Cementing our Knowledge of Geology: Edmonton to Cadomin

Edmonton Geological Society Fieldtrip
September 17 and 18, 2016

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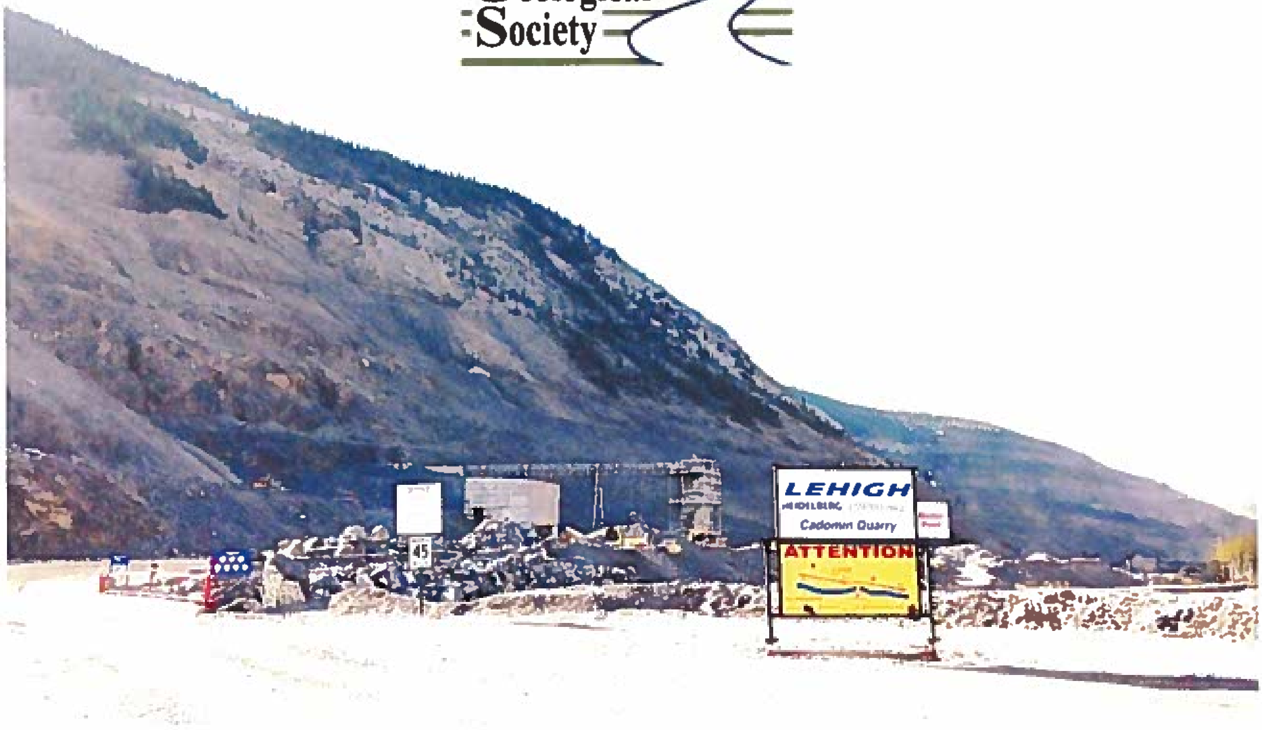
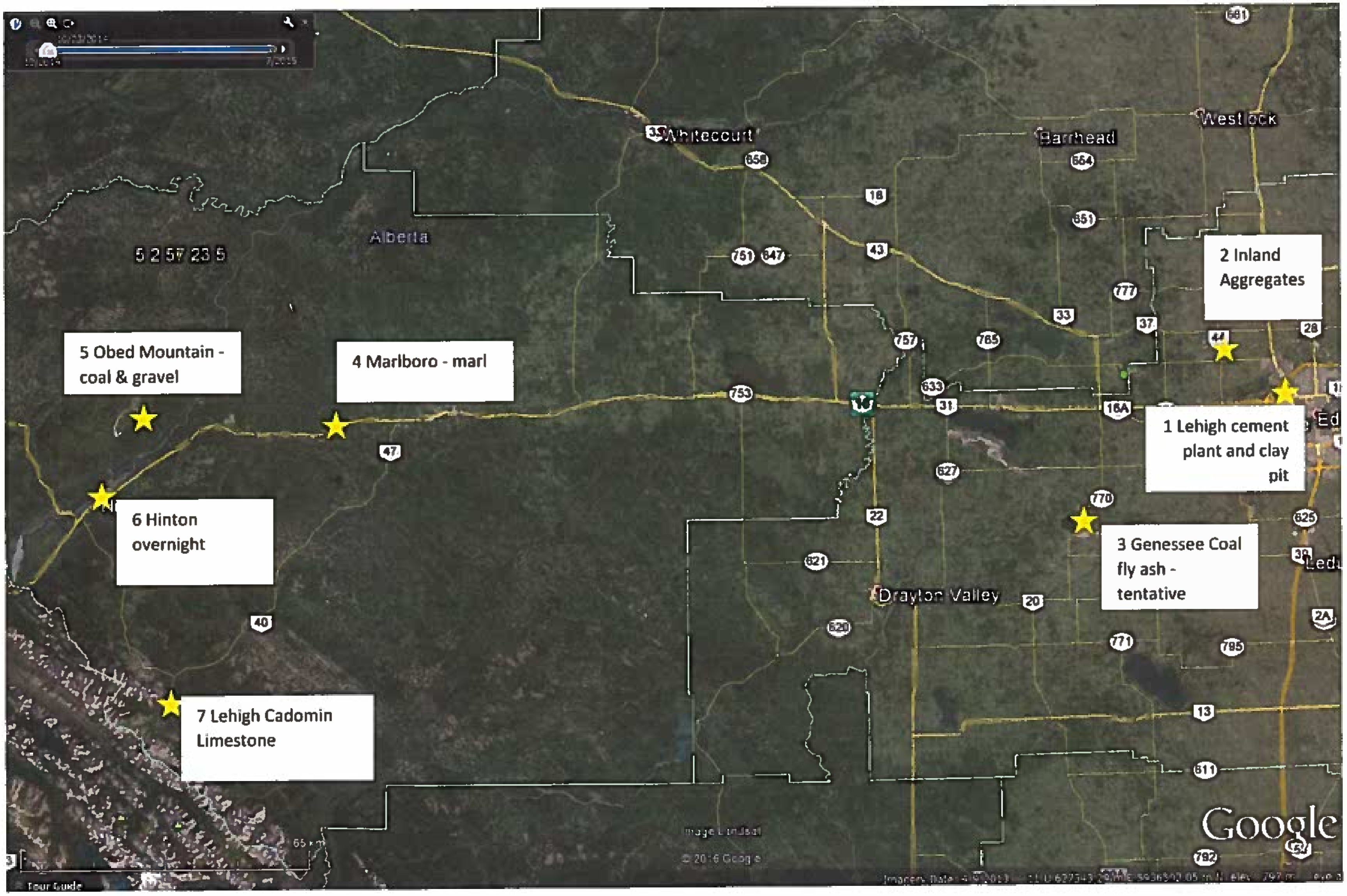
Edmonton
Geological
Society



Field Trip Stops and Points of Interest



Field Trip Stops and Points of Interest (POI)

km	Stop or POI	UTM NAD83 Coordinates
0	Stop - Lehigh Cement Plant - Edmonton	327759 m E 5939959 m N Zone 12
28	Stop – Inland Aggregates Villeneuve Gravel Pit	314524 m E 5951225m N Zone 12
99	POI – Genesee Coal Plant (fly ash)	679553 m E 5913853 m N Zone 11
305	POI - Marlboro	514042 m E 5933663 m N Zone 11
345	POI – Obed Mountain	477798 m E 5928259 m N Zone 11
367	Stop – Hinton – overnight **– START SUNDAY AT 8:00 AM**	459362 m E 5915962 m N Zone 11
425	Stop – Lehigh Cadomin Limestone Quarry	477644 m E 5872665 m N Zone 11

Locations and km are approximate

Acknowledgements

Lehigh Heidelberg Cement Group

Thank-you to the good people of Lehigh Heidelberg Cement Group for welcoming us into their facilities and sharing their knowledge about cement and concrete.

- Dan Thillman (Sales Manager, Alberta and Regional Manager, Supplementary Cementitious Materials)
- Len Broad (Cadomin Quarry Manger)
- Lee Therres (Villeneuve Pit Operations Manager)

Alberta Geological Survey

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Athabasca Minerals Inc.

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Edmonton Geological Society

Marilyn Huff, Michelle Gabereau, Matt Grobe, and Joan Waters from the executive of the EGS are thanked for providing logistical support for this field trip. Marilyn also contributed comments towards improving the field guide. Thank-you to the membership of the EGS for attending the trip.

Table of Contents

1 Purpose

This trip is meant to introduce or reintroduce attendees to the geology between Edmonton and Cadomin, Alberta, with a particular focus on the industrial minerals in cement and concrete.

2 Introduction to This Field Trip Guide

A map and list of stops and points of interest (POI) is located behind the front cover of the guide. Points of interest will be drawn to your attention as we approach and drive past them. The guide begins with some general information about cement and concrete, and the industrial minerals that form these valuable construction materials. The guide proceeds into more detailed information organized according to the list of stops and points of interest (POI) that is located behind the front cover of the guide.

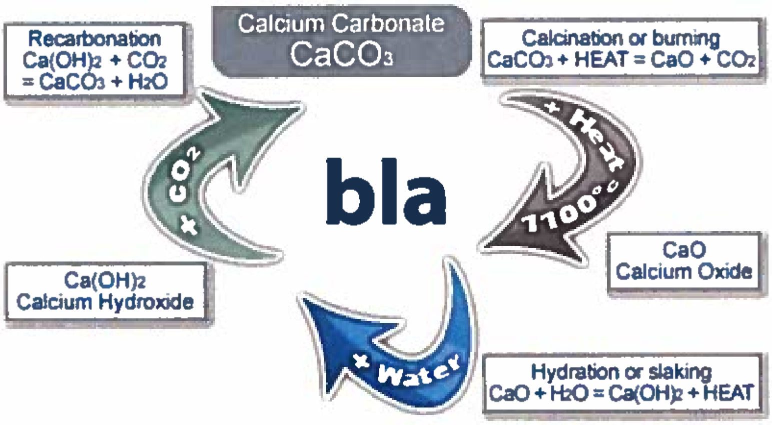
3 Background

3.1 Cement

Cement is a binding agent made with calcined lime which is mixed with other materials, including sand, gravel (aggregates) and water. When it sets and hardens, cement forms strong construction materials including mortar and concrete. Ready-mixed concrete is the dominant product containing cement. The two major categories of cement are non-hydraulic and hydraulic.[1] See a "History of Cement" in the Appendix 1.

Non-hydraulic cement must be used in dry conditions and sets and dries while reacting with carbon dioxide naturally present in air. Non-hydraulic cement is susceptible to chemical attack.

Lime Cycle



British Lime Association
https://www.google.ca/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwid6bac6vrOAhUh44MKHU6BAgkQjRwIBw&url=http%3A%2F%2Fwww.britishlime.org%2Feducation%2Flime_cycle.php&psig=AFQjCNElY8zbgup67Vxd7OZtqfr8yzUqtg&ust=1473254336235148

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[1] "Cement Made Simple" http://www.cement.ca/en/Cement-Manufacturing.html; last accessed August 29, 2016.

Hydraulic cements (e.g., Portland cement) will set in wet conditions. The cement hardens due to a chemical reaction between the dry ingredients and water that forms mineral hydrates with low solubility. Hydraulic cement is much less prone to chemical attack than non-hydraulic cement.

Portland Cement: see Appendix 2 "The Right Mix for the Job" from the Cement Association of Canada (http://www.cement.ca/en/Manufacturing/Types-of-Portland-Cement.html; last accessed August 29, 2016)

3.2 Materials for making cement:

3.2.1 Clinker

The raw materials used to produce cement are calcium carbonate, silica, alumina and iron oxide. The calcium carbonate is usually from limestone (in some cases marl) and the other components are derived from clay, shale, sand, fly ash and iron ore. The ideal "cement rock" is rarely found, but highly desirable, with the following composition:[2]

77 to 78% $CaCO_3$
14 % SiO_2,
2.5 % Al_2O_3
1.75 % Fe_2O_3
<3 % $MgCO_3$
<0.4 % Na_2O
0.3 % K_2O

Clinker is the solid material with the appropriate chemistry required for the production of cement. Clinker is ground up and mixed with gypsum and/or other materials and sold to the customer.

- **Lime or calcium oxide, CaO**: from limestone, chalk, shells, shale, or calcareous rock
    - Limestone from sedimentary rocks of marine origin is the most common source because it is relatively ubiquitous[3]
- **Silica, SiO_2:** from sand, old bottles, clay, or argillaceous rock
- **Alumina, Al_2O_3:** from bauxite, recycled aluminum, clay
- **Iron, Fe_2O_3:** from clay, iron ore, scrap iron, and fly ash
    - Flux that lowers the melting point of silica

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[2] Macfadyen, John D. "Cement and Cement Raw Materials" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).

[3] Macfadyen, John D. "Cement and Cement Raw Materials" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).

Setting Agent

- **Gypsum, $CaSO_4.2H_20$: found naturally occurring or product of flue-gas desulfurization**
    - Regulates the setting time of the cement

Compounds in Clinker	**Formula**	**Shorthand form**	**% by weight**[1]
Tricalcium aluminate	$Ca_3Al_2O_6$	C_3A	10
Tetracalcium aluminoferrite	$Ca_4Al_2Fe_2O_{10}$	C_4AF	8
Belite or dicalcium silicate	Ca_2SiO_5	C_2S	20
Alite or tricalcium silicate	Ca_3SiO_4	C_3S	55
Sodium oxide	Na_2O	N	Up to 2
Potassium oxide	K_2O	K	
Gypsum	$CaSO_4.2H_2O$	$C\underline{S}H_2$	5

[1] http://www.engr.psu.edu/ce/courses/ce584/concrete/library/construction/curing/Composition%20of%20cement.htm; last accessed September 6, 2016

Cement manufacturers adjust the quantities of cement making materials to control the compounds in the clinker and the properties of the cement.

