total professional staff of the Ground Water Branch is about 500 officers, consisting mainly of geologists and hydraulic engineers with smaller numbers of physicists, chemists, and mathematicians. A very interesting discussion was held with Dr. A.N. Sayre who outlined the organization and operations of the Branch.

I visited the Report Section, which handles the editing and distribution of all water-supply papers, pamphlets, and reports. C.L. McGuinness (Chief of Report Section) showed me various types of reports and made available a comprehensive selection of reports and notes. Generally, reports describe the occurrence, availability, and quality of ground water in specified areas, and they are usually divided into three main parts:-

(a) General description of the whole area, including an introduction and a general treatment of the geography, geology, and ground-water conditions. This gives the background for presentation of detailed hydrological information.

(b) Systematic descriptions of the geological units in the area. These cover the water-bearing properties of the units and the quality of the ground water, as well as the normal geological information.

(c) Detailed hydrological descriptions of subareas. These show ground-water conditions in detail. Well logs, water-level records, and pumping inventories are generally given in these sections. Estimates of availability of ground water and perennial yields are given here.

The legends of geological maps accompanying water-supply reports always include a brief statement of the water-bearing properties of each stratigraphical unit shown on the maps.

In this report I am using the American terminology for bores and wells. All types of holes sunk to tap water supplies are called wells in America. There are four main types of wells used - dug, drilled, driven, and jetted. Dug wells are large-diameter wells and are equivalent to our wells; the other three types of wells are equivalent to our bores.

J.G. Ferris (Chief Engineer) discussed ground-water hydraulics and showed me some of the engineering techniques used in conducting and analysing aquifer performance tests. The term "aquifer performance test" is preferred to the term "pumping test" because it is the aquifer, and not the pump, that is under consideration. In general, the method consists of pumping one well and observing the draw-down of the water levels in it and other nearby wells. A graphical or mathematical treatment of the observed data will yield much useful information and enable the determination of aquifer coefficients. An analysis of the observed field data requires a thorough knowledge of the theory concerning the test, in order to obtain consistent and reliable results. It was emphasised that it is impossible to simply fit the data into a formula and grind out the answer.

Although many ground-water investigations are of a qualitative nature, quantitative studies are an integral part of the complete evaluation of occurrence and availability of ground water. A review of the progress made to date in quantitative studies of ground-water hydrology is given by Ferris & Sayre (1955). This paper also gives more than 200 selected references on the subject.

The value of an aquifer as a fully developed source of water depends largely on two inherent characteristics: its ability to store and its ability to transmit water. These two characteristics, referred to as the coefficients of storage and transmissibility, are the foundation on which quantitative studies are constructed. Ground-water hydraulics is described by Ferris as the process of combining observed field data on water levels, water-level fluctuations, natural or artificial discharges, etc., with suitable equations or computing methods to find the hydraulic characteristics of an aquifer. The selection of equations - such as the Theis, Thiem, or Jacob equations - to be used for analysis is governed largely by the physical conditions of the aquifer being studied. Often the initially calculated results may require revision as a field investigation proceeds.

During a short discussion, T.E. Eakin, Chief of Foreign Hydrology Section, outlined the development of a small ground-water organization. He stressed the need for engineers in any organization handling ground-water investigations. If a separate ground-water section is formed within the geological section of the Bureau, it is recommended that a hydraulic engineer be included in the strength of the new section.

DENVER, COLORADO

The branch office of the Ground Water Branch for the Rocky Mountain area is at Denver. Most of this section's work is confined to the states of Colorado, Wyoming and New Mexico. The projects are carried out in co-operation with the various State authorities. The Hydrological Laboratory of the Ground Water Branch is also stationed at Denver.

Discussions were held with S.W. Lohman, Chief of Denver Branch, and T.G. McLaughlin, District Geologist for Colorado. These discussions covered the following subjects:-

(1) Types of water resources investigations.
(2) Methods of field work and collection of data.
(3) Systems of recording well data.
(4) Use of water-table, depth-to-water, and bedrock contour maps.
(5) Methods of carrying out pumping tests of wells, with and without use of observation wells.
(6) Interpretation of electrical and gamma-ray logs of wells.

