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Alberta Geological Survey Research

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See table of contents

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Article abstract

Geological research and survey work by the Alberta Geological Survey is concentrated in three main areas — energy resources, mineral resources and environmental geology. The collective results of current investigations reveal some exciting new perspectives on Alberta's geology, particularly with regard to the faciès and depositional environments of the oil sands, petroleum and coal-bearing strata of the plains, the industrial mineral potential of the province, and the region's Quaternary stratigraphy and glacial history.

Articles

Achievements in the Provincial Surveys

This is the first article in a new, open-ended series intended to focus interest on some of the specialized studies underway in provincial geological surveys. In-house publications by these organizations sometimes do not receive the general circulation which they deserve, and it is to be hoped that this series will bring to the attention of a wider audience some of the important scientific results obtained by survey officers. It is anticipated that some articles, such as this one, will provide broad overviews of a wide range of survey activities, while others will deal with particular, specialized studies, of which there are many unique to a particular region or province within Canada.

Alberta Geological Survey Research

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Summary
Geological research and survey work by the Alberta Geological Survey is concentrated in three main areas—energy resources, mineral resources and environmental geology. The collective results of current investigations reveal some exciting new perspectives on Alberta's geology, particularly with regard to the facies and depositional environments of the oil sands, petroleum and coal-bearing strata of the plains, the industrial mineral potential of the province, and the region's Quaternary stratigraphy and glacial history.

Résumé
L'Alberta Geological Survey concentre sa recherche et ses relevés dans trois principaux domaines de la géologie: les ressources énergetiques, les ressources minières et la géologie de l'environnement. Le résultat global des investigations en cours nous ouvrent d'intéressantes perspectives sur la géologie de l'Alberta, tout particulièrement en ce qui concerne les faciès et conditions de sédimentation des sables bitumineux et des couches productrices du charbon et du pétrole des plaines, le potentiel minier industriel, la géologie glaciaire et la stratigraphie du Quaternaire de la région.

Introduction
The mandate of the Alberta Geological Survey is to elucidate the geological framework of the province and to make this knowledge broadly available to the public. Emphasis is placed on determining the nature and origin of Alberta's energy and mineral resources and on understanding those dynamic geological processes which affect societal interaction with the earth and its resources. In these regards, the Alberta Geological Survey is similar to geological surveys in equivalent jurisdictions across Canada and indeed throughout the world.

In two important ways, however, the Alberta Geological Survey is unique in Canada. First, it is organizationally distinct in the sense that it does not function as part of a line government department (e.g., Mines and Minerals/Energy and Natural Resources). Rather, it is part of a separate crown institution wholly dedicated to research in the natural and applied sciences, the Alberta Research Council. As such, the Alberta Geological Survey does not have direct legislative or regulatory responsibility within the government and is not specifically involved in computing mineral or energy reserves. In Alberta these functions are respectively discharged by Alberta Energy and Natural Resources and the Alberta Energy Resources Conservation Board. Thus, all of the Survey's human and monetary resources are dedicated to geological research and survey work.

Second, the Alberta Geological Survey is unique amongst provincial surveys in its blend of expertise, which is overwhelmingly dominated by the soft rock side of the geosciences. This is a natural reflection of the predominantly sedimentary character of Alberta's rocks, the paucity of metallic mineral deposits in Alberta and the province's dependence on the energy industry. Of thirty-one professional staff, about three-quarters are stratigraphers and sedimentologists.

The work of the Alberta Geological Survey can be viewed as falling into three categories: 1) energy resources research, including oil sands, coal and petroleum; 2) mineral resource surveys, predominantly relating to industrial minerals; and 3) environmental geology research, emphasizing Quaternary geology and reclamation research. The intent of this article is to convey something of the nature and scope of ongoing work in each of these three areas.

Energy Resources
The deposits and reservoirs encompassed by research projects in energy resources are shown in Figure 1. With emphasis on oil sands, coal and non-conventional petroleum, the program complements and perhaps foreshadows the mainstream efforts of the Alberta energy industry, which are concentrated in the search for and development of conventional oil and gas.

Oil Sands Geology
Figure 2 illustrates the stratigraphic distribution of the major oil sands and heavy oil reservoirs of Alberta. All are presently under active investigation by the Alberta Geological Survey.

Each deposit study has three essential components: 1) facies analysis and interpretation of depositional environments and paleogeography, in order to develop predictive capability regarding the three-dimensional geometry of the reservoir sands and the intervening shales in the subsurface; 2) petrologic characterization of the reservoirs and the enclosing rocks, to determine geotechnical behaviour and assist with physical and numerical modelling of the reservoirs; and 3) regional mapping of entire deposits (structural maps, isopachs, sand/shale ratio maps, bottom water maps, net pay maps, and so on) as a basis for judgements regarding reserves estimation, pilot plant siting and *in-situ* process transferability.

Facies Analysis. Reconstruction of Mannville Group facies and depositional environments has reached advanced stages of refinement in a number of deposits.

In the Lower Mannville Gething and McMurray Formations (Fig. 2) deposition took place against a background of subsidence and impending transgression by the Boreal Sea. In the Peace River Deposit (Fig. 1) Gething deposition evolved from basal continental sedimentation, with channel sands and associated muds and local coals, to tidal flat and shallow marine sand sedimentation with local development of large upward-fining tidal channel deposits (Rottenfusser, 1982a). The best oil sands in the Peace River River Deposit are found in these tidal channel sands. In the Athabasca Deposit (Fig. 1) the McMurray Formation was dominated by deep channel sedimentation in a coastal plain fluvial complex (Mossop and Flach, 1983). The geometry and paleohydrology of the deep channels is now worked out in considerable detail (Flach and Mossop, 1982). It remains to be seen how the Peace River and Athabasca interpretations of the Lower Mannville Group fit into the broader paleogeographic mosaic that other workers are uncovering in various parts of Alberta, British Columbia and Saskatchewan.

In southern Alberta, study of the middle Mannville Glauconitic Sandstone (Fig. 2) is now complete and reveals a progradational beach sequence grading upwards from lower and middle shoreface sands, through foreshore and backshore sediments, to continental deposits at the top. The north-south trending sand belt, which includes the best heavy oil reservoirs, was locally dissected by channels and/or tidal inlets. The seaway at the time is inferred to have been to the east of the Suffield block (Tilley, 1983; Tilley and Longstaffe, in press).

For the middle and upper Mannville a number of relatively advanced studies now provide sufficient basis for reasonable speculation on the nature and form of ancient shoreline trends (Fig. 3). In the Wabasca Oil Sands area (Fig. 1) Kramers (1982) describes a barrier island/coastal complex with the sea to the northwest of the deposit (Fig. 3). In the Cold Lake-Lloydminster area (Fig. 1) Wightman (1982)

