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Saskatchewan Geological Survey

Potash in Saskatchewan

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SUMMARY

Soluble potassium salts present in a crystalline form in some bedded salt deposits supply most of the world's demand for potassium for agricultural and industrial use. During the search for oil in southern Saskatchewan in the early 1940s, sylvite (KCl) and carnallite ($KCl.MgCl_2.6H_2O$) were noted in salt core but uncertainties as to markets, depth of the deposits and the feasibility of solution mining delayed potash exploration for ten years. Eventually, what are thought to be the largest deposits of high-grade potash in the world were outlined.

The potash deposits in southern Saskatchewan occur within the uppermost 60 metres of the Middle Devonian Prairie Evaporite at depths in excess of 900 metres. Their northern limit roughly parallels the Yellowhead highway. They extend a few kilometres into Manitoba, and southwards, at increasing depth, into North Dakota and northeastern Montana. Individual potash-rich beds are extensive and consistent in grade and thickness. Local thickening occurs where carnallite, not sylvite, is the dominant potash mineral. Other anomalous sequences in which beds normally potash bearing are halitic or missing are related to non-deposition, erosion, or dissolution. Four groups of potash-bearing halite beds have been distinguished: the Esterhazy, White Bear, Belle Plaine, and Patience Lake Members.

The preferred ore is a clean mixture of sylvite and halite (sylvinite). Carnallite and insolubles are avoided wherever possible because of their detrimental effects on mine stability, ore grades and refining processes. The ore is extracted by shaft mining or dissolved and brought to the surface as brine. Flotation or crystallization processes separate the potash from the salt and the refined product, potassium chloride, is supplied as a fertilizer ingredient and also for chemical and other industrial uses. Some salt is processed for food salt, some is used directly as road salt, but the bulk of the salt tailings is impounded at the surface as waste. Excess brine may be injected into underground rock formations.

Problems with shaft sinking and with solution mining experiments beset the pioneering potash companies and it was 1962 before continuous production was under way. In 1964 the world's first potash solution mine came on stream. The conventional mines are between 950 and 1075 metres deep. There are three mines near the Manitoba border in the vicinity of Esterhazy, six east and west of Saskatoon and a deeper solution mine at Belle Plaine, between Regina and Moose Jaw.

The ten potash mines in Saskatchewan presently account for more than seven million tonnes of potash* or about 25 per cent of the annual world production. The biggest customer for Saskatchewan's potash is the United States (about 65 per cent of sales); followed by Brazil, Japan, Canada (chiefly Ontario and Quebec), India and recently, the People's Republic of China. Altogether, shipments to 25 countries were recorded in 1980. Sales were worth just over $1 billion; provincial revenues from potash amounted to $280 million, and approximately 4,050 people were directly employed in the industry.

At present, the Saskatchewan mines have a total annual design capacity of nearly thirteen million tonnes potassium chloride product (equivalent to about eight million tonnes K_2O). Most facilities are being expanded to some degree; the capacity of the Lanigan mine should be tripled by 1983 and a new mine is being planned for the Bredenbury area.

In other parts of Canada, two exploratory potash shafts are being sunk in New Brunswick with the intent of developing two mines; development of a potash mine is being planned in Manitoba following favourable exploration results; and potash exploration programs have recently been reported in Cape Breton, Newfoundland and at prospects elsewhere in New Brunswick and Manitoba.

*metric tons K_2O equivalent

ACKNOWLEDGEMENTS

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INTRODUCTION

An alkaline substance leached from wood ashes was a valued commodity for centuries. This became known as 'pot ash' from the large iron pots in which it was made. Chemically, it was crude potassium carbonate mixed with other salts. Potash has since become a term widely applied to various naturally occurring potassium salts and the commercial products derived from them.

Soluble potassium salts distributed extensively in some underground salt deposits, such as those of Saskatchewan, New Mexico, Germany and the Soviet Union, are the main source of potassium compounds consumed in industry. These potash deposits are of particular importance to the agricultural industry which demands a soluble source of potassium in large quantities as a fertilizer ingredient. Potassium salts are also recovered at the surface from concentrated lake brines, for instance from the Dead Sea in Israel; Searles Lake, California; the Great Salt Lake of Utah and Lake Cha-erh-han of China. Some potassium nitrate is recovered from the unique Chilean nitrate deposits.

In Saskatchewan, the thickness, richness, flatness and wide extent of the potash beds, and the common presence of a strong salt roof, make up for any disadvantage of depth and permit a high degree of mechanization in extraction methods. At the same time, because of the low cost-high bulk nature of the product and the inflexibility inherent in highly mechanized operations, the mining economics are sensitive to minor anomalies in the ore both at the rock face and in the processing systems. Formidable problems related to shaft sinking through water-bearing strata were successfully overcome but an awareness of the threat of water incursion remains, governing underground practise.

Twenty years' experience of potash mining in Saskatchewan (including the rehabilitation of an accidentally flooded mine) and the extraction of some 100 million tonnes of potassium chloride prove that conventional mining in a salt body at depths averaging one kilometre is a viable operation. The viability of solution mining as a means of potash recovery has also been proven.

The Saskatchewan potash industry has established a significant international market for its product and is presently undergoing a period of expansion. New or expanded mines are being planned for the eighties and increasing attention is being given not only to the investigation of new technology, products, distribution systems and markets but also to environmental concerns.

HISTORICAL BACKGROUND

Plant ash was a source of alkali for the early glass, soap and cloth industries. Kali or saltwort, a sodium-rich maritime plant common in the Mediterranean region, was used as a flux by Egyptian and Roman glassmakers. As the art of glassmaking spread inland, woodland plants, particularly hardwoods and ferns were used instead (Douglas and Frank, 1972). Solutions leached from their ashes were boiled to dryness in iron pots and the crude alkaline residue became known as 'pot ash'. With the growth of industrial Europe potash became a commodity much in demand. For many years wood ash from the hardwood forests cleared by the early settlers in North America was a source of potash for the insatiable European market and provided a welcome cash crop.

During the latter part of the 18th century, the rapid pace of chemical discovery, the proliferation of names for the same chemical substance and the cumbersome descriptive phrases, such as 'fixed vegetable salt of marine acid' (i.e. potassium chloride), all emphasized the need for a system for naming chemicals.

The alkali metals potassium and sodium had not been isolated and named when in 1787 four leading French chemists published *Methode de Nomenclature Chimique*, a system of nomenclature which is basically that used in inorganic chemistry today. For the three common alkalis recognized at that time, vegetable, mineral and volatile, the names potash, soda and ammonia (*potasse, soude* and *ammoniac*) were proposed, the ideas of Guyton de Morveau. His critics, particularly in England and Germany, objected because the terms (having previously been used to denote impure commercial alkalis) were ambiguous. It seemed that uncertainty would continually arise as to whether chemical or popular language was meant. There was also the real possibility of confusion between the mild alkalis (i.e. the carbonates) and the caustic alkalis (i.e. the hydroxides). Instead of 'potash' entirely new names, with no connotations, were suggested; spodium (Hopson in 1789), tartarin (Kirwin in 1794), planalkali (Dickson in 1796), lixiva (Black in 1803), but it was Guyton's terms that became generally accepted (Crosland, 1962). Guyton also introduced names for the salts of '*acide marin*' (i.e. the chlorides), taking muriate and the adjective muriatic from *muria*, the Latin word for brine. Then in 1807 Humphry Davy isolated a new metal from solid caustic potash and accordingly named it potassium. The salts of potassium, in accordance with the chemical theory of the time, were viewed as compounds of the metallic oxide. The fertilizer trade later adopted the oxide as its standard and kept some of the late 18th century terminology (see Table 1). Berzelius' symbols for the elements were based on Latin names and since he favoured certain names current in Germany on etymological grounds, the symbol for potassium, K, was taken from kalium the latinized version of kali.

Table 1
Some Potash-Related Terminology

	Chemical or Mineral Name	Chemical Formula	Common or Trade Name
Element	potassium (kalium)	K	potash (adjective)
	sodium (natrium)	Na	soda (adjective)
Mineral	sylvite (or sylvine)	KCl	potassium salts
	carnallite	$KCl.MgCl_2.6H_20$	
	halite	NaCl	salt, common salt, rock salt
Ore	sylvinite	sylvite + halite	
	carnallitite	carnallite + halite	
Product	potassium chloride	KCl	potash, muriate of potash†
Unit of Measure	potassium oxide	K_20	potash†
Other Compounds	potassium sulphate	K_2SO_4	sulphate of potash†
	potassium carbonate	K_2CO_3	pot ash* (crude), pearl ash (pure)
	potassium hydroxide	KOH	caustic potash, lye, potash lye
	potassium nitrate	KNO_3	nitre, saltpetre, nitrate of potash†
	sodium carbonate	Na_2CO_3	soda ash

*original usage
†fertilizer trade

Conversion Factors

1. Based on muriate with 61 per cent K_20 content
   multiply given tons of KCl by 0.61 to determine tons of K_20
   multiply given tons of K_20 by 1.64 to determine tons of KCl
2. Based on a short ton of 2000 lbs and a metric ton or tonne of 2205 lbs (2204.52 lbs)
   multiply short tons by 0.9 (0.9072) to determine metric tons or tonnes
   multiply metric tons or tonnes by 1.1 (1.1023) to determine short tons

POTASH TERMINOLOGY AND PRODUCTS

Some potash-related terminology, with the appropriate chemical formulae, is given in Table 1.

Only a few mineral names are applicable to Saskatchewan potash. In the natural crystalline state sodium chloride is halite, potassium chloride is sylvite (or sylvine) and a mixture of the two is sylvinite. This is the richest and preferred ore. Carnallite is a potassium magnesium chloride mineral. Its presence lowers the ore grade.

Formal rock names are also few. The potash beds are part of the Prairie Formation, a Middle Devonian evaporite sequence commonly referred to as the Prairie Evaporite (Figure 1). It is largely rock salt or halite. Individual potash beds have no names, but groups of beds, apparent on geophysical well logs, are named the Esterhazy, White Bear, Belle Plaine and Patience Lake Members. The Prairie Evaporite is underlain by the Winnipegosis Formation and overlain by the Dawson Bay Formation.

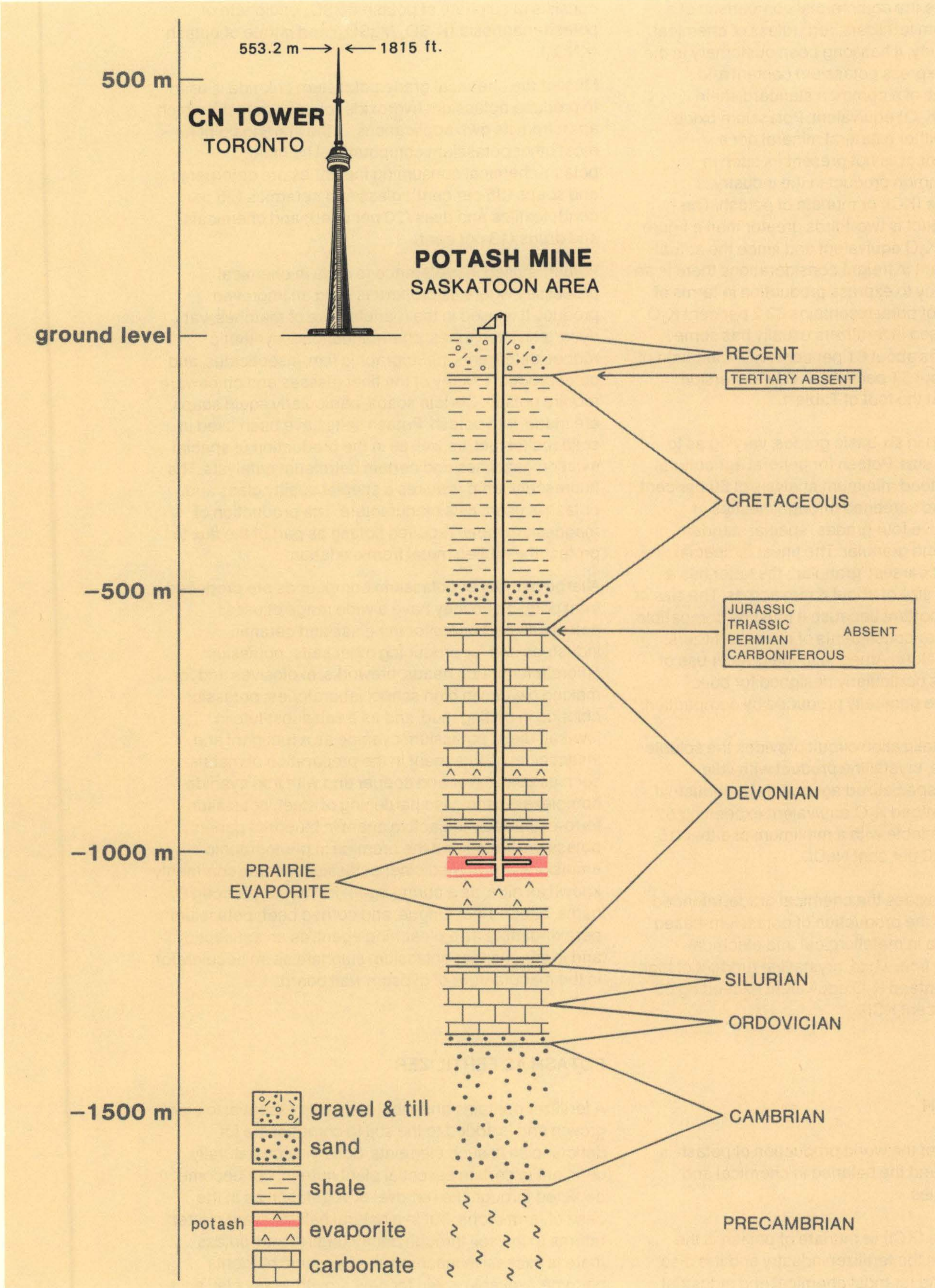


Figure 1 — Diagrammatic section through a potash mine shaft near Saskatoon

In order to facilitate the commercial comparison of a variety of potassium fertilizers, regardless of chemical composition or purity, it has long been customary in the fertilizer trade to express potassium content and production in terms of a common standard, their potassium oxide (K_2O) equivalent. Potassium oxide however, being neither a natural mineral nor a manufactured product, is not present as such in fertilizers. The common product in the industry is potassium chloride (KCl) or muriate of potash. The weight of KCl product is two-thirds greater than a figure quoted as tons of K_2O equivalent and since the actual tonnage is important in freight considerations there is an increasing tendency to express production in terms of KCl. Pure muriate of potash contains 63.2 per cent K_2O equivalent. That used in fertilizers usually has some impurity and grades about 61 per cent K_2O. (Sulphate of potash grades about 51 per cent K_2O.) Conversion factors are given at the foot of Table 1.

Potash is produced in six basic grades, varying as to purity and particle size. Potash for general agricultural use, with a guaranteed minimum analysis of 60 per cent K_2O, is crushed and screened through meshes of different sizes to give four grades: special standard, standard, coarse and granular. The finest is 'special standard' and the coarsest 'granular'; the latter has a maximum particle size of about 4 mm across. The size of the particles is important because it must be compatible with that of the other constituents of mixed fertilizers. There is a trend in North America to the greater use of the coarser grades particularly designed for bulk blending. These are generally produced by compaction.

An additional crystallization circuit provides the soluble grade; a fine, white, crystalline product with little impurity, suited to specialized agricultural or industrial use. It has a guaranteed K_2O equivalent exceeding 62 per cent and is available with a maximum of either 0.5 per cent NaCl or 1.0 per cent NaCl.

Further refining provides the chemical grade, intended for use primarily in the production of potassium-based chemicals and also in metallurgical and electrical applications. It is a fine, white, crystalline product of high purity with a guaranteed K_2O equivalent exceeding 63 per cent (99.7 per cent KCl).

USES OF POTASH

About 96 per cent of the world production of potash is used in fertilizers, and the balance in chemical and associated industries.

Potassium chloride (KCl) or muriate of potash is the common product in the fertilizer industry and it is also the basic compound for most chemical and industrial uses. Of the potassium fertilizers used in agriculture, well over 90 per cent is muriate of potash and the remainder consists of sulphate of potash (K_2SO_4), sulphate of potash-magnesia ($K_2SO_4.MgSO_4$) and nitrate of potash (KNO_3).

Most of the chemical grade potassium chloride is used to produce potassium hydroxide (caustic potash), which, apart from its own applications, is the starting point for most other potassium compounds. The major potash-chemical consuming industries are detergents and soaps (35 per cent); glass and ceramics (25 per cent); textiles and dyes (20 per cent); and chemicals and drugs (13 per cent).

Potash is used in preference to soda in chemical processes where its properties yield an improved product. It is used in the manufacture of matches, vat dyes, television tubes, pharmaceuticals, synthetic rubber, detergents, photographic film, insecticides, and other products. Many of the finer glasses and chinaware require potash. Certain soaps, particularly liquid soaps, are made with potash. Potash salts have been used in solid rocket fuel, as well as in the production of special aviation gasolines and certain petroleum catalysts. The fluorescent lamp requires a special quality glass and potash is used in its manufacture. The production of magnesium metal requires potash as part of the flux to protect the molten metal from oxidation.

A large number of potassium compounds are produced from potash and they have a wide range of uses: potassium carbonate for the glass and ceramic industries and for producing other salts; potassium chlorate for match heads, fireworks, explosives and for making oxygen in high school laboratories; potassium chloride in drilling mud, and as a salt substitute in low-salt diets; potassium cyanide as a fumigant and insecticide, as a reagent in the preparation of metals such as gold, silver and copper and with iron cyanide complexes in the case hardening of steel; potassium ferro-cyanide as the active agent in blueprint papers; potassium iodide and the bromide in photographic emulsions and in medicine; potassium nitrate, commonly known as nitre, as a curing agent for meats, particularly hams, bacon, beef tongue, and corned beef; potassium permanganate as a bleaching agent, as an antiseptic, and in saccharine; potassium sulphate as an accelerator in the manufacture of gypsum wall board.

POTASH AS FERTILIZER

A fertilizer contains chemical elements essential to plant growth and is added to the soil to compensate for deficiencies in such elements. Soils may be naturally deficient in certain essential plant nutrients or become depleted through the removal of vegetation as in the case of farm crops. But in a natural habitat, plant matter returns to the soil through decay (or fire) and, unless there is excessive leaching, the inorganic nutrients become available again for new growth. Many clay soils are able to supply sufficient potassium for the indefinite growth of natural vegetation, if not of crops.

Many soils are deficient in nitrogen, phosphorus or potassium, three elements that are needed in quantity by plants. Even in areas with no potassium deficiency the application of potash ensures the maximum effectiveness of the other fertilizer ingredients. Potassium contributes to healthy plant growth, aids in synthesis and translocation of starch and sugars, is essential for good flower colour and ripeness in fruits, stiffens straw in cereals, promotes development of root systems and enables the plant to withstand adverse conditions of soil, climate and disease.

Although used to a small extent on its own, potash is usually applied in compound fertilizers, mixed according to crop type, soil condition and climate. The proportion of ingredients is indicated by the notation on packaged fertilizers, such as 5-10-15, the percentage content by unit weight of nitrogen, phosphate and potash in that order.

Plants differ in their food requirements. Since potassium is found largely in plant foliage, leaf crops such as hay, alfalfa and tobacco remove considerable amounts of potassium from the soil. Cereals also have a high potassium requirement, though an appreciable portion may be returned to the soil in crop residues such as straw. The starch and sugar crops, potatoes and sugar cane or beet, for example, need large amounts of potassium.

The chloride is the usual potassium salt used in fertilizers. It is readily soluble, has a higher effective K_2O content than the sulphate and is simpler and cheaper to produce. The sulphate is used where the chloride ion causes difficulty by 'burning', and in areas of low rainfall where it tends to build up in the soil. The chloride ion has also been found to have a detrimental effect on certain crops, hence the sulphate may be preferred as a fertilizer for tobacco, potatoes, sugar beet and some fruit crops. Potassium sulphate is more accepted in Europe where it is produced from the mineral kainite and from muriate.

ORIGIN OF POTASH

Potassium is present in most types of rock in combination with other elements, commonly aluminium and silicon, as in such primary minerals as the feldspar orthoclase and the micas muscovite and biotite. Micas are resistant to weathering but orthoclase in certain circumstances decomposes and its potassium goes into solution. Much of this potassium enters newly formed clay minerals, or is retained in the soil or is taken up by plants, but some is carried away in solution and reaches the sea. Other potassium minerals are also unstable and contribute to the accumulation of potassium in sea-water. As on land, the potassium content of the water is reduced by reaction with fine-grained material, while some potassium is incorporated in glauconite and other minerals forming on the sea floor. Also, certain seaweeds, particularly the giant kelps, have the power of preferentially extracting and accumulating potassium from sea water.

Although in igneous rocks the overall potassium content is more or less equal to that of sodium, the sodium feldspars weather more readily than the potassium varieties and the sodium tends to remain in solution. As a result, sea-water is strongly enriched in sodium relative to potassium.

Under arid conditions, the gradual evaporation of sea-water from landlocked basins during the geological past resulted in successive layers of sediments rich in calcium and magnesium carbonate (limestone and dolomite); calcium sulphate (gypsum and anhydrite); sodium chloride (rock salt or halite); and finally, the very soluble chlorides and sulphates of potassium and magnesium (potash). Although the earlier part of this sequence is common in the geological column, the latter is not, in that the concentration necessary for precipitation of potassium and magnesium salts was seldom reached, or else these were removed by later leaching. Nevertheless, although rare, where potash does occur, the deposits may be extensive and of great economic importance. Present-day brines, rich in potassium and other valuable minerals, are found in some salt lakes and inland seas.

DISCOVERY OF POTASH

Soluble potassium salts were first discovered in the rock salt deposits of the Stassfurt region of Germany in 1839. Eventually, aggressive exploitation put an end to the old method of making potash, and also created an international market for potassium fertilizer.

Germany supplied the world with potash from 1861 until the First World War when supplies from this source were cut off. In North America, the resulting shortages and grossly inflated prices, along with the realization of the importance of potash to the agricultural wealth of a nation, were an incentive to search for salt deposits similar to those in Europe. This resulted in the discovery of potash in New Mexico in 1925.