3.2.2 Carbonates

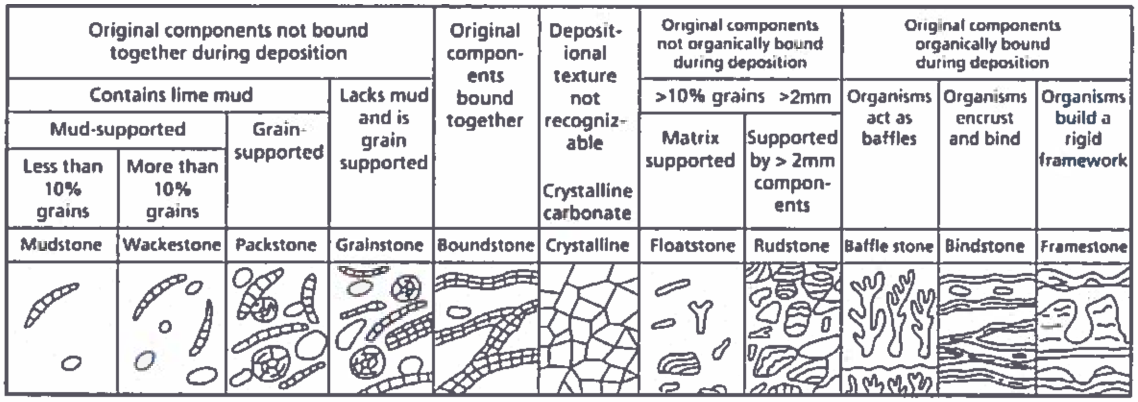
The following section is summarized from Freas et al. "Limestone and Dolomite" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).

Carbonate rocks constitute about 15% of the earth's sedimentary crust. Limestone (primarily formed of calcite) and dolomite are by far the most commonly produced carbonates for industrial purposes. Most carbonates mined are processed into cement and aggregates. Dolomite is better for aggregates as it is harder than calcite.

The colour of carbonate rocks does not correlate with mineral purity – only a small amount of impurities can dramatically affect colour. The Palliser limestone we will see at the Cadomin Quarry is generally dark grey and brown and the colour is likely a result of carbonaceous material (i.e., organics) and iron oxide.

Table 1. Physical properties of some common carbonate minerals

Mineral	Physical Properties	Common Color
Calcite ($CaCO_3$)	Hexagonal crystal system, commonly good rhombohedral cleavage. Mohs hardness, 3; specific gravity, 2.72.	Colorless or white but may be other colors because of impurities
Dolomite ($CaCO_3 \bullet MgCO_3$)	Hexagonal crystal system, commonly good rhombohedral crystals with curved faces. Mohs hardness, 3.5–4.0; specific gravity, 2.87.	White or pink
Aragonite ($CaCO_3$)	Orthorhombic crystal system. Mohs hardness 3.5–4.0; specific gravity, 2.93–2.95.	Colorless, white, or yellow, but may be other colors because of impurities
Siderite ($FeCO_3$)	Hexagonal crystal system, commonly distorted rhombohedral crystals. Mohs hardness, 3.5–4.0; specific gravity, 3.7–3.9.	Brown or black
Ankerite ($Ca2MgFe(CO_3)_4$)	Hexagonal system, commonly rhombohedral crystals. Mohs hardness, 3.5–4.0; specific gravity, 2.9.	White, pink, or gray
Magnesite ($MgCO_3$)	Hexagonal, usually in granular or earthy masses. Mohs hardness, 3.5–4.5; specific gravity, 2.96–3.1.	White or yellowish but may be other colors because of impurities.



Dunham's (1962) carbonate classification scheme with Embry & Klovan (1971) modifications. From Tucker, Maurice E., 1991: Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks, 3rd ed., p.129.

The depositional environment and postdepositional history of the carbonate sediments affects the size, shape, purity, and other economically significant characteristics of the carbonate rock deposit. This is a great topic for discussion with our field trip mates!

See Alberta Geological Survey Publication Special Report 102 for an assessment of the distribution and potential of current limestone and dolomite prospects in the Alberta Foothills and Front Ranges outside of parks, First Nations lands, and current mineral tenure areas.[4]

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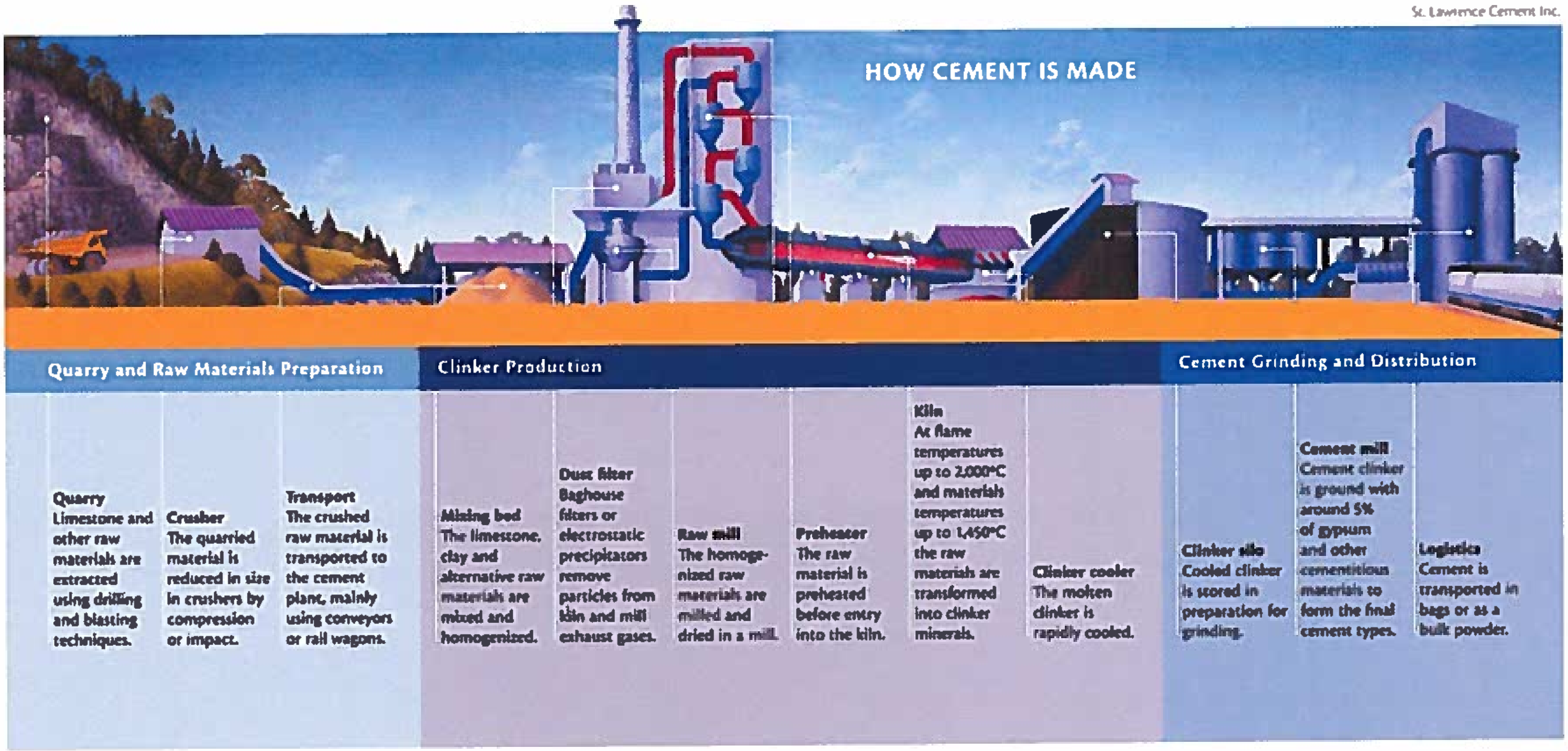
[4] Krueger, K., Kluczny, P. and Dahrouge, J. (2016): Limestone and dolomite prospects for industrial use in the Alberta Foothills and Front Ranges; Alberta Energy Regulator, AER/AGS Special Report 102, 16 p.



St. Lawrence Cement Inc.

Quarry and Raw Materials Preparation

Quarry Limestone and other raw materials are extracted using drilling and blasting techniques.

Crusher The quarried material is reduced in size in crushers by compression or impact.

Transport The crushed raw material is transported to the cement plant, mainly using conveyors or rail wagons.

Clinker Production

Mixing bed The limestone, clay and alternative raw materials are mixed and homogenized.

Dust filter Baghouse filters or electrostatic precipitators remove particles from kiln and mill exhaust gases.

Raw mill The homogenized raw materials are milled and dried in a mill.

Preheater The raw material is preheated before entry into the kiln.

Kiln At flame temperatures up to 2,000°C and materials temperatures up to 1,450°C the raw materials are transformed into clinker minerals.

Clinker cooler The molten clinker is rapidly cooled.

Cement Grinding and Distribution

Clinker silo Cooled clinker is stored in preparation for grinding.

Cement mill Cement clinker is ground with around 5% of gypsum and other cementitious materials to form the final cement types.

Logistics Cement is transported in bags or as a bulk powder.

Cement manufacturing handout: "Cement Made Simple" http://www.cement.ca/en/Cement-Manufacturing.html; last accessed August 29, 2016.

3.3 Setting of Portland Cement

The following is summarized from Michel Michaux et al. "Cement Chemistry and Additives" Schlumberger Oilfield Review Vol. 1 No. 1 (April 1989)

Aluminates and Gypsum

Aluminates react most strongly at the beginning of hydration and the reaction rate affects how the cement flows. The reaction is fast and is slowed down by using gypsum to prevent "flash set" which is the premature stiffening of the cement. The gypsum dissolves in the water releasing calcium and sulphate ions that react with the aluminate and hydroxyl ions released by the aluminates to form trisulphoaluminate hydrate (ettringite). Ettringite precipitates onto the aluminate grains and stops further hydration. Cement low in C_3A is sulfate resistant

$$2C_3A + 27H \rightarrow C_2AH_8 + C_4AH_{19} \rightarrow 2C_3AH_6\ \text{(calcium aluminate hydrate)} + 15H$$

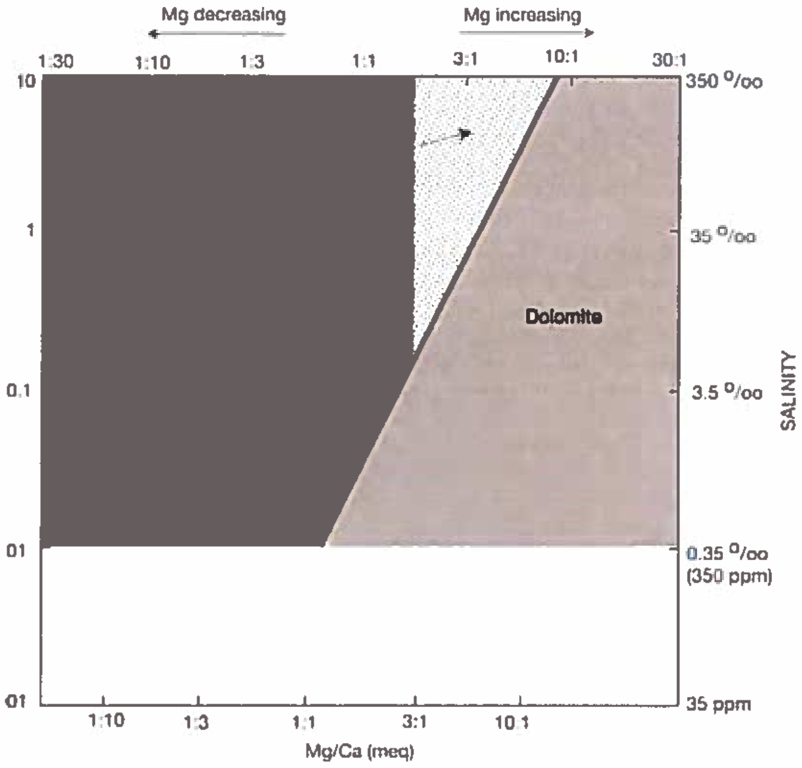


FIGURE 6.13 The preferred fields of occurrence of dolomite, calcite, magnesian-calcite, and aragonite plotted as a function of salinity and Ca/Mg ratios. Note that dolomite can putatively form at progressively smaller Mg/Ca ratios with decreasing salinity owing to slower crystallization rates and relative scarcity of competing foreign ions at low salinities. [After Folk, R. L., and L. S. Land, 1975, *Mg/Ca ratio and salinity: Two controls over crystallization of dolomite.* Am. Assoc. Petroleum Geologists Bull., v. 59, Fig. 1, p. 61, reprinted by permission.]

From Boggs, Sam, Jr. 2012, *Principles of Sedimentology and Stratigraphy*, 5th ed., Upper Saddle River, New Jersey: Pearson Prentice Hall, p. 157.