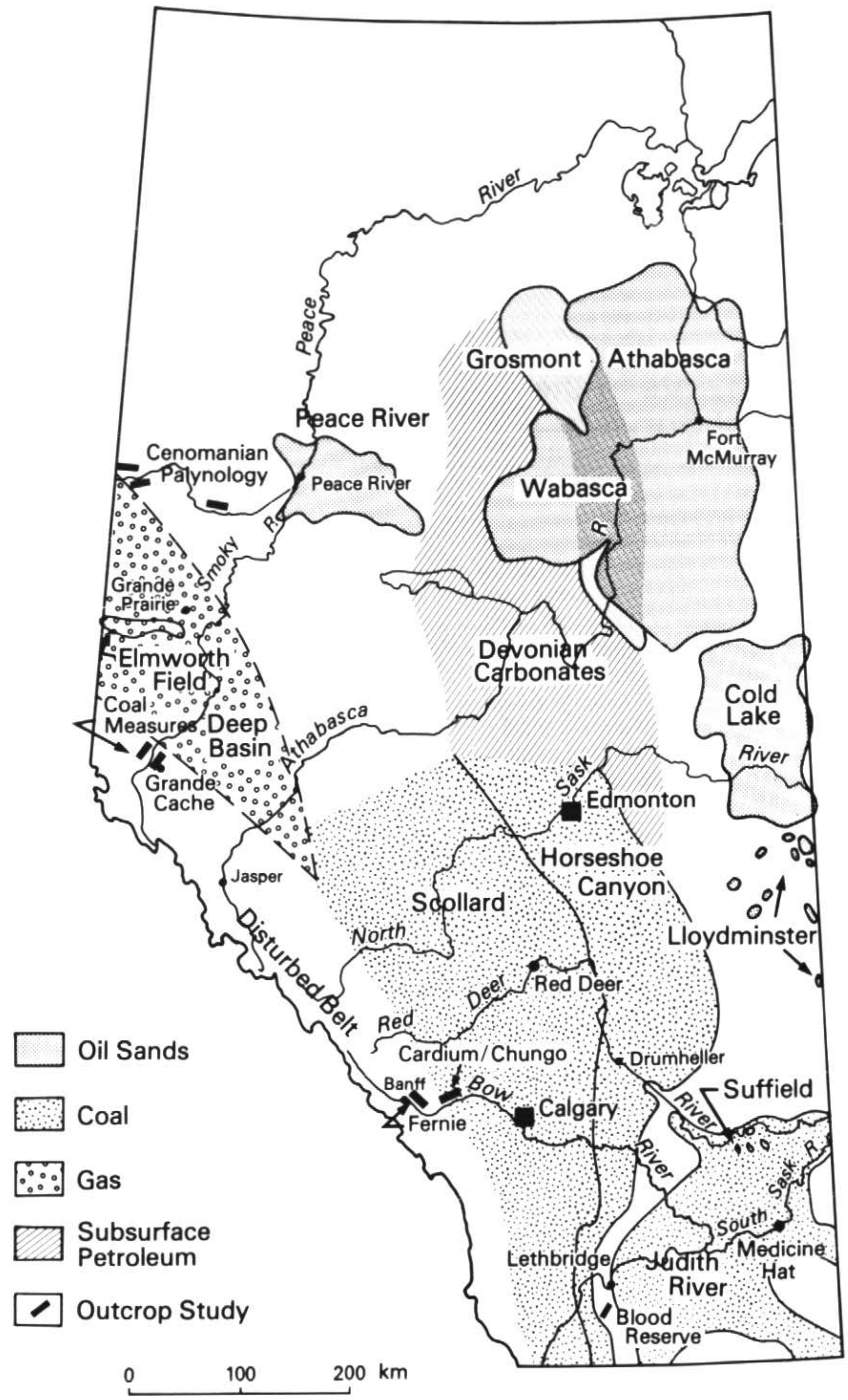

Figure 1 *Study areas for energy resources research at the Alberta Geological Survey—oil sands and heavy oil deposits, dominantly in the subsurface save for the outcrop region around Ft. McMurray; coal-bearing strata, here shown in outcrop expression but extending westward into the subsurface as well; the Deep Basin gas play; petroleum geology studies relating to subsurface Devonian carbonates; and specialist research in structural geology (Grande Cache Coalfield), palynology (Cenomanian microfloras in the Peace River country) and ichnology (relating to most of the illustrated energy resources plus the Jurassic Fernie and the Cretaceous Cardium, Chungo and Blood Reserve Formations)*

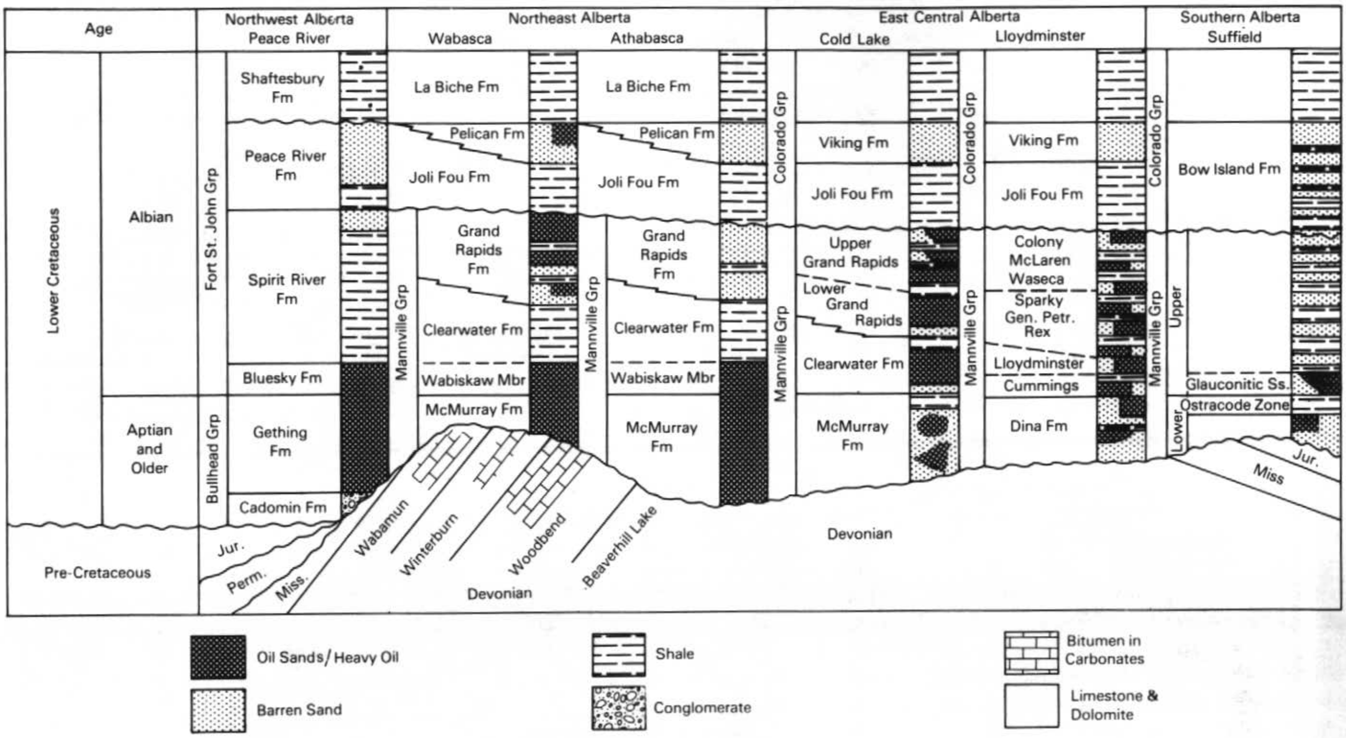

Figure 2 *Correlation chart of bitumen-bearing strata in the Lower Cretaceous clastics and subcrop Devonian carbonates of Alberta (adapted from an unpublished figure by J.W. Kramers). See Figure 1 for the locations of the stratigraphic columns*

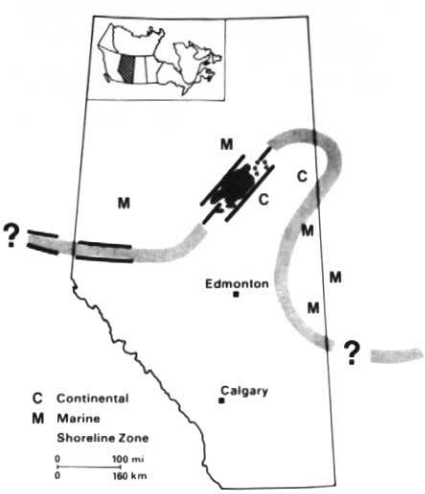

Figure 3 *Generalized reconstruction of Upper Mannville paleogeography in Alberta (based on an unpublished figure by J.W.Kramers), drawing on the recent results of Alberta Geological Survey studies in various oil sands and natural gas deposits (see text)*

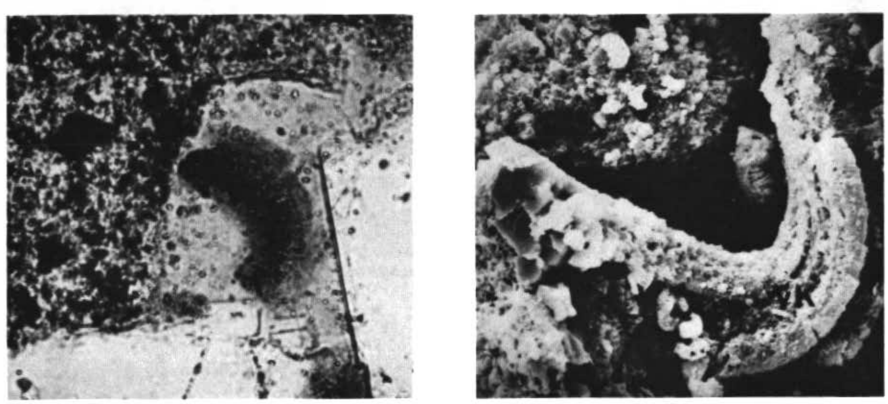

Figure 4 *Vermicular kaolinite (vK) of authigenic origin in pores of the heavy oil-bearing Glauconitic Sandstone of the Suffield area (from Tilley and Longstaffe, in press), shown in thin-section and scanning electron photomicrographs. Bar scale (right) is 20µ*

and O'Connell (pers. com.) interpret the complex upper Mannville succession as variably continental and marine (Wightman *et al.,* 1983), with the seaway to the east (Fig. 3). These interpretations are somewhat at odds with those of Putnam and Oliver (1980), who invoke sedimentation in anastomosed channel systems (see discussion by Wightman, *et al.,* 1981). In correlative strata of the Deep Basin of northwest Alberta (Fig. 1), Cant (1983; in press) interprets the middle part of the Spirit River Formation (Fig. 2) as a series of wave-dominated shoreline sequences grading from nonmarine clastics and coals in the south to fully marine deposits in the north. Figure 3 thus represents a conjectural synthesis of upper Mannville paleogeography, for refinement, modification or transformation in response to future work.