Widespread underground salt deposits in Western Canada are indicated by salt springs and seepages near the edge of the sedimentary basin. Their association with Devonian formations was noted as early as 1858 by Henry Youle Hind, geologist on the Canadian Red River, Assiniboine and Saskatchewan expeditions of 1857 and 1858. Rock salt was discovered in the Fort McMurray district of Alberta in 1907, and in 1928 a well drilled for oil near Unity in western Saskatchewan bottomed in half a metre or so of salt. Deep drilling at Neepawa, Manitoba and Simpson, Saskatchewan, tapped brine which resulted in commercial operations in the 1930s. In all, there was only a handful of deep wells drilled on the prairies between the wars, but exploration for oil and gas intensified during the Second World War and led to the incidental discovery of potash in Saskatchewan, and eventually to oil in the Devonian reefs of Alberta.

The potassium salts sylvite and carnallite were first recognized in August 1942, in salt core from the well Norcanols Radville No. 1 (Lsd 16-36-5-19w2) drilled by Imperial Oil Limited about 110 kilometres due south of Regina. The strange-looking red salt penetrated at 2330 metres was described by J. C. Sproule, the geologist in charge, as looking like a glassy volcanic breccia. His initial identification of the mineral sylvite, based in part on taste "identical with that of pure potassium chloride purchased from the drugstore," was soon confirmed by the results of analysis at several laboratories. Sproule visualized a rare salt deposit of considerable size and realized its potential economic importance (Imperial Oil Limited communication).

The discovery well (the deepest at the time in Saskatchewan) had an inauspicious end. The bit and a considerable portion of the drill stem became seized in the hole. A whipstock diversion was attempted but this also seized up and the hole was abandoned early in January 1943. The Department of Natural Resources' annual report for 1943 (p. 38) includes this statement: "It is with regret that the department is obliged to announce the loss of Norcanols Radville No. 1 well." The missed opportunity to test some promising oil shows was regretted. No mention was made of potash.

In 1943 potash was again encountered, in Norcanols Ogema No. 1 well (Lsd 4-24-7-23w2), but in this and other early discoveries (see Figure 7A), the salt lies at considerable depth and potash values are not particularly high. The latter can be attributed to drilling based on seismic anomalies, which as subsequently became apparent, are often basement-controlled sites of salt solution where the salt beds are partially leached.

It was also during the war that natural gas was discovered in Lower Cretaceous sands near Unity, and two years later, in 1946, in a test of deeper horizons, Verbata No. 2 well (Lsd 7-24-41-24w3) penetrated 140 metres of salt, and core grading 21.6 per cent K_2O over 3.35 metres was recovered. This was probably the first indication of potash beds of commercial grade, and at the depth of 1056 metres, shaft mining (as opposed to solution mining) was considered feasible. However, it was the thickness, purity (over 99 per cent NaCl) and the availability of water and natural gas that made solution mining of the halite beds an immediately attractive proposition. Plans were made by the Prairie Salt Company, a subsidiary of Dominion Tar and Chemical Company, to brine the salt. (Other substances brought to the surface during solution mining were to remain the property of the Crown.) After further test drilling a salt refinery was erected and production began in 1949.

MINERALOGY OF SASKATCHEWAN POTASH

Compared to most other potash deposits those of the Prairie Evaporite have a simple mineralogy. The potash-bearing zones consist predominantly of halite (NaCl) with two potassium chloride minerals, sylvite (KCl) and carnallite ($KCl.MgCl_2.6H_2O$). Insoluble claylike material, largely anhydrite with lesser amounts of quartz, dolomite and clay minerals, is also present. Iron oxide staining, from pale flesh to deep blood-red, is pervasive and gives the glassy, crystalline, breccia-like rock its distinctive appearance; superficially more like an igneous than a sedimentary rock.

Sylvite and carnallite occur together and separately. They are present within the halite as scattered crystals, thin-layered crystal concentrations or thick potassium-rich beds. Even the richer potash beds contain more halite than potash minerals. The richest of the potash ore is sylvinite, a mixture of halite and sylvite.

The halite is transparent or cloudy, colourless or with a smoky grey or brownish hue. It shows perfect cubic cleavage and appears as masses of interlocking crystals. Individual crystals may be up to ten centimetres in diameter. Chevron and hopper crystals occur locally. Blue and violet halite is occasionally present, the colour occurring in irregular patches, films or wisps. Thermally sensitive yellow salt which turns blue on being brought to the surface is another rarity.

Sylvite is similar in appearance, crystal habit and cleavage to halite, but is less dense, more bitter in taste and is less brittle, deforming readily under direct pressure. It is more susceptible to solution than halite and on the outer surface of a salt core, sylvite crystals may be slightly recessed. Sylvite crystals are clear or cloudy, from white to pink, light orange or red. Their size ranges up to about four centimetres in diameter.

Carnallite, unlike halite and sylvite, is orthorhombic and lacks cleavage. It loses water at relatively low temperature which destroys its structure and it also dissolves away by attracting and absorbing water from the atmosphere, i.e. it is deliquescent. (It is because of this property that carnallitic core deteriorates in storage.) Unlike sylvite, carnallite squeaks when cut or scratched with a knife (or when walked on). Carnallite is mainly red but may be colourless, milky white, yellow or almost black. It is soft and brittle with a dull, greasy lustre and bitter taste. Crystals range in size from fine-grained to more than ten centimetres across.

The central area of each potash member is composed of sylvinite. Laterally there is a sharp change to carnallitic sylvinite or carnallitic halite. This carnallitic margin is narrower in stratigraphically higher members (see Figures 6a and 6b). Where a member is enriched in carnallite its thickness is about 30 per cent greater than average. Carnallite-rich beds, probably of considerable areal extent, have been reported in wells at Moose

Mountain (T10 R2w2), Parkerview (T27 R10w2), Foam Lake (T30 R12w2), Nokomis (T30 R22w2), east of Watrous (T31 R24w2) and at Wilkie (T40 R19w3). Unexpected rounded masses or pods of carnallite, a few metres wide, are sometimes encountered in mining.

The present distribution of carnallite is not an original feature of deposition, but appears to be related to subsequent leaching and redistribution of magnesium chloride brines. This conclusion is founded on geochemical evidence. The salinity of the parent brine is imprinted on the crystals and may be interpreted by trace element analysis. On evaporation, rubidium ions have a tendency to substitute for potassium ions in the crystal lattices of potassium minerals, and similarly bromine for chlorine. Studies of the potash salts conclude that nearly all crystals present must be secondary since trace element values indicate salinities too low to have resulted in primary precipitation. Much of the sylvite appears to be secondary after carnallite.

GEOLOGY OF THE SASKATCHEWAN POTASH DEPOSITS

Saskatchewan potash deposits are of Middle Devonian age and occur in beds near the top of a thick sequence of halite and anhydrite known as the Prairie Evaporite (see Figure 2). This formation, more than 200 metres thick in places, lies deeply buried beneath much of the Great Plains of Saskatchewan at depths between 400 and 2750 metres. The Prairie halite is the thickest, most widespread of several Devonian salt deposits and is the only one in which potassium minerals are known to be present. Older, well-developed salt beds occur in Alberta and marginally in west-central Saskatchewan. Younger salt beds are also found in Saskatchewan. These Devonian salts were laid down in a basin of deposition referred to as the Elk Point Basin after the Elk Point area of Alberta where they are extremely thick.

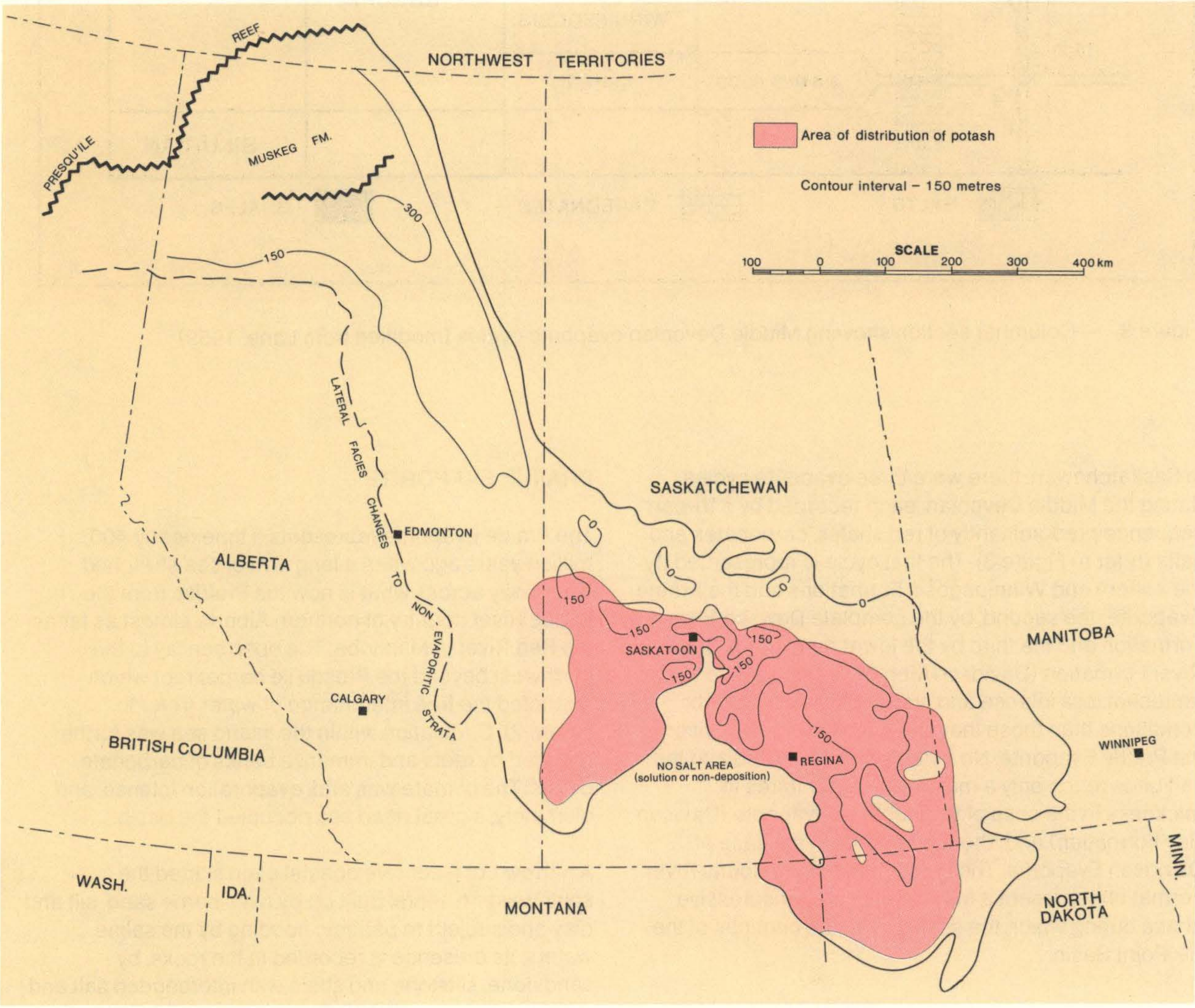


Figure 2 — Isopach map of the Prairie Evaporite in the Elk Point Basin (Holter, 1969, modified by Worsley and Fuzesy, 1979)

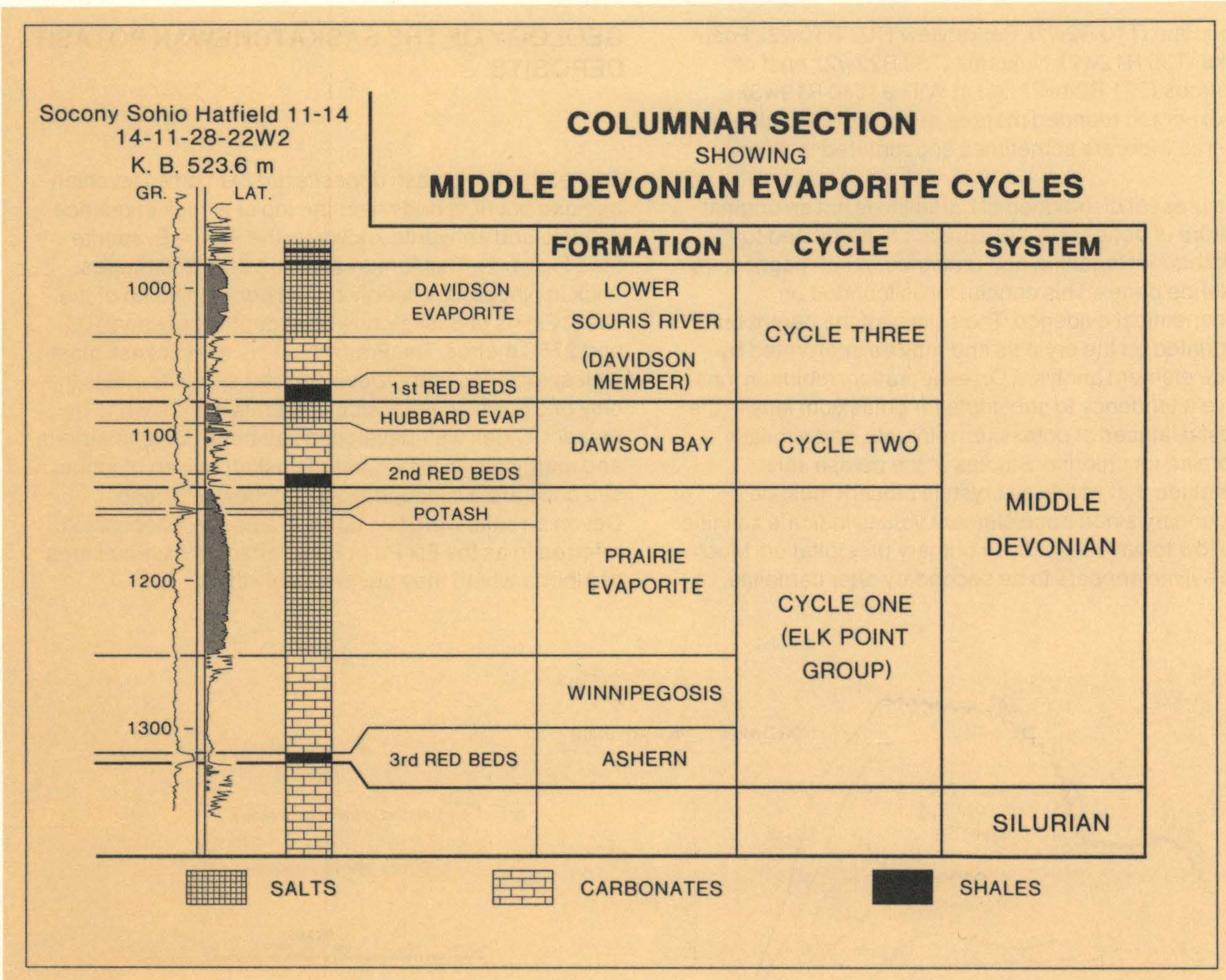


Figure 3 — Columnar section showing Middle Devonian evaporite cycles (modified from Lane, 1959)

In Saskatchewan, there were three evaporite cycles during the Middle Devonian, each recorded by a tri-part sequence predominantly of red shales, carbonates and salts (refer to Figure 3). The first cycle is represented by the Ashern and Winnipegosis Formations and the Prairie Evaporite; the second, by the complete Dawson Bay Formation and the third by the lower beds of the Souris River Formation (Davidson Member). The last two cycles represent less intense and less persistent evaporitic conditions than those that prevailed during deposition of the Prairie Evaporite. No potash was deposited and the salt beds reach only a maximum of 20 metres in thickness in the case of the Hubbard Evaporite (Dawson Bay Formation) and about 60 metres in the case of Davidson Evaporite. The higher beds of the Souris River Formation represent a transitional and transgressive phase during which the sea overran the confines of the Elk Point Basin.

PRAIRIE EVAPORITE

The Prairie Evaporite represents a time nearly 400 million years ago when a long arm of sea stretched diagonally across what is now the Prairies from the Peace River country of northern Alberta almost as far as the Red River in Manitoba. The open sea lay to the northwest beyond the Presqu'ile barrier reef which restricted the free interchange of water (refer to Figure 2). Circulation within the inland sea was further reduced by reefs and immense banks of carbonate debris. The climate was arid, evaporation intense, and ultimately, a great dead sea occupied the basin.

A narrow but extensive coastal plain skirted the southwestern shore. Built up by river-borne sand, silt and clay and subject to periodic flooding by the saline waters, its presence is recorded in the rocks, by sandstone, siltstone and shale with interbedded salt and gypsum. A similar shoreline deposit probably existed along the northeastern shore but here all evidence of it has been eroded away (Nelson, 1970).

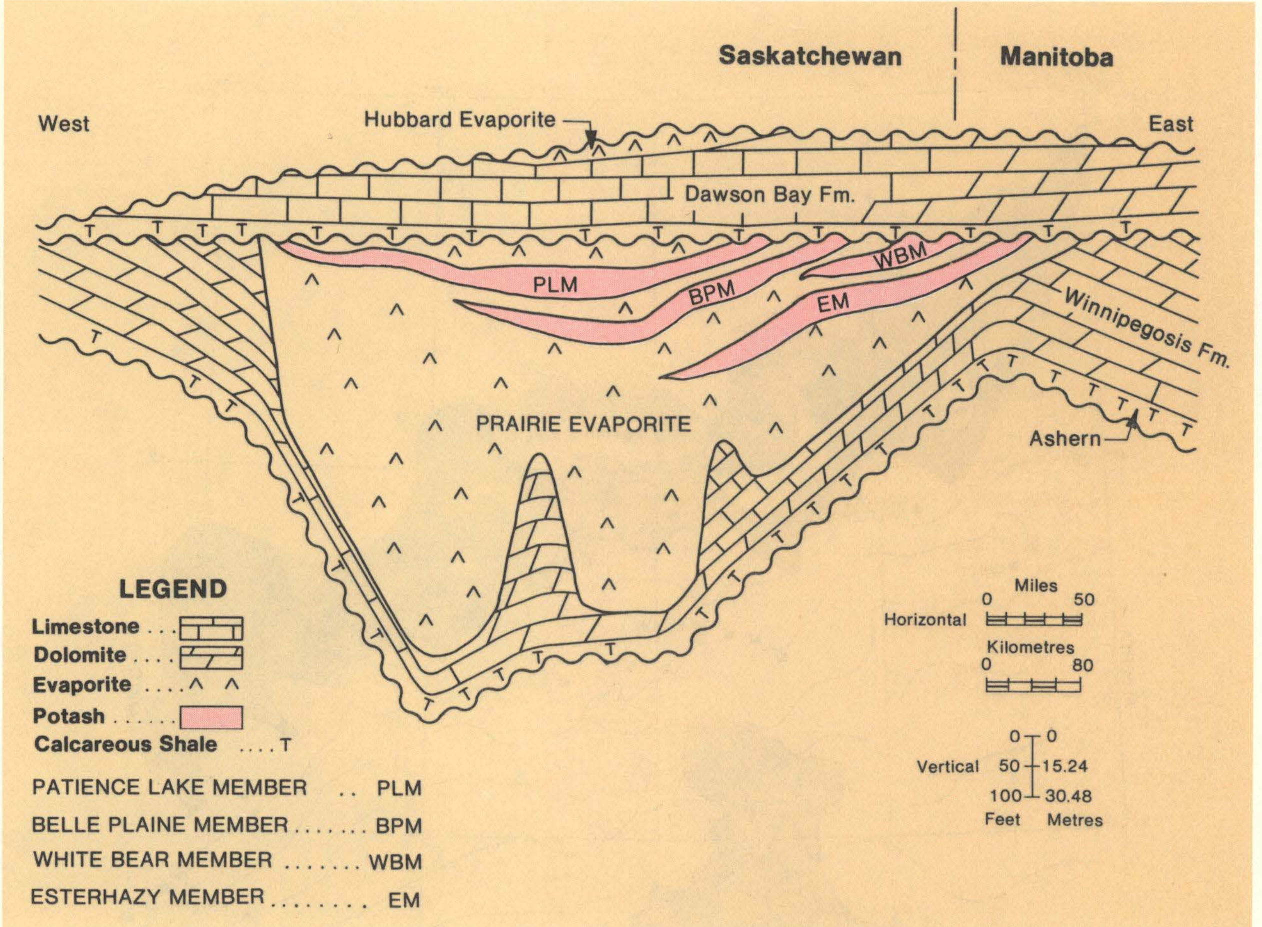


Figure 4 — Diagrammatic cross-section through the Prairie Evaporite in Saskatchewan and Manitoba (modified from Potash in Saskatchewan, 1973)

As the water evaporated, first anhydrite and then halite beds accumulated rapidly. Insoluble material became increasingly common in the water as the sea shrank in size and was deposited as thin seams or disseminated amongst the evaporite salts. As conditions approached desiccation the remaining bitterns collected in broad depressions at the extreme southeastern end of the basin, and potassium and magnesium salts were precipitated.

During this time periodic incursion of less salty water freshened the brine, temporarily stopping precipitation of bittern salts, although halite continued to form. Following deposition the salt beds were exposed to the erosive effect of wind and rain until sealed by the muds of the incoming Dawson Bay sea.

The Prairie Evaporite lies upon Winnipegosis carbonates and is unconformably overlain by red and green mudstones of the Second Red Beds of the Dawson Bay Formation (Figure 4). In the Devonian outcrop area of southern Manitoba and in parts of the subsurface, the Prairie Evaporite is absent and the Dawson Bay Formation lies directly on the Winnipegosis Formation.

The Prairie Evaporite does not crop out and its northern edge, which approximates to a line drawn west-northwest through Prince Albert, lies near sea level, 400 to 800 metres beneath the surface. Only anhydrite is present here; the edge of the salt is up to 100 kilometres farther south. Depths increase southwards. In the Moose Jaw-Regina area the salt is more than 1500 metres deep and near the southern edge of the salt basin, in northeastern Montana and in North Dakota, it lies at depths ranging from 1700 to more than 3650 metres. Figure 5 is a depth of burial map of the Prairie Evaporite in Saskatchewan. Only the salt area has been contoured. Local irregularities are attributed to solution channelling (or present surface relief) and in the south-central part of the province there is a large triangular area, sometimes referred to as the Swift Current platform, from which the salt has been dissolved and only anhydrite remains. Seismic data corroborated by exploratory drilling have been used to establish the limit of this salt-free salient and its tributary feature, the Hummingbird trough, which extends southwards a few kilometres into Montana. With incomplete seismic coverage the northern limit of the salt is mapped with less certainty. Its trace is complicated by sharp relief on the Winnipegosis surface.