A large variety of papers, publications, and notes prepared by the Ground Water Branch were given to me. These included papers - called Ground Water Notes - which are not normally available outside the Branch. The main purpose of my visit to Denver was to see at first hand a water resources investigation in progress. I was fortunate that the survey of the ground-water resources of the Denver area had commenced in 1956.

GROUND-WATER INVESTIGATION OF THE DENVER AREA

The project is a detailed study of part of the Denver Basin in the vicinity of the City of Denver. The geologist in charge, G.H. Chase, showed me the layout of the project and some of the field operations.

Since 1945 there has been a large development of water supplies from wells in the Denver area, due to the rapid growth of the City of Denver and the surrounding districts. Large numbers of wells have been drilled in the shallow alluvium of the valley of the South Platte River and its tributaries, and into artesian aquifers at depths as great as 2000'. Hundreds of these wells have been drilled for industrial, community, and municipal use, and thousands have been drilled for domestic use - largely for lawn irrigation during Denver's periodical water shortages. Very little information as to the extent of development of ground water in Denver and the effects of this development on the water levels has been compiled. There are many indications that water levels in some aquifers are declining rapidly, and that some suburban communities, as well as some industries within Denver, may exhaust their supplies in the near future.

A detailed study of Denver's ground-water resources has been needed for many years. In 1956, it was decided that the Ground Water Branch carry out this study on a co-operative financial basis, half of the necessary funds being provided jointly by the Colorado Water Conservation Board and the Denver City Water Board. The following table shows the estimated cost of the project:-

Financial Year	City Funds	State Funds	Federal Funds	Total
1957	$5,000	$5,000	$10,000	$20,000
1958	10,000	5,000	15,000	30,000
1959	10,000	5,000	15,000	30,000
1960	10,000	5,000	15,000	30,000
1961	5,000	5,000	10,000	20,000
TOTALS	$40,000	$25,000	$65,000	$130,000

The programme permits the employment of two full-time ground-water geologists or engineers during the first year, and at least three during the remainder of the programme. In addition, a number of part-time or seasonal employees are used for surveying parties, well inventory, etc. The whole project was planned in detail before it started in July, 1956. Field work will finish in July, 1959, and the final results will be published as a Water Supply Paper of the U.S.G.S. in 1961. Progress reports and preliminary maps will be made available to the co-operating agencies at the end of each year of the project. This will avoid undue delay in making information available. The types of information commonly requested include many regional aspects such as water-level trends, subsurface correlations, long-time yields, transmissibility and recharge, bedrock data for well-construction purposes, and quality of water. As the project progresses, more accurate answers can be given to these queries.

The three principal sources of ground water in the Denver area are: (a) the alluvium in the South Platte Valley and its principal tributaries; (b) the conglomeratic sandstones in the lower part of the Arapahoe Formation; and (c) the basal Laramie-Fox Hills sandstone.

Ground water in the alluvium of the South Platte and its tributaries is available in large quantities in many places. Because of the rapid rate of recharge, there apparently has been no serious decline in water levels, except locally. The water is not very satisfactory for domestic use, but it is suitable for irrigation and for many industrial uses. Aquifers in both the Arapahoe Formation and the basal Laramie-Fox Hills sandstones appear to be greatly over-developed, and there are already indications of large declines in water levels. The rate of recharge is low, and most of the water is being taken from storage. The water is of good quality and is suitable for most uses.

The main objectives of the project are listed below:-

(1) Determinations of transmissibility and storage (or specific yield) for each of the significant aquifers of the area.

(2) Estimations of return flow to the South Platte River, especially within and south of the City of Denver.

(3) Subsurface correlation of strata using (a) well samples, (b) drillers' logs, and (c) electrical and gamma ray logs of persistent and significant sands and sandstones.