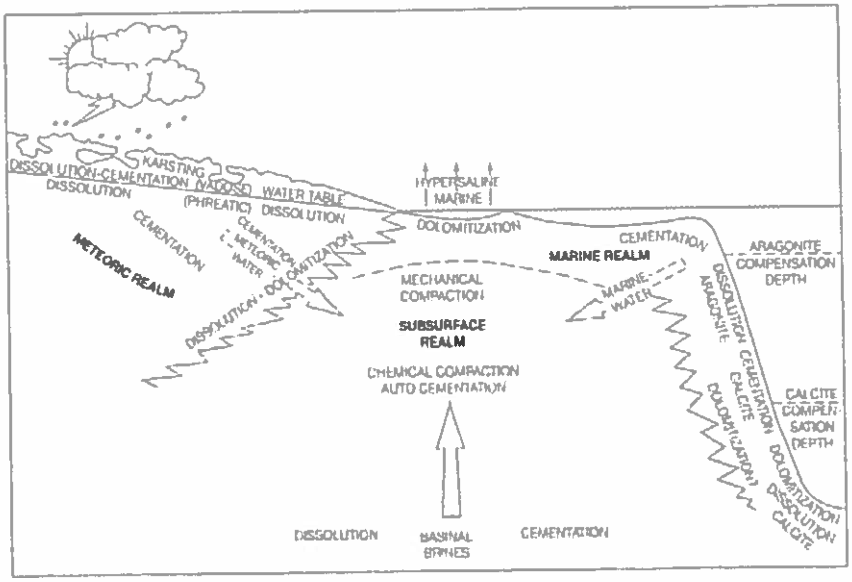


FIGURE 6.14 The principal environments in which postdepositional modification of carbonate sediments occurs. The dominant diagenetic processes that occur in each of the major diagenetic realms are also indicated. See text for details. [From Moore, C. H., 1989, *Carbonate diagenesis and porosity*. Fig. 3.1, p. 44, reprinted by permission of Elsevier Science Publishers, Amsterdam.]

From Boggs, Sam, Jr. 2012, *Principles of Sedimentology and Stratigraphy*, 5th ed., Upper Saddle River, New Jersey: Pearson Prentice Hall, p. 159.

Silicates

The silicates (approximately 80% of Portland cement) react with water to form calcium silicate hydrate, which is largely amorphous (also known as C-S-H gel) and gives the cement its strength. The C-S-H gel will coat the silicate grains reducing hydration until the permeability of the gel increases, growing the rate of hydration. Calcium hydroxide is called portlandite and saturates the cement's aqueous phase increasing the pH to between 12.5 and 13.

Tricalcium silicate, C_3S:

Hydrates and hardens rapidly. It is largely responsible for Portland cement's initial set and early strength gain.

$$2C_3S + 6H \rightarrow C_3S_2H_3 \text{ (calcium silicate hydrate)} + 3CH \text{ (calcium hydroxide aka portlandite)}$$

Dicalcium silicate, C_2S:

Hydrates and hardens slowly. It is largely responsible for strength gain after one week.

$$2C_2S + 4H \rightarrow C_3S_2H_3 \text{ (calcium silicate hydrate)} + CH \text{ (calcium hydroxide aka portlandite)}$$

Flux

Ferrite is a fluxing agent which reduces the melting temperature of the raw materials in the kiln (from 1650 °C to 1425 °C). It hydrates rapidly, but does not contribute much to strength of the cement paste. Tetracalcium aluminoferrite (C_4AF) is present in clinker because of the need for flux in cement making. C_4AF hydrates similar to aluminate as described above.

3.4 Pozzolans and Supplementary Cementitious Materials (SCM)

Unless otherwise indicated, the following is summarized from Hoffman, Gretchen K. "Pozzolans and Supplementary Cementitious Materials" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).

Pozzolans and SCMs are natural or artificial materials that are either substitutes for traditional cement making materials or are additives used to enhance certain chemical or physical properties of cement and concrete.

Pozzolans are siliceous, or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Volcanic ash – tuff, opal, diatomaceous earth and some clays and shales are natural pozzolans. Most natural pozzolans are processed by either grinding or calcination to improve their reactivity.

SCMs are finely divided and non-crystalline or poorly crystalline materials similar to pozzolans that possess latent cementing properties that are activated in the presence of Portland cement and water. SCMs include ground, granulated blast furnace slag (GGBFS) and high-calcium fly ash. Blast furnace slag is a byproduct of pig-iron production and fly ash is a byproduct of burning coal.

Table 1. Physical and chemical properties of pozzolans and SCMs

Properties	Silica Fume	Ground, Granulated Blast Furnace Slag (GGBFS)	Fly Ash (Class C and Class F)	Calcined Clay, Shale	Diatomite	Rice Hull Ash
Physical	Very fine, tiny spheres (0.1 µm), high surface area—acts as filler	Angular, ground to <45 µm	Fine-grained, spherical, <45 µm	<45 µm rough texture because of grinding	Very fine-grained (1 µm). Porous skeletal remains of single-cell plants	Highly cellular, creating large surface area, >45 µm
Chemical	Amorphous silica	Silicate glass, high in calcium	Aluminosilicate	Aluminosilicate glass; may contain quartz, feldspar, mica	Amorphous silica	Pure silica, noncrystalline

Adapted from Malhotra and Mehta 1996; Lohtia and Joshi 1995.

Table 3. Natural and artificial pozzolans and SCMs classified by reactivity

Degree of Reactivity	Material
Cementitious and pozzolanic	GGBFS (cementitious) High-calcium fly ash (cementitious and pozzolanic)
Highly active pozzolans	Silica fume Rice hull (or husk) ash from electrical generation
Normal pozzolans	Low-calcium fly ash Natural pozzolans—clay, shale, diatomaceous earth, opaline cherts
Weak to very weak pozzolans	Slowly cooled blast furnace slag Bottom ash Boiler slag Field burnt rice hull ash

Adapted from Malhotra and Mehta 1996.

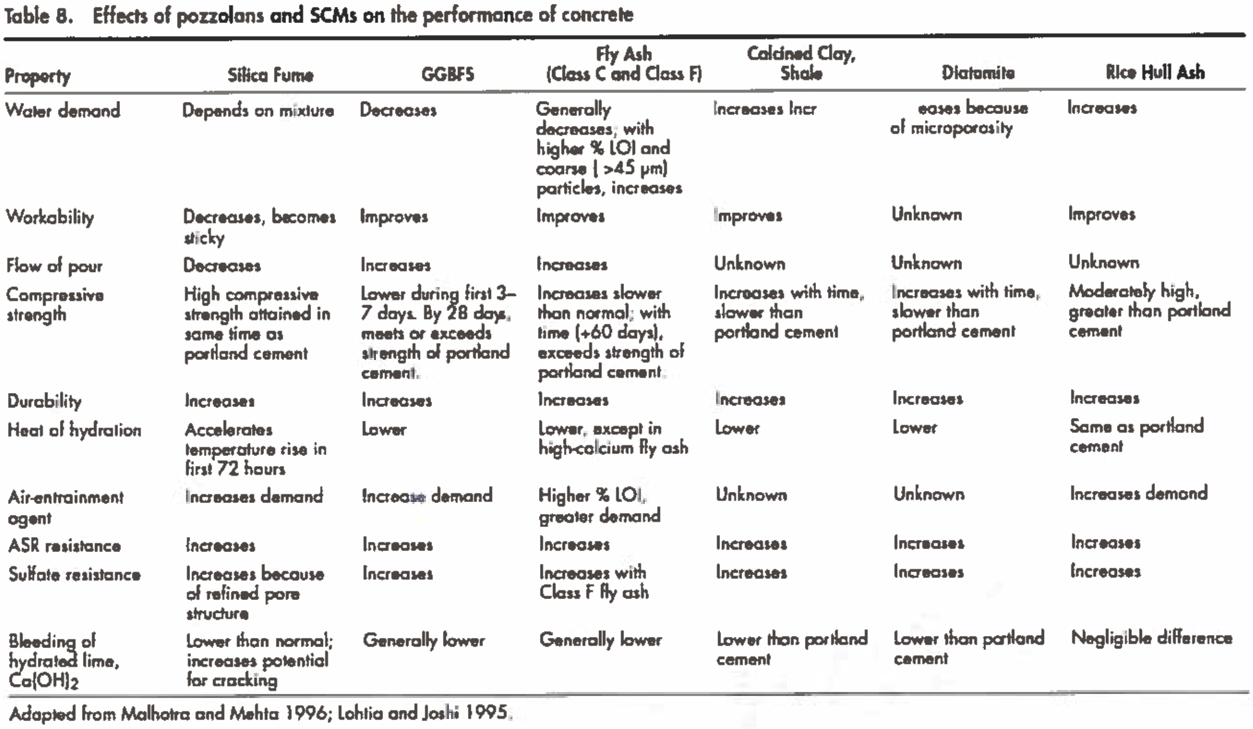
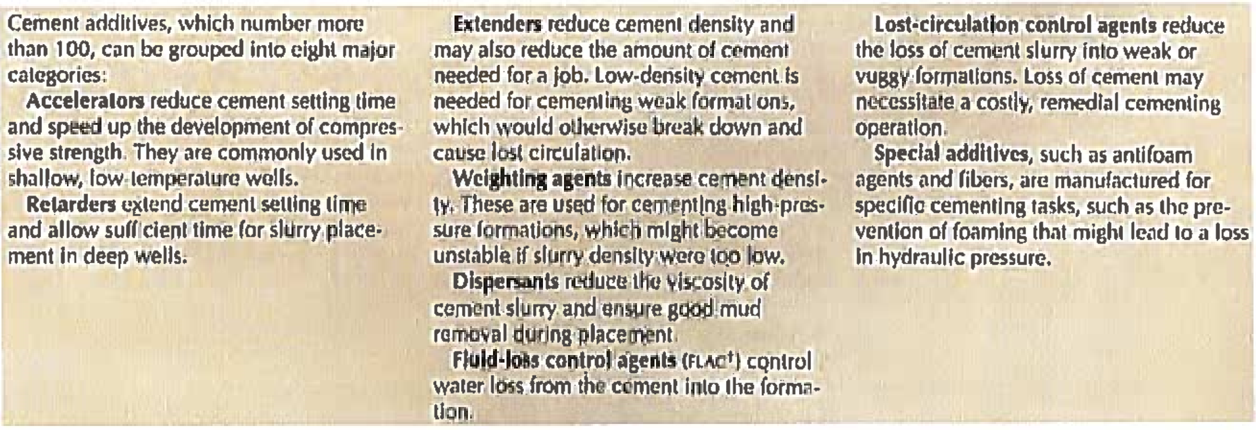


Table 8. Effects of pozzolans and SCMs on the performance of concrete

Property	Silica Fume	GGBFS	Fly Ash (Class C and Class F)	Calcined Clay, Shale	Diatomite	Rice Hull Ash
Water demand	Depends on mixture	Decreases	Generally decreases; with higher % LOI and coarse (>45 μm) particles, increases	Increases Incr	eases because of microporosity	Increases
Workability	Decreases, becomes sticky	Improves	Improves	Improves	Unknown	Improves
Flow of pour	Decreases	Increases	Increases	Unknown	Unknown	Unknown
Compressive strength	High compressive strength attained in same time as portland cement	Lower during first 3–7 days. By 28 days, meets or exceeds strength of portland cement.	Increases slower than normal; with time (+60 days), exceeds strength of portland cement.	Increases with time, slower than portland cement	Increases with time, slower than portland cement	Moderately high, greater than portland cement
Durability	Increases	Increases	Increases	Increases	Increases	Increases
Heat of hydration	Accelerates temperature rise in first 72 hours	Lower	Lower, except in high-calcium fly ash	Lower	Lower	Same as portland cement
Air-entrainment agent	Increases demand	Increase demand	Higher % LOI, greater demand	Unknown	Unknown	Increases demand
ASR resistance	Increases	Increases	Increases	Increases	Increases	Increases
Sulfate resistance	Increases because of refined pore structure	Increases	Increases with Class F fly ash	Increases	Increases	Increases
Bleeding of hydrated lime, $Ca(OH)_2$	Lower than normal; increases potential for cracking	Generally lower	Generally lower	Lower than portland cement	Lower than portland cement	Negligible difference

Adapted from Malhotra and Mehta 1996; Lohtia and Joshi 1995.

Additives for Well Cement



Cement additives, which number more than 100, can be grouped into eight major categories:

Accelerators reduce cement setting time and speed up the development of compressive strength. They are commonly used in shallow, low-temperature wells.

Retarders extend cement setting time and allow sufficient time for slurry placement in deep wells.

Extenders reduce cement density and may also reduce the amount of cement needed for a job. Low-density cement is needed for cementing weak formations, which would otherwise break down and cause lost circulation.

Weighting agents increase cement density. These are used for cementing high-pressure formations, which might become unstable if slurry density were too low.

Dispersants reduce the viscosity of cement slurry and ensure good mud removal during placement.

Fluid-loss control agents (FLAC†) control water loss from the cement into the formation.

Lost-circulation control agents reduce the loss of cement slurry into weak or vuggy formations. Loss of cement may necessitate a costly, remedial cementing operation.

Special additives, such as antifoam agents and fibers, are manufactured for specific cementing tasks, such as the prevention of foaming that might lead to a loss in hydraulic pressure.

Michel Michaux et al "Cement Chemistry and Additives" Schlumberger Oilfield Review Vol. 1 No. 1 (April 1989).

3.5 Global Cement Industry

Cement production increases during times of economic and population growth, and due to private and government spending on infrastructure (which may coincide with economic downturns). Marketing the advantages of concrete to spending agents, and financial or other support to concrete suppliers may add to the growth of cement production.[5]

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[5] Macfadyen, John D. "Cement and Cement Raw Materials" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).

The raw materials used to make cement are evolving to include more recycled "wastes" from other industrial processes and additives like pozzolans and supplementary cementitious materials to customize the properties of the cement.