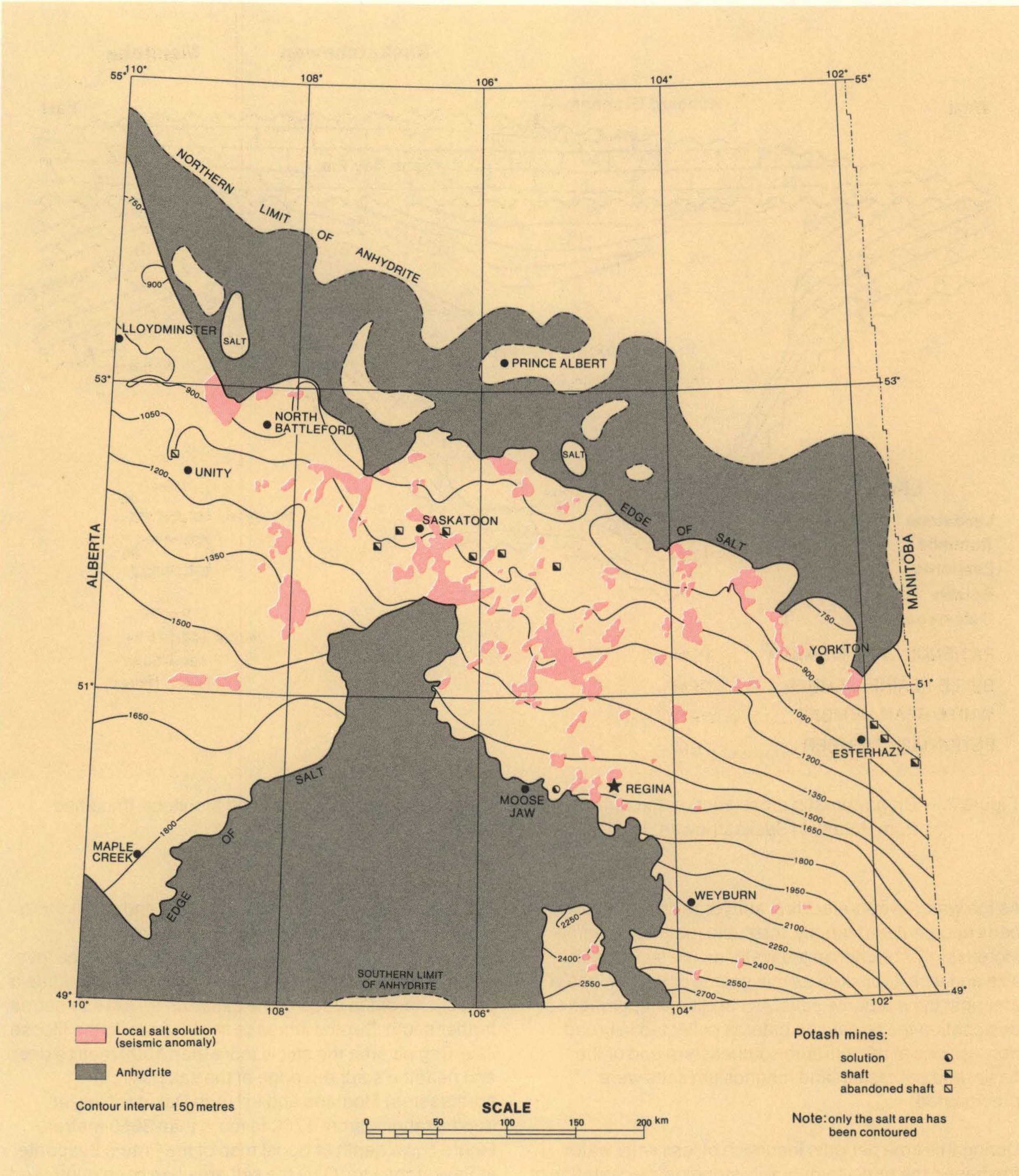


Figure 5 — Depth of burial of the Prairie Evaporite in Saskatchewan (contours modified from Holter, 1969; Hamilton, 1971)

Mounds and banks of dolomitized lime mud, some with abundant coral and sponge fragments, are common in the Winnipegosis Formation particularly in the Saskatoon region. These carbonate build-ups may attain a considerable height (up to 105 metres), but appear to be restricted in areal extent. They are accumulations of waterborne debris and mud rather than coral reefs. The vertical transition from Winnipegosis carbonate to Prairie halite is commonly gradational, and since the banks influenced later sedimentation patterns in their vicinity, a lateral change from carbonate to halite is also apparent. Bank-flanking anhydrite interfingers with the bedded halite of the basin and an extensive sequence of anhydrite and dolomite, the Shell Lake Member, thinly caps the banks in the Saskatoon area and slopes away from their summits into the adjacent salt.

The bulk of the Prairie Evaporite is halite; some dolomite is present near the base, beds and laminae of anhydrite are common in the lower part, and potash-rich beds alternate with barren halite in the upper part of the formation. Insoluble clay-like material becomes increasingly prevalent upwards in the succession, particularly in the Saskatoon region. It occurs in interstices between crystals, in partings, thin seams, or beds a metre or so thick, in fracture fillings and solution channels. Laterally extensive layers serve as excellent stratigraphic markers, above, below and within the ore zones.

The contact between the Prairie Evaporite and the basal red beds of the overlying Dawson Bay Formation although irregular is generally sharp. Indications of some mixing of uppermost salt with earthy material are seen locally. The coloured basal mudstones, between 6 and 9 metres thick, are overlain by discontinuous carbonates characterized by fossiliferous microcrystalline limestone (Dunn, 1981).

Potash Members

The uppermost 60 metres of Prairie Evaporite include four groups of potash-bearing beds. These are, in ascending order: the Esterhazy, White Bear*, Belle Plaine, and Patience Lake Members. Their stratigraphic positions are illustrated in Figure 4. Each member consists of one or more beds of potash interbedded with more or less barren halite. An individual potash bed may be as much as 7 metres thick. The members, as designated are commonly between 6 and 15 metres, although thicker sequences occur where carnallite is the dominant potash mineral. The members are separated by 1 to 45 metres of halite with minor potassium-rich layers, the interbeds of Holter (1969). The potash members and interbeds thin in a southwesterly direction causing an overall thinning of the potash interval, for instance, from 50 metres at Yorkton to 30 metres south of Weyburn.

Bevelling by pre-Dawson Bay erosion has affected the Patience Lake Member and, over a lesser area, the Belle Plaine Member. But even where truncated the Patience Lake Member is commonly overlain by 1 to 10 metres of salt. More than 20 metres are present southeast of Regina and close to 30 metres near the U.S. border. This salt-capping or salt-back is of critical importance in mining potash from the Patience Lake Member in that an effective seal is needed to protect the mine from water in the overlying Dawson Bay Formation.

*The White Bear beds merit member status in the southeastern part of Saskatchewan (Worsley and Fuzesy, 1979), elsewhere in the province their original name, White Bear Marker Beds (Holter, 1969), is still appropriate.

The areal extent and thickness of the four potash-bearing members are shown in Figures 6a and 6b. Apart from the White Bear, successively higher members extend farther towards the northwest. Regions of maximum development differ for each member and are reflected in their names.

The Esterhazy Member is present east of the Third Meridian (106°), south of the latitude of Saskatoon (52°), and extends a few kilometres into Manitoba. It is limited to the east by erosion (approximately on the line of the Assiniboine River) and in the border area around Moosomin (T13 R31w1) by non-deposition. The Esterhazy Member is rarely more than 15 metres in thickness except along the northern flank and in a few isolated areas. In Manitoba, thicknesses between 3 and 9 metres have been penetrated and although the member as a whole is not as thick as farther west, the lowest 2 to 3 metres is consistently high-grade, commonly non-carnallitic and, away from its eroded edge, has a minimum salt-back thickness in excess of 14 metres.

The White Bear Member is best developed in the southeastern corner of the province, in the vicinity of Moose Mountain (T10 R2w2) and north and east of Estevan. There it is from 6 to 9 metres thick. It is present marginally in Manitoba. The White Bear beds grade into halite beyond the Third Meridian and north of 51°.

The Belle Plaine Member extends from the Manitoba border to the Alberta border north of Maple Creek. It is thickest, about 12 to 15 metres, in the west and the north. Potash is impoverished or absent in the Patience Lake area (T37 R2w3) and northeast of Viscount (T34 R25w2).

The Patience Lake Member is not present in Manitoba but roughly from the Second Meridian (102°) it extends west-northwest to the Alberta border and as far north as the Unity area. It is thickest, about 20 metres, southeast of Saskatoon.

Thickness and Structure

In Saskatchewan the Prairie Evaporite is commonly more than 150 metres thick (see Figure 7A). Sequences in excess of 200 metres were penetrated in several boreholes in the St. Denis area (T38 R1w3) some 40 kilometres east-northeast of Saskatoon; near Outlook (T31 R8w3) 60 kilometres southwest of Saskatoon, and in the Touchwood Hills area (T30 R16 to 21w2) 20 kilometres south of Quill Lakes. Variations in thickness due to deposition are gradual but more abrupt changes result from complete or partial salt solution, pre-Dawson Bay erosion, or underlying build-ups of Winnipegosis carbonates. Where there is no halite the Prairie Evaporite is usually less than 50 metres thick, although in some bank-related areas such as Shell Lake (T50 R8w3), there may be as much as 75 metres of anhydrite.

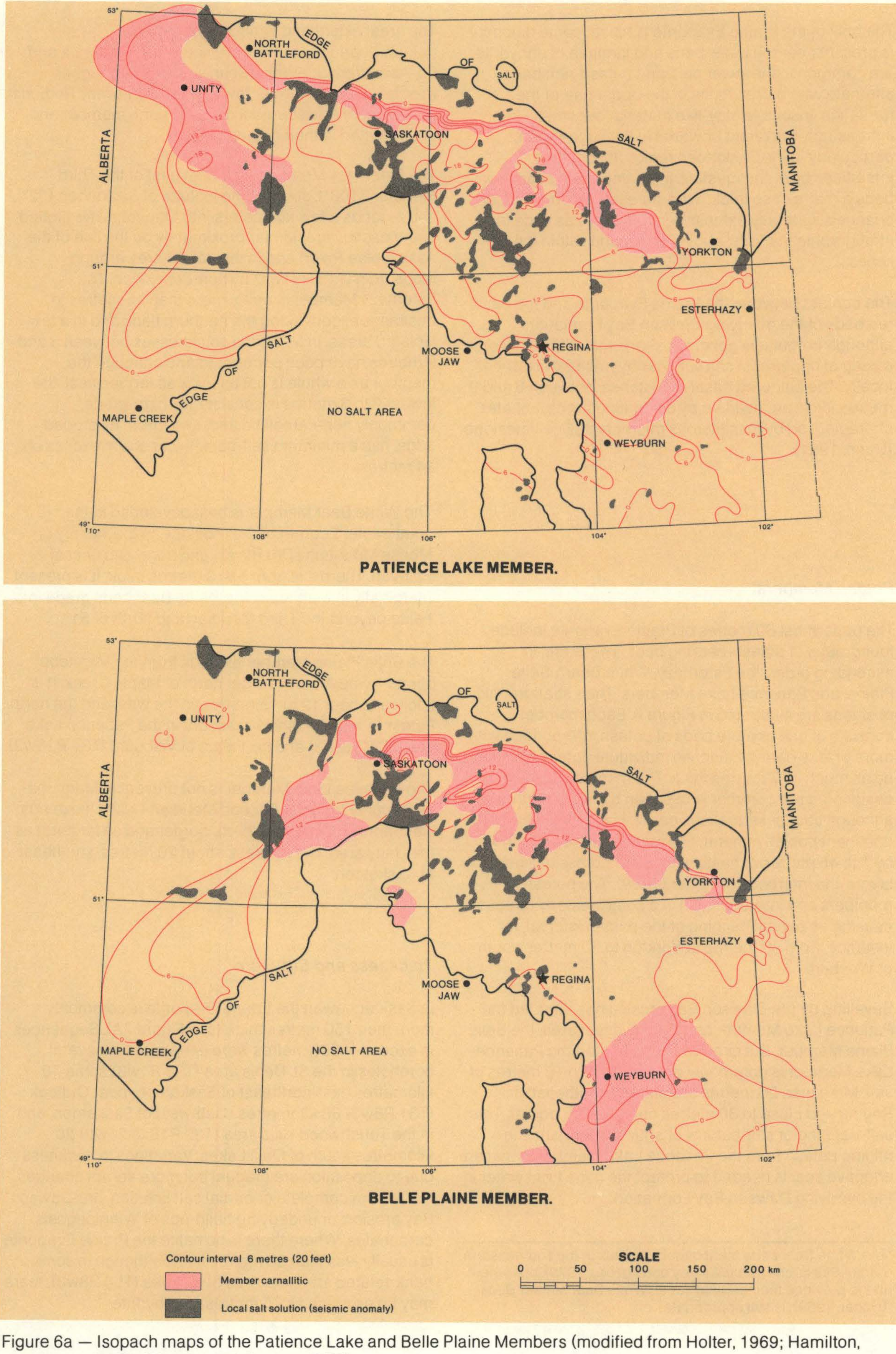


Figure 6a — Isopach maps of the Patience Lake and Belle Plaine Members (modified from Holter, 1969; Hamilton, 1971; Worsley and Fuzesy, 1979)

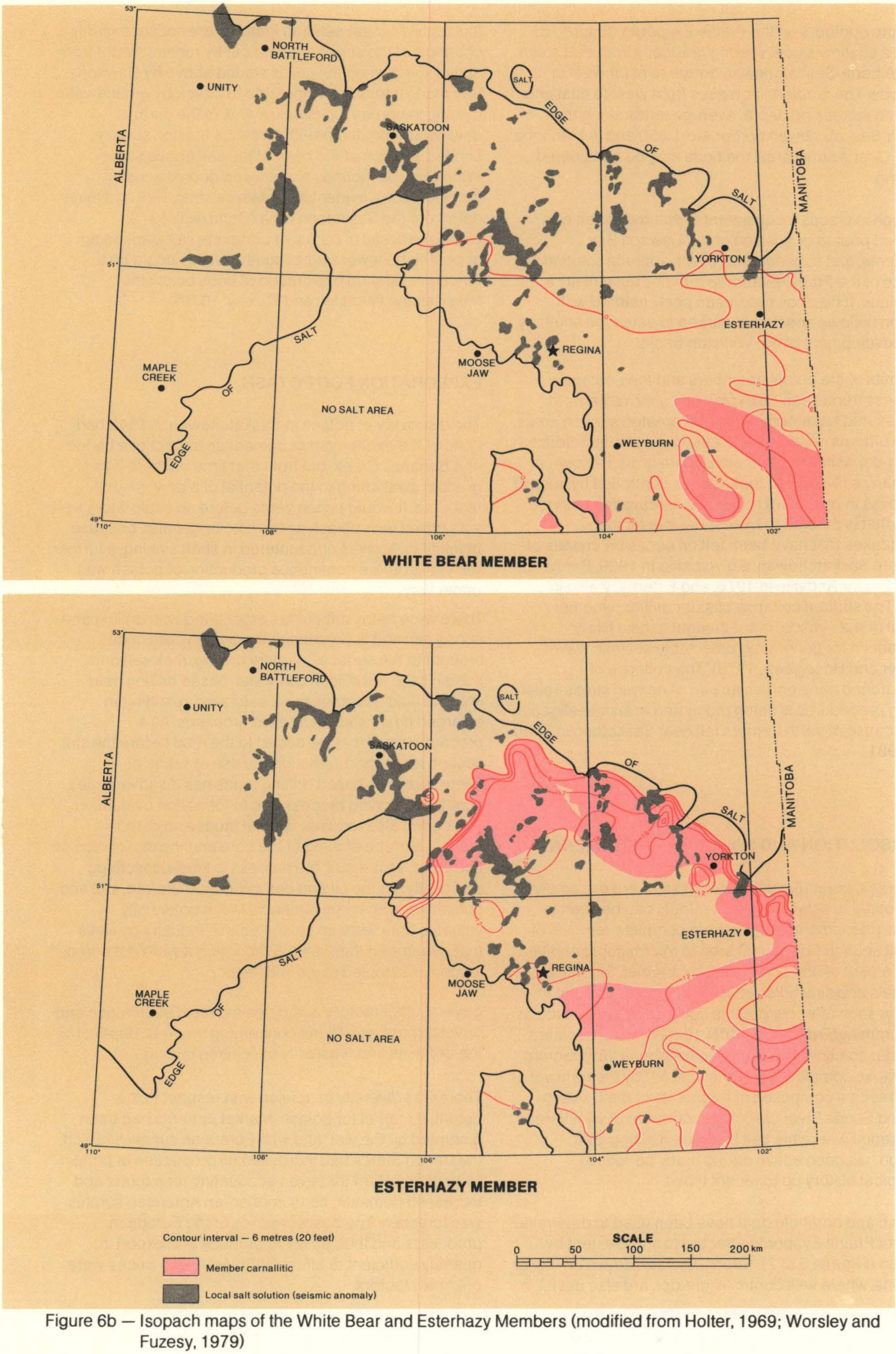


Figure 6b — Isopach maps of the White Bear and Esterhazy Members (modified from Holter, 1969; Worsley and Fuzesy, 1979)

Structure contours on the Prairie Evaporite (Figure 7B) depict a shallow slope, veering gradually from due south at the Alberta-Saskatchewan border to southwest in Manitoba. The gradient increases from west to east and also with increasing depth. Average ratios along the Alberta-Saskatchewan border are 1:450 and in Manitoba 1:160. Over a small area, the beds may be considered flat-lying.

Although in places a considerable volume of salt was removed prior to deposition of the Dawson Bay sediments, and subsequently by intra-stratal solution, the surface of the Prairie Evaporite remains essentially a time plane. It has, however, been pock-marked with solution hollows and down-warped towards the south by later development of the Williston Basin.

The limits of the potash members and their common thickness trends can be explained by movements in deep-seated basement rocks that created sunken areas where bitterns collected and raised areas characterized by non-deposition and erosion. There is also evidence that many salt-solution features are controlled by lines of weakness in basement rocks. It is reactivation of these zones that is thought to be responsible for the earthquakes that have been felt on occasion in parts of southern Saskatchewan, e.g. Avonlea in 1909, Bengough in 1972, near Radville in 1976, and Esterhazy also in 1976. The sudden collapse of salt-cavities, whether natural or man-made, is not thought to be a likely mechanism for generating detectable seismic waves (Horner and Hasegawa, 1978). The collapse of underground mine entries as part of normal stress-relief mining procedures is being monitored in an investigation of the cause of earth tremors felt near Saskatoon in 1980 and 1981.

SALT SOLUTION AND SOLUTION PHENOMENA

Evaporites, particularly the potash salts, are extremely susceptible to solution, and its effects can be seen in various phenomena ranging from complete removal of the salt section from a vast area to microscopic crystal replacement of one potash salt by another. Salt-filled channels and sink holes in some potash beds point to solution soon after deposition; collapse features such as the Hummingbird trough (49°N 104°W) are associated with later solution. The overlying beds may flex, fracture or collapse completely into the void left by the removal of salt. Breccias composed of fragments of the Dawson Bay and Souris River carbonate rocks are of widespread occurrence where the salt beds are missing. Salt solution has been active during many periods in geological history up to recent times.

Seismic and borehole data have been used to determine areas of Prairie Evaporite affected to some extent by solution (Figures 5 or 7). Structure maps drawn on higher horizons, where well control is greater, are also useful in this regard. Linear solution features are not necessarily channels in the sense of being cut by running water from above. Even when the salt is sealed above by Dawson Bay muds it remains vulnerable to attack by groundwater moving in porous rocks below and, in the north, downward from the pre-Cretaceous erosion surface. Limited solution at the base of the salt above some Winnipegosis mounds has caused depressions in younger rocks, evident in certain seismic, well and mine data from the Saskatoon area (Gendzwill, 1978). Localized areas of partial or complete salt solutioning appear to be fewer farther south, but this could be a function of limited exploration of beds below the Mississipian (Worsley and Fuzesy, 1979).