(4) Extending and detailing available maps of subsurface geology, with special emphasis on aspects significant to the hydrology of the area.

(5) Study of the quality of the water in the various aquifers, including significant changes occurring as water moves from recharge areas towards the centre of the Denver Basin. Correlation of the quality of water with specific strata or groups of strata.

(6) Estimate of pumpage for various purposes.

(7) Preparation of recharge estimates.

(8) Compilation of bedrock contour maps.

(9) Compilation of water-table and depth-to-water contour maps for the alluvium; compilation of piezometric surface maps for the artesian aquifers.

(10) Establishment of a network of observation wells to permit study of fluctuations of water levels and piezometric surfaces.

(11) Determination of the most efficient future use of water from each of the aquifers.

The main investigations being carried out in order to achieve the objectives of the project are listed below:-

A. Geological Investigations

Surface geological mapping, with emphasis on correlation of water-bearing sands, gravels, sandstones, and conglomerates. Hydrologically - similar adjacent units of formations of different ages are considered together. Special attention is paid to the areal extent of various types of alluvium and to the outcrop areas and structure of all artesian aquifers and aquicludes. Most of this mapping is done using aerial photographs, and detail is transferred to topographical base maps at a scale of 1 to 24,000. Limited areas are mapped using plane table and alidade, if deemed necessary.

All available drillers' logs, electrical logs, gamma-ray logs, and geologists' logs are collected, filed and used in correlations and computations. Samples of cuttings and cores are collected from as many drill holes as possible. Also, surface samples are collected for comparison and analysis. All this information is needed in order to draft depth-to-bedrock maps, in the interpretation of water-table contours, and in interpretation of surface geological mapping.

B. Geophysical Investigations

Many electrical and gamma-ray logs are done at wells to aid in delimiting structure and lenticular water-bearing beds, in correlation, in refinement of storage-volume estimates, and in preliminary regional quality-of-water studies for the most persistent and important water-bearing horizons.

C. Hydrological Investigations

An initial well inventory to include representative wells and springs from all aquifers in the area. A uniform distribution is being maintained until information from the entire area is assembled. There are about 5,000 wells in the project area, and it is anticipated that several thousand wells and springs will be included in the inventory.

Water-table and piezometric mapping, with emphasis on areas where pronounced cones of depression have developed from pumping.

A limited amount of exploratory drilling to determine the thickness and extent of the shallow aquifers, and to observe fluctuations of water levels produced naturally or by pumping during aquifer performance tests.

Pumping tests and flow tests are conducted for each aquifer to determine storage, transmissibility, and recharge rates. The results of laboratory tests of surface and well samples are used to supplement and check results obtained in the field tests.

D. Chemical Investigations

A large number of water samples from various aquifers are being collected and analysed to determine the quality of the water. Water analyses by commercial laboratories will be collected and utilised. Field conductivities will be determined for as many wells as possible in each of the aquifers. Periodical checks on the quality of water in each aquifer are being made to show any significant changes in the movement of the ground waters.

Well and spring locations are plotted weekly on topographical maps at scales of 1 to 24,000 and 1 to 31,680. Field data for representative wells are then plotted on transparent overlays to permit more efficient answering of current requests for information, and to facilitate the preparation of preliminary maps and progress reports. Tabulation and evaluation of well data is greatly aided by the use of a punch-card filing system, which allows rapid sorting of information. Preparation of the final report is begun early in the project, with repeated revision being made as the project progresses. The project will provide a sound basis of hydrological facts for use by the State and its administrative sections in promoting full yet safe development of the ground-water resources of the Denver area. It will enable sound planning of the uses of the ground water in the future expansion of this rapidly growing area.

HYDROLOGICAL LABORATORY, DENVER

The field and laboratory services of this laboratory are available to all field offices of the Geological Survey throughout the U.S.A. The laboratory is well equipped to make determinations of physical and hydrological properties of water-bearing and of allied non-water-bearing soil and rock samples. Because basic and allied research is necessary for the improvement of field and laboratory techniques, and for the clarification and understanding of hydrological concepts, several research projects are undertaken each year.