Petrologic Characterization. The second component of each deposit study encompasses the petrography and diagenesis of the oil sands reservoirs and the associated strata, using thin-section and scanning electron microscopy. A complete diagenetic sequence for the Peace River Deposit has now been worked out (Rottenfusser, 1982b). Reservoir quality has been significantly affected by a complicated diagenetic history involving, in their probable order of emplacement, pyrite cementation, quartz overgrowth, feldspar overgrowth, dawsonite cementation, kaolinite authigenesis, montmorillonite authigenesis and illite authigenesis. The clay minerals are most abundant in the water-bearing sands. Dawsonite, an unusual sodium-aluminum carbonate mineral, occurs in only the richest oil sands. Secondary porosity was formed after feldspar overgrowth but before precipitation of kaolinite. Oil migration took place after part of the kaolinite had formed.

Another reservoir where petrologic parameters play an important role in the definition of reservoir quality is in the Suffield Heavy Oil area (Fig. 1). The reservoir sand is composed of quartz, chert, sedimentary rock fragments, trace amounts of feldspar and 2 to 30 weight percent clay. Kaolinite, the dominant clay mineral (Fig. 4), occurs as small platelets, forming grain linings and pore bridges; vermicular overgrowths; and silt-sized rock fragments. Lesser amounts of illite, smectite and mixed layer clays occur as ridges on grain surfaces and as pore bridges. Illite also occurs as needlelike projections. The most argillaceous sands, located at the top of the Glauconitic sequence, contain only very fine kaolinite. Quartz overgrowths contribute to porosity reduction in the cleaner sands. Minor amounts of secondary porosity can be identified by the presence of partly leached feldspar grains (Tilley and Longstaffe, in press).

Deposit Mapping. Regional subsurface mapping of entire deposits, the third component of each oil sands study, is now relatively advanced for the Athabasca, Wabasca and Peace River Deposits. Publication of results for the northern portion of the Athabasca Deposit is anticipated for the coming year (Flach, in press). Literally dozens of basic and derivative maps need to be generated for each deposit if there is to be a cogent basis for resource evaluation and assessment of the suitability and transferability of various *in-situ* extraction technologies. An example of such a map, for the Athabasca Deposit, is shown in Figure 5.

Coal Geology

The Alberta Geological Survey's research on coal is centred on the geology of Cretaceous and Tertiary coal measures in the Alberta plains (Fig. 1). Facies studies, based on surface exposures and the logs and cores derived from extensive drilling programs, are used as tools for predicting seam thickness and continuity. This work is augmented by research in coal petrology and coal chemistry. A comparatively modest effort is devoted to the structural geology of deformed coal measures in the foothills and front ranges.

Facies Studies. Figure 6 illustrates the stratigraphic positions of the major coal zones in the Upper Cretaceous-Tertiary sequence of south-central Alberta. Facies studies of virtually all of these strata are either currently in progress or are recently completed.

Study of the Judith River Formation is greatly facilitated by superb three-dimensional exposure (Fig. 7) in the badlands of Dinosaur Provincial Park, along the Red Deer River (Fig. 1). The park has been recently designated as a UNESCO World Heritage Site for its diverse and abundant assemblage of dinosaurian remains. Koster (1983) interprets the sand bodies as representing sedimentation in two fundamentally different types of channel—vertically aggraded sands in low-sinuosity channels, and laterally accreted units, with well-preserved accretion bedding, in high-sinuosity channels.

Rahmani (1982, 1983) has worked out a detailed facies reconstruction for the coal-bearing Bearpaw-Horseshoe Canyon transition sediments (Fig. 6) exposed in the Drumheller area (Fig. 1). The lower part of the sequence is an upward-coarsening delta deposit comprising prodelta, delta front and distributary channel sediments, capped by a coal seam. The upper part of the sequence contains four units, each of which represents a complete barrier and back-barrier island complex of beach, tidal channels and shoals, lagoons and oyster beds, with a capping coal seam. The complex was probably deposited in a macro- to mesotidal river estuary, in an embayment flanked by mesotidal barrier islands.

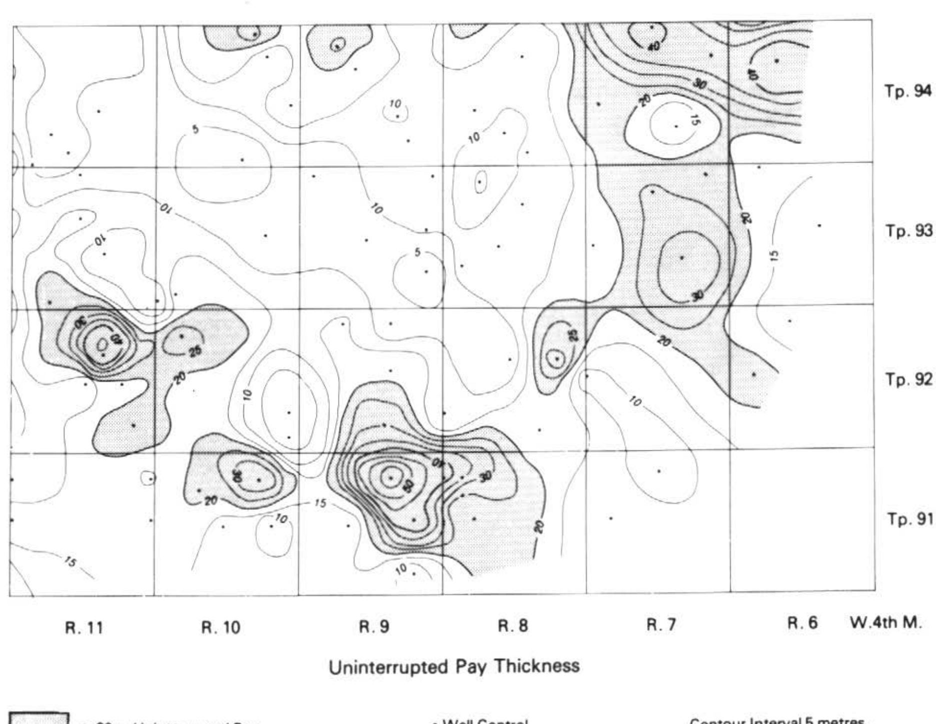

Figure 5 *Isopach of uninterrupted pay thickness (oil sands with greater than 8 weight percent bitumen saturation through intervals devoid of shale breaks over 3 m thick), in part of the Athabasca Oil Sands Deposit (adapted from a drafted map by Flach, in press)*

Higher in the Horseshoe Canyon Formation (Fig. 6) a subsurface facies study has been completed on the Carbon-Thompson coal zones (Nurkowski and Rahmani, 1982). Figure 8 illustrates the stratigraphic and paleogeographic implications of the proposed depositional model, a model that has considerable utility in predicting lateral variability in coal seam thickness and quality.

Facies studies of other parts of the Upper Cretaceous coal-bearing sequence – Horseshoe Canyon Formation (Waheed, 1983; McCabe, 1983) and the Ardley coal zone of the Scollard Member (Nurkowski, 1983) – are currently in progress.

Coal Chemistry and Rank. Regional variation in the rank and quality of shallow plains coals (to about 300 m depth) has been the subject of a stratigraphic and statistical study of more than 600 coals (Nurkowski, 1982, and in press). In addition to developing new methods for relating moisture content to rank and original depth of burial, the study shows that coal rank varies systematically from subbituminous C in the east to high volatile bituminous C in the west. The increase in rank towards the Rocky Mountains can be related to greater original Tertiary overburden thickness in that direction rather than to tectonic effects on coalification. The work is based on burial depth/equilibrium moisture relationships originally discerned by Hacquebard (1977). Figure 9 illustrates how the coal rank gradient cuts across the stratigraphy and shows the reconstructed topographic profile of central Alberta.