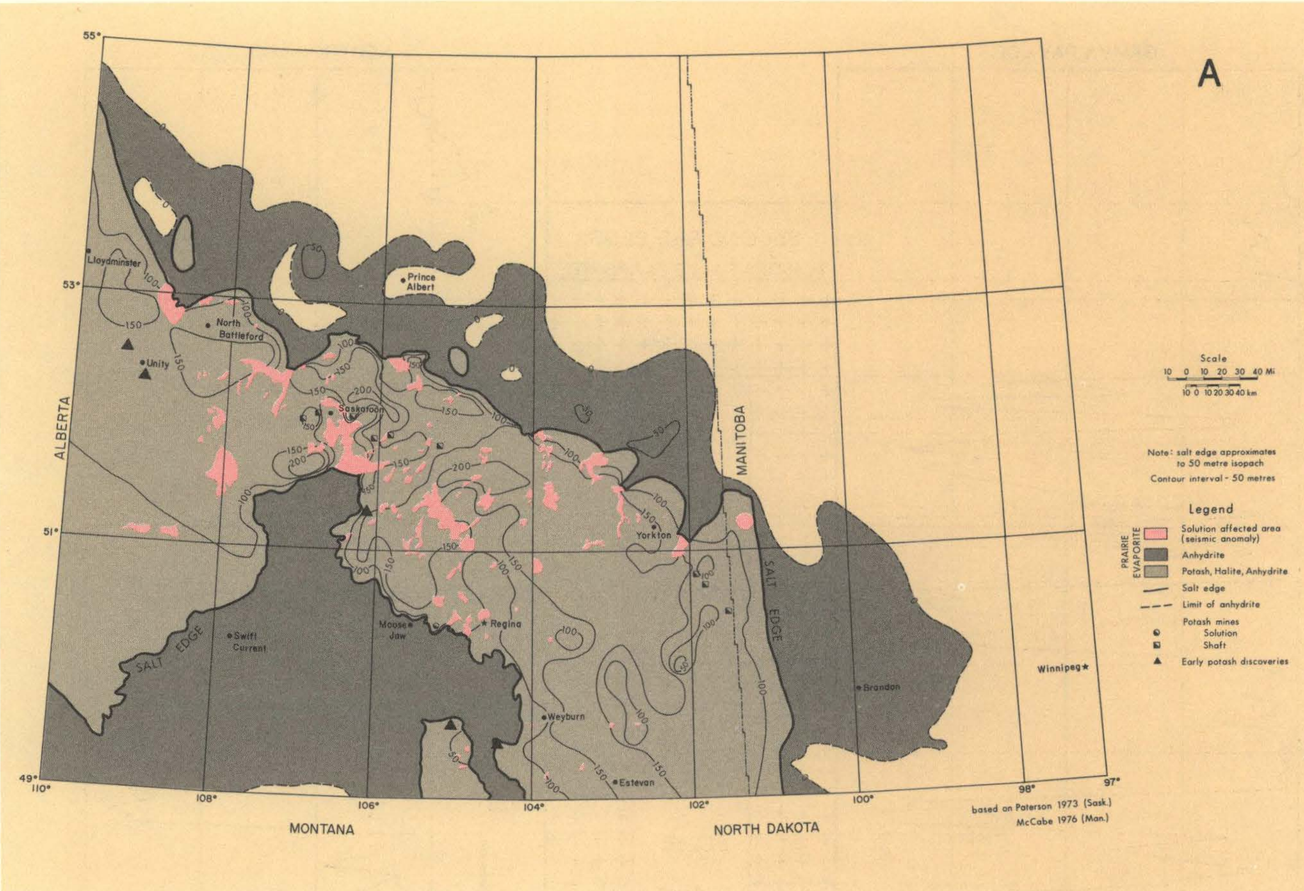
EXPLORATION FOR POTASH

The discovery of potash in Saskatchewan in 1942 had none of the excitement or immediate impact of a Leduc or a Bonanza Creek, but from that time on there was a gradual awakening to the potential of a new mineral resource. It would be ten years before an exploratory well was drilled with potash as the sole target and, because of initial difficulties encountered in shaft sinking, a further ten years before continuous production of potash was under way.

There were many difficulties associated with drilling and coring salt and in preserving the potash core once brought to the surface. In rotary drilling, rock salt and potash salts will dissolve in water-based drilling mud until the fluid becomes brine saturated, resulting in enlarged holes and associated problems. As a precaution, salt may be added to the mud before the salt section is reached, although the use of saline or alternatively oil-based drilling muds has disadvantages both to the drilling process and to formation evaluation. Salt coring also requires special muds and care to prevent surface etching of the core and the dissolution of carnallite; as a result, the process is time-consuming and costly. To the oil and gas industry, therefore, salt and potash were an inconvenience. Much potentially valuable data were lost to the potash industry by wells that penetrated the Prairie Evaporite but were not cored, logged or sampled in the salt section.

Several other factors acted against rapid exploration and development: questions concerning markets, depth of the deposits and feasibility of solution mining.

There was diversity of opinion with respect to the potential market for potash. Market patterns had been disrupted by the war, and with European supplies cut off, the United States had increased its production of potash to such an extent that even accounting for exports and increased domestic consumption, an American surplus was foreseen. The postwar policy of the European producers and their ability to produce and export in quantity sufficient to affect North American prices were unknown factors.



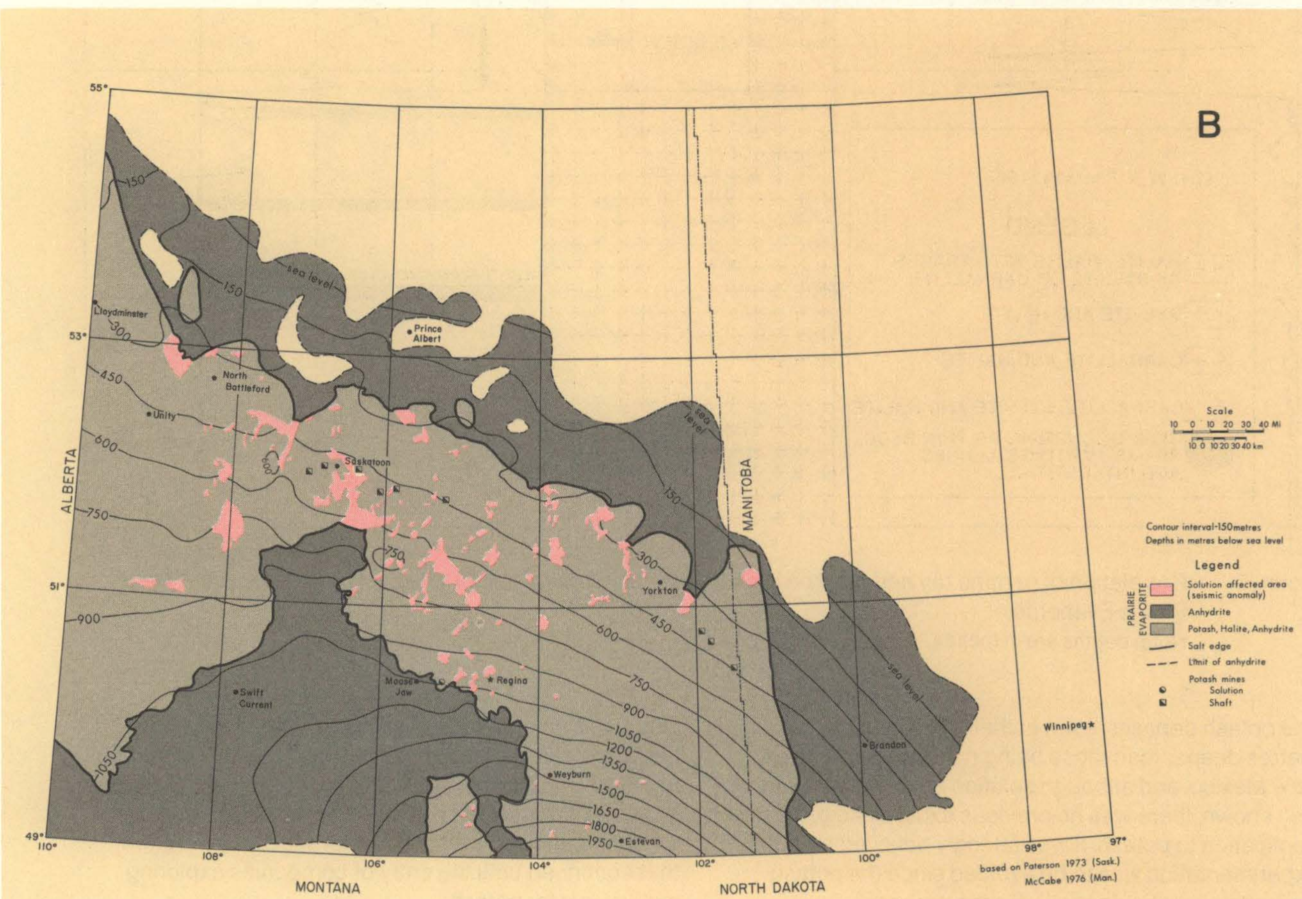


Figure 7 — The Prairie Evaporite in Saskatchewan and Manitoba. A. Isopach map B. Structure contour map

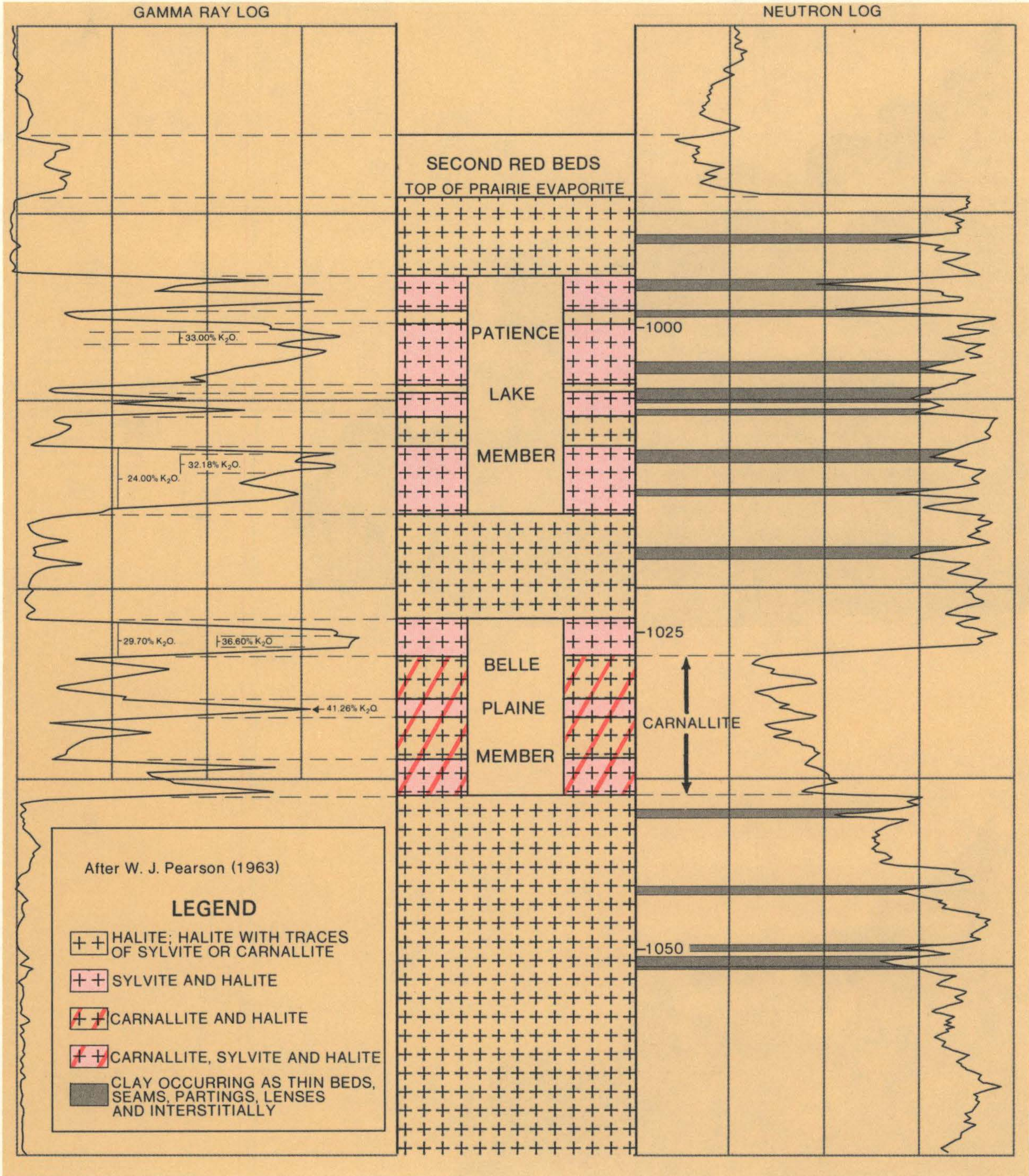


Figure 8 — Correlation of gamma ray and neutron logs with the mineralogy and lithology of the upper part of the Prairie Evaporite
Note: depths are in metres.

The potash deposits, even at their shallowest were 600 metres deeper than those being mined in Europe and New Mexico, and although solution mining of salt was well known, there was no previous experience of its application to potash. It was strongly believed that undue experimentation was to be avoided since the potash deposits might be destroyed in the process.

Questions were being asked in the Saskatchewan Legislature in 1949 about the slow pace of development. In order to speed things up the provincial government provided financial assistance to oil and gas companies for coring and sampling in the salt section, a program that continued until the entry of companies exploring exclusively for potash.

Until the early fifties it was still hoped that potash would be found at shallower depths farther north. The apparent continuity of the salt beds with those in northern Alberta was promising since the Fort McMurray salt was only 200 metres deep. In the summers of 1949 and 1950 the Department of Natural Resources drilled a series of stratigraphic test holes in the timber belt of central Saskatchewan where the bedrock geology was unknown. A purpose of the program was to determine the extent of the salt beds and although this drilling proved to be well to the north of the salt, it did help to eliminate the possibility of shallow potash in Saskatchewan. By 1951 the salt area had been tentatively defined. Near the Manitoba border the potash zone was found to be about 100 metres closer to the surface than at Unity, and in the Saskatoon area, lower zones were found well below the upper portion of the salt. However, the Verbata No. 2 discovery well at Unity still showed the richest, most mineable occurrence of potash, and in 1951 Western Potash Corporation was granted the first permit to explore for potash, in an area surrounding this old well.

A withdrawal arrangement, whereby potash companies could participate in wildcat oil or gas drilling for a six-month period before taking out the more restrictive regular exploration permit, was introduced in 1952 and from that time on interest and activity in potash exploration increased. By 1956 all six of the potash producers from New Mexico held withdrawals or permits in Saskatchewan.

A spin-off from the introduction of radioactivity logs in 1950 was their application in potash exploration (Figure 8) and, with the right suite of logs, it eventually became possible to assess potassium-rich salt beds quantitatively with an accuracy comparable to that of chemical core analysis.

Depth, grade, quality and extent of the ore bed; thickness and nature of the salt-back immediately above the ore; and water-bearing zones in the overlying rocks, are all important factors which must be considered in the search for a potential mine. A significant thickness, 10 to 15 metres or more, of strong, impermeable rock, either salt or unworked potash ore, must be present above the selected mining horizon to ensure support and to act as a water seal between mine openings and the overlying strata. Clay, or shale seams are a potential hazard.

The salt and potash beds were originally chemical precipitates from sea water and thus, provided they have not been disturbed, folded or faulted, have lateral continuity of thickness and grade. Anomalies and discontinuities in the salt beds are most effectively detected by seismic surveys and these proved to be an essential accompaniment to exploratory drilling.

Intensive exploratory drilling, for instance on the scale necessary to outline a metallic orebody, is not undertaken. This is partly because of the continuity of the potash deposits and partly because in the eventuality that a mine is developed a significant amount of ore has to be left surrounding each borehole to provide protection aginst the influx of water or brine through the borehole from overlying water-bearing strata.

Once the presence of potash in an area has been confirmed by one or two wells, an adequate assessment of the quality, quantity and mineability of the deposit can be achieved at a density of four wells per township providing a seismic survey is available. At this point the feasibility of production can be judged. If the project is carried through to completion approximately nine wells per township will be necessary to plan the mine lay-out before the pilot hole for the shaft is drilled. These figures are based on areas of Saskatchewan where the potash potential has been assessed.

When the location of a shaft has been chosen, a pilot hole is drilled at the site of the shaft. This provides precise data on the nature, strength and water-bearing characteristics of the rock to be penetrated. Coring pin-points zone transitions, fractures and shale partings, and provides samples for porosity-permeability determinations and other laboratory tests. Drill stem tests are run to evaluate the flow potential of water-bearing zones and a comprehensive geophysical logging program reveals essential information on the physical nature of the strata above and immediately below the proposed mining level.

DEVELOPMENT OF THE POTASH INDUSTRY IN SASKATCHEWAN

There are nine shaft mines and one solution mine operating in Saskatchewan. There is also an abandoned shaft near Unity. Mine locations, together with lease or permit areas, are shown in Figure 9. Details of mine ownership and capacity are listed in Table 2 and their history is graphed in Figure 10 and detailed in the Appendix.

The first commercial production of potash in Saskatchewan was attempted in 1951 by Western Potash Corporation Limited (reorganized in 1955 to Continental Potash Corporation Limited) on land acquired in the Unity district. The company attempted to develop a solution method of mining potash salts similar to that used in producing common salt, but the experiment proved unsuccessful. Instead, a shaft was begun in 1952 and by the summer of 1961, after numerous problems and delays, was excavated to a depth of 558 metres when it was inundated by water and sand to within 106 metres of the surface. The shaft was rehabilitated but no more work was done. In 1968 it was sealed and the site abandoned.

Table 2
Potash Industry in Saskatchewan

Company or Operator	Mine Location	Initial Production	Capacity[1] million tonnes per year	
			KCl	K_2O
Central Canada Potash	Colonsay	1969	1.36	0.82
Cominco Ltd.	Vanscoy	1969	0.82[8]	0.50[8]
International Minerals and Chemical Corporation (Canada) Limited (IMCC)	Yarbo K-1 Gerald K-2	1962 1967	3.81	2.32
Kalium Chemicals Limited	Belle Plaine	1964	1.36[8]	0.85[8]
Potash Company of America	Saskatoon	1958, 1965	0.69[8]	0.42[8]
Potash Corporation of Saskatchewan (PCS) Mining Limited				
Allan Division[2]	Allan	1968	1.36 (1.59 '81)	0.83 (0.97 '81)
Cory Division[3]	Saskatoon	1968	1.36	0.83
Lanigan Division[4]	Guernsey	1968	0.91 (1.00 '81) (2.90 '83)	0.54 (0.60 '81) (1.74 '83)
Rocanville Division[5]	Rocanville	1970	1.27 (1.81 '81)	0.78 (1.11 '81)
Esterhazy Division[6]	—	—	(0.95)[7]	(0.58)[7]
		Total	12.94 (16.62 '83)	7.89 (10.12 '83)

[1]Design capacity December 31st, 1980
[2]Operator of Allan Potash Mines owned by PCS 60%; Texasgulf Potash 40%
[3]Formerly Duval Corporation of Canada
[4]Formerly Alwinsal Potash of Canada Limited
[5]Formerly Sylvite of Canada Division, Hudson Bay Mining and Smelting Co., Limited
[6]Production agreement with IMCC based on purchase of former Amax Potash Ltd. reserves and production contract
[7]Included in IMCC capacity figures
[8]Cominco, Kalium, PCA expansions total 0.92 million tonnes KCl (approximately 0.56 million tonnes K_2O) by 1982.

Potash Company of America, the first of the producers from New Mexico to begin exploration in Saskatchewan, successfully completed shaft sinking and began production in 1958. However, production was suspended the following year because of water seepage in the shaft, and the mine remained unproductive until 1965. The other nine mines all came into production during an eight-year period starting with the International Minerals and Chemical Corporation (Canada) Limited K-1 mine near Esterhazy in August 1962 and ending with the Sylvite of Canada mine at Rocanville in September 1970.

The solution mine at Belle Plaine came on stream within five years of initial exploration and its capacity has since been expanded. Other attempts at solution mining were made in the fifties and sixties at Nokomis (General Petroleums of Canada Ltd.), Findlater (Imperial Oil Limited), Boulder Lake and Yorkton (Southwest Potash Corporation), but all were unsuccessful. Altogether about 40 firms abandoned or suspended exploration projects during this period.