A wide selection of equipment is available for the collection of both consolidated and unconsolidated materials. This equipment varies from hand or power-driven augers, which obtain "disturbed" samples, to hand or power-driven core barrels, for taking "undisturbed" samples. Trained personnel, vehicles, and specialised equipment are available to assist in sampling programmes or field projects.

The principal tests that are currently being made at the laboratory are as follows:-

(1) <u>Grain density, bulk density, and porosity</u>

The porosity is computed by using the data obtained in the laboratory for grain density and bulk density.

(2) <u>Moisture equivalent, specific retention, and specific yield</u>

Several centrifuges are used to determine the moisture equivalent which is converted to a close approximation of the specific retention. The specific yield is the amount of water that will drain from soil or rock by gravity, expressed as a percentage of the total volume of soil or rock. It is computed by subtracting the specific retention from the porosity.

(3) <u>Permeability and capillarity</u>

"Undisturbed" samples can be tested in the apparatus, which consists of 35 constant-head permeameters and 45 variable-head permeameters, in a constant temperature/constant humidity room. The coefficient of permeability of "disturbed" unconsolidated samples can be determined in the same apparatus, after the sample has been packed by a compaction table. De-aired tap water is normally used as the test fluid.

(4) <u>Particle-size analysis</u>

The distribution of sand and gravel is determined by mechanical sieving, and the distribution of clay and silt is determined by use of hydrometers. Completed particle-size analyses are shown as curves on semilogarithmic graph paper.

(5) <u>Moisture content and soil-moisture tests</u>

Constant temperature ovens, dessiccators, and accurate balances are used to determine moisture content. The Atterberg limits (also known as limits of consistency) indicate the effects of variations in moisture on the plasticity of soils, and can be determined in the laboratory.

(6) <u>Conductivity and pH of samples</u> can be determined by use of a number of meters.

Several research projects relating to problem of disposal of radioactive waste from nuclear reactors were being conducted for the Atomic Energy Commission. These projects related to diffusion in porous media, infiltration into open-bottom and screened wells, and infiltration from surface pits down to water table.

The Chief of the laboratory, A.I. Johnson, showed me a number of tests in operation at the time of my visit. My impression was that the laboratory is very modern and efficiently operated by experienced personnel.

SALT LAKE CITY, UTAH

A district office of the Ground-Water Branch is maintained at Salt Lake City. As the Utah State Geological Survey consists of only one geologist, this district office handles all ground-water work in Utah. Nearly all of this work is done in co-operation with the Utah State Engineer's office, which provides a portion of the requisite funds. The technical staff consists of seven geologists and three engineers. Two of the engineers and one geologist are stationed at field offices in Richfield and Cedar City.

The functions of the district office were discussed with its Chief, H.A. Waite. The other officers showed me the lay-outs of investigations they are handling. Two main types of ground-water investigations are carried out in Utah:

(a) Basic data type

A comprehensive network of observation wells is arranged, and a schedule of periodical measurements of water levels at a number of different time intervals is maintained. A complete pumping inventory is made. Thus, valuable information on long-term ground-water fluctuations and pumping effects is obtained. Two such projects were in progress at the time of my visit, each one handled by an engineer, in areas where there is danger of over-development of ground-water supplies.

(b) Specific Investigations

These projects range considerably in size and scope. All are concerned with the finding and describing of ground-water reservoirs, areas of intake and discharge, and the factors which govern the quantity, quality, and movement of water in the reservoirs. Quantitative considerations for any area include total storage, perennial yields, and safe maximum draw-off per year.

The regional geology and particularly the stratigraphy of the area under consideration is established. All available information on aquifers and sub-surface geology is obtained from wells and drillers' logs, and a pumping inventory is made and maintained. Chemical assays of the ground waters are made at periodical intervals. Sometimes drilling is required to obtain additional geological information and to establish observation wells for pumping tests. Electrical and gamma-ray logging of wells is carried out where necessary.