In 2015, approximately 4.6 billion tonnes of cement was produced globally. Only Canada and Japan saw a decrease in production from 2014 to 2015.[6]

Future trends in the industry appear to be in processing technology: automation of process controls, larger kiln and mill systems, and more efficient grinding systems. Additionally, substituting pozzolans and SCM to reduce SO_2 and NO_x emissions, and industrial by-products to reduce CO_2 emissions from the calcination of limestone is growing. Consolidation of smaller companies into larger international companies is a trend that has already been observed.[7]

Main world producers - The G20 Group

Cement production (Million tonnes)

Country	2001	2007	2008	2009	2010	2011	2012	2013	2014	2015	
China	661.0	1 381.2	1 388.4	1 644.0	1 881.9	2 063.2	2 137.0	2 359.0	2 438.0	2 350.0	
India	102.9	170.5	185.0	205.0	220.0	270.0	239.0	272.0	280.0	270.0	
European Union	225.6	269.1	250.8	209.0	192.1	191.6	170.5	157.5	165.8	172.0	e
USA	88.9	95.5	86.3	63.9	65.2	68.6	74.0	77.2	83.2	83.4	
Brazil	39.4	45.9	51.6	51.7	59.1	63.0	68.0	71.9	72.0	73.0	p
Turkey	30.0	49.3	51.4	54.0	62.7	63.4	63.8	70.8	72.6	72.8	
Russian Federation	28.7	59.9	53.5	44.3	50.4	56.1	53.0	55.6	68.4	69.0	p
Japan	79.5	71.4	67.6	59.6	56.6	56.4	59.3	61.7	61.9	59.5	
Korea, Rep. of	52.0	52.2	51.7	50.1	47.4	48.2	46.9	47.3	47.0	49.1	p
Saudi Arabia	20.0	30.3	37.4	37.8	42.5	48.0	43.0	48.0	51.8	54.0	p
Indonesia	31.1	35.0	38.5	36.9	39.5	45.2	53.5	52.0	54.2	54.4	p
Mexico	33.2	38.8	37.1	35.1	34.5	35.4	36.8	37.0	39.4	40.0	p
Germany	32.1	33.4	33.6	30.4	29.9	33.5	32.4	31.9	32.5	32.0	e
Italy	39.8	47.5	43.0	36.3	34.4	33.1	26.2	23.1	21.4	20.8	
France	19.1	22.1	21.2	18.1	18.0	19.4	18.0	17.5	16.4	15.6	
Canada	12.1	15.1	13.7	11.0	12.4	12.0	12.5	12.1	12.8	12.5	
Argentina	5.5	9.6	9.7	9.4	10.4	11.6	10.7	11.9	11.8	12.2	
South Africa	8.4	13.7	13.4	11.8	10.9	11.2	13.8	14.9	13.8	14.0	p
Australia	6.8	9.2	9.4	9.2	8.3	8.6	8.8	8.6	9.0	9.1	p
United Kingdom	11.9	12.6	10.5	7.8	7.9	8.5	7.9	8.5	9.2	9.6	e

Notes: p: Preliminary - e: Estimate

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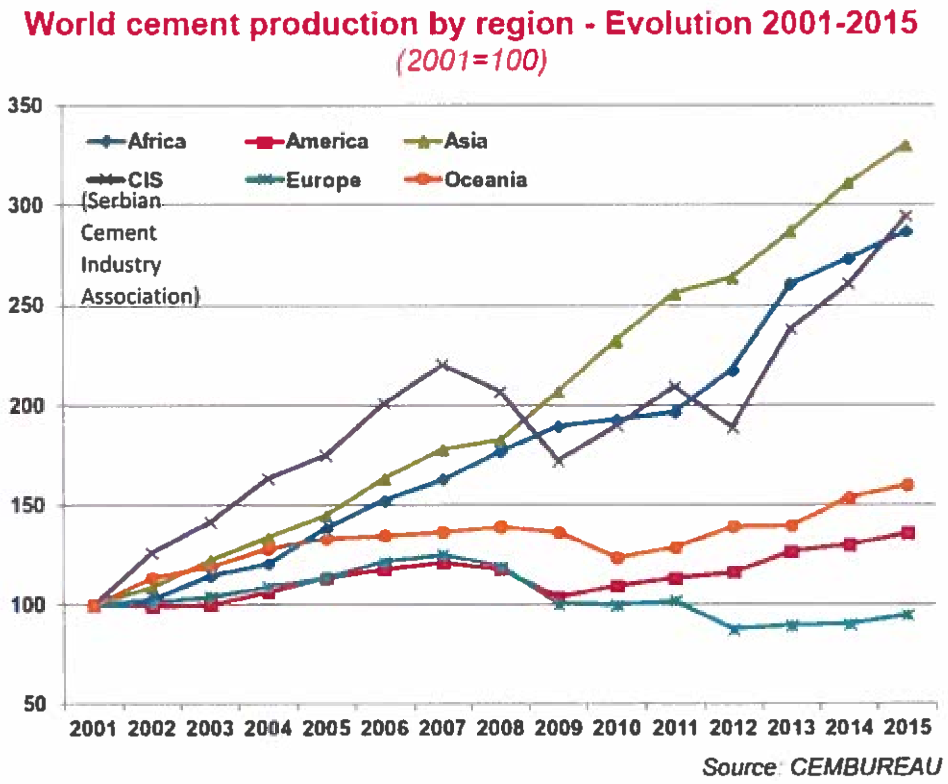
[6] CEMBUEAU Activity Report 2015 http://www.cembureau.eu/sites/default/files/AR2015.pdf; Last accessed August 28, 2016.

[7] Macfadyen, John D. "Cement and Cement Raw Materials" and Hoffman, Gretchen K. "Pozzolans and Supplementary Cementitious Materials" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).



CEMBUEAU Activity Report 2015 http://www.cembureau.eu/sites/default/files/AR2015.pdf; Last accessed August 28, 2016.

3.6 Canadian Cement Industry

The following section is summarized from the Cement Association of Canada.[8]

The Cement Association of Canada has eight member companies operating 16 cement plants and 45 distribution centers that produce over 98% of the cement consumed in Canada. Vertical integration is common in the construction industry with companies having cement, ready mix concrete, aggregate, and construction divisions.

2012 Statistics:

- Members produced over 13 million tonnes of cement, worth more than $1.6 billion.
- 3.4 million tonnes were exported, mostly to the U.S.
- Employed over 27,000 Canadians in the production of cement, ready mix concrete, and concrete construction materials.
- 1,100 plants nation-wide produce concrete products, such as ready-mix concrete, pipes, pre-cast structures, bricks, and blocks

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[8] *http://www.cement.ca/en/Economic-Contribution.html, last accessed August 28, 2016.*

- Approximately 28.1 million cubic metres of concrete (about one cubic metre per Canadian) are used each year in construction projects to:
    - pave roads, highways, sidewalks, and parking lots
    - build homes, apartments, and office towers
    - construct sewers and water treatment facilities
    - build storage and waste management facilities for agriculture
    - build bridges, ports, airports, dams, power plants, and oil wells

Alberta has two cement plants: Lafarge (Exshaw) and Lehigh Hanson (Edmonton) with 2.466 million tonnes annual clinker capacity.

3.7 Portland Cement Concrete

The following is summarized from Hack and Bryan "Aggregates" in Industrial Minerals & Rocks: Commodities, Markets, and Uses 7th Edition, Edited by Jessica Elzea Kogel; Society for Mining, Metallurgy, and Exploration (U.S.) (2006).

Portland cement concrete is a strong, durable, construction material formed when Portland cement hardens around coarse and fine aggregates. Aggregates are strong, hard, durable, sound, inert particles that are used alone or combined with a binding agent to achieve a purpose, commonly construction. Sand and gravel and crushed stone are common construction aggregates. Aggregates make up between 70 and 80% of concrete by volume or 75-85% by weight.

Concrete mixes are adjusted by varying the water to cement ratio, adjusting the combination of coarse and fine aggregates, and adding admixtures that reduce water demand, increase strength, slow or increase the rate of setting, reduce heat of hydration, decrease permeability and shrinkage, increase durability and frost resistance, and for colour. The aggregates must be combined properly for a dense mixture with minimal void space – void spaces are filled with set cement.

Aggregate properties important to concrete are hardness, durability, soundness, absorption, specific gravity, surface texture, particle shape, cleanliness, size and grading, and chemical inertness.

The manufacture of cement, concrete, and concrete products in Canada is governed by a variety of Canadian Standards Association (CSA) standards. These standards form the backbone of the National Building Code of Canada (NBCC) and of provincial building codes.[9]

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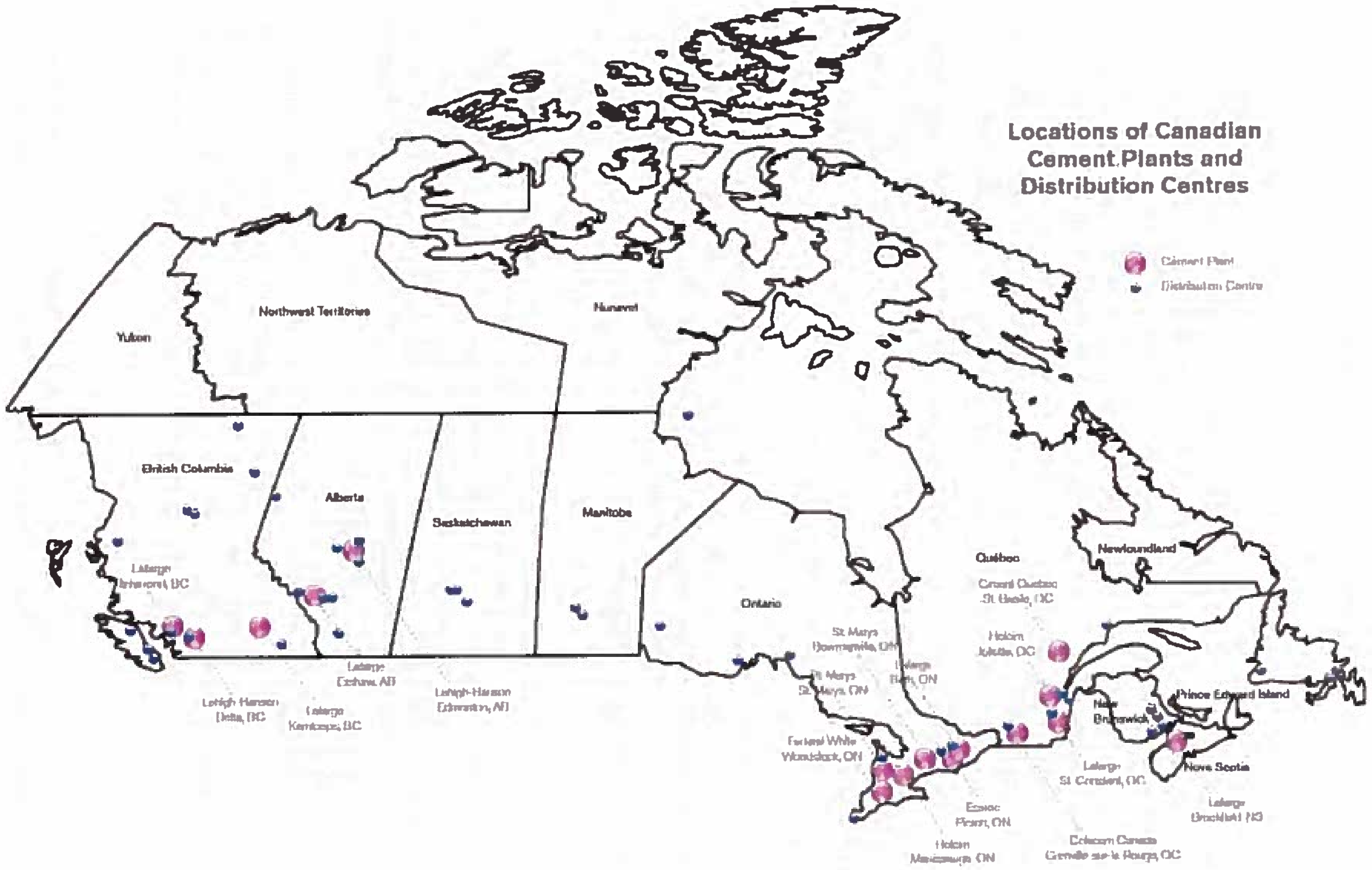
[9] http://www.cement.ca/en/Codes-and-Standards.html; last accessed September 11, 2016



Cement Association of Canada http://www.cement.ca/images/content/CanadianCementPlantsDistributionCenters-e.jpg; Last accessed August 28, 2016

3.8 Geological Setting of Limestone in West-Central Alberta

Limestone is found in all provinces in the Western Canada Sedimentary Basin. Huge reserves of limestone are exposed in Cambrian, Devonian and Mississipian formations in the Rocky Mountains and Foothills of Alberta (Holter, 1976), as well as in Devonian strata in the northeast along the Athabasca and Clearwater rivers. Commercial production to date is within the Cadomin, Nordegg, Rocky Mountain House, Exshaw, Crowsnest Pass and Fort Mc Murray regions.

Within the Rocky Mountain and Foothills, the Exshaw and nearby Gap quarries produce limestone from the Devonian Palliser Formation. The Summit Lake quarry in Crowsnest Pass produces from the Carboniferous Livingstone Formation. The Fish Creek quarry near Nordegg and, the Cougar Ridge and Clearwater quarries near Rocky Mountain House, utilize equivalent Carboniferous strata of the Pekisko Formation. Formerly, the Cambrian Eldon Formation was a source of limestone at Kananaskis.

Limestone in the Cadomin area is actively quarried at one of two quarries located in Nikanassin Range. The active McLeod quarry target two separate belts of exposed Palliser Formation for high-calcium limestone. Some exploration and development has also occurred in the Brûlé/Folding Mountain area, targeting high-calcium limestone of the Mississippian Pekisko Formation of the Rundle Group, where an approximately 18 m thick interval of high-calcium limestone was identified (Krueger, K., Kluczny, P. and Dahrouge, J., 2016).

In the northern part of the Rocky Mountains and Foothills of Alberta, limestone is known to occur within both Paleozoic and Triassic sequences. Paleozoic limestones are described in the Upper Devonian Fairholme Group and Palliser Formation, Upper Devonian to Lower Carboniferous Banff Formation, and Mississipian Rundle Group. Limestone units of the Palliser and Banff Formations, and the Rundle Group are exposed by the Folding Mountain Anticline.