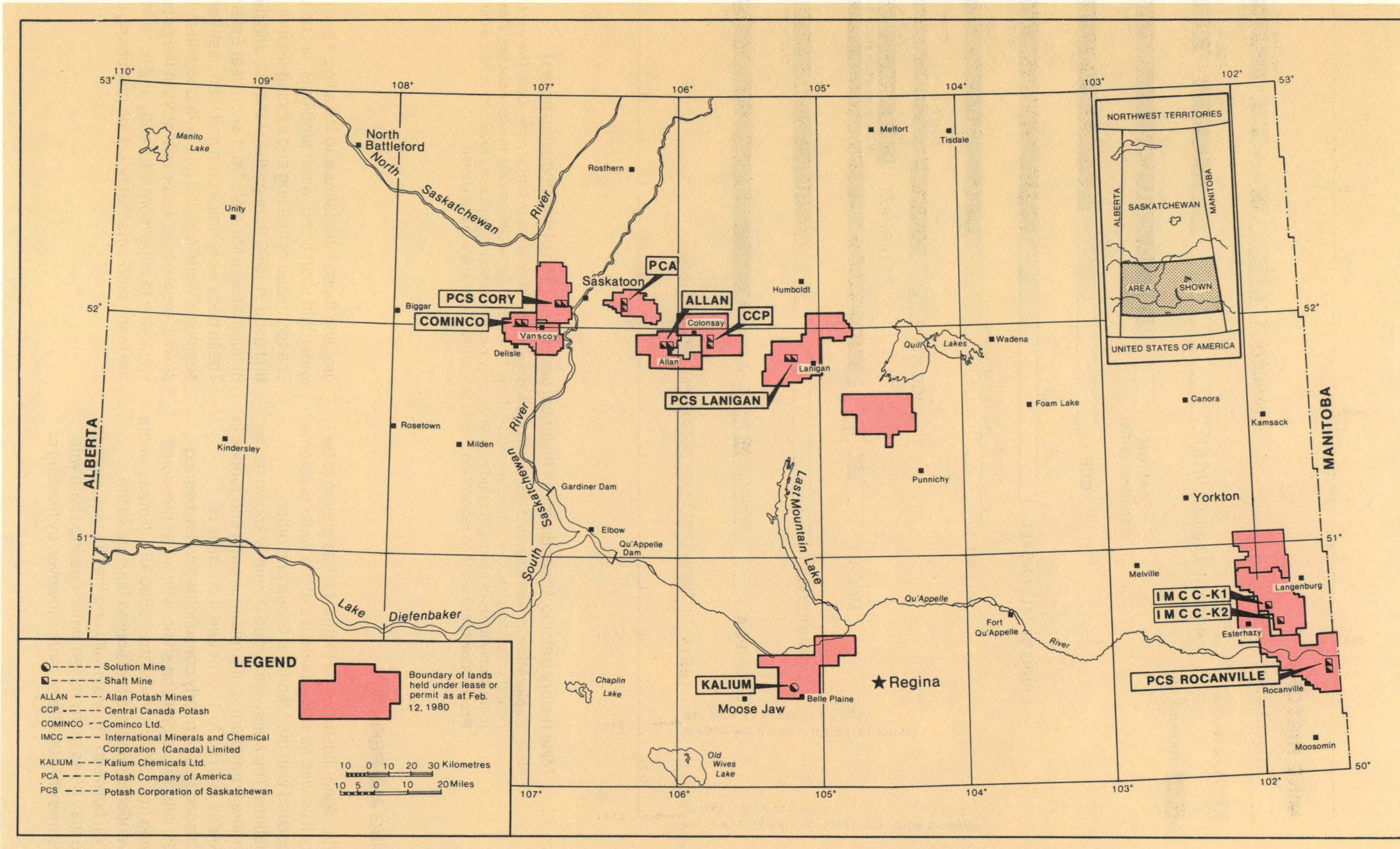


Figure 9 — Potash mines, lease and permit areas in Saskatchewan

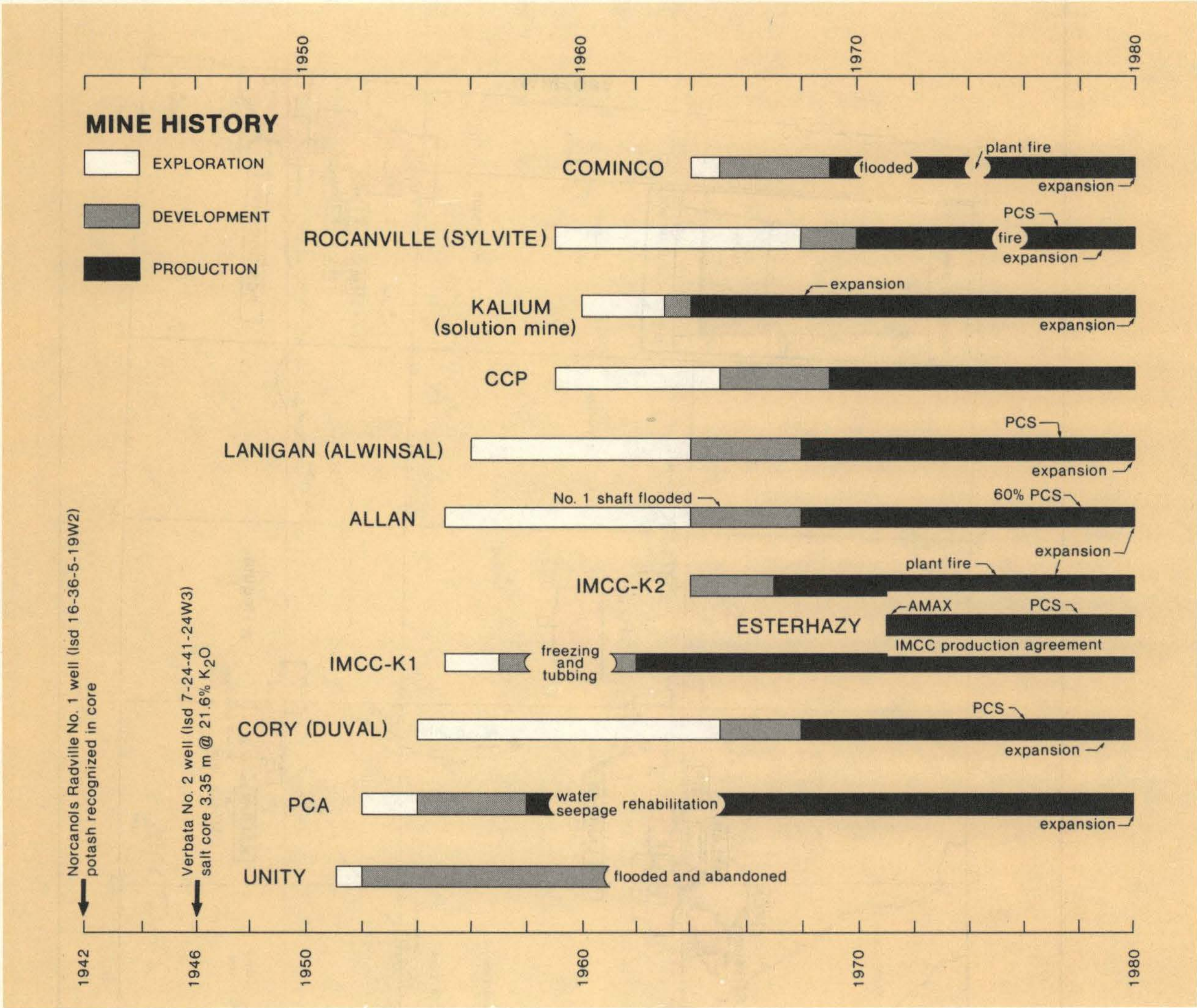


Figure 10 — Mine history (refer to Appendix for an historical account of each of the producing mines)

Note: **Exploration** includes earliest test drilling, withdrawal, permit or lease in future mine area. The exploration period preceding IMCC-K2 mine was essentially that of K1; the two mines are interconnected. **Development** relates only to shaft sinking (including freezing) or plant erection in the case of Kalium solution mine. **Production** breaks due to renovation, high inventories, or strikes are not shown.

MINING AND REFINING

Shaft sinking, illustrated by Figure 11, has proven to be difficult as well as costly because of the water problems associated with the Mannville Group and other formations. The Mannville Group (formerly known as the Blairmore Formation) is of Cretaceous age and ranges in thickness from 60 to 150 metres. It consists of unconsolidated to poorly consolidated water-bearing sands, silts, mudstone and shale, with water pressures ranging from 2700 to more than 5500 kPa in areas where conventional mining is considered feasible. In the interval between the Mannville and the Prairie Evaporite there may be as many as ten water-bearing strata with pressures of 7500 kPa or more. However, by freezing or grouting these formations and installing a permanent watertight shaft lining, water problems can be overcome. The technique of freezing and tubbing (Figure 12) was first used in 1960 through the Mannville and the Jurassic at International Minerals No. 1 shaft near Esterhazy. These beds were first frozen and then cast-iron segments were installed and bolted together as the shaft sinking progressed. Later operators in the potash field were able to cope more efficiently and economically with the many problems that beset the pioneering companies.

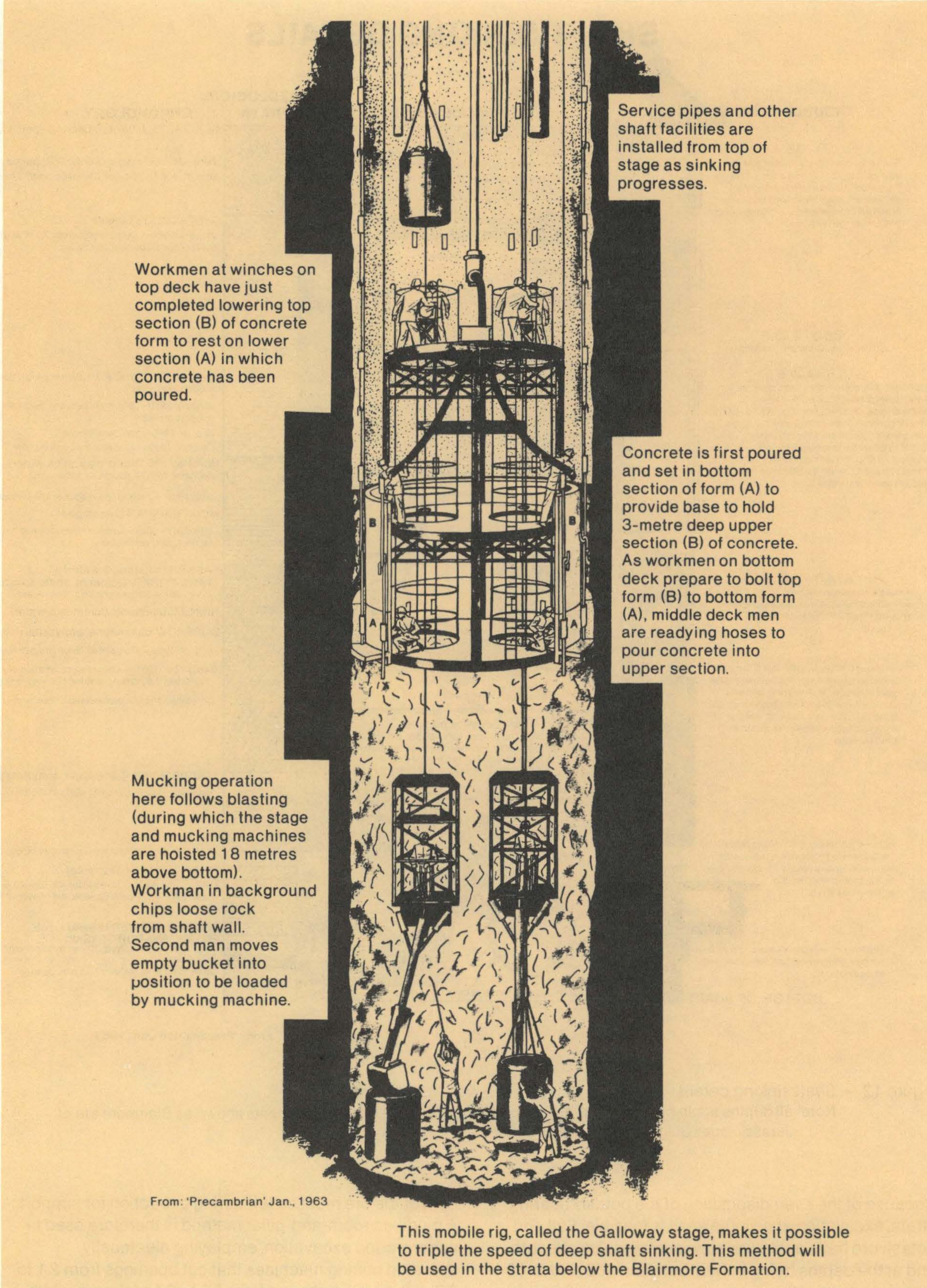


Figure 11 — Diagrammatic representation of shaft sinking operations

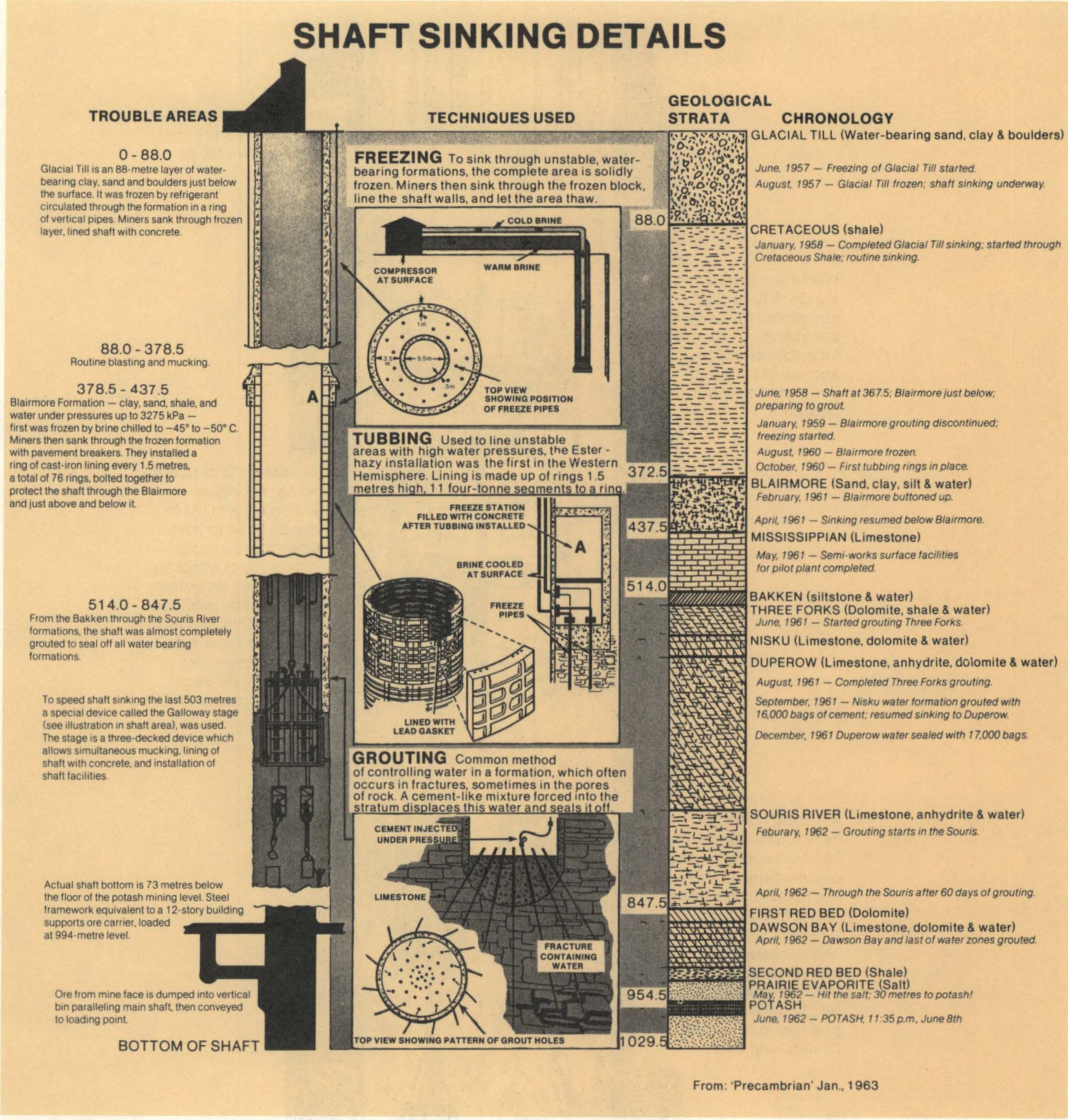


Figure 12 — Shaft sinking details

Note: all depths are in metres. In the K-1 mine shaft the lower part of the sediments shown as Blairmore are of Jurassic age (Guliov, 1967, Paterson, 1968).

Because of the even disposition of the potash-bearing strata, excavation at a single level is feasible. Salt and potash ore have a relatively low compressive strength and at the depths being mined, between 950 and 1100 metres, weight of the overlying strata causes plastic flow or creep. This characteristic controls the choice of shape, size and spacing of mine openings. About 65 per cent of the ore must be left during extraction for support. A modified room-and-pillar method is therefore used in underground excavation, employing electrically operated mining machines that cut openings from 2.1 to 3.7 metres in height and from 3.9 to 8.1 metres in width (Figure 13). The rooms may reach considerable dimensions, for example, at the Rocanville mine, parallel

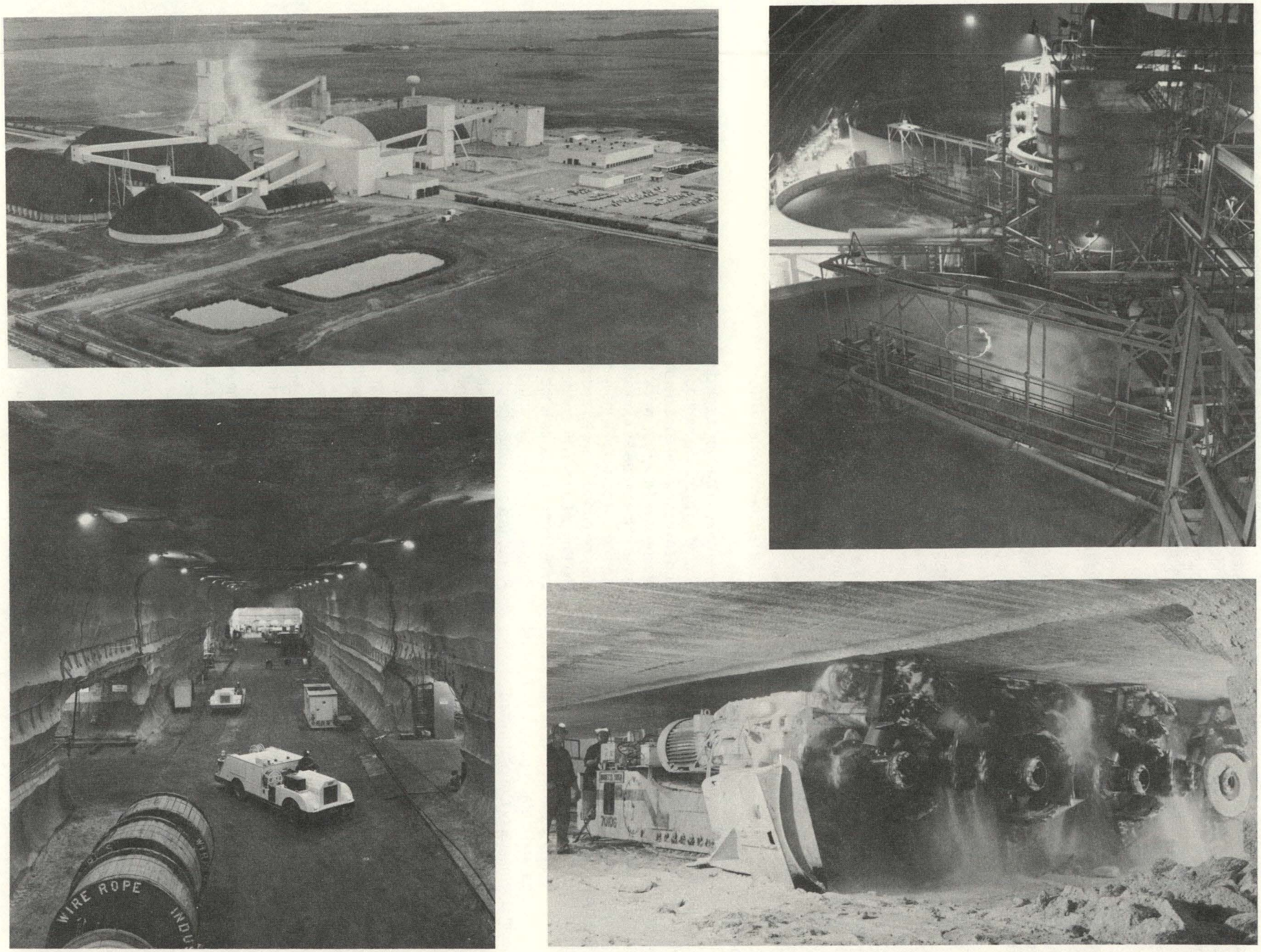


Figure 13 — Potash mining and refining. Clockwise from top left: surface facilities including headframes, refining plant and storage silos; thickeners — KCl recovery process; a continuous mining machine at work; a maintenance room 960 metres below the surface. (Photographs courtesy of Potash Corporation of Saskatchewan)

rooms 2.4 metres high, 20.4 metres wide and more than 1500 metres long are excavated, each representing the removal of some 150 000 tonnes of ore. In a new mining method proposed for the expanded Lanigan mine, parallel rooms ultimately 4.6 metres high and 13.7 metres wide will be excavated in four passes. At the Cory mine, many small rooms perhaps 60 metres long, 9 metres wide and 3.4 metres high are angled off a single entry. This is the so-called 'chevron' pattern of mining. At Allan a variety of angled patterns has been tried (Schabas, 1980). Shuttle cars or portable conveyors transfer broken ore to a main conveyor for haulage to the shaft. Some primary crushing usually takes place underground before the ore is hoisted to the surface.

In the plant, the ore is finely crushed, deslimed, and the potassium chloride removed by flotation. The potassium chloride is then dried and screened to provide as many as four different grades of potash: granular, coarse, standard and special standard muriate. Compactors may be used to increase the proportion of the more desirable granular and coarse grades. Chemical and soluble grades of muriate are also produced from evaporation and crystallization circuits that are fed with fines and dusts collected throughout the plant.

In the solution mining process, a selected pattern of cased wells is drilled and hot weak brine is pumped into potash beds lying at a depth of about 1600 metres below the surface. The injected brine dissolves the sylvite and halite and the resulting potash-rich solutions are circulated back to the surface for refining. This involves a sequence of evaporation and crystallization whereby crystals of potassium chloride are precipitated, drawn off, dried and screened.

Compared to most coal and metal mining, potash mining in Saskatchewan is remarkably straightforward. However, in the Saskatoon area, where thin clay and shale layers are present above and below the potash ore, structural problems have developed around some mine openings. Over time, pressures build up, and cause the clay layers to separate and the strata to buckle into the opening. This can be largely overcome by mining techniques in which the deformation is controlled by stress-relief methods, involving planned failure of certain rooms in order to relieve stress and ensure the stability of others. The chevron type of extraction patterns have been found to provide stress-relief (Schabas, 1980). In areas with a thin salt-back, this situation could cause serious problems if the Dawson Bay Formation (locally bearing high-pressure waters) was breached.

Major areas of salt solutioning or carnallite can be avoided in the initial selection of a mine site, but small-scale features within the potash beds are as yet difficult to detect, and are uncovered only as the working face advances. These features may be so small as to be merely a geological curiosity; others such as washouts or bodies of barren halite known as 'salt-horses' may cause minor mining problems. The decision has to be made whether to continue mining in the hope that the salt body is only a metre or so thick or to change direction and work around it. In recent years underground seismic work has been successfully used to predict the extent of such barren bodies once encountered.

POTASH, SALT AND THE ENVIRONMENT

The recovery of potash yields almost twice as much sodium chloride as potassium chloride; an amount equivalent, at 1980 production levels, to triple the total shipments of the Canadian salt trade. This huge quantity is a liability rather than an asset, and although brine from the potash solution mine at Belle Plaine is used in the production of fine vacuum-pan salt by The Canadian Salt Company Limited and some of the salt from the Esterhazy mines is sold as road salt, most is disposed of as waste. The salt from the potash refineries varies as to purity and particle size, but in general, that from mined ore is comparable to any mined rock salt and would need further refining for some uses. Rock salt is used largely for snow and ice control, a market that appears to have reached a plateau (Barry, 1979).

Elsewhere in the world, salt disposal practices differ according to mining method, location, markets, climate and environmental considerations. At one of the two prospective New Brunswick mines it is proposed to sell some of the waste as road salt and bury the remainder in worked-out portions of the mine; at the other, the salt may be buried or brined and piped several kilometres to the Bay of Fundy (The Leader-Post, 26.10.79). Potash mines near the sea, as is the Boulby mine in the United Kingdom, are at an advantage in this respect. The River Rhine, as a consequence of salt-disposal, has suffered from salt pollution and an alternative to brine discharge by the Alsatian potash refineries is being sought. The mining practice at certain potash mines in West Germany involves the dewatering and backfilling of waste salt underground. In the United States, the industry in New Mexico benefits from scanty rainfall and high evaporation rates so that surface waste disposal is less of an environmental hazard than elsewhere.