Investigations of the geology and ground-water resources of five areas were in progress at the time of my visit. These projects ranged in size from one involving two geologists for a period of three years, to one involving one geologist for six months.

U.S. ATOMIC ENERGY COMMISSION

GRAND JUNCTION, COLORADO

I visited the Exploration Division of the U.S. Atomic Energy Commission at Grand Junction on 26th and 29th October. H.E. Stocking, Chief Geologist, outlined the work being done by the Division in the Colorado Plateau area and in the Grants area in New Mexico. Recently the strength of the Division was reduced from 200 to about 70 technical officers. This was due to curtailment of exploratory work by the Atomic Energy Commission. Most of the field work is now directed to development of uranium mines by assessment of drill hole data and underground sampling, and by surface and underground mapping.

The chemical laboratory at Grand Junction carries out chemical tests and mineralogical-petrological studies of drill cores and specimens submitted by field officers and the public. The instrument laboratory maintains instruments and does radiometric assays and samples. Assays of samples either in or out of equilibrium can be made. At the time of my visit tests were in progress to enable radiometric logging of non-cored drill holes to determine both the width and the grade of radioactive ore bodies. Only the total figure, width times grade, can be obtained at present.

I attended a meeting of the Grand Junction Geological Society in Grand Junction where an interesting talk on "uranium geology and potentialities in South America" was given by D.L. Everhart of the A.E.C.

BIG INDIAN WASH AREA, UTAH

On 27th and 28th October I was taken on a short field trip to examine several mines in the Big Indian Wash area. The trip enabled me to see something of the geology and uranium deposits of part of the Colorado Plateau. My guides were P.H.Dodd and N.A. Salo, both of the A.E.C.

Big Indian Wash area is in eastern Utah, 70 miles south-west of Grand Junction. Travelling from Grand Junction by road, we passed through the town of Moab, which is the local supply centre for uranium mines and is an A.E.C. buying point for uranium ores. A privately-owned uranium treatment plant operates at Moab treating 2,000-2,500 tons of ore per day, using an acid leach followed by resin-in-pulp extraction.

Since 1948, the Colorado Plateau has been the scene of intensive prospecting and exploration for uranium deposits. Deposits that have yielded significant production are mostly restricted to fluvial sedimentary rocks of (a) the Morrison Formation and the Entrada sandstone of Upper Jurassic age and (b) the Shinarump conglomerate and the Chinle Formation of Upper Triassic age. The major uranium deposits of the Big Indian Wash area are tabular bodies in the lower 20 feet of the Moss Back member of the Chinle Formation. The deposits occur in a discontinuous mineralized belt, about 12 miles in length, along the south-western limb of the Lisbon Valley anticline. Total reserves of uranium ore are estimated by the A.E.C. to be about 6,000,000 tons. Descriptions of the geology and uranium deposits of the area are given in papers by Isachsen and Evensen (1956) and Lekas and Dahl (1956). Both papers are available in the Canberra Library and I will not repeat their descriptions here. The three mines examined during my visit were Mi Vida Mine, Continental No. 1 Mine (both in the Moss Back member of the Chinle Formation) and Rattlesnake open pit (in the Salt Wash member of the Morrison Formation).

Mi Vida ore deposit was found by C. Steen in 1952 by exploratory diamond drilling. This was the first discovery of uranium ore in the Moss Back member of the Chinle Formation. Mine production is 8,000 tons of ore per month, the average grade of the ore being 0.35% U_3O_8. The ore is trucked 40 miles by road to the treatment plant at Moab. The orebody is 3,000 feet long and averages 400 feet in width; the thickness ranges from a knife edge to 35 feet. At Continental No. 1 Mine the deposit is 1200 feet long and 100 feet wide, and the thickness ranges from a knife edge to 12 feet. The average grade of the ore is 0.40% U_3O_8.