Foothills Coal Measures. In the Grande Cache coalfield north of Jasper National Park, Lower Cretaceous coal measures are mined in a complex structural setting, characterized by low angle thrusts and chevron folds. A computer model, using geological data from outcrops and drill holes, allows for downplunge projection of distinct cylindrical domains (Langenberg, 1982) and better definition of coal seam geometry. The results are being directly applied in mine planning and in the search for additional reserves with appropriately low stripping ratios.

Petroleum Geology

The Alberta portion of the Western Canada Sedimentary Basin is now a relatively well explored petroleum province. The continued vitality of the industry centres around

Figure 7 *Judith River Formation channel sands exposed in the badlands of Dinosaur Provincial Park, southeast of Drumheller. Note the prominent accretion bedding (sloping sand-mud couplets) in juxtaposed and truncated sets (from Koster, 1983)*

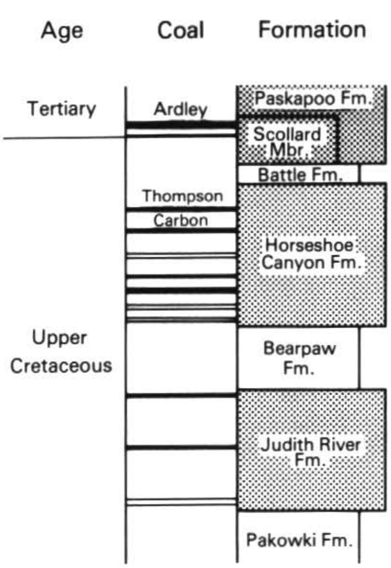

Figure 6 *Generalized stratigraphic column of the coal-bearing sequence in the plains of southern Alberta. Outcrop areas for these formations are shown in Figure 1*

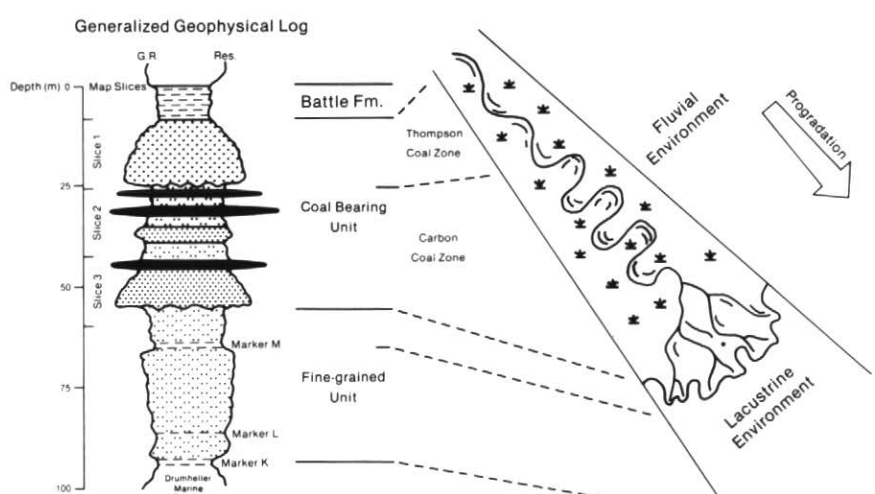

Figure 8 *Generalized lithologic column and interpreted depositional environments for the Carbon-Thompson coal zone of the upper Horseshoe Canyon Formation (Fig. 6). The paleotransport direction of the fluvial system was toward the southeast, with maximum coal development in the inter-channel areas along similarly oriented trends (from an unpublished figure by J.R. Nurkowski)*

successful exploration for ever more subtle and elusive traps and, in support of enhanced recovery applications, on better geological and petrophysical understanding of the known reservoirs. Research in the Alberta Geological Survey is focused on some of the particularly problematic traps, such as the Deep Basin gas reservoirs of northwestern Alberta, and on regional synthesis work relating to specific subsurface strata, such as the Devonian carbonate complexes of north-central Alberta (Fig. 1).

Deep Basin. In addition to completed facies studies on the Spirit River Formation of the Deep Basin (Fig. 1), Cant (1983) has completed a petrographic analysis of some of the gas reservoirs. Of the postulated ultimate resources of the Deep Basin (up to 11 x $10^{12} m^3$, Masters, 1979), only a small percentage is hosted in conventional sandstone and conglomerate reservoirs. The remainder is trapped in very fine-grained sandstones known as "tight sands". The tight sands have been subjected to porosity loss due to formation of quartz overgrowths, crushing of sedimentary rock fragments and cementation by carbonates and clays. The extraordinary characteristic of the tight sands is that they have permeabilities which are less than some shales (Fig. 10) and may themselves form the seals which trap gas in the basin by retarding updip flow. Thus, the Spirit River gas deposits can be considered to have resulted from a combination of stratigraphic and diagenetic trapping.

Devonian Carbonates. Study of the Subcrop Carbonate Trend – bitumen-bearing Paleozoic carbonates beneath the regional pre-Cretaceous unconformity (Fig. 2) – has been to date concentrated in the eastern part of the Grosmont complex (Harrison, 1982; Fig. 1). This work is the subject of a separate article in this Geoscience Canada series (Harrison, in prep.). Further research is now in progress on the remainder of the Grosmont complex (Walker and Harrison, in prep.) and on other Devonian carbonate rocks to the south in the conventional oil producing part of the province (Fig. 1). Strata under study include Beaverhill Lake, Woodbend and Winterburn Group carbonates (Fig. 2), specifically the carbonate buildups of the Cooking Lake, Leduc and Nisku Formations. Interpretative maps and cross-sections resulting from this work are released in the form of open file reports (e.g., Ing and Harrison, in prep.).

Specialist Studies

The paucity of preserved macrofossils in the Alberta Cretaceous means that the alternative paleontological disciplines of palynology and ichnology assume much greater importance, both as age indicators and as tools for sedimentological and paleoecological reconstruction. Palynology and ichnology play a central role in most of the Survey's facies work relating to oil sands, coal and petroleum resources.

Palynology. A ten-year study of the Cenomanian microfloras of the Peace River area is now virtually complete. Based on rich microfloral yield from the Shaftesbury, Dunvegan and Lower Kaskapau Formations in northwestern Alberta (Fig. 1), the published monograph (Singh, 1983) is anticipated to serve as an international standard for Cenomanian zonation.

Ichnology. In ichnology, the past year has brought to fruition a number of fundamental studies on trace fossil morphology, ethology and classification (e.g., Pemberton and Frey, 1982; in press). In addition, a number of collaborative studies with Alberta Geological Survey scientists and industry geologists have been initiated or completed. An example of the utility and timeliness of such studies is that by Pemberton *et al.* (1982), which, in the absence of diagnostic sedimentological or other paleoenvironmental evidence, shows that the McMurray Formation channel complex (Mossop and Flach, 1983) was physiographically situated in a coastal plain setting, with saltwater conditions developed at least locally, perhaps as salt wedges in the channels or as marine to brackish interchannel bays.