The potash mines in Saskatchewan adopted not only the mining and processing technology of the New Mexican mines but also their surface waste disposal practices. The tailings, i.e. wet salt, slimes and brine are impounded at the surface in dyked areas. However, it was found that natural evaporation was less than calculated and it has become necessary at most mines to dispose of excess brine by well injection into deep porous rock formations. Rainfall and run-off in the plant vicinity have also created some problems.

Environmental studies have been undertaken at the University of Saskatchewan to identify any health effects of potash dust, to investigate the movement and

Table 3
Maximum Percentages* of Mineral Components in Potash Members

	Sylvite	Carnallite	Halite	Insolubles
Patience Lake Member	30+	50+	80+	10+
Belle Plaine Member	33	68	80+	6
White Bear Member		insufficient	data	
Esterhazy Member	30+	9	80+	2

Densities: Sylvite 1.98 g/cc
Carnallite 1.61 g/cc
Halite 2.16 g/cc
Insolubles 2.60 g/cc

Potash ore is commonly 2.0 - 2.1 g/cc (or tonnes/m^3)
or 125 - 130 lb/ft^3
(density varies with composition)

* by weight
Sources: percentages after Holter (1971)
densities (except potash) from Schlumberger (1974) Table 10-1, p. 104

accumulation of salts in soils around potash refineries, and to examine the effect on trees and crops of airborne salt.

The potash industry was established in the province before environmental issues became an important control in the resource industry. Environmental impact studies are now an accepted preliminary to any new or expanded project. These have been prepared for the proposed expansion of the Potash Corporation of Saskatchewan mines at Rocanville [Kilborn (Saskatchewan) Ltd., 1978], and Lanigan (Saskatchewan Research Council, 1979). A similar study for the proposed new mine at Bredenbury will be conducted by the Corporation.

GRADE AND RESERVES

As a source of potassium, sylvite is the desirable mineral since it contains 63.2 per cent K_2O equivalent, whereas carnallite contains ony the equivalent of 16.9 per cent K_2O. A maximum content of about 30 per cent sylvite is common to all potash members (Table 3). Ore being mined from the Esterhazy Member in the Manitoba border area has a minimal amount of insoluble material and considerable quantities of carnallite. The converse is true for ore being mined from the Patience Lake Member around Saskatoon. Excessive amounts of carnallite and insolubles are avoided wherever possible in mining operations because of their detrimental effects on mine stability, ore grades and refining processes. On the other hand, carnallite contains 8.7 per cent magnesium (34 per cent $MgCl_2$) and is therefore also of considerable economic potential in its own right.

The grade of the potash ore being mined in Saskatchewan is generally higher than that mined in many other countries of the world. Ore extracted by conventional mining methods averages between 21 and 27 per cent K_2O, although in some areas it is greater than 30 per cent K_2O. By comparison, the average grade of ore now being mined in New Mexico and Europe is reported to be about 15 per cent K_2O. In the Soviet Union grades between 14 and 21 per cent K_2O are reported and in the United Kingdom the ore being mined reportedly averages more than 25 per cent K_2O.

By applying several limiting criteria including member thickness, depth of burial, salt-back thickness, and mineral grade, Holter (1969) presented a series of economic potential maps indicating the areas of greatest potential for potash exploitation (refer to the composite map, Figure 14). Data suggesting low potash potential sometimes result from exploratory drilling of structural anomalies for oil and gas. Tests in less structurally disturbed areas would likely show thicker potash beds of higher grade. For this reason, the potential solution mining area is probably more extensive than that shown in Figure 14.

It has generally been accepted that it would be uneconomic to operate a conventional potash mine much below 3,500 feet (1067 metres) in that the costs of sinking deeper shafts and assuring adequate support would be prohibitive. This depth estimate was made in the mid-1950s before there were any potash mines in the province. Experience gained during the operation of the Saskatchewan mines and preliminary studies in rock mechanics encourage the belief that this figure is unnecessarily conservative (W. H. Potts, personal communication 1978). At the Boulby mine in the United

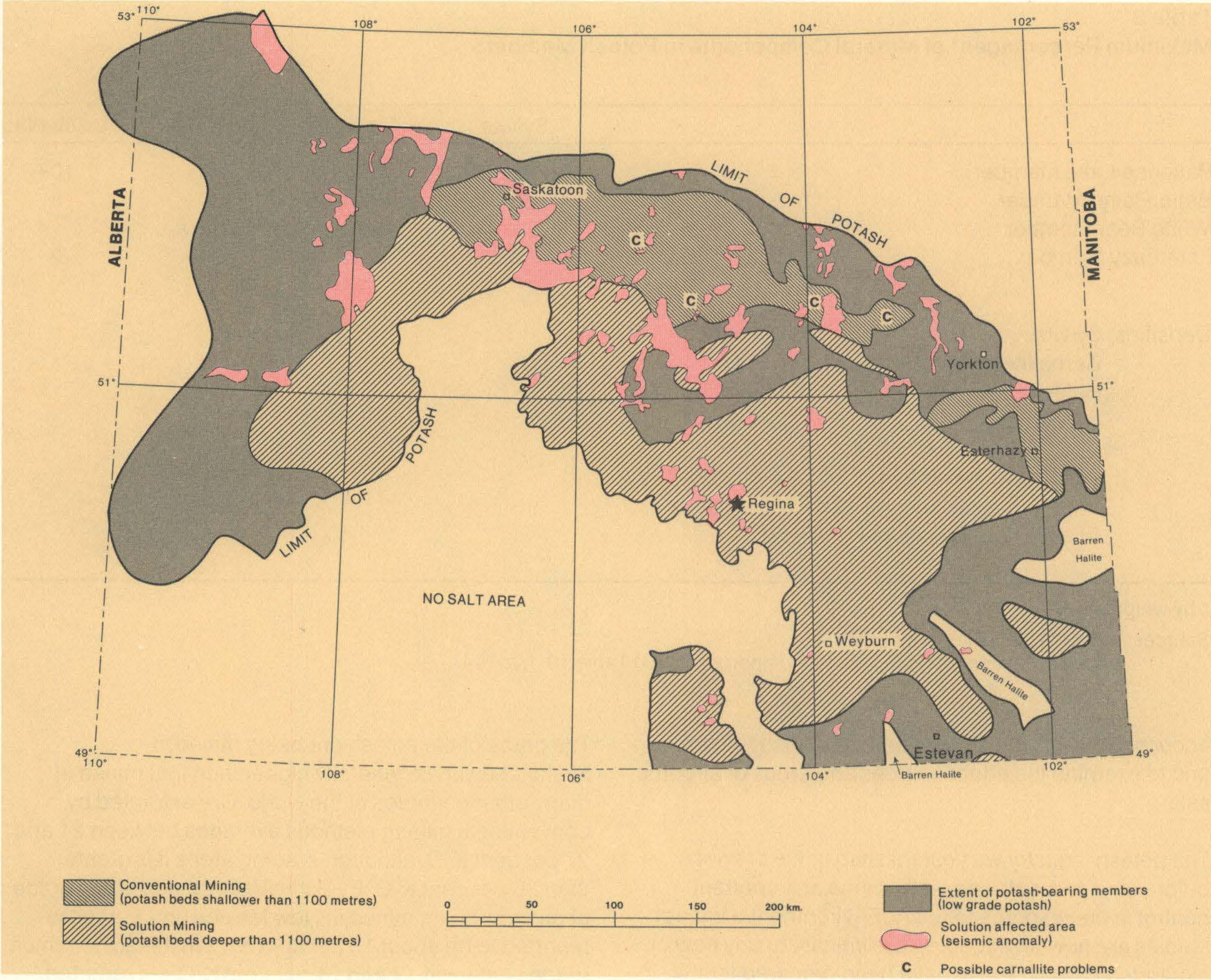


Figure 14 — Economic potential map (modified from Holter, 1971; Worsley and Fuzesy, 1979)

Note: the minimum criteria used in compiling Figure 14 were: **conventional mining** less than 3,600 ft. to top of Prairie Evaporite, 20 ft. salt-back thickness, 30% sylvite grade in best 8 ft. interval; **solution mining** more than 3,600 ft. to top of Prairie Evaporite, 20 ft. salt-back thickness, 30 ft. member thickness (comprising a single member or two members if separated by less than 10 ft. of interbeds).

Kingdom the potash beds are reached at 1070 metres and two shafts have been sunk to depths of about 1150 metres, the deepest in the U.K. Also, a depth of 1200 metres was reached in the course of potash operations in West Germany in 1974 (Notholt, 1974). For the economic potential map (Figure 14) the boundary between conventional and solution mining areas was arbitrarily taken at 1100 metres; a rounded-up metric conversion of 3,500 feet which conveniently includes all Saskatchewan shaft mines (the deepest is about 1075 metres).

Over twenty years ago, before there were any potash mines in Saskatchewan, Goudie (1957) estimated reserves recoverable by conventional mining to be 5.8 billion tonnes K_2O equivalent. Applying similar criteria of depth, thickness, grade, salt-back, recovery and single level extraction, Holter (1969 and 1971) arrived at a somewhat lower figure of 4.5 billion tonnes K_2O equivalent. He estimated that an additional 62.6 billion tonnes K_2O equivalent were recoverable by solution mining techniques.

Using a recovery rate of 360 000 tonnes K_2O equivalent per Km^2 (about 1.6 million short tons KCl/square mile) and including Manitoba, Barry (1979) calculated reserves for single and double level extraction as 10.5 and 14.0 billion tonnes K_2O equivalent respectively. He concluded that solution mining, in areas where the potash beds are between 1070 and 2500 metres deep, would account for at least a further 42 billion tonnes K_2O equivalent.

The United States Bureau of Mines in tabulating potash resource estimates (Singleton, 1978, Table 5) showed that Canada* has approximately half the total world potash resources. The latest Bureau of Mines figures for

*The data related solely to Saskatchewan

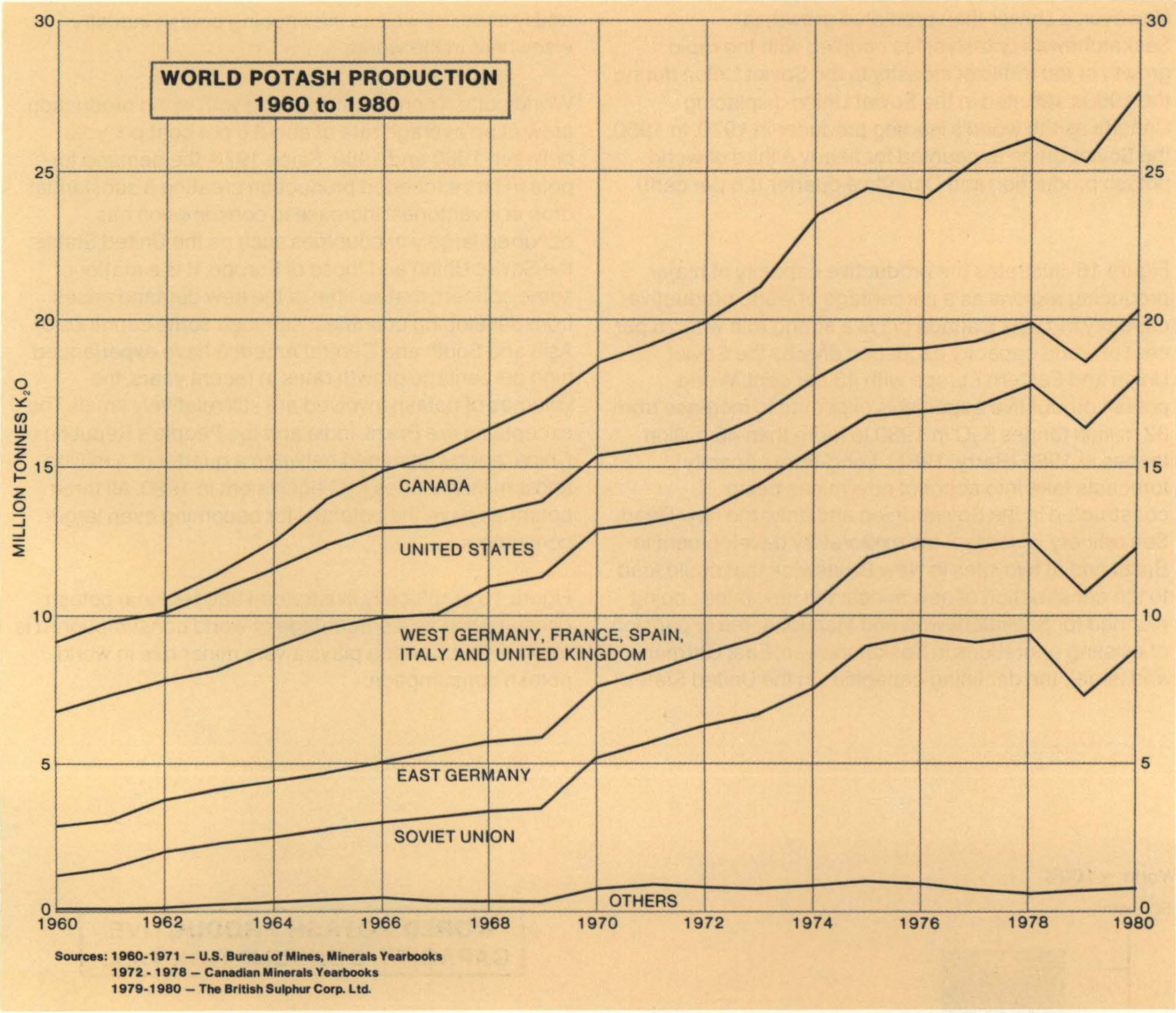


Figure 15 — World potash production 1960 to 1980

Canadian deposits, nearly all of which are in Saskatchewan, are 70 billion tonnes K_2O equivalent total resource including 2.7 billion tonnes classified as reserves (R. H. Singleton, personal communication 1979).

WORLD PRODUCTION AND CONSUMPTION OF POTASH

World potash production increased from 9.2 million tonnes K_2O equivalent in 1960 to 27.6 million tonnes in 1980. This represents an average long term growth rate approaching 6 per cent a year. During this period, North America's share of world production rose from 25 per cent to 35 per cent; that of the Soviet Union and Eastern Europe from 30 to 40 per cent; while Western Europe's share declined from 40 to 20 per cent.

Six countries, each producing several million tonnes K_2O annually, account for about 95 per cent of the world's present potash production. They are the Soviet Union, Canada, East Germany, West Germany, United States and France. Substantial quantities of potash, currently between one hundred thousand and a million tonnes a year, are produced by Israel, Spain, Italy and the United Kingdom. The People's Republic of China and Chile also produce potash. The bulk of world production is in the form of potassium chloride or muriate of potash. The United States and a number of European countries also produce sulphates of potash. Chile produces potassium nitrate. Figure 15 shows graphically the world production of potash for the years 1960 to 1980. The 1979 downturn reflects a sharp fall in Soviet Union production.

Germany dominated world potash production until the Second World War, and even now, after well over a century of exploitation, the German deposits supply a fifth of world production. Following division of the country into East and West Germany after the war, the United States assumed the position of the world's leading producer. It took the new Canadian potash industry just seven years to overtake that of the United States in 1968.

However, a slower than predicted growth in Saskatchewan potash sales coupled with the rapid growth of the fertilizer industry in the Soviet Union during the 1960s, resulted in the Soviet Union displacing Canada as the world's leading producer in 1970. In 1980, the Soviet Union accounted for nearly a third of world potash production and Canada a quarter (26 per cent).

Figure 16 illustrates the productive capacity of major producing regions as a percentage of world productive capacity in 1980. Canada plays a strong role with 25 per cent of world capacity exceeded only by the Soviet Union and Eastern Europe with 43 per cent. World potash productive capacity is expected to increase from 32 million tonnes K_2O in 1980 to more than 46 million tonnes in 1989 (Barry, 1981). Long-term capacity forecasts take into account new mines being constructed in the Soviet Union and Italy; the new Dead Sea refinery in Jordan; the exploratory development in Brazil and at two sites in New Brunswick that could lead to the construction of new mines; the new mines being planned for Saskatchewan and Manitoba; the expansion of existing operations in Saskatchewan, East Germany and Israel; the declining capacities in the United States and France; as well as the ongoing potash industry elsewhere in the world.

World potash consumption along with world production grew at an average rate of about 6 per cent per year between 1960 and 1980. Since 1976, the demand for potash has exceeded production creating a substantial drop in inventories. Increase in consumption has occurred largely in countries such as the United States, the Soviet Union and those of Europe. It is a matter of some concern that so little of the new demand arises from developing countries. Although some countries of Asia and South and Central America have experienced high percentage growth rates in recent years, the volumes of potash involved are still relatively small. The exceptions are Brazil, India and the People's Republic of China; each consumed between a quarter of a million and a million tonnes K_2O equivalent in 1980. All three countries have the potential for becoming even larger consumers.

Figure 16 graphically illustrates 1980 regional potash consumption as a percentage of world consumption. It is obvious that Canada plays a very minor role in world potash consumption.

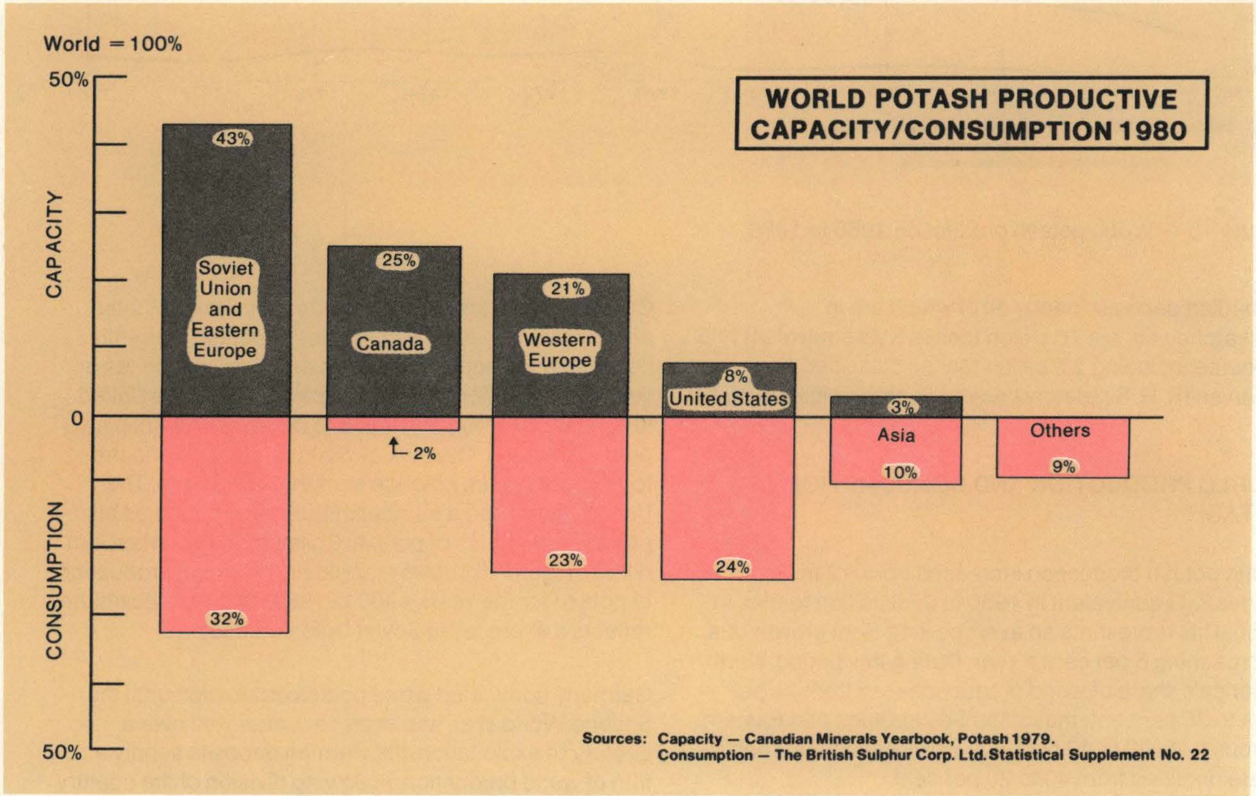


Figure 16 — 1980 potash productive capacity and consumption as a percentage of estimated world capacity and consumption

Note: capacity percentages do not show a small proportion (less than .1%) in Chile. Consumption percentages relate to 1979/80 fertilizer year; industrial potash consumption is not included.

Undoubtedly the vast developing regions of the world provide the key to the future market for potash. Growth of world demand will depend upon the degree of agricultural innovation, availability of capital, and the degree of social and political stability achieved in these countries. Earlier, overly optimistic demand forecasts failed to take into consideration the ability of developing countries to raise foreign exchange for imports, to improve rail and truck transportation, farmer education, farm credit and the state of agricultural technology.

World-wide potash fertilizer consumption in 1977 is related to cultivated area and to population in Table 4. Comparable figures for 1961-65 are also given. These statistics indicate those regions of the world with the largest potential need for potash and also those where recent increases in potash fertilizer consumption have been most significant.

In 1977, the average potash fertilizer consumption per hectare of arable land and permanent crop in Europe was close to four times the world's average and more than ten times greater than that in Africa, Asia and Oceania. North and Central America combined, and the Soviet Union both consume about a third as much potash per hectare as does Europe, although, because of lower population density, consumption per capita is comparable. Comparing potash fertilizer consumption in the early 1960s with 1977, all regions show increases, but in terms of volume the fourfold increase in the Soviet Union is the most impressive. South America increased its consumption of potash fertilizer by about 400 per cent during this period but is still below the world average relative both to cultivated area and to population.