The host rock at both mines is calcareous sandstone with lenses of siltstone and calcareous conglomerate. Rapid horizontal and vertical changes of facies, characteristic of fluvial deposits, are common in the lower part of the Chinle Formation. Carbonaceous material in the form of carbonized tree fragments is widespread in the host rock. The principal ore minerals are uraninite and montroseite (hydrated vanadium oxide). They occurred mainly as disseminations filling pore spaces in sandstone and conglomerate and also as grains replacing calcite and clay cement. Much of the uraninite occurs as replacement of carbonaceous plant material. Pyrite is fairly abundant within the orebodies.

Orebodies in the Chinle Formation are not restricted to channels or any particular stratigraphical unit; most, however, are in sandstones or coarse clastics in the lower part of the formation. Although the tabular orebodies are irregular in outline, the trend of elongation usually parallels the course of the stream that deposited the sandstone lens or channel fill containing the orebody.

Ore deposits in the Morrison Formation, such as the Rattlesnake uranium-vanadium deposit, are localized in the thicker part of sandstone lenses by sedimentary structures such as channels and intersections of crossbeds. At Rattlesnake Mine the ore minerals consist of carnotite and hydrated vanadium oxides with small amounts of uraninite. The orebody is being worked by open pit and underground methods; the average grade of ore extracted is 0.20-0.25% U_3O_8.

The genesis of the sandstone-type deposits of the Colorado Plateau is still widely debated. However, it is generally agreed that the ore-bearing solutions, irrespective of their origin, migrated along the sedimentary beds that now contain the deposits, following the more permeable channels. It appears likely that permeability of the coarse clastic sediments was the dominant physical ore control. In addition, the distribution of carbonaceous matter, pyrite, calcite, and clay has influenced the localization of ore, probably by precipitation of uranyl ions from the uranium-bearing solutions.

During my short visit, I gained the impression that ground water may have played an important part in the formation of the uranium-vanadium deposits. It is possible that circulating ground water dissolved the uranium and vanadium which were disseminated through the sedimentary rocks or overlying tuffs, and deposited them in the right chemical environment. Undoubtedly, carbonaceous matter, lime content, and possibly iron content of the sandstones were important factors in the precipitation of the uranium ore deposits.

BINGHAM CANYON COPPER MINE, UTAH

On 1st November I accompanied Mr. S.E. Jerome of Kennecott Copper Corporation on a visit to Bingham Canyon Open-pit Mine, 30 miles south-west of Salt Lake City. The mine is one of the largest copper mines in the world; 163,000 tons of waste are being removed daily, which permits mining an average of 90,000 tons of ore per day.

The ore body is a "porphyry copper" deposit situated in the Oquirrh Mountains. The country rocks are part of the Oquirrh

Formation (quartzite and limestone) of Pennsylvanian age, which has been intruded by a number of granitic stocks. Only the Bingham stock contains sufficient minerals to be worked as a mine. Chalcocite and chalcopyrite are disseminated through the Bingham stock as tiny crystals, as seams, or as coatings on fractures. The ore contains less than 1% copper plus small amounts of molybdenum and minute amounts of gold and silver. Only the large size and uniform mineralization of the orebody, allowing large-scale highly-mechanised operations, make it economically possible to recover valuable metals from such low-grade material. The sides of the huge amphitheatre-like pit are cut into benches, the bottom bench being about 2,000 feet below the top bench on the western side of the open pit. Diamond drilling has shown that the orebody extends for at least 3,000 feet below the present bottom of the open pit. Ore and waste are removed from the benches and hauled out of the open pit by railway trucks. The waste goes to disposal areas 6 miles away, and the ore goes 15 miles to the two concentrating plants at Magna.

There has been excellent development of zoning in the sediments around the Bingham stock. The stock itself is mainly granitic with a good deal of granite porphyry. Syenite, quartz monzonite, granodiorite, and quartz diorite also form parts of the stock. The texture is mainly granitoid but in places it is fine-grained or porphyritic with pink orthoclase crystals. There are several large lead-zinc mines in the limestone of the Oquirrh Formation near the Bingham stock. These are replacement bodies which have been deposited in the favourable environment of the limestone from metalliferous solutions emanating from the stock along fractures.