3.8.1 Rundle Group

The Rundle Group (Mississipian) comprises the Mount Head and Livingstone formations in the Mountains and the Turner Valley, Shunda and Pekisko formations in the foothills and plains. In west-central Alberta, the Rundle Group, comprises shallow-marine platform and ramp carbonates which prograded westward over deep water shales and carbonates of the Banff Assemblage. The lower Rundle Group is subdivided into the transgressive carbonate Pekisko Formation, and two regressive successions of restricted-marine carbonates and subordinate anhydrite of the Shunda and Turner Valley formations.

3.8.2 Banff Formation

In west-central Alberta the Banff Formation is a heterogeneous association of carbonates and fine-grained siliciclastics deposited on poorly differentiated carbonate platforms. The Banff Formation (168 m) is divided into four units: a bottom recessive unit (~120 m); a unit of interbedded crinoidal and silty limestone (~15 m); a middle-upper unit of argillaceous limestone (~46 m); and an upper unit of siltstone and silty limestone (~9 m) (Mountjoy, 1959). Westward, the uppermost Banff Formation grades laterally into the Rundle Group.

3.8.3 Palliser Formation

The Palliser Formation (Late Devonian) in west-central Alberta consists mainly of outer shelf and basinal carbonates of the Sassenach Basin. The Palliser Formation (180-240 m) consists of massive dark-grey and dark-brown, fine- to medium grained limestone with thin intervals of dolomitic limestone, dolomite, calcareous shale and chert. The Palliser Formation is divided into the Morro and overlying Costigan members, which are separated by an unconformity.

Morro Member: dominated by carbonates with significant lateral facies variations.

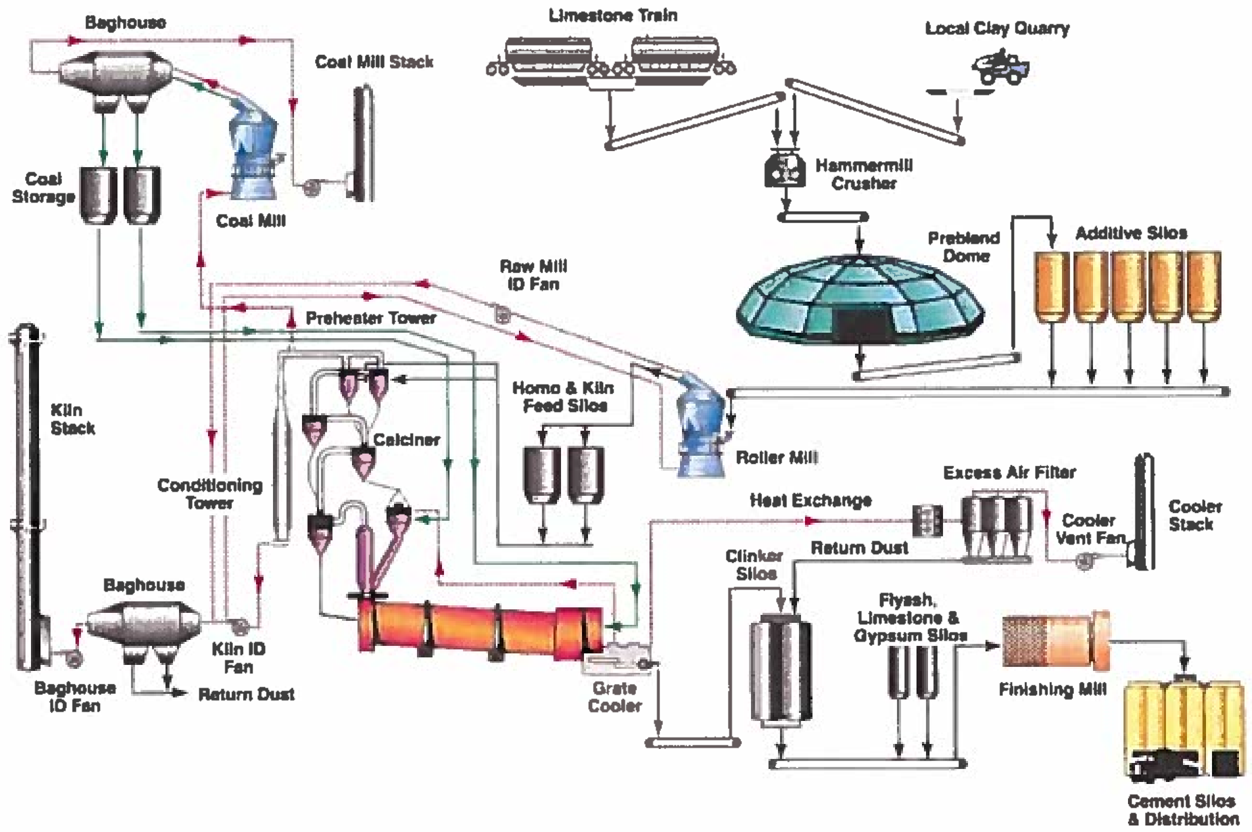
Costigan Member: consists of open-marine fossiliferous limestones and shales, with local evaporitic sedimentation.

4 Detailed Stop and Point of Interest Descriptions

4.1 Stop - Lehigh Hanson Cement Plant – Edmonton

The Edmonton Cement Plant opened in 1956. Limestone from the Cadomin Quarry is railed approximately 306 km eastward to the Lehigh Hanson Cement Plant in Edmonton where it is processed with clay from a local clay pit to form clinker. The clinker is then milled with fly ash, limestone, and gypsum in varying amounts to create a range of cement products.

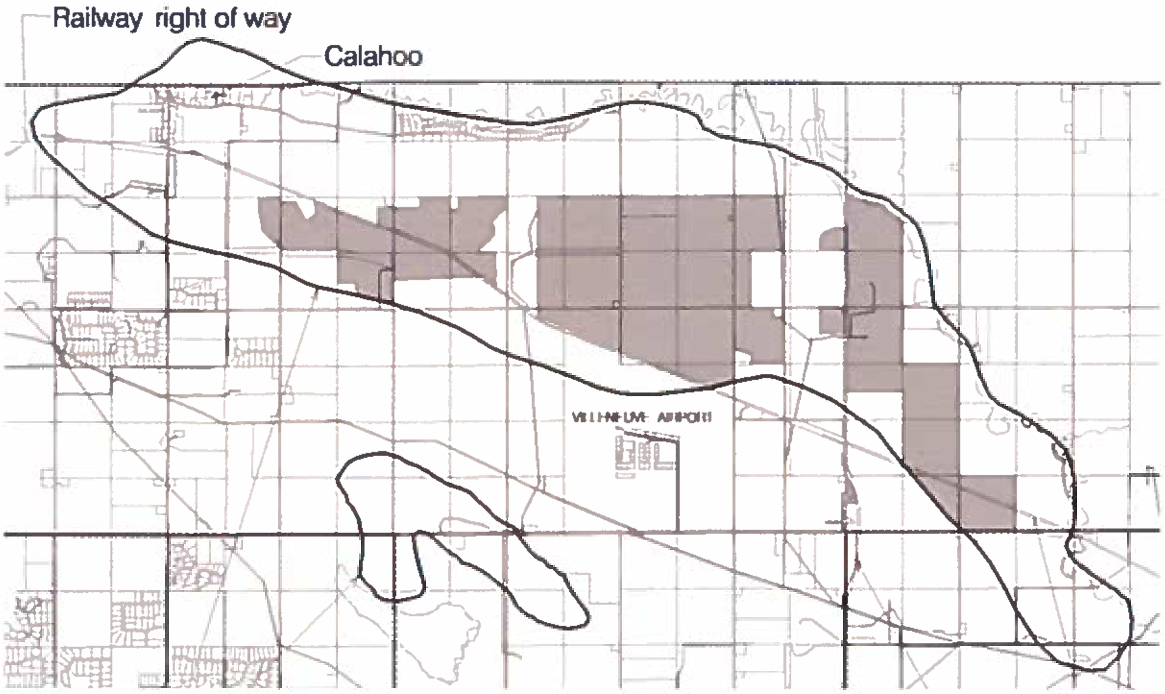
LEHIGH
HEIDELBERGCEMENT Group



4.2 Stop – Inland Aggregates Villeneuve Gravel Pit

See Appendix 3 for a description of the geology of the Villeneuve sand and gravels from Edwards et al. "Sand and Gravel Geology and Resources: A Field Trip to Recent Alluvial, Quaternary Glaciofluvial and Preglacial Fluvial Deposits Near Edmonton, October 2, 2001" AGS, EUB.

The map below shows the Villeneuve area gravel deposits in the black outline. The grey shaded areas are zoned for aggregate extraction. Note how much of the gravel deposits are sterilized as a result of public concern over the number of gravel pits in the region. However, the zoning does provide certainty to gravel producers that they will not be prohibited from expanding into areas zoned for extraction.[10]



4.3 Point of Interest – Genesee Coal Mine and Electricity Generating Station

The following information is from the Westmoreland Coal Company;
http://westmoreland.com/location/genesee-mine-alberta/; last accessed Sept. 8, 2016

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[10] Peel, R.D. (2004) Sustainable Development of the Aggregate Resources of Alberta. University of Alberta, Edmonton, Alberta.

The Genesee Mine is a 7,378 ha surface strip mine located in Central Alberta north of the Town of Warburg and south of Lake Wabamun. The mine operates two active pits and supplies sub-bituminous coal to the three units at the Genesee Generating Station which are owned by Capital Power and TransAlta Utilities and operated by Capital Power. The mine has been supplying coal to the station since 1988 and is the newest mine in the division.

Coal is uncovered using the two draglines (1 – M8750; 1 – M8200) and a pre-stripping fleet (1 – P&H 4100, 3 – 830E's, 1-Cat 789). The exposed coal is hauled directly from the mine to the generating station. Current annual production of the mine is more than 5.0 million tonnes. The mine is a joint venture between Capital Power and Westmoreland and the contract runs for the Life of the Mine.

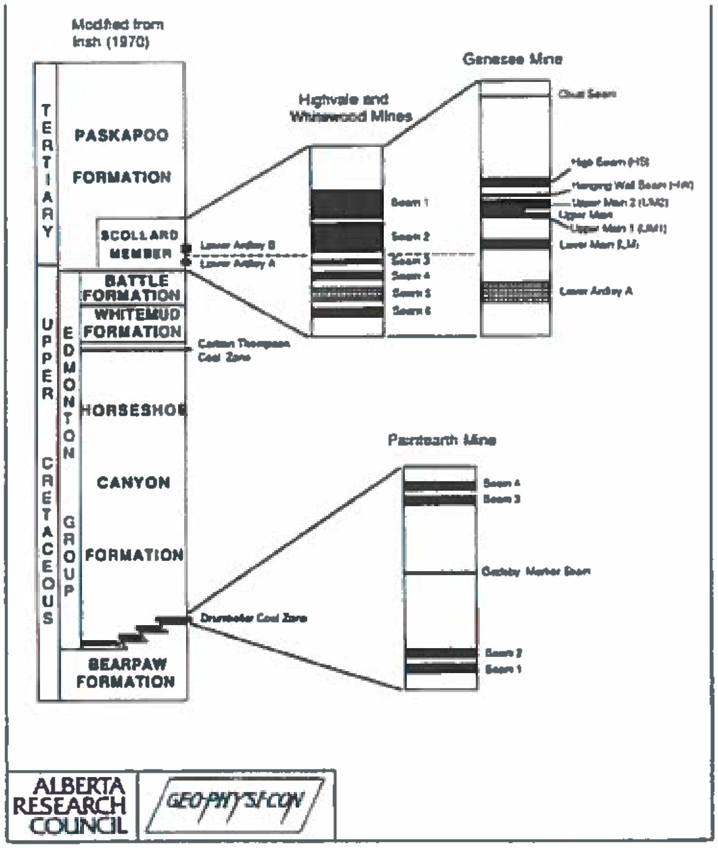
Genesee Mine won the 2008 Alberta Chamber of Resources Major Reclamation Award for Land Reclamation. The mine has also been ISO 9001 and ISO 14001 certified since 2001.

Geology of the Genesee Coal Mine Area

The Genesee Mine is one of two active coal mines in the Lake Wabamun area that are mining coal from the subcrop edge of the Ardely Coal Zone in this region.

The bedrock geology consists of Paleocene, non-marine, coal-bearing rocks of the Paskapoo Formation and Scollard Formation. The coal deposits of Genesee belong to the Ardley Coal Zone of the Scollard Formation.

The Paskapoo Formation forms most the overburden above the coal zone and consists dominantly of grey-coloured salt and pepper sandstone. Beneath the Paskapoo, the Scollard Formation consists of interbeds of finer grained clastics and coal. The coal seams are separated by interbeds of sandstone, siltstone, mudstone, bentonite, and concretionary horizons. The mineable resources come from the Lower Ardley B coal zone (Figure 3). The coal seams in the Lower Ardley A are uneconomic. Three mineable seams are present in the Lower Ardley B and are locally named, from top to bottom, High Seam (HS), Upper Main seam (UM), and Lower Main seam (LM).



Stratigraphy of the Genesee, Highvale, and Paintearth Mine areas. Note the Scollard Member was elevated to formation status by Gibson (1977).

Gibson, D.W. (1977): Upper Cretaceous and Tertiary coal-bearing strata in the Drumheller-Ardley region, Red Deer River valley, Alberta. Geological Survey of Canada, Paper 76-35, 41 p.

Genesee Generating Station

http://www.capitalpower.com/generationportfolio/CA/Genesee/Pages/default.aspx

The three units at Genesee are responsible for providing more than 1,200 megawatts (MW) of base load power to the Alberta electricity grid. Electrical power is generated from burning more than 5.0 million tonnes of thermal coal supplied annually from the adjacent Genesee mine. A valuable byproduct from the burning of coal is fly ash, the mineral matter in the coal that remains after combustion.

Genesee Fly Ash

Fly Ash and Bottom Ash are produced as a byproduct of the Genesee Facility and used as ingredients of cement and concrete products. As well they may be used as filler in asphalt and may be present in other products widely used in construction. Fly ash is also often used for soil stabilization. The composition of the fly ash is dependent on the constituents of the coal burned and may vary for this reason.