Table 4
Potash Fertilizer Consumption Per Hectare of Arable Land and Permanent Crop, and Per Capita

		Average consumption 100 grams K_2O equivalent			
	Geographic region	per hectare of arable land and permanent crop		per capita	
		1961-65	1977	1961-65	1977
population per hectare of arable land decreases ↓	Asia*	20	50	5	10
	Europe	340	588	118	175
	South America	19	100	10	47
	Africa	7	18	4	9
	N. & C. America	105	210	95	159
	Soviet Union	50	232	51	209
	Oceania	38	53	80	113
	World	75	159	33	57

* includes an estimate for China

Source: 1978 FAO Fertilizer Yearbook, Table 12, Food and Agriculture Organization of the United Nations

SASKATCHEWAN PRODUCTION AND SALES OF POTASH

Continuous potash production in Saskatchewan began in 1962 and reached 7.3 million tonnes K_2O equivalent per year in 1980. This is shown graphically along with design capacity in Figure 17. The rapid expansion of the potash industry between 1967 and 1970 followed by seven years of production well below capacity can be seen on this graph. Since 1977 the mines have been producing at more than 80 per cent of their total designed or name-plate capacity. By 1979, expansion at K-2, Cory (Phase I) and Rocanville (Phase I) had increased total design capacity from 7.40 to 7.89 million tonnes. Completion of current expansion projects at Lanigan (Phases I and II), Rocanville (Phase II), Allan (Phase I), Cominco, Kalium and P.C.A. will provide additional capacity of approximately 2.23 million tonnes K_2O equivalent (about 3.7 million tonnes KCl product) by 1983. This will increase design capacity to more than 10 million tonnes K_2O equivalent (see Table 2). The Bredenbury mine is expected to produce 2 million tonnes of potash (K_2O) annually (3.27 million tonnes KCl product). If plans proceed as scheduled the plant will open in the fall of 1986.

Saskatchewan potash is marketed as the muriate. Annual sales from 1962 to 1980 are shown in Figure 18.

The United States has been by far the largest consumer of Saskatchewan potash accounting for 64 per cent of total sales in 1980. Shipments offshore made up 31 per cent, with the remaining 5 per cent sold within Canada, chiefly to Southern Ontario and Quebec. In offshore markets the largest buyer was Brazil, purchasing nearly 7 per cent. Other major importing countries were Japan (5.5 per cent), India (4 per cent) the People's Republic of China (3.5 per cent) and South Korea (2 per cent). Destination and tonnage of these shipments are illustrated in Figure 19.

Sales in 1980 totalled 7.13 million tonnes K_2O equivalent: the coarse grade made up about 40 per cent of sales; granular and standard grades each about 25 per cent; soluble 9 per cent, and chemical 1 per cent.

Saskatchewan continues to increase its share of the United States market. Canadian producers supplied 74 per cent of this market in 1980 compared to 59 per cent in 1972. Offshore, the logistics of potash movement favour Canada in the Pacific rim countries and the Saskatchewan industry continues to strengthen its position there. The People's Republic of China is a market of large potential. Most countries in South America and the Caribbean are less accessible but are nonetheless potential markets for Saskatchewan potash, as demonstrated by the substantial shipments to Brazil.

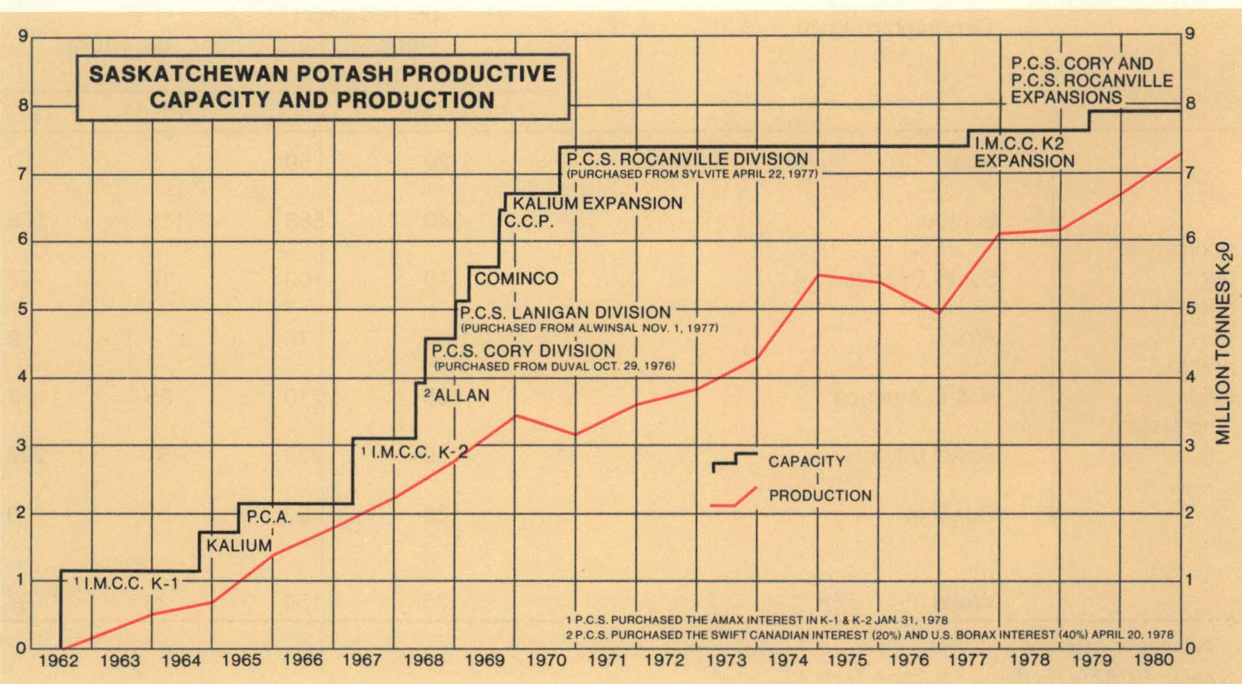


Figure 17 — Production and productive capacity of the Saskatchewan potash industry 1962 to 1980 (updated from Figure 14 Saskatchewan Mineral Resources Annual Report 1979-80. Abbreviations explained on Figure 9)

Note: capacity steps represent design capacity of new or expanded mine.

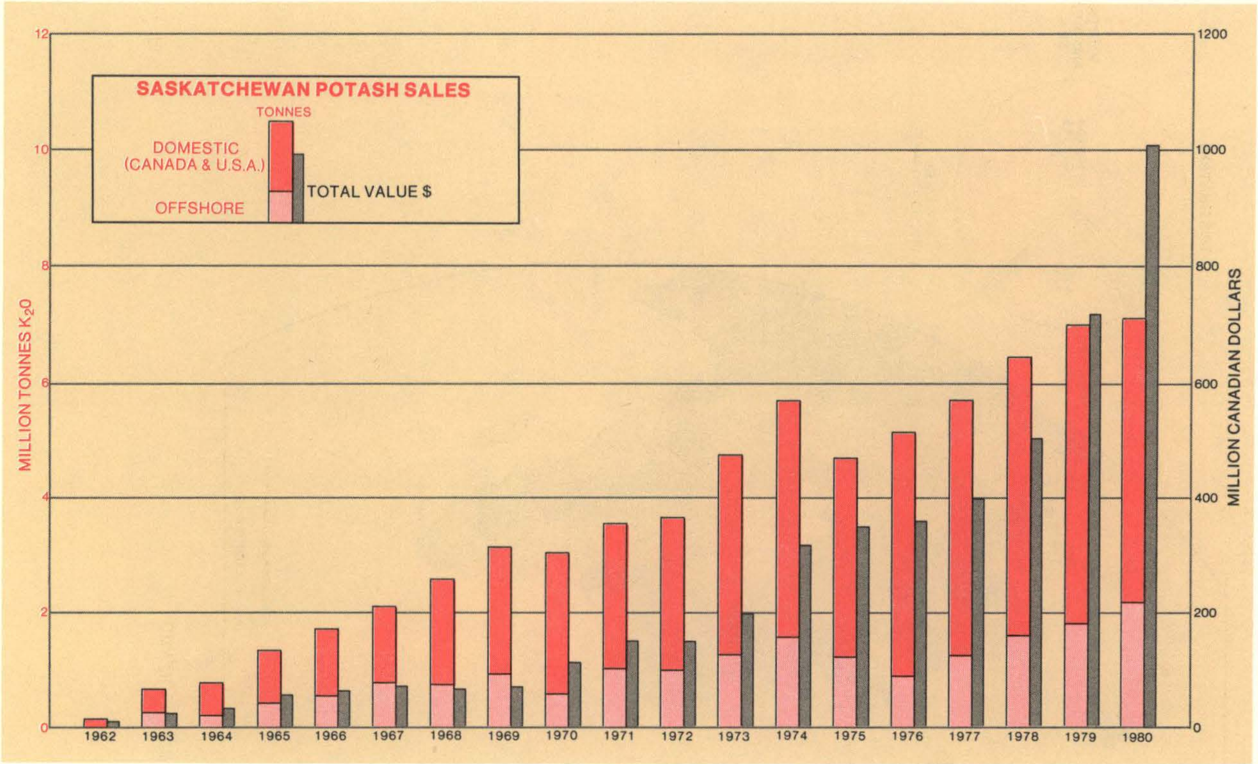


Figure 18 — Annual sales by the Saskatchewan potash industry 1962 to 1980 (updated and redrawn from Figure 13 Saskatchewan Mineral Resources Annual Report 1979-80.)

POTASH AND THE GOVERNMENT

The Saskatchewan potash industry expanded rapidly during the 1960s leading to oversupply and disruption of established trade patterns. Seven new mines came on stream between April 1967 and September 1970 raising productive capacity to 7.4 million tonnes K_2O equivalent or nearly half the world's consumption at that time. The Soviet Union also added significantly to productive capacity during the 1960s.

Earlier forecasts of a dramatic increase in potash consumption as a reflection of the increasing demand for food were not realized, and sales lagged far behind capacity thus creating cash flow problems for the potash companies in Saskatchewan. About $675 million had been invested in the new mines, a large part of it in shaft sinking. The mines were highly mechanized with advanced technology in the processing systems and operating at less than full capacity increased unit costs.

Intense price competition among the companies resulted and the average price per tonne K_2O equivalent fell from $41.37 f.o.b. mine in 1965 to $21.90 in 1969. Sales that year were only 3.2 million tonnes K_2O equivalent representing less than 50 per cent productive capacity.

Some layoffs occurred as the industry adjusted and there were fears that some mines faced bankruptcy and closure, thus creating more unemployment and revenue loss to the province.

The drastic price cuts affected other world potash producers, particularly those in the United States. Low-priced imports resulted in production cutbacks, layoffs and a depressed local economy in New Mexico where the industry is concentrated. This led to charges that potash was being 'dumped' in the United States. Action was initiated in Congress to impose quotas and tariffs on imported potash.

On January 1, 1970, prorationing of potash production to market demand was introduced by the Saskatchewan government as a means of stabilizing the production and price of potash in Saskatchewan. Production was limited to around 40 per cent of productive capacity and a floor price of $33.75 per short ton ($37.20 per tonne) K_2O equivalent was established. This in effect shared the available market among all Saskatchewan producers and brought an end to price cutting.

An immediate result of prorationing was an increase in revenue to the industry from potash sales (although production was to remain stagnant for several years). Sales valued at $69 million for 3.2 million tonnes K_2O equivalent in 1969 rose to $116 million for 3.1 million tonnes in 1970, the first year of the program.

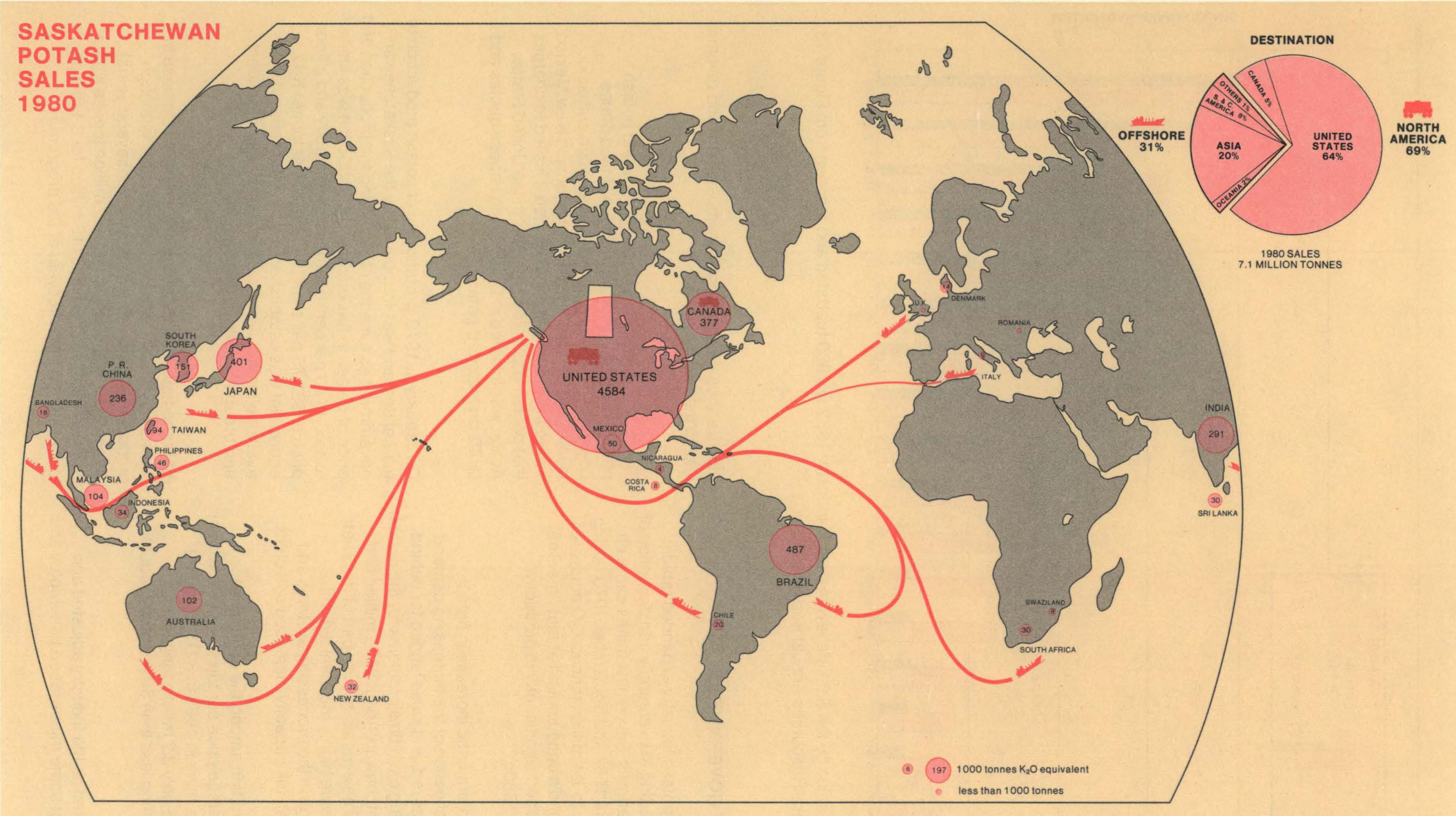


Figure 19 — Destination and tonnage of Saskatchewan potash sales 1980 (sales and destinations, Saskatchewan Mineral Resources; routes diagrammatic after Canpotex)

As a result of prorationing the Saskatchewan mines became viable operations, employment stabilized and, with the improvement in the industry's financial position, royalties and taxes payable to the province were increased. The United States relaxed its effort to restrict potash imports from Saskatchewan, anti-dumping action was forestalled, and the industry in New Mexico revived. Producers around the world generally accepted the minimum price established in Saskatchewan as the basis for world potash pricing and the market stabilized.

However, the shortfall caused by the withdrawal from the market of some three million tonnes K_2O equivalent per annum was taken up by increased production in other parts of the world. In 1971-72, the potash industry was operating at 48 per cent capacity in Saskatchewan but 89 per cent in the United States and 82 per cent in Western Europe. Initially, all Saskatchewan producers supported prorationing, including payment of a proration fee. But company affiliation gave Central Canada Potash a guaranteed market for all its production and when this marketing ability was not considered in the revised 1972 prorationing formula, the company challenged the constitutionality of the potash conservation regulations, claiming damages for lost markets. The federal government joined the suit against Saskatchewan. The floor price and production limits were suspended in August 1974 (owing to the accelerated demand for Saskatchewan potash); the litigation remained before the courts.

With the industry prospering and firmly established, the Saskatchewan government developed a new potash policy in the belief that the province and its people were entitled to a fair share of benefits from potash production. Its objectives were to increase revenues, to encourage expansion, and to ensure a degree of public ownership in the expanded industry. Accordingly, a new reserve tax was formulated (inversely related to capital investment), and a Crown corporation was created. The Potash Corporation of Saskatchewan was created by an order in council on February 4th, 1975 with a mandate to develop mines and undertake joint ventures.

The potash reserve tax regulations were passed by order in council in November 1974. The producers resented the new tax claiming it was too high. The tax formula

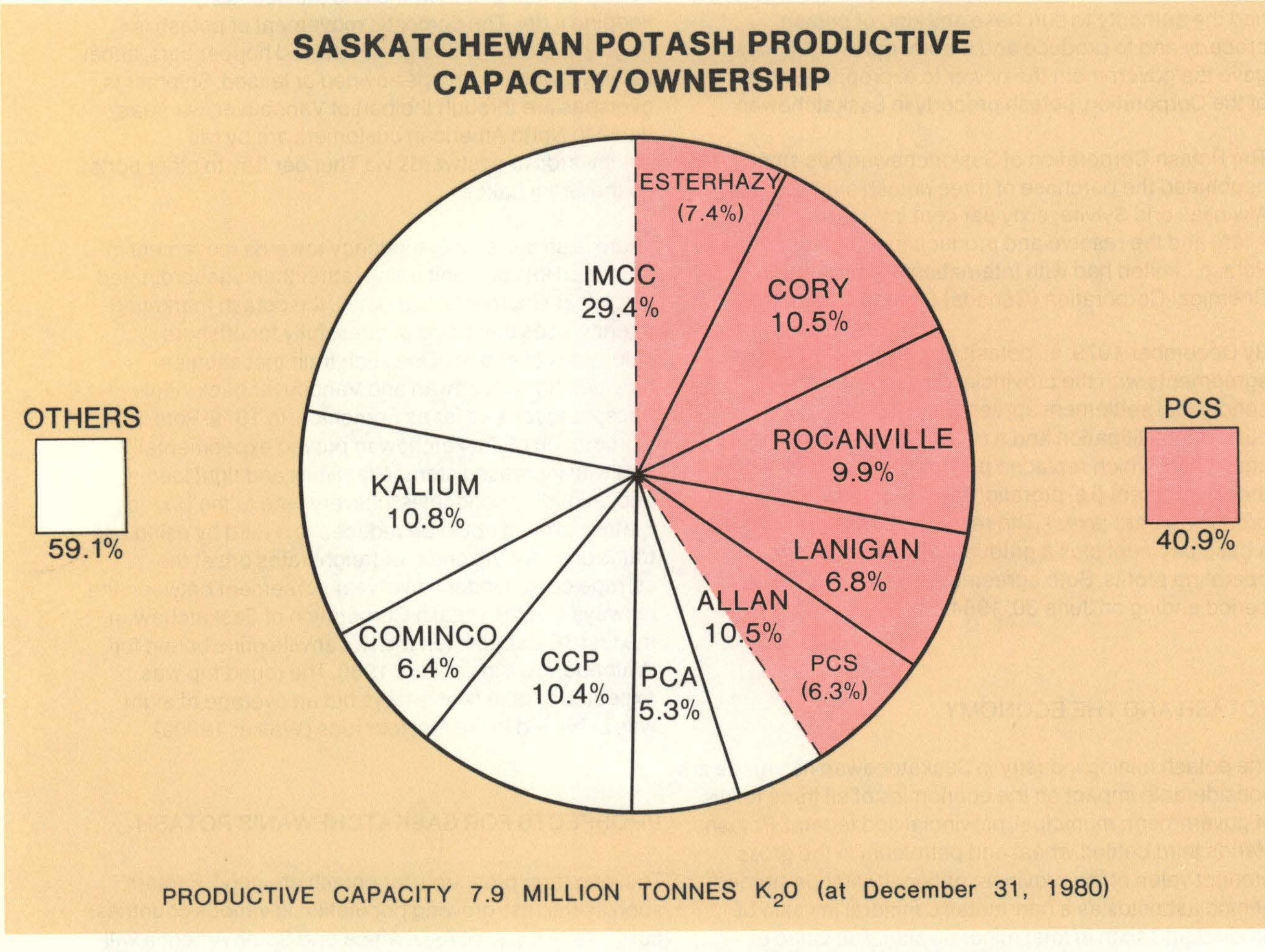


Figure 20 — Ownership of productive capacity as a percentage of total annual productive capacity of the Saskatchewan potash industry (updated and redrawn from Figure 15 Saskatchewan Mineral Resources Annual Report 1978-79)

included a number of factors; annual capacity and production, ore grade, average selling price, and capital investment. Difficulties arose in acquiring data on which not only to assess the tax but also to ensure a fair tax. The situation was aggravated by the concurrent action of the federal government in declaring provincial mining taxes and royalties non-deductible for federal income tax purposes. In June 1975 most of the potash companies jointly challenged the constitutional validity of the reserve tax in the courts and withheld provincial taxes. A similar action was taken in October 1975 in respect of proration fees.

An adversary relationship between government and industry developed that was not conducive to joint ventures, and producers stalled on their own expansion plans. Seeing the future of the potash industry in trouble the government concluded that the only way to properly manage the resource was to own approximately fifty per cent of the industry. It was announced in the Throne Speech on November 12th, 1975 that effective control of the potash industry would be acquired through public ownership.

In January 1976, with the enactment of Bill 1 (The Potash Development Act, 1976) and Bill 2 (The Potash Corporation of Saskatchewan Act, 1976) the Corporation had the authority to purchase any kind of potash property and to produce and market potash. Bill 1 also gave the government the power to expropriate, on behalf of the Corporation, potash property in Saskatchewan.

The Potash Corporation of Saskatchewan has since negotiated the purchase of three potash mines: Duval; Alwinsal; and Sylvite; sixty per cent interest in a fourth, Allan; and the reserve and production agreement Amax Potash Limited had with International Minerals and Chemical Corporation (Canada) Limited (Figure 20).