REFERENCES

C.I.M.M., 1948 - Structural geology of Canadian ore deposits, a symposium. Canad.Inst.Min.Metall.,Geol.Div.

C.I.M.M., 1957 - Mining, metallurgy, and geology in the Algoma uranium area. Canad.Inst.Min.Metall.,Algoma Br.

C.I.M.M., 1957 - The mining industry of Northwestern Quebec. Canad.Inst.Min.Metall., Northwestern Quebec and Hurricanaw Br.

Condon, M.A., 1956 - Report on visit to North America. Bur.Min.Resour.Aust.Rec. 1956/149.

D.M.T.S., 1957 - Summary of activities in 1956. Can.Dept.Min.Tech.Surv.

Ferris, J.G. and Sayre,A.N.1955-The quantitative approach to ground-water investigations. Econ.Geol., 50th Anniv.Vol., 714-747.

G.S.C., 1957 - Geology and economic minerals of Canada. Geol.Surv.Can.Econ.Geol.Ser. 1.

Isachsen, Y.W. and Evensen, C.G., 1956 - Geology of uranium deposits of the Shinarump and Chinle Formations on the Colorado Plateau. Prof.Pap.U.S.Geol.Surv. 300, 263-280.

Jenney, C.P., 1957 - Exploration in New Brunswick 1932-1957. Min.Br.New Brunswick.

Lang, A.H., 1956 - Prospecting in Canada. Geol.Surv.Can.Econ. Ser. 7.

Lekas, M.A. and Dahl, H.M., 1956 - The geology and uranium deposits of the Lisbon Valley Anticline, San Juan County, Utah. Inter-mountain Ass.Petrol. Geol. Field Conference, 161-168.

McLaughlin, T.G., 1956 - Ground water in Colorado and the status of investigations. Colo.Water Conserv.Board, Ground-water Ser., Circ. 4.

Meinzer, O.E., 1923 - The occurrence of ground water in the United States. U.S. Geol.Surv.Water Supply Pap. 489.

R.M.A.G., 1955 - Geology of Front Range Foothills west of Denver. Rocky Mt. Ass.Geol., Field Conference Guidebook.

Thomas, H.E., 1952 - Ground-water regions of the United States - their storage facilities. U.S. Congress, Phys. Econ. Foundation Nat.Resour. 3.

Toombs, R.B. and Simpson, R.A., 1957a - A survey of the petroleum industry in Canada during 1956. Can.Dept.Min. Tech.Surv.,Miner.Resour.Div.,Circ. 23.

______, 1957b ____ A survey of the natural gas industry in Canada during 1956. Can.Dept.Min.Tech.Surv., Miner.Resour.Div.,Circ. 24.

Wenzel, L.K., 1942 - Methods for determining permeability of water bearing materials. U.S. Geol.Surv.Water Supply Pap. 887.