Mineral Resources

Research on Alberta's mineral resource base centres on the province's abundant

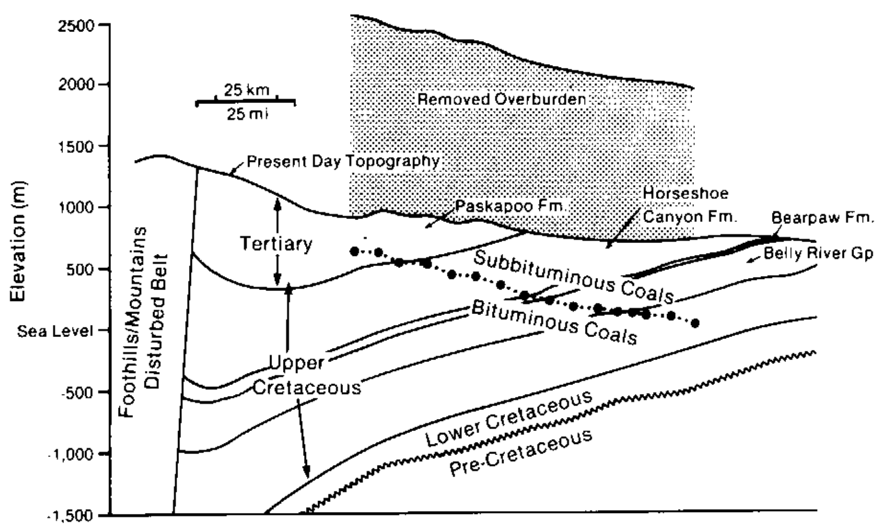

Figure 9 *Generalized structural cross-section of Upper Cretaceous/Tertiary coal measures in the central Alberta plains, showing that the near-surface subbituminous coals give way down dip to higher rank bituminous coals along a boundary that parallels not the present day topography but the reconstructed topography as it existed prior to major Tertiary/Quaternary erosion (after Nurkowski, in press)*

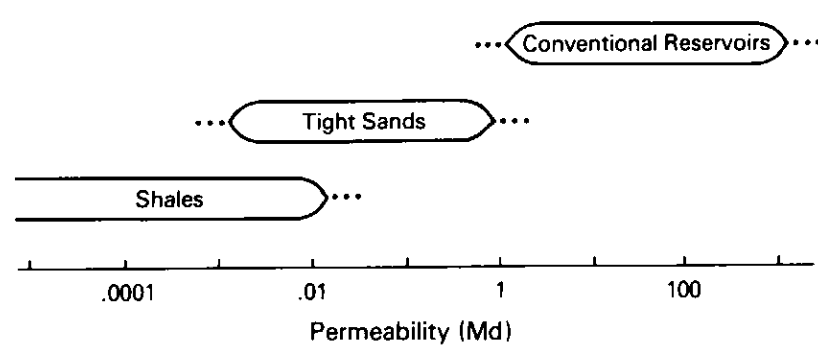

Figure 10 *Comparative permeability ranges for the "tight sands" of the Deep Basin (Fig. 1) relative to conventional hydrocarbon reservoirs and seal-rock shales (adapted from Cant, 1983). The plot points to the possibility that the tight sands may act as their own leaky seals to gas generated deeper in the basin*

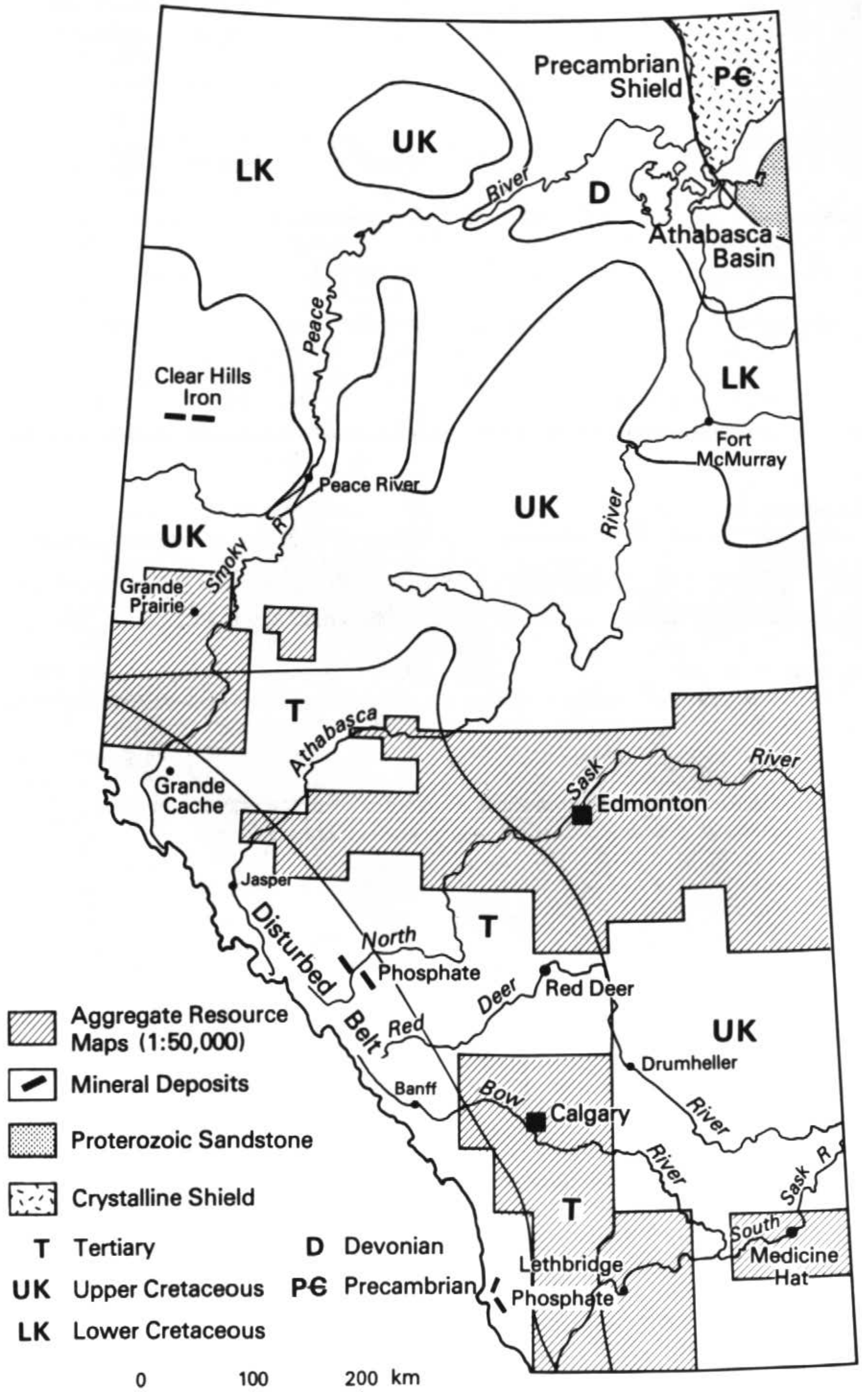

Figure 11 *Study areas for mineral resources research at the Alberta Geological Survey, and generalized bedrock geology of the province. Many surveys of industrial mineral resources are province-wide in scope and are not shown. Others are unique to specific terrains—phosphate in the disturbed belt, the Clear Hills oolitic iron formation in the Peace River country, the Precambrian crystalline shield and Athabasca Basin in northeastern Alberta, and ceramic clays in Upper Cretaceous nonmarine strata of southern Alberta*

and diversified industrial minerals—aggregate, ceramic clay, sulphur, lime, marl, dolomite, salt, gypsum, phosphate, heavy minerals—as both primary resources and by-products from the beneficiation of other earth resources. In addition, the Alberta Geological Survey has conducted research on the Cretaceous Clear Hills iron formation in the Peace River country, placer gold concentrations in Alberta rivers, and on the uranium potential of the Proterozoic Athabasca Basin of northeastern Alberta (Wilson, 1983). Assessment of the mineral potential of the crystalline Precambrian Shield in northeastern Alberta is encompassed in a detailed and comprehensive geological survey of the region. Current projects relating to mineral resources are illustrated in Figure 11.

Industrial Minerals

Phosphate. Four geological formations, or groups, are known to contain phosphate beds within the Alberta Cordillera. These are the Mississippian Exshaw Formation, the Permo-Pennsylvanian Rocky Mountain Group, the Triassic Spray River Group and the Jurassic Fernie Group. The Fernie Group seems to have the best potential for phosphate mining (Fig. 12). A high grade bed of variable thickness (greater than 15 percent P_2O_5, 0.2 to 1.0 m) occurs in many of the western exposures of the group, from Jasper to the Crowsnest Pass region. Although many of these occurrences are within Banff and Jasper National Parks, a potentially exploitable area lies west of Nordegg (Macdonald, 1982; in press).

Salt and Gypsum. Evaporites abound in the Western Canada Sedimentary Basin, recurring throughout the stratigraphic column and scattered widely over the basin

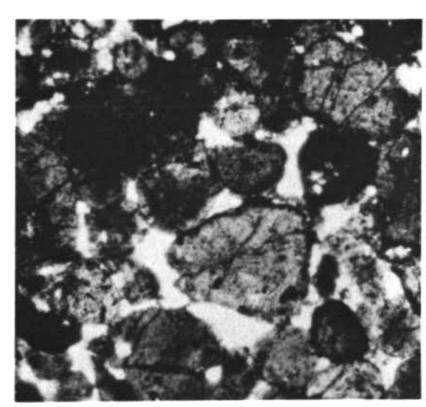

Figure 12 *Thin-section photomicrograph of fluorapatite pellets, cemented by calcite, from the Jurassic Fernie Formation in the Crowsnest Pass area of southwestern Alberta (photo by D.E. Macdonald)*

region. Economic mineral potential for the evaporites is nonetheless somewhat limited. The thickest, most extensive salt deposits are the upper Lotsberg and Prairie Evaporite salts, both of which have excellent exploitation potential. The Peace Point and Fort McMurray Deposits have the best gypsum development potential for Alberta (Table I). The Peace Point Deposit has excellent quality, with average grades running 95 percent gypsum over thicknesses of 5 to 10 metres, and reserves estimated in the order of one billion tonnes (Hamilton, 1982).