By December 1979, all potash companies had signed agreements with the provincial government: a conditional settlement agreement which set aside outstanding litigation and a potash resource payment agreement which replaced previous taxes collected by the government (i.e. proration fees, reserve taxes and producing tract taxes). The resource payments consist of a base payment plus a graduated payment based on operating profits. Both agreements were for a five-year period ending on June 30, 1984.

POTASH AND THE ECONOMY

The potash mining industry in Saskatchewan has made a considerable impact on the economies of all three levels of government: municipal, provincial and federal. Potash stands third behind wheat and petroleum in the gross product value of the province; nationally stands second behind asbestos as a non-metallic mineral in value of product and sixth in total mineral value. The value of potash sales for the years 1962 to 1980 can be seen in Figure 18. In 1980, sales were worth just over $1 billion; provincial revenues from potash royalties and resource payments amounted to $280 million, and approximately 4,050 people were directly employed in the industry.

Communities in the vicinity of a mine benefit through the construction of new schools, new housing, new and improved public service, and new potash-related jobs. The involvement of the potash company in community life can also add to its vitality. An example is Esterhazy, a town of just over 3,000 people near IMCC's K-1 and K-2 mines. Company employees live in communities within 80 kilometres of the mine but mostly in Esterhazy, and in addition there are 158 jobs in the town servicing the potash company of which 120 are in transport. Potash is trucked to Northgate on the international border where it is transferred to railcars for shipment into the United States (Cashman, 1979).

The railways have made a significant investment in the potash industry in the form of spur lines, track improvements, and hopper cars. In return, they receive substantial revenues from the transport of potash. Problems associated with the transport and storage of a high-volume, low-cost, heavy, slightly corrosive, product, such as potash, are great and are aggravated by the seasonal nature of demand and the necessity for keeping it dry. The domestic movement of potash is largely in specially designed covered hopper cars, either railway-owned or shipper-owned or leased. Shipments overseas are through the port of Vancouver, whereas those to North American customers are by rail southwards or eastwards via Thunder Bay to other ports on the Great Lakes.

There is an increasing tendency towards movement in train-load lots and unit trains rather than uncoordinated single car shipments. Canpotex, the potash marketing agency, uses unit trains successfully for offshore shipments of potash. One such train that shuttles between Saskatchewan and Vancouver back-hauls phosphate rock as far as Edmonton. In 1979, Potash Corporation of Saskatchewan proved experimentally that with increased storage facilities and tight loading and unloading schedules, delivery time to the United States cornbelt could be reduced to a third by using unit trains and that the cheaper freight rates offset the storage costs. Under a five-year agreement between the railways and the Potash Corporation of Saskatchewan the first 78-car train left the Rocanville mine bound for Waterloo, Iowa in January 1980. The round trip was expected to take twelve days but an average of eight was achieved in the first four runs (Walker 1980a).

PROSPECTS FOR SASKATCHEWAN'S POTASH

The long term prospects for potash are good. Factors such as the fast-growing population in various countries, particularly those of Asia, Africa and South America will call for more extensive agricultural programs involving greater use of potash to increase food production. On the other hand, there is concern that the worldwide energy shortage and the resulting increase in farming costs and fertilizer prices will reduce demand in the developed countries and that they, like the countries of the Third World, will have difficulty in finding money to spend on potash.

The future of the western Canadian potash industry is promising. Announced expansions will be completed by 1983 and there is the likelihood of a new mine in the Bredenbury area in the mid-eighties. Some of the existing conventional mines have the capability for further expansion both underground and in the processing plant; limiting factors are hoisting capacity and plant size. Extraction on a second, or even third level, or additional shafts are other options that may prove more economically attractive than a new mine. Many of the constraints that must be considered for a conventional mine do not apply to solution mining and, in addition, a smaller area is required in that a solution cavern can involve all potash beds in one locality. Factors of primary importance are control of brine quality, cavern shape and energy costs.

New, more intensive, mining methods, such as long-wall extraction, new products, new markets and new waste disposal systems are future possibilities. The Potash Corporation of Saskatchewan (PCS) is studying the possibility of utilizing the province's sodium sulphate to produce sulphate of potash, an alternative to muriate for fertilizer use, as well as other potassium chemicals and byproducts. Certainly the closest and perhaps an undeveloped market for potash is Saskatchewan itself and at the University of Saskatchewan, in a three-year soil research project funded by PCS, the agricultural and silvicultural use of potash in this province will be investigated.

Exports of potash from the Soviet Union may in the future alter established market patterns. The two exploratory shafts in New Brunswick, exploration in Newfoundland and Cape Breton, the possible development of deposits in Manitoba and of a new mine in Brazil, are among other factors which may affect the industry in Saskatchewan. But this province, with nearly half the world's known potash resources (probably the largest high-grade deposits in the world), its favourable location with respect to the mid-western United States and established Pacific rim markets and the developing market in the People's Republic of China, and with an established and experienced industry, has a marked advantage over other potash regions.

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APPENDIX

POTASH MINES IN SASKATCHEWAN

Listed by company in the historical order in which they, or their immediate forerunners, first explored for potash in Saskatchewan. (See also Figure 10).

1. PCA
2. PSC CORY
3. IMCC K-1 & K-2
4. ALLAN
5. PCS LANIGAN
6. CCP
7. KALIUM
8. PCS ROCANVILLE
9. COMINCO

1.

PCA	Shaft No. 1	Lsd 6-16-36-3w3
	Shaft No. 2	Lsd 11-9-36-3w3
	Producing Member: Patience Lake.	

Potash Company of America (a Division of Ideal Basic Industries Inc.)

Potash Company of America was the first of the producers from New Mexico to explore for potash in Saskatchewan. By the end of 1953 the company had selected an area 20 kilometres east of Saskatoon and the following year started preparations for shaft sinking near the south end of Patience Lake. A refrigeration system was installed to freeze the water-bearing formations and by 1956 shaft sinking had begun. The shaft was completed in 1958 and production of potash from the 1016 metre (3,333 foot) level began in November 1958, with the first shipment of muriate being made in March 1959. The mine continued to operate until November 1959, when production was suspended due to seepage of water into the shaft. A program of grouting and shaft repairs was completed in 1962. After rehabilitation of the underground workings and the installation of new milling equipment, the mine recommenced production in the spring of 1965. A second shaft was completed 950 metres (3,120 feet) south of the first in March 1969. It is presently used for ventilation and safety purposes but is designed for production should conditions warrant a second mill and refinery. The present plant has an annual capacity of about 690 000 tonnes (760,000 short tons) KCl product which with upgrading and the installation of additional equipment in the mill will reportedly be expanded to about 1 million tonnes (1.15 million short tons) by 1982 at a cost of about $30 million.

Potash Company of America is also developing a potash mine in New Brunswick.

2.

PCS CORY	Shaft No. 1	Lsd 11-18-36-6w3
	Shaft No. 2	Lsd 6-18-36-6w3
	Producing Member: Patience Lake.	

Potash Corporation of Saskatchewan Mining Limited, Cory Division (formerly Duval Corporation of Canada)

In November 1954 Duval Sulphur & Potash Company, another of the potash producers from Carlsbad, New Mexico, was granted a six-month exploration licence to drill for potash in four areas of the province. An area due west of Saskatoon where nine exploratory holes had been drilled was eventually taken to lease in April 1964 and the following year the project got under way at a site 13 kilometres west-southwest of the city. Shaft sinking followed the established technique of freezing to penetrate the Mannville Group* and other water-bearing zones above it. Tubbing was used through the Mannville but the thinner zones below were sealed by grouting. Two shafts 260 metres (850 feet) apart were completed and production from the potash bed at a depth of 1010 metres (3,315 feet) began during 1968. Duval was the first potash mine to be acquired by the Potash Corporation of Saskatchewan. It was purchased on October 29, 1976, for $128.5 million. Renamed Cory, after a nearby railway point, it has been upgraded and expanded. The speed of the hoist has been doubled, underground storage capacity increased and a fifth mining machine acquired. Travel distance to the working face, previously 6.5 kilometres from the shaft, has been shortened by breaking a new underground entry and a new centrifuge has been installed in the mill. The annual capacity has been increased from 1.09 to 1.36 million tonnes (1.2 to 1.5 million short tons) KCl product. A potassium sulphate pilot plant is being built at the Cory mine.

*Formerly known as the Blairmore Formation.

3.

IMCC K-1 & K-2	K-1	Lsd 1-24-20-33w1
	K-2	Lsd 7-27-19-32w1
	Producing Member: Esterhazy.	

International Minerals and Chemical Corporation (Canada) Limited

International Minerals and Chemical Corporation (Canada) Limited is a wholly-owned subsidiary of International Minerals and Chemical Corporation, the western world's largest producer of chemical fertilizer and fertilizer materials and the owner of one of the Carlsbad potash mines. In 1955, under its former name Canadian Flint and Spar Company, it participated with Tidewater Oil Company, in an oil-potash test on the eastern side of the province. Rich potash ore was indicated and, after further testing, a shaft was begun in the spring of 1957 at a site near Yarbo, 14 kilometres northeast of Esterhazy. After overcoming a number of shaft-sinking problems by freezing and new tubbing techniques introduced from Europe, the potash deposit was reached at a depth of 954.6 metres (3,132 feet) in June 1962. Since that time this mine has been in continuous operation. Production increased rapidly in the first few years and in 1965 hoisting capability was expanded to the annual equivalent of 1.8 million tonnes (2 million short tons). In 1967 heavy media separation was installed in the plant.

A second shaft, named K-2 by the company, was begun in 1964 and completed in 1967 at a location near Gerald, 10 kilometres southeast of the original K-1 shaft. The two mines are connected underground. Additional capacity at K-2 was provided by a new heavy media circuit that came on stream in 1976 in spite of a destructive fire the previous year. The mine was closed for part of 1976 because of high inventories.

In 1971, IMCC contracted to mine and process potash for 40 years for Amax Potash Limited, a U.S. company to whom it had sold some of its reserves. Some seven years later, on January 31, 1978, Amax sold these reserves, and the long-term production agreement with IMCC, to the Potash Corporation of Saskatchewan for $85 million. The current contract, for 0.95 million tonnes (1.05 million short tons) KCl, represents 25 per cent of IMCC's annual productive capacity. At present, the productive capacity of the K-1 and K-2 mines is reported to total 3.8 million tonnes (4.2 million short tons) KCl product. International Minerals and Chemical Corporation sold its potash property in New Brunswick to Denison Mines Limited early in 1979 and has since announced plans to increase compacting capacity at the K-2 mine by 272 000 tonnes (300,000 short tons) per year and to purchase another continuous mining machine. The development of potash deposits near St. Lazare in Manitoba is being considered.

4.

ALLAN	Shaft Nos. 1 & 2	Lsd 5-22-34-1w3
	Producing Member: Patience Lake.	

Allan Potash Mines, jointly owned by Potash Corporation of Saskatchewan and Texasgulf Potash Company; operated by Potash Corporation of Saskatchewan Mining Limited, Allan Division

United States Potash Company, another Carlsbad potash producer, began exploratory drilling in Saskatchewan in 1955. The company merged with Pacific Coast Borax Company in 1957 to form United States Borax and Chemical Corporation, a subsidiary of the British mining company Rio Tinto Zinc Corporation Limited. Exploration in the province continued, but in 1960 difficulties encountered by other potash companies caused U.S. Borax to defer its program and its Saskatchewan office was closed. However, prospects improved and Allan Potash Mines, a partnership of U.S. Borax (40%), Homestake Potash Company (40%) and Swift Canadian Company (20%) was formed to develop the property at Allan. The site is 45 kilometres east-southeast of Saskatoon, where 16 test holes had been drilled. The simultaneous sinking of two shafts 150 metres (500 feet) apart was begun in the spring of 1964 through ground previously frozen to a depth of 640 metres (2,100 feet). The shafts were lined with concrete and cast-iron tubbing was used through the Mannville. The company experienced particular difficulties in the No. 1 shaft by flooding from this formation and to prevent delay, it was decided to convert the No. 2 shaft to production instead of service as was originally intended. This was completed to 1128 metres (3,700 feet) in 1967, to be followed by shaft No. 1 in early 1968. The first ore was hoisted soon afterwards from the 1036 metre (3,400 foot) level. Design capacity at the mill is 1.36 million tonnes (1.5 million short tons) KCl product a year.

Texasgulf Potash Company acquired its 40 per cent interest in the Allan mine from Homestake in 1969 and effective January 1, 1970, a new company APM Operators Ltd. was incorporated to operate the mine. The Potash Corporation of Saskatchewan purchased its 60 per cent share in Allan Potash Mines from United States Borax and Chemical Corporation and Swift Canadian Company Limited on April 20, 1978, for $85.8 million. PCS also acquired the option to purchase control of APM Operators which it exercised in 1980. Annual capacity will be expanded to 1.59 million tonnes (1.75 million short tons) KCl product during 1981 by removal of bottlenecks at the surface and underground.

5.

PCS LANIGAN	Shaft No. 1	Lsd 4-28-33-23w2
	Shaft No. 2	Lsd 3-28-33-23w2
	Producing Member: Patience Lake.	

Potash Corporation of Saskatchewan Mining Limited, Lanigan Division (formerly Alwinsal Potash of Canada Limited)

An area around Lanigan was one of four withdrawn for exploration in 1956 by Winsal of Canada Limited, a company representing West German potash interests. A French potash company operating in Alsace also became involved, and in 1959 Alwinsal Potash of Canada Limited was formed to explore and develop potash deposits in Saskatchewan. In 1964, the company announced plans to go ahead with development at its property near Lanigan, where it had drilled 18 exploratory wells, including 3 shaft pilot holes. A site just south of the village of Guernsey had been chosen; the target was a potash bed some 1006 metres (3,300 feet) below the surface. A single shaft, wide enough for two hoists, was constructed with double welded steel cylinders interfilled with high strength concrete to provide water-tight protection through the Mannville and lower water-bearing formations. Although more costly than tubbing, the solid double-steel lining has proven satisfactory. Alwinsal came into production late in 1968 with a capacity of 0.9 million tonnes (1 million short tons) KCl product. The mine was purchased by the Potash Corporation of Saskatchewan on November 1, 1977, for $76.5 million. It was shut down for six months in 1978 while mining equipment was reclaimed and upgraded, underground storage increased and on the surface, standby fuel systems installed. This was part of an expansion project (Phase I) that with extensive modifications to the milling circuits will increase capacity to 1 million tonnes (1.1 million short tons) KCl by mid-1981. The sinking of a second shaft, already under way at the time of purchase, was completed in April 1979, and is intended for men and materials. By taking advantage of the two production hoists in the No. 1 shaft and with new surface facilities the Lanigan property will be able to triple its capacity.

A $430 million expansion project (Phase II) was announced in October 1980, involving ten new mining machines, a new refinery building, additional product storage, and a new rail loading facility. Two new mining blocks will be opened up underground and the hoist speed doubled. The project is scheduled for completion in 1983, increasing capacity to 2.9 million tonnes (3.2 million short tons) KCl product.

6.

CCP	Shaft No. 1	Lsd 9-21-34-27w2
	Shaft No. 2	Lsd 16-21-34-27w2
	Producing Member: Patience Lake.	

Central Canada Potash (a Division of Noranda Metal Industries Limited); formerly partly owned (49%) by C.F. Industries Inc.

In 1965 Noranda Mines Limited announced plans to develop a potash mine and mill on their property in the Viscount-Colonsay area, about 70 kilometres east-southeast of Saskatoon. Central Farmers Fertilizer Company of Chicago, one of the largest fertilizer distributors in the United States, had agreed to purchase most of the muriate produced and also held an option to acquire a 49 per cent interest in the project. First drilled by Duval in 1955, this property had been acquired by Noranda from Consolidated Morrison Exploration Ltd. who had been exploring here since 1959. A number of test holes and a shaft pilot hole had been drilled. Twin shafts 134 metres (440 feet) apart were sunk during 1965 on a site nine kilometres southeast of Colonsay, to reach the potash ore at 1021 metres (3,350 feet). Freezing and tubbing were employed through the Mannville and Devonian water-bearing zones. Shaft sinking was completed by early 1969 and production started later that year. In June 1970, Central Farmers (C.F. Industries Inc.) exercised its option and acquired a 49 per cent interest in the company newly formed to operate the mine, Central Canada Potash Co. Limited. In 1976 the hoist speed of the production shaft was doubled and new drying and compacting equipment installed. The plant has a rated capacity of 1.36 million tonnes (1.5 million short tons) KCl product per annum.

C.F. Industries sold its interest in the mine to Noranda late in 1978 and by amalgamation on January 31st, 1979 Central Canada Potash became a division of Noranda Metal Industries Limited (a wholly-owned subsidiary of Noranda Mines Limited).

7.

KALIUM Plant SE¼ Sec 14-17-24w2

Kalium Chemicals Limited (a Division of PPG Industries Canada Ltd.)

Standard Chemical Limited entered the potash field early in 1960 and initiated an experimental solution mining operation near Belle Plaine, between Regina and Moose Jaw, where the potash beds are about 1600 metres (5,300 feet) below the surface. After about two years this operation proved to the satisfaction of the participants in the venture, Pittsburgh Plate Glass Company (now PPG Industries Inc.) and Armour Industrial Chemical Company, that solution mining of potash was feasible and economical. Kalium Chemicals Limited, the new company formed to take over the operations of Standard Chemical Limited, started construction of a potash plant near Belle Plaine in May 1963. The plant began production on schedule early in October 1964 with an initial capacity of 540 000 tonnes (600,000 short tons) of product annually. An expansion program begun in 1968 has increased capacity to its present level of 1.36 million tonnes (1.5 million short tons) KCl product a year. In 1971, PPG Industries obtained Armour's 50 per cent interest in Kalium. Further expansion was announced in July 1980 under the terms of the Potash Resource Payment Agreement. Reportedly more than $20 million will be spent on replacing equipment and an additional turbine generator. This expansion should be completed by the end of 1981.

8.

PCS ROCANVILLE Shaft No. 1 Lsd 13-22-17-30w1
Shaft No. 2 Lsd 12-22-17-30w1
Producing member: Esterhazy

Potash Corporation of Saskatchewan Mining Limited, Rocanville Division (formerly Sylvite of Canada Division of Hudson Bay Mining and Smelting Co. Ltd.)

In the spring of 1959 Tombill Mines Limited, a former Canadian gold producer, took an option on S.A.M. Exploration Limited's property straddling the Saskatchewan-Manitoba border and in March 1960 took out a permit in the Ste. Marthe-Rocanville area of Saskatchewan (T17 R30w1) where high-grade potash with a thick salt-back had been penetrated. In 1966, after 13 test holes and encouraging preliminary engineering studies, Tombill combined with Francana Oil and Gas Ltd. to form a new development company, Sylvite of Canada Ltd., and the property was taken to lease. Sylvite later became a division of Hudson Bay Mining and Smelting. Twin shafts located 157 metres (515 feet) apart were sunk in 1968 to reach potash ore at a depth of 960 metres (3,150 feet). Prior to excavation the surrounding rock formations had been frozen to a depth of about 457 metres (1,500 feet). Several lining techniques were used in the shaft: single sheet steel lining in the glacial till; cast-iron tubbing in the Mannville and other major water-bearing zones; conventional concrete lining in the rest of the shaft above the salt, and a combination of concrete and polyurethane in the more plastic salt section to prevent rupture of the concrete under pressure. Sylvite began production in September 1970 with a design capacity of 1.1 million tonnes (1.2 million short tons) KCl product annually. In July 1975 a fire damaged the production headframe and electrical installations, and production was suspended for about three months.

The Rocanville mine was purchased by the Potash Corporation of Saskatchewan for $144 million on April 22, 1977. By mid-1979, with hoist speed doubled, ore and product storage increased, a fourth compactor installed, its capacity had been increased to 1.27 million tonnes (1.4 million short tons) KCl. The second phase of the expansion plan, scheduled to be completed by late 1981, will add 540 000 tonnes (600,000 short tons) to the annual productive capacity. This phase includes the acquisition of two more mining machines and an addition to the mill.

9.

COMINCO Shaft Nos. 1 & 2 Lsd 11-16-35-8w3
Producing member: Patience Lake

Cominco Ltd. (name changed from The Consolidated Mining and Smelting Company of Canada Ltd. in 1966)

The Consolidated Mining and Smelting Company of Canada Ltd., a large mining company controlled by Canadian Pacific Investments, was the first Canadian-based firm to develop a potash mine in Saskatchewan. Exploration of their potash deposits 40 kilometres southwest of Saskatoon began in 1964, confirming the existence of a bed 3 metres (10 feet) thick. Sinking of twin shafts at Vade, between Vanscoy and Delisle, was started in July 1965, and despite the fact that the Manville is thicker here than elsewhere, work was completed in 1968, well ahead of schedule. The shafts, about 150 metres (500 feet) apart, are concrete lined with cast-iron tubbing reinforcing the section through the Mannville. The potash bed was reached at a depth of 1075 metres (3,526 feet) and the mine commenced operation in January 1969. It operated satisfactorily until August 1970 when, during a routine grouting procedure in the No. 2 shaft, an aquifer was penetrated with the result that the mine was completely flooded in five days. The mine was dewatered, the equipment restored or replaced and production recommenced in September 1972. During the two-year period of closure, the plant was kept in operation and sales were maintained by the purchase of ore from the Duval mine. In 1974 a fire in the concentrator caused considerable damage and the plant was shut down for three months. The opportunity was taken to install a computerized system to handle the entire concentrating and loading operations.

The equipment required to produce the original design capacity of 1.1 million tonnes (1.2 million short tons) KCl product was never installed. Consequently the capacity of the operation has been about 0.82 million tonnes (0.9 million short tons) KCl product.

In July 1980 the department approved an expansion under the terms of the Potash Resource Payment Agreement which will increase capacity to 1.1 million tonnes (1.2 million short tons) as originally designed. This expansion will involve the construction of a second head frame over No. 2 shaft and the installation of a hoist for men and materials. The No. 1 shaft will then be used exclusively for production. These changes along with minor alterations to the plant and an additional mining machine will cost about $30 million. Expansion should be completed in 1982.