Coal from the Genesee Mine generally contains more than 15% ash. Approximately 99.5% of the ash is recovered. Fly ash is sold to the cement industry for use as an additive in the manufacturing of Portland cement.

Fly ash is a dust-like byproduct formed from coal combustion with a consistency similar to talcum powder. Fly ash from Genesee Unit 1 and Unit 2 is separated from the flue gas using an electrostatic precipitator (ESP). The ESP, which is about the same size as a large apartment building, uses static electricity to capture fly ash which is then vibrated off and collected in large hoppers or bins.

Fly ash from Genesee Unit 1 and 2 has been used in concrete for construction of airport runways, roads, and building construction. Unsold ash is transported and stored in licensed landfills within the Genesee Mine.

4.4 Point of Interest – Marlboro

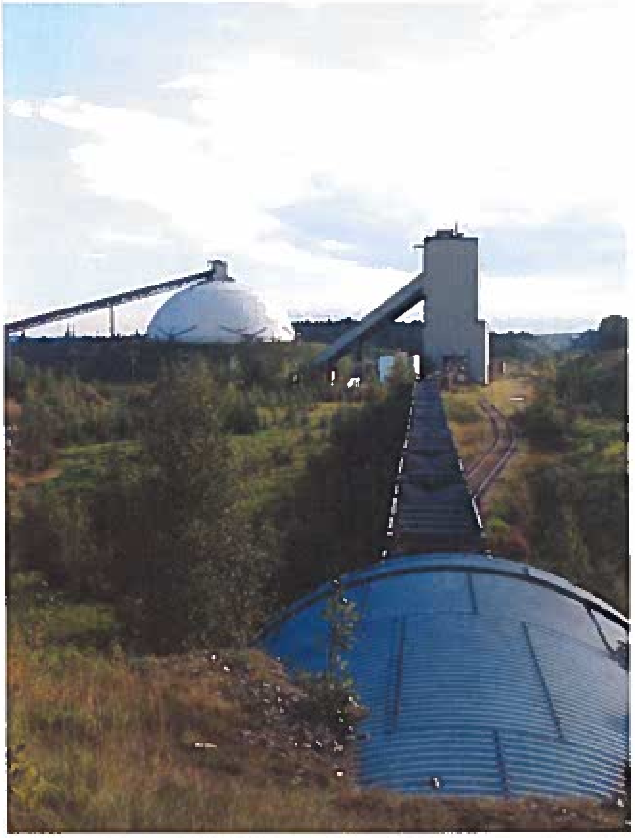
See Appendix 4 for "MARLBORO: Lonely Chimney in the Muskeg"
(from Mussieux, R. and Nelson, N.(1998). A Traveller's Guide to the Geological Wonders of Alberta. The Provincial Museum of Alberta, 254 p.)

4.5 Point of Interest – Obed Mountain

4.5.1 Coal

Summarized from Westmoreland "About Obed Mountain Mine" http://obed.ca/about-obed/*, last accessed September 11, 2016.*

The Obed Mountain Mine is a thermal coal mine (7,460 ha) that opened in 1984 and ceased production in 2012. When it was operating, coal was exported internationally via Vancouver – currently the mine is not operating and is under reclamation because overburden thickness and depressed coal prices makes the coal uneconomic to recover. There are still 2.6 million tonnes (proven) and 84.7 million tonnes (measured resources) of coal remaining in situ. The plant has a production capacity of 3.2 million tonnes of coal per year (0.2 million tonnes produced in 2012).



When operating, the mine utilizes a dragline and shovel to remove the overburden, with the shovel loading the coal onto haul trucks. Coal is hauled to an adjacent processing plant, where it is crushed, cleaned and dried. From the processing plant, the coal is sent to a storage and rail-loading facility by an 11 km-long conveyor for further transportation by rail to port.

Water management practices were developed to divert clean surface runoff water around the mine area; these systems are referred to as primary drainage systems.

Water from the mine pits and mine spoils are managed separately by systems referred to as secondary drainage systems, designed to ensure safe, stable, and efficient operations and minimize any adverse affect of sediment-laden drainage from the mine on the water quality of the natural surface water.

The containment ponds at the Obed Mountain Mine contain ground water and water used in the process of washing coal. Coal is washed to remove matter such as rock and clay. The ponds contain water, mixed with naturally occurring material, mainly clay, mud, shale, and coal fines. The containment ponds are used to settle out the solid material from the water, and the water is typically recycled into the coal wash plant.

When water reaches the containment ponds, a flocculant - an organic substance – typically is added to help settle clay, dirt, and other sediment. Flocculants are commonly used to help purify drinking water.

Reclamation activities have been conducted within the mining area, in accordance to applicable regulations. As at Dec. 31, 2012, the mining areas and facilities measured approximately 1,911 ha. Approximately 624 ha, or 33% of the total mine area, has been reclaimed and converted to permanent vegetation, lake development, and commercial forest.

The mine was staged down in 2003 due to depressed coal prices and reopened in 2009 when prices increased. If the economics are right in the future, perhaps coal will be mined from Obed Mountain again.

The following is from Macdonald, D.E., Langenberg, C.W. and Gentzis, T. (1989): A regional evaluation of coal quality in the foothills/mountains region of Alberta; Alberta Research Council, ARC/AGS Earth Sciences Report 1989-02, 76 p.

The Obed-Marsh coal zone lies at the top of the Paleocene Paskapoo Fm. The coal is subbituminous A to high volatile bituminous C in rank.

Depositional environments

The prerequisites for accumulation of thick peat deposits are: 1) an adequate supply of plant matter, 2) a balance between the groundwater level and peat surface, and 3) the absence or limited presence of detrital clastic sediments (Teichmuller 1982). Peat accumulation can occur adjacent to river systems with well-developed floodplains (Jerzykiewicz and McLean 1980). However, McCabe (1984) points out that it is unlikely that thick, low-ash peats will accumulate adjacent to such an environment because of the almost continuous flooding events typical of such systems. However, coals found in an alluvial setting may have formed in swamps that were protected in time and/or space from such clastic flooding events. Several authors have recently suggested that raised swamps, with their upward domed shape and very low ash and sulfur contents may explain how swamps could be spatially protected.

The depositional environments surrounding the Obed-Marsh coals are separable into three time/lithostratigraphic units: 1) clastics which immediately preceded the coal-forming time, 2) interburden clastics, and 3) the coal zone itself.

The clastics that were deposited immediately prior to coal formation are part of the largely non-coal-bearing Paskapoo Formation. Several excellent roadcut exposures of this unit can be found along the road to the Obed Mountain mine (section OM3, figure 42). Such exposures show typically fine- to medium-grained sandstones and several channel features such as lateral accretion bedding; large-scale, trough-cross stratification; scoured and pebble-based channels; stacked channels; peat mats at the base of channels; and upward fining sequences (figure 42). Regionally, the Paskapoo Formation is largely composed of sandstone and extends over a very wide area (Green 1972). The previous existence of a river system involving braidplains or slightly meandering sands is a resonable depositional setting for the Paskapoo. Jerzykiewicz (1985) associates the sequence with an anastomosing river system and attributes the coal zone and interbedded clastic sediments to the fine-grained coaly termination of a major depositional cycle.

The sedimentological interpretation for the interbedding of clastics with the Nos. 1 and 2 seams is illustrated on a representative section from the mine (section OM1, figure 42). The sequence from the upper part of the No. 1 seam to the base of the No. 2 seam records an initial rise in the water table, which drowned the peat-forming environment, followed by the introduction of a crevasse splay unit. Small meandering fluvial river systems, interrupted by low water tables and the development of paleosols, characterize the remainder of the sequence.

The coal-forming environment interpretation must then be consistent with the braidplain interpretation for the underlying strata and the small fluvial interpretation for the interburden sediments. Coal petrographic techniques were used to help establish an interpretation for the coal-forming environments of the Nos. 1 and 2 seams. A more complete description of the coal petrology can be found in Gentzis et al. (1989).

4.5.2 Gravel

On the top of Obed Mountain, there is a preglacial gravel deposit overlying the Paskapoo Formation (515 ha).[11] This cobble-rich (boney) deposit is covered by 0.3 to 0.35 m of soil and 1 to 2 m of glacial till overburden. The gravel deposit has had limited exploration with an excavator and was measured repeatedly to 3 to 4 m in depth – the full depth and extent of the deposit is yet to be determined.

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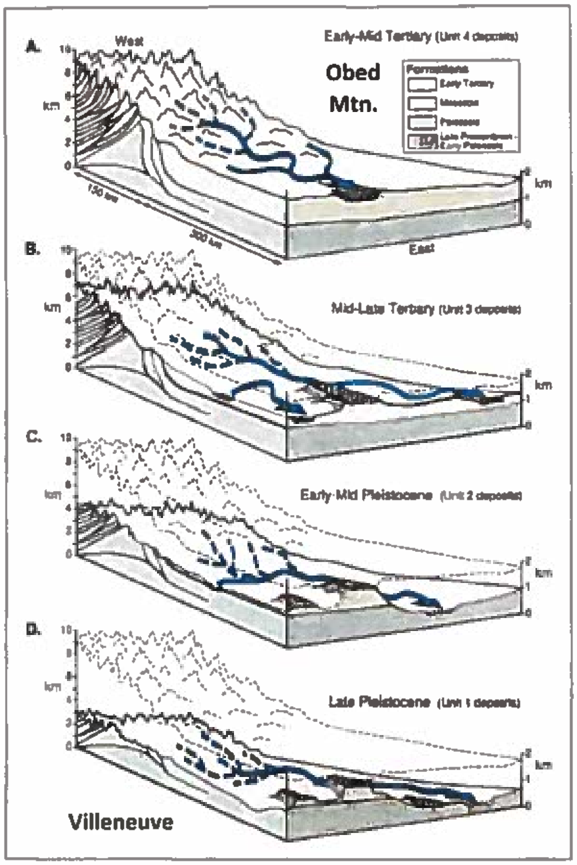
[11] Edwards, W.A.D. and Budney, H.D. (2009) Alberta Sand and Gravel Deposits with Aggregate Potential (GIS data, polygon features) AGS DIG 2004-0034.

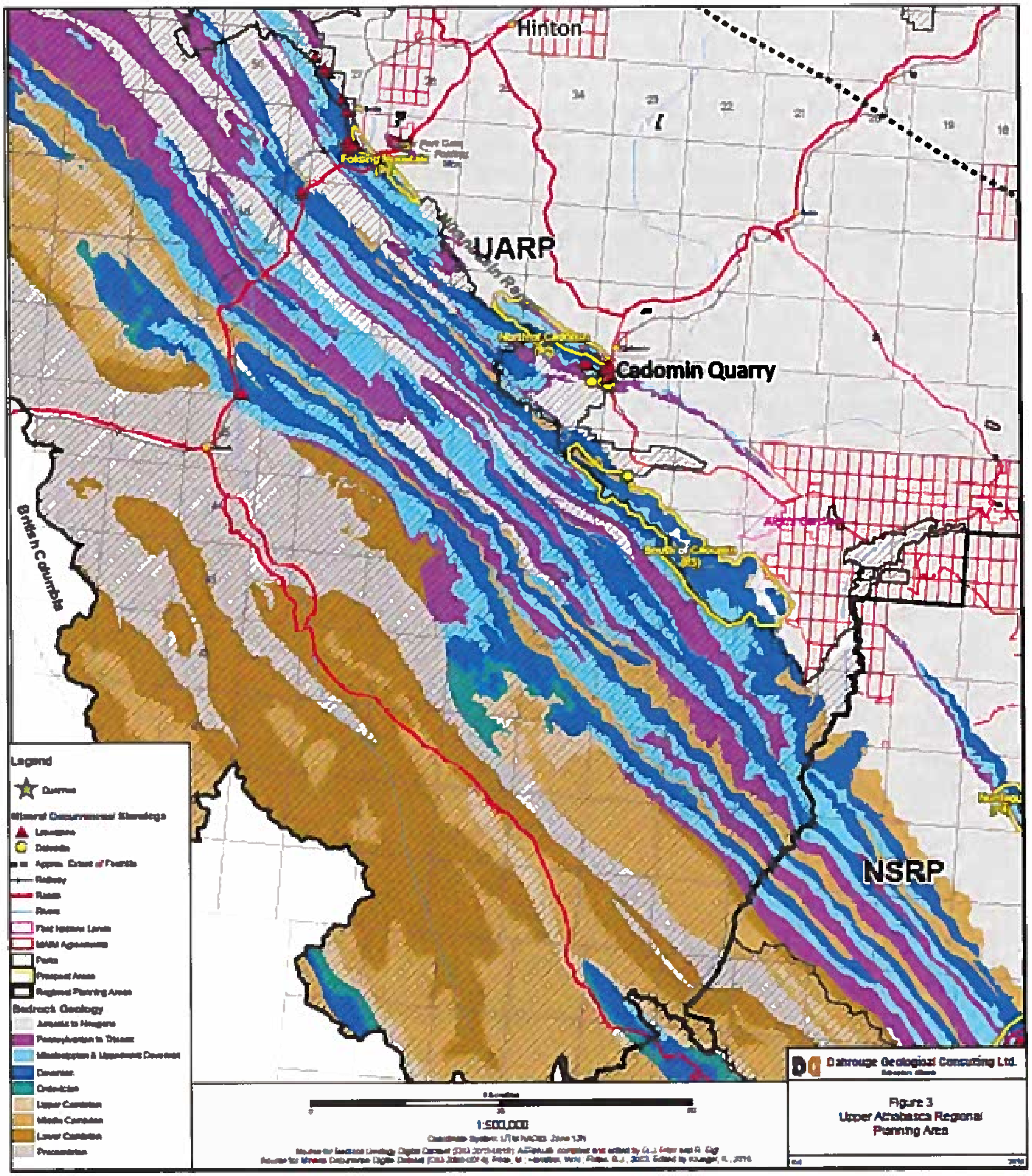


OFR 1994-06 Edwards, W.A.D. and Scafe, D. (1996) Mapping and Resource Evaluation of the Tertiary and Preglacial Sand and Gravel Formations of Alberta. AGS OFR 1994-06.