Industrial Clays. Various Alberta clays and shales exhibit widely divergent ceramic properties. A recently completed study on the geological factors controlling refractoriness (Scafe, 1981) indicates that the ceramic potential of a given material can be related to its proportional kaolinite content, or to its calcite content. For example, the higher refractoriness of the Kootenay Formation in the Crowsnest Pass area compared to the Bow River area is attributable in large part to the greater amount of kaolinite present in material from the Crowsnest Pass. Within either geographic area, samples containing similar amounts of kaolinite have notably different refractoriness due to variations in the amount of calcite. Similar tendencies are noted in other formations. On the basis of multiple regression analysis it has been determined that 72 percent of the variation in refractoriness can be explained by the 7 oxides normally determined by chemical analyses, with calcium oxide explaining 43 percent of the variation.

Aggregate. Aggregate is one of Alberta's most important industrial mineral commodities. Sand and gravel represent the principal types of mineral aggregate, however there are parts of the province in which this resource is becoming scarce. Haul distances of 50 km or more are not uncommon. The Alberta Geological Survey's Aggregate Inventory assesses known sand and gravel resources and explores for additional reserves, but also conducts research on the availability and potential of such alternate commodities as expandable clays and crushed stone. Data on the amount, availability and aggregate potential of various materials are being incorporated into regional overview assessments, for use by municipalities and rural jurisdictions concerned with planning and management of aggregate resources (Edwards, 1982; Edwards and Hudson, 1983). Aggregate mapping at 1:50,000 now covers 21 percent of the province, encompassing 82 percent of the population (Fig. 11).

Precambrian Shield

The last of 37 geological maps are complete in draft form for the crystalline Precambrian Shield of northeastern Alberta (for example see Godfrey, 1984). A number of synthesis reports are also either published or are prepared for publication (Langenberg and Nielson, 1982; Langenberg, 1983). The complex of granitoids, gneisses and metasediments in northeastern Alberta was subjected to two distinct cycles of metamorphism (Fig. 13). During the Archean metamorphic cycle some of these rocks were subjected to high-pressure granulite facies conditions (M_1). In a second cycle, probably related to remobilization during the Hudsonian Orogeny, the complex was subjected to conditions of granulite-amphibolite facies metamorphism, retrograding to greenschist facies conditions. Microprobe mineral analysis of coexisting garnet-biotite and garnet-cordierite pairs, principally from the metasediments, allows estimation of P-T conditions across the granulite-amphibolite transition. A moderate-pressure granulite facies event ($M_{2\text{-}1}$) and a low-pressure amphibolite facies overprint ($M_{2\text{-}2}$) also have been identified. The widespread formation of granitoids by anatexis and ultrametamorphism during $M_{2\text{-}1}$ is indicated by their Aphebian ages and their initial high strontium ratios. Some granitoids show minerals characteristic of both cycles of metamorphism, but other granitoids contain minerals characteristic of the second cycle only. All rocks were subjected to a retrograde phase of greenschist facies conditions ($M_{2\text{-}3}$) (Langenberg and Nielson, 1982).

Environmental Geology

The Environmental Geology Section of the Alberta Geological Survey is concerned with 1) the surficial geology and Quaternary stratigraphy of the province and, 2) reclamation, particularly as it relates to plains coal mines. Figure 14 shows the localities and map areas that are the subject of current projects.

Quaternary Research

Sand River Map Area. An example of Quaternary studies is the project on the Sand River map sheet in east-central Alberta (Fig. 14). The project is concerned with providing information necessary for land use planning in the region of the Cold Lake Oil Sands. The study consists of three components: 1) surficial geology; 2)

TABLE I. Selected chemical analyses of Alberta gypsum deposits

	Kananaskis		Fort McMurray			Peace Point			Head Creek		Fetherstonehaugh Creek			Mowitch Creek		
Contituent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CaO	32.39	32.58	31.40	31.66	30.86	32.18	32.72	32.70	31.50	32.92	32.77	32.86	32.63	31.90	32.02	27.80
SO_3	44.94	45.31	36.89	41.05	40.25	45.91	44.48	45.87	32.04	46.14	44.92	45.51	44.64	43.28	45.83	38.42
SiO_2	1.00	.56	7.15	3.51	5.72	0.64	—	.11	4.16	.02	—	—	.20	1.51	1.91	11.91
R_2O_3*	.32	.20	.73	.35	.49	—	.55	.28	.46	.04	.30	.19	.54	.49	.32	.40
MgO	.80	.28	.20	.37	.14	0.22	.77	.20	5.32	.06	.75	.41	.71	1.41	—	1.51
Na_2O	n.a.**	n.a.	n.a.	n.a.	n.a.	n.a.	.02	—	.04	—	.03	.01	.02	n.a.	n.a.	n.a.
K_2O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	—	—	.18	—	.02	—	—	n.a.	n.a	n.a.
L.O.I.+	19.19	19.32	21.65	21.51	21.31	21.02	21.40	21.66	26.85	20.70	21.86	21.49	21.37	21.51	20.00	19.90
TOTAL	98.64	98.25	98.02	98.45	98.77	99.97	99.94	100.82	100.55	99.88	100.65	100.47	100.11	100.10	100.08	99.94
H_2O at 200°C	n.a.	n.a.	16.64	18.51	17.92	n.a.	20.00	20.67	13.34	19.82	19.92	20.52	20.09	n.a.	n.a.	n.a.
Calculated Mineral Composition																
$CaSO_4.2H_2O$	84.15	87.73	79.25	88.21	85.58	98.73	95.47	97.23	63.75	94.71	95.19	97.88	96.00	89.45	95.57	82.62
$CaSO_4$	9.88	7.68	—	—	.26	—	.08	—	2.25	2.53	.81	—	—	2.86	2.17	—
$CaCO_3$	1.62	1.50	8.60	4.00	5.09	.04	1.27	1.75	17.51	1.84	2.55	1.18	1.14	2.84	—	1.59
$MgCO_3$	1.67	.59	.42	.77	.29	.46	1.61	.42	11.13	.13	1.57	.86	1.49	2.95	—	3.16
Others++	1.32	.76	8.75	5.47	7.55	.74	1.52	1.42	5.91	.67	.53	.55	1.48	2.00	2.34	12.57
TOTAL	98.64	98.26	98.03	98.45	98.77	99.97	99.95	100.82	100.55	99.88	100.65	100.47	100.11	100.10	100.08	99.94

*Includes Al_2O_3, Fe_2O_3, TiO_2, P_2O_5
**not analyzed for
+ Loss On Ignition
++ Mainly quartz and clay minerals, plus any excess of CaO, SO_3, H_2O or L.O.I.

Quaternary stratigraphy; and 3) bedrock topography.

In addition to the production of surficial geology maps (1:50,000 and 1:250,000 scale) using a newly developed mapping method, the project has resulted in recognition of previously unknown types of glacial-thrust terrain, developed over very large areas (Fenton and Andriashek, in press). Glacial-thrusting in one area, for example, has produced a depression of 37 square kilometres and an adjacent thrust ridge over 90 metres high and containing about 2.7 cubic kilometres of sediment. Such terrains characteristically exhibit marked geotechnical instability and need to be better understood for engineering purposes in the construction of roads and pipelines and in strip mine operations.

The stratigraphic studies have led to the definition of eight Quaternary formations on the basis of physical properties, stratigraphic position and geophysical characteristics (Andriashek and Fenton, 1982; Fenton and Andriashek, in press). Subsurface structure and isopach maps, together with cross-sections, show the distribution and composition of each formation (Fig. 15).

The bedrock topography component includes maps showing structure contours on the bedrock, drift thickness and preglacial channel morphology (Gold, Andriashek and Fenton, 1983; Fenton and Andriashek, in press). The mapping has allowed for the delineation of a number of previously unrecognized preglacial and interglacial channels cut into the bedrock.