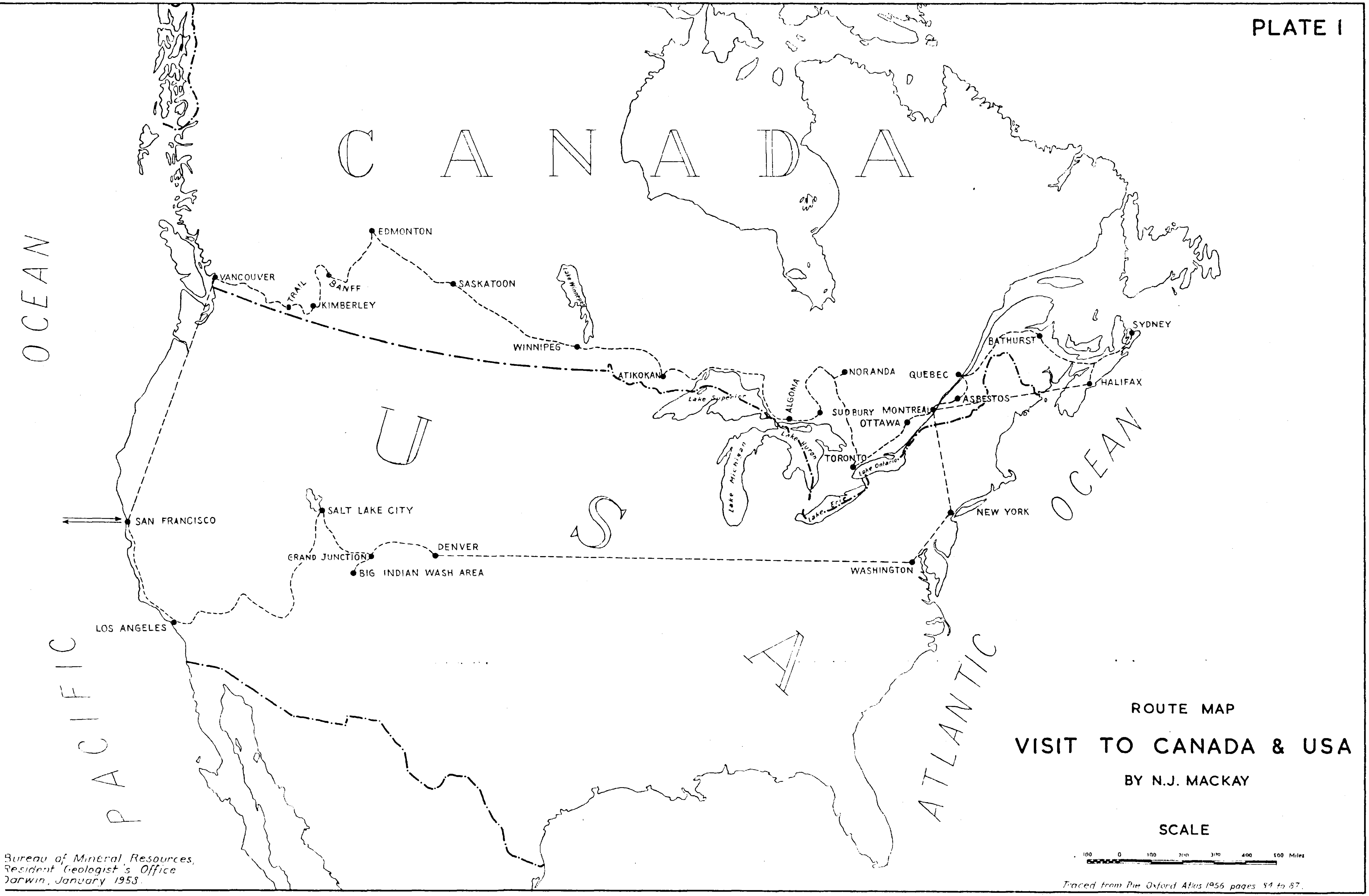
PLATE I
CANADA
U S A
PACIFIC OCEAN
ATLANTIC OCEAN
VANCOUVER
TRAIL
BANFF
KIMBERLEY
EDMONTON
SASKATOON
Lake Winnipeg
WINNIPEG
ATIKOKAN
Lake Superior
ALGOMA
NORANDA
SUDBURY
QUEBEC
BATHURST
SYDNEY
HALIFAX
ASBESTOS
MONTREAL
OTTAWA
Lake Huron
Lake Michigan
TORONTO
Lake Ontario
Lake Erie
NEW YORK
WASHINGTON
SAN FRANCISCO
SALT LAKE CITY
GRAND JUNCTION
DENVER
BIG INDIAN WASH AREA
LOS ANGELES
ROUTE MAP
VISIT TO CANADA & USA
BY N.J. MACKAY
SCALE
100 0 100 200 300 400 500 Miles
Bureau of Mineral Resources,
Resident Geologist's Office
Darwin, January 1958.
Traced from The Oxford Atlas 1956 pages 84 to 87.