4.6 Stop – Hinton – overnight

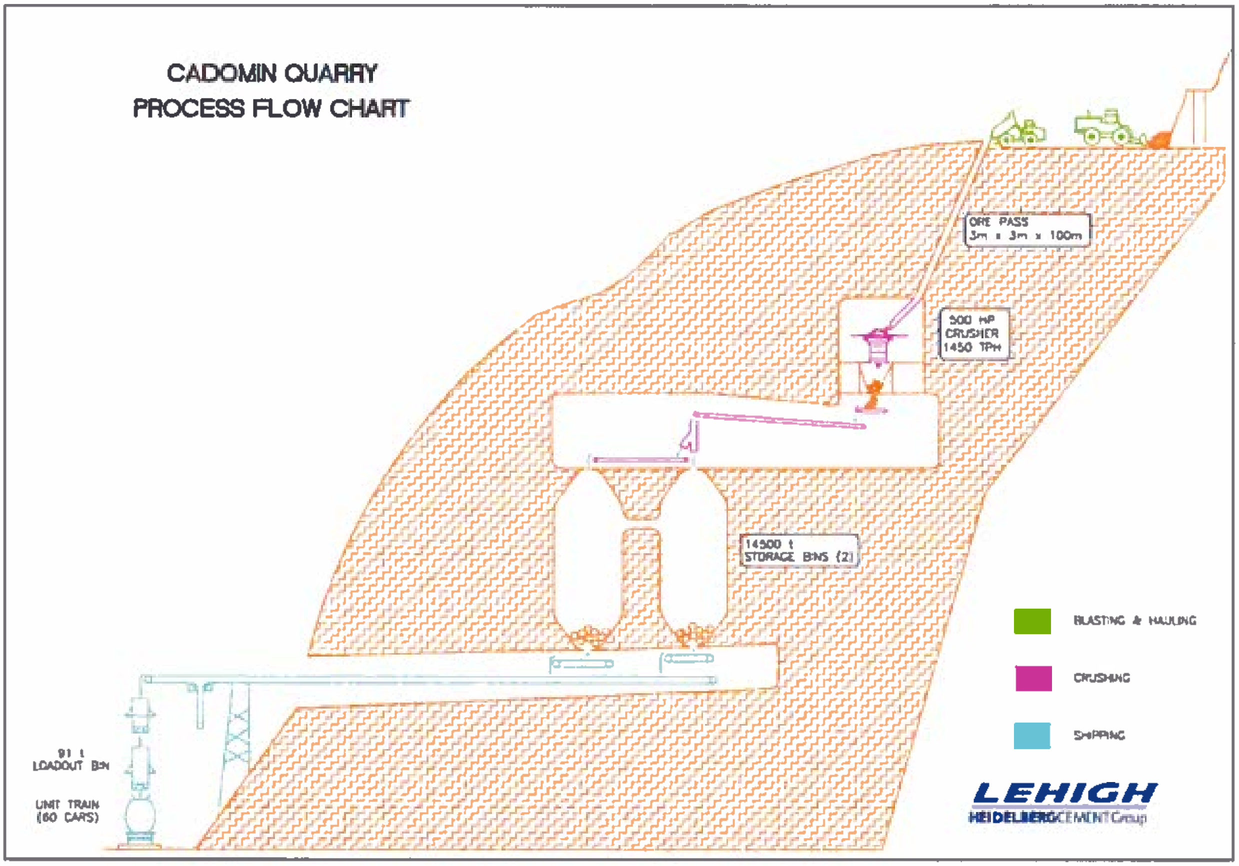
Staying overnight at the Econolodge. Group supper at Boston Pizza just across the highway from the motel. Hot breakfast provided in the breakfast room of the motel. Vans are leaving Sunday morning at 8:00. Lunch on Sunday will be provided to you.

4.7 Stop – Lehigh Hanson Cadomin Limestone Quarry



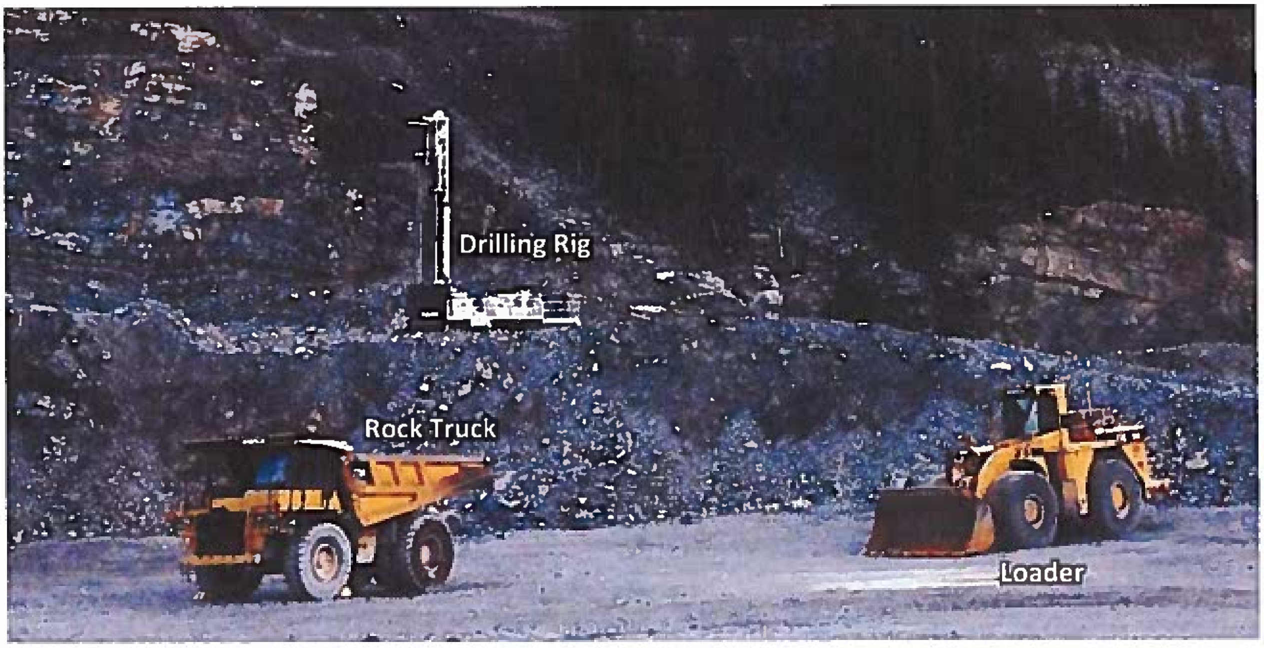
Krueger, K., Kluczny, P. and Dahrouge, J. (2016): Limestone and dolomite prospects for industrial use in the Alberta Foothills and Front Ranges; Alberta Energy Regulator, AER/AGS Special Report 102, 16 p.

The current mining operation involves drilling, blasting (every 2 to 3 weeks), loading the blasted rock into rock trucks, and dumping the rock into the ore pass in the quarry floor (see flow diagram below). Gravity moves the rock down the ore pass (3 m x 3 m with 54 degree slope) approximately 100 m to the underground crusher. The rock is crushed to six inch minus and dropped into storage bins. From the storage bins, the rock travels 400 m along a conveyor to the transload where it is loaded into railcars. Gravity is also used to advance the rail cars forward by simply disengaging and reengaging the braking system on the railcars. The limestone is railed approximately 306 km eastward to the Lehigh Hanson Cement Plant in Edmonton. Although production varies, a typical week might see 300 railcars leaving the quarry. The mine operates year round employing 15 people who are bussed to site from Hinton.

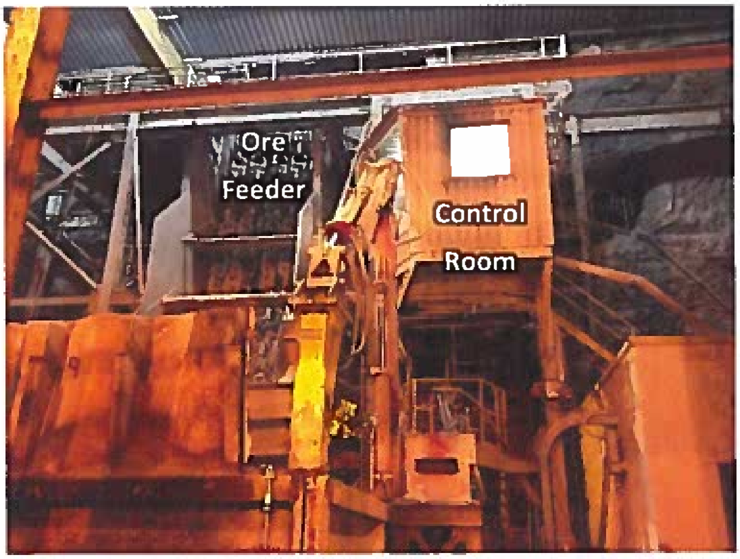


Mining in the Cadomin Quarry began in the South Quarry in the 1920s and 1930s. The operation moved into the North Quarry for two reasons: 1) thicker dolomite was found in the South Quarry as mining proceeded westward and 2) the next mining phase in the South Quarry required the construction of a haul road to the top of the mountain whereas the existing road network could be used to access the North Quarry. After the current phase of the North Quarry is mined out, Lehigh will proceed to mine out the South Quarry then return to the North Quarry to exhaust the remaining limestone. This mining sequence maximizes the use of the underground processing infrastructure.

There is greater than 100 million tonnes of limestone in Lehigh's mineral lease which equates to a mine life of approximately 100 years.



Mining equipment at the Cadomin Quarry



In the belly of the Palliser Fm. - view from the ore feeder down to the 700 m long tunnel that leads outside.

The quality of the Palliser Formation limestone is high with calcium ranging from 86 to 96 %.[12] The calcium content is consistent throughout the formation and calcium is not measured as part of the quality control program. Three higher magnesium dolomite beds occur in the Palliser but only one is visible to the eye near the top of the formation. In the past, the dolomite beds were mapped using drill cores and by testing for magnesium and then wasted. For approximately the past fourteen years, Lehigh has had success blending the dolomite with the limestone. Drill core samples are sent to the cement plant in Edmonton where the magnesium content of the carbonate rock is measured so that the quarry can blend the higher and lower magnesium carbonates to even out the chemistry of the material reaching the cement plant. The rock that is railed to Edmonton typically has the following chemistry:[13]

$CaCO_3$	92.32 %
Fe_2O_3	0.16 %
SiO_2	1.74 %
Al_2O_3	0.34 %
$MgCO_3$	3.28 %
SO_3	0.216 %
K_2O	0.23 %

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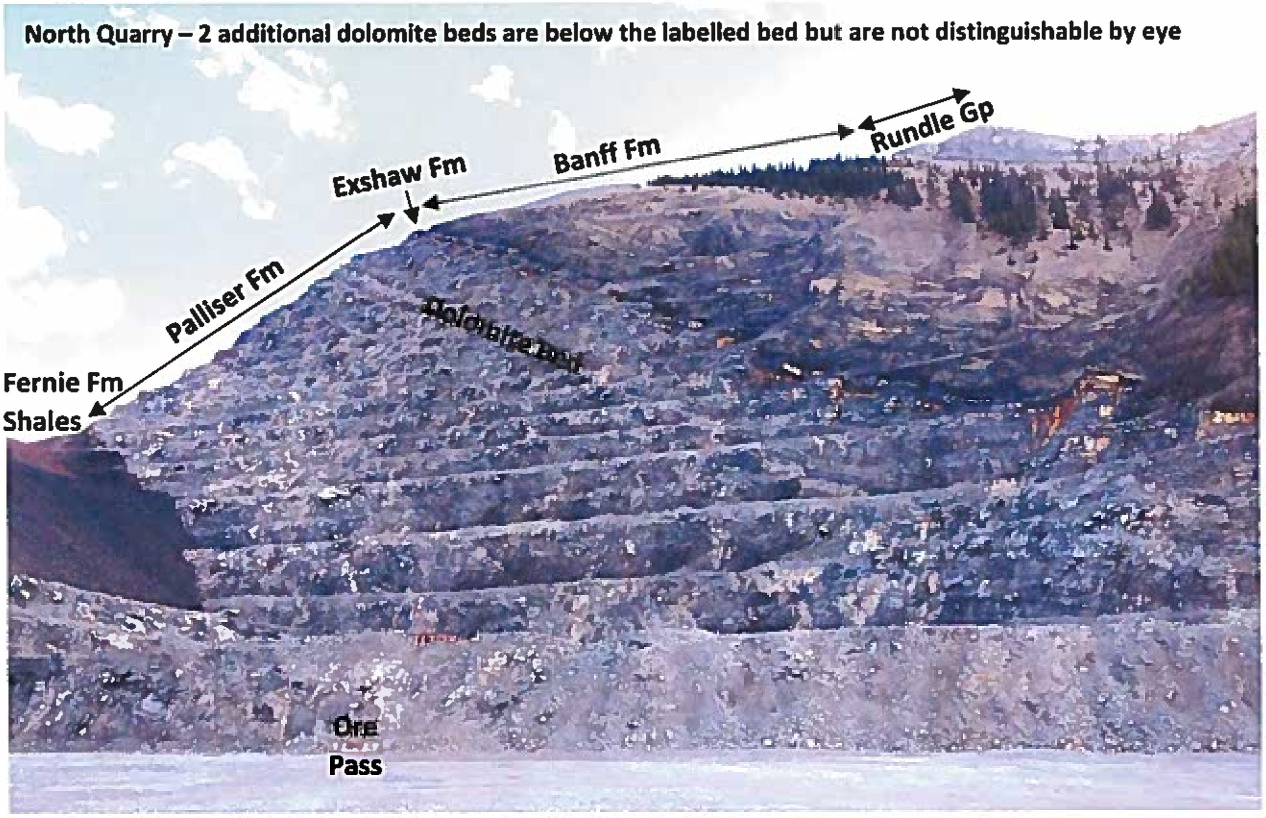
[12] Holter, M.E. (1975): Limestone resources of Alberta; Alberta Research Council, ARC/AGS Economic Geology Report 4, 100 p.