Data from the stratigraphic and bedrock topography components are being used in another Research Council study on the groundwater resources of the Cold Lake Deposit area and by some of the petroleum companies developing the deposit.

Southern Alberta Synthesis. Synthesis mapping of southern Alberta, from latitude 49° to 54° and the Saskatchewan border to the disturbed belt (Fig. 14), is now practically complete. The results, based on over 40 years of research and survey work in the area, will be released at 1:500,000 and 1:1,000,000 scale maps (Shetsen, in press a), to be ultimately appended to the northern boundary of the Quaternary map of the United States. The project has allowed for the recognition of three separate Laurentide ice lobes in the region and has given rise to a modified technique for glacial provenance studies utilizing pebble lithologies (Shetsen, 1982; in press b). The technique allows for the differentiation and correlation of till units on the basis of their pebble contents and for the detection of local influences in relation to overall provenance (Fig. 16). The technique is based on the observation that coarser pebble fractions are affected by local dilution to a greater extent than finer fractions.

Till Facies—Southeastern Alberta. A separate study of Quaternary stratigraphy in the Medicine Hat-Lethbridge area (Fig. 14) is based on multiple till sequences exposed along infilled valleys of the preglacial South Saskatchewan River. Correlations based on physical properties of the tills have been facilitated by using facies models to explain variability. These models also provide information on aspects of the behaviour of the continental glaciers that deposited the sediments. The oldest package of glacial sediment in the area contains several lithologically different tills that have been interpreted as a thick basal meltout facies and a thin supraglacial meltout facies deposited by the same advance. A second glacier advanced over perma-frozen ground, depositing a basal-meltout facies and a unit with several inter bedded diamicton and silty sand beds deposited during ablation of the ice. The third advance in the area resulted in erosion and deformation of the preexisting till, with final deposition of an extensive upper till unit (Proudfoot, 1982).

Reclamation Research

Decisions regarding the reclamation of disturbed lands are extremely difficult for governments and developers alike due to the lack of workable models for predicting the steady-state hydrologic, hydrochemical and soil salination conditions in the reconstituted landscape. The Plains Hydrology and Reclamation Project, funded by the Alberta Heritage Trust Fund, ad-

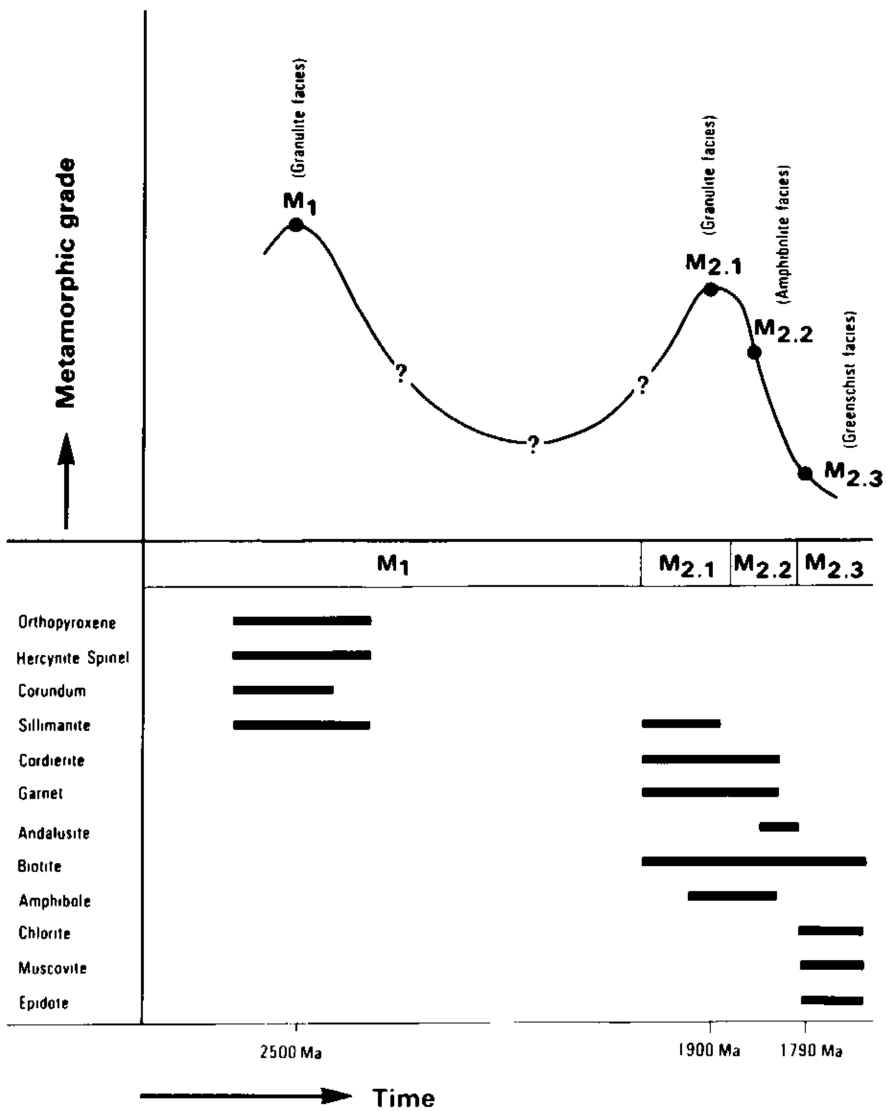

Figure 13 *Path of metamorphism and related mineral growth in rocks of the Canadian Shield of northeastern Alberta (from Langenberg and Nielson, 1982)*

dresses these issues. The project has recently completed year four of a five-year program to characterize the geology, hydrogeology and soils conditions in the areas of the Battle River and Wabamun coal mines in the Alberta Plains (Figs. 14 and 17). Extensive instrumentation of the sites and voluminous analytical work have allowed for the following interim conclusions (Moran, *et al.*, 1983). First, the groundwater in the mine spoil is two to five times more saline than in unmined aquifers, as a result of leaching of pre-existing salt and oxidation of sulphur-bearing compounds. Second, both recharge and water table positions in the mine spoil appear to be strongly influenced by ponds in the spoil. Where ponds are absent, spoil resaturation is slow. Third, post-mining water supply must be sought in relatively deep aquifers that are comparatively unaffected by salinization.

The objective of this project is to develop a predictive framework that will permit projection of reclamation success and impact of mining on water resources over the long term. Differences in the physical and chemical properties of the pre-mining soils, overburden, and subsurface water will be used as keys for predicting post-mining conditions. The predictive framework is to be based on an understanding of processes acting within the landscape so that in the future, mine sites not totally analogous to those studied can be evaluated as well.

The Alberta Geological Survey

The Alberta Geological Survey employs a full-time staff of 60 scientists and technologists and has an operating budget in excess of 3 million dollars. Approximately half of the budget comes from the Provincial Treasury as part of the normal operating grant to the Alberta Research Council. The balance is largely supplied by the departments and agencies of the Provincial government that use the research capabilities of the Alberta Geological Survey. Contract work for industry generates a small revenue.

Because the vast majority of the research and survey work conducted by the Alberta Geological Survey is funded by public monies, and because much of the input data for the studies are derived from the public domain, results of the work are designed to receive widespread circulation in both the public and private sectors. Many of the scientific papers and reports resulting from the various projects are published in technical journals. In addition, the Alberta Research Council produces its own publications—Maps, Earth Science Bulletins, Earth Science Reports and Open File Reports. The Alberta Geo-