[13] Provided by Len Broad (Lehigh Hanson Cadomin Quarry Manager)



See Appendix 5 for pages 23 to 28 of Holter, M.E. (1975): Limestone resources of Alberta; Alberta Research Council, ARC/AGS Economic Geology Report 4, 100 p.

In the North Quarry, we can see the Upper Devonian and Mississippian (Carboniferous) carbonate rocks thrust over the younger Jurassic Fernie Formation shales.

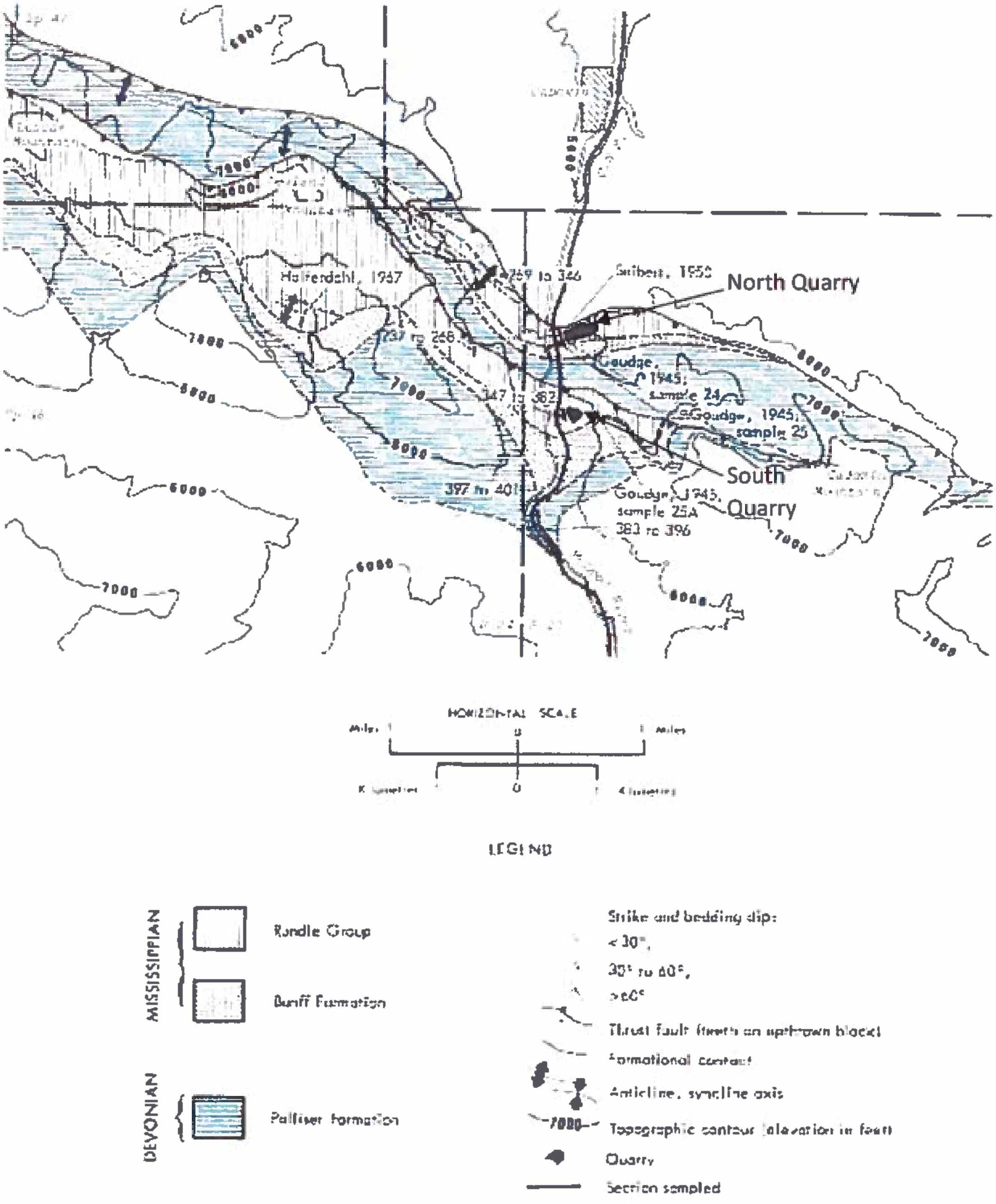
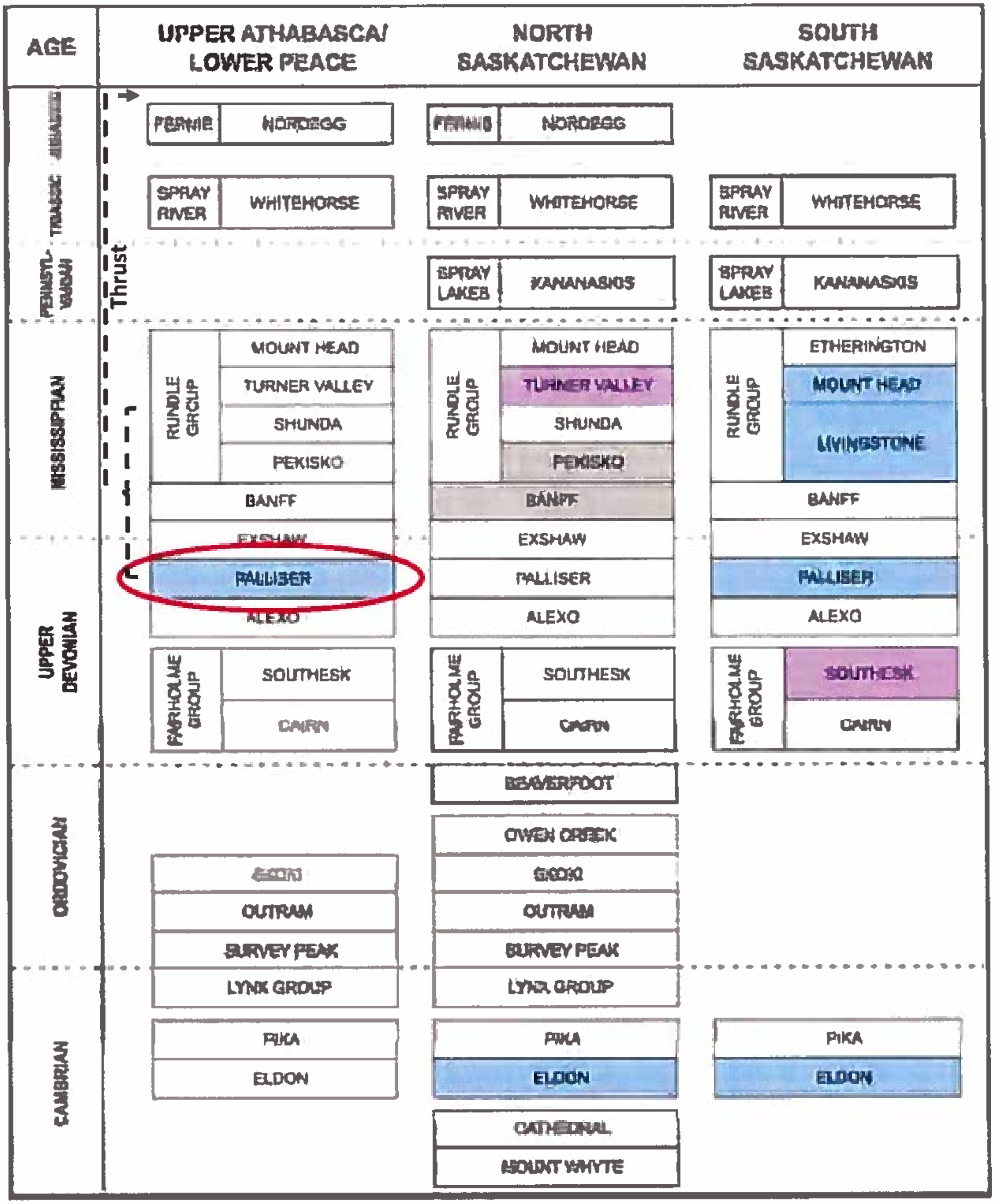


Figure 16. Geology of the Cadomin area (after MacKay, 1929)

Holter, M.E. (1975): Limestone resources of Alberta; Alberta Research Council, ARC/AGS Economic Geology Report 4, 100 p.



- * Blue denotes high-calcium limestone formations with current or historic production
- * Purple denotes high quality dolomite formations with current or historic production
- * Grey denotes limestone formations with current or historic aggregate or building stone production
- * Sourced from Holter (1976) and Alberta Geological Survey (2015): Alberta Table of Formations, Alberta Energy Regulator, URL https://www.aer.ca/documents/catalog/TOF.pdf [2016-11]

Krueger, K., Kluczny, P. and Dahrouge, J. (2016): Limestone and dolomite prospects for industrial use in the Alberta Foothills and Front Ranges; Alberta Energy Regulator, AER/AGS Special Report 102, 16 p.

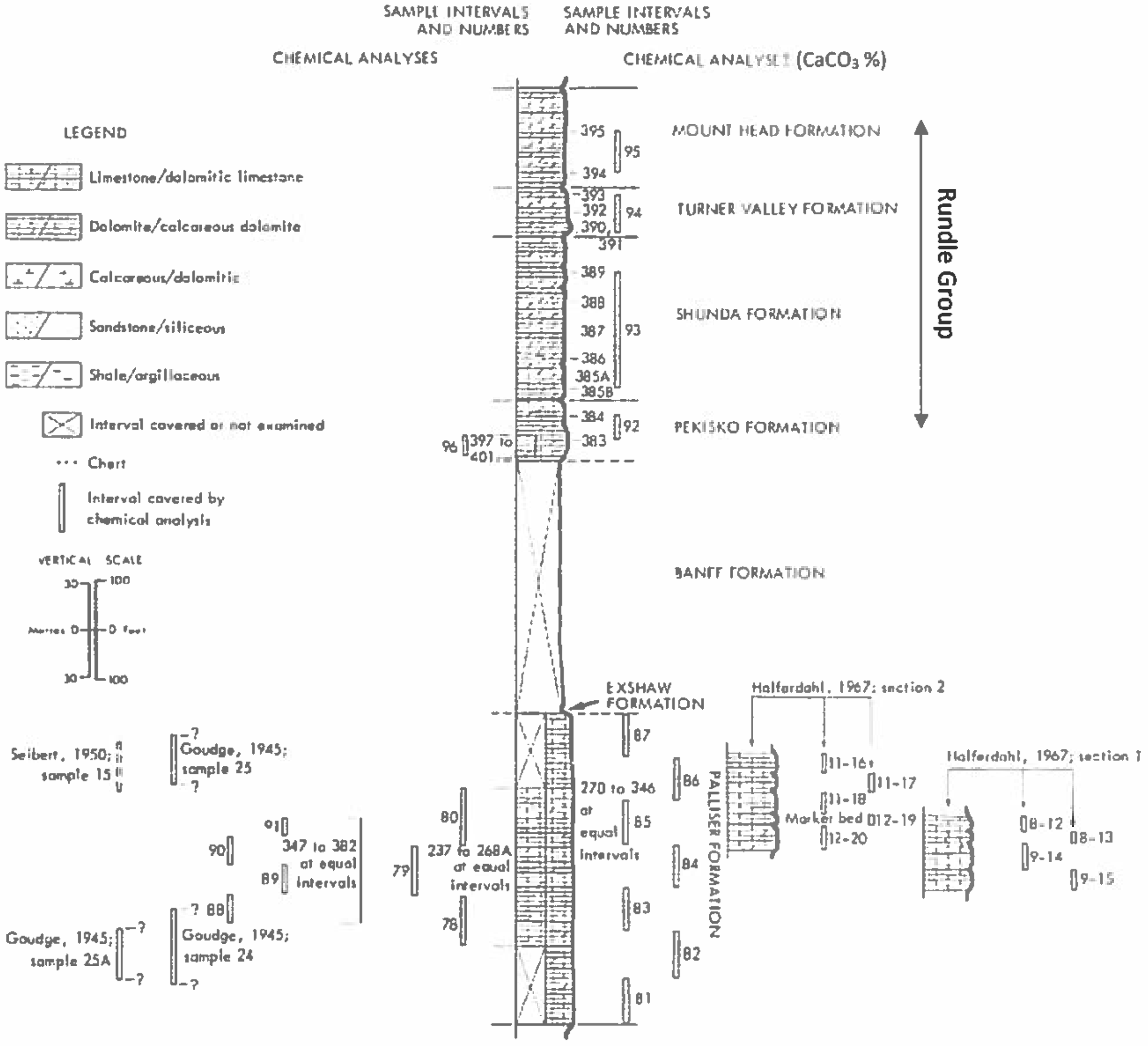


Figure 17. Composite section, limestone-bearing strata, Cadomin area

Holter, M.E. (1975): Limestone resources of Alberta; Alberta Research Council, ARC/AGS Economic Geology Report 4, 100 p.

APPENDIX 1

History of Cement - Cement Association of Canada

What do you think is holding the pyramids together?

Cement and concrete might be synonymous as household terms, but are by nature different: cement, an ultra-fine gray powder, binds sand and rocks into a mass or matrix of concrete. Indeed, cement is the key ingredient of concrete.

Semantics aside, concrete is the signature material in driveways, patios, basements, and a host of other Canadian household items. It is also the world's most widely used building material. Annual global production of concrete hovers around 5 billion cubic yards, a volume approximated by yearly cement production levels of about 1.25 billion tons.