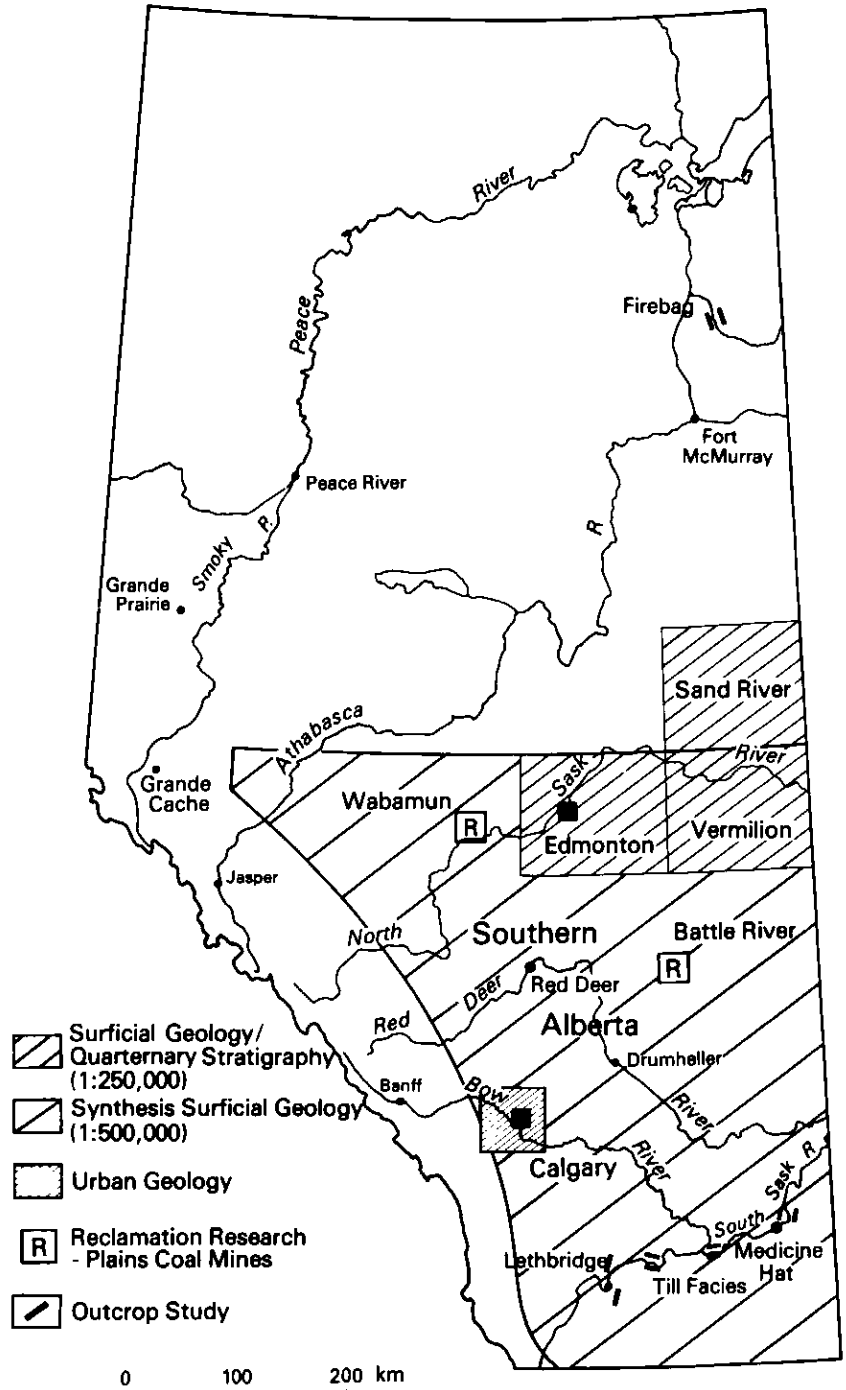

Figure 14 *Study areas for environmental geology research at the Alberta Geological Survey—surficial geology and Quaternary stratigraphy for selected outcrop localities (Firebag River in the oil sands area, and along the South Saskatchewan River); specific 1:250,000 NTS sheets (supported by extensive drilling in the Sand River, Vermilion and Edmonton areas), and in synthesis form (Southern Alberta study); detailed urban geology of the Calgary area (Edmonton is already complete); and reclamation research related to surface coal mines in the Battle River and Wabamun areas*

logical Survey also maintains a formalized information geology service, backed by all of its resident expertise and by the GEODIAL index of geological literature on Alberta. Inquiries from industry, government, the media and the public are coordinated through this function.

Further information on the projects referred to in this article, or on any of the other projects conducted by the Alberta Geological Survey, is available through reference to the Alberta Geological Survey Annual Report of Investigations (1982, 1983).

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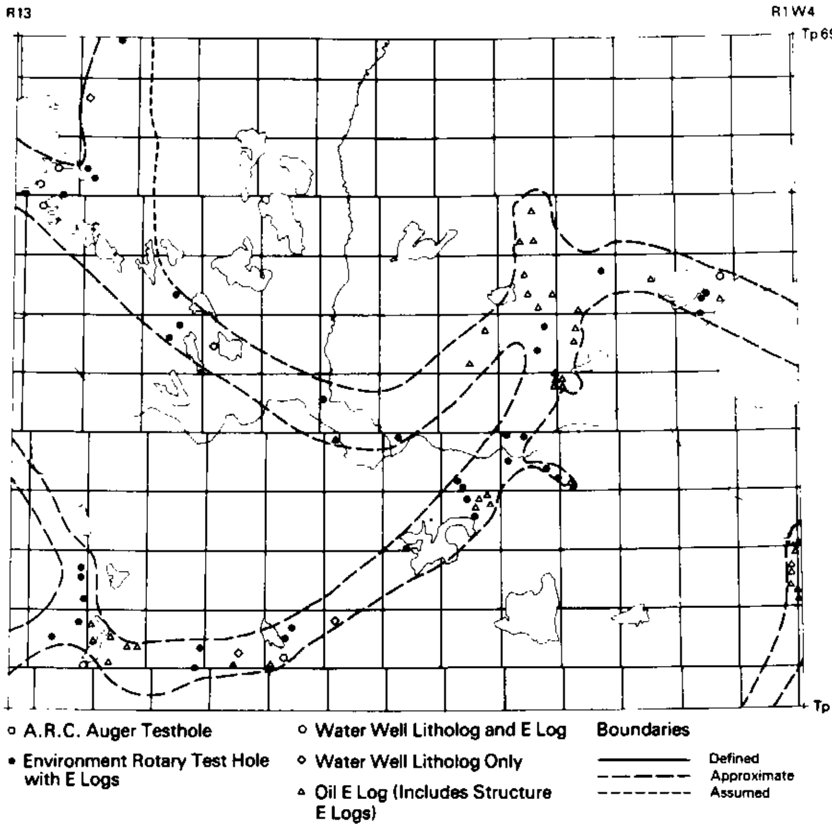

Figure 15 *Subsurface distribution of the Quaternary Empress Formation (Unit 1 Saskatchewan Sand and Gravel), confined to the deepest parts of the pre-glacial valleys in the Sand River map area (from an unpublished figure by L.D. Andriashek and M.M. Fenton)*

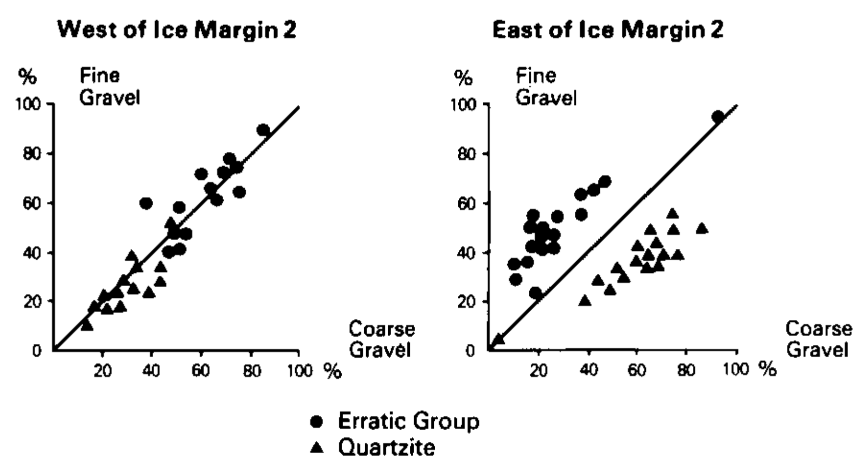

Figure 16 *Interrelation of coarse and fine pebble fractions in till, reflecting the dominance of long-range provenance lithologies (left-hand plot) relative to lithologies dominated by local influences (right-hand plot) (from Shetsen, in press). Where the till pebble composition has been diluted by locally derived fluvial gravel, the coarse fraction is enriched in quartzites relative to the finer fraction. In the undiluted provenance lithologies, no such differentiation is observed*

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Figure 17 *Aerial photograph of the Vesta and Diplomat coal mines along the Battle River near Forestburg (Fig. 14). The Plains Hydrology and Reclamation Project features extensive instrumentation of both the mine spoil (light-tones, ribbed areas) and adjacent undisturbed farmland, in order to derive predictive models regarding the long term movement of salts liberated through accelerated weathering of the disturbed bedrock and carried by the local groundwaters*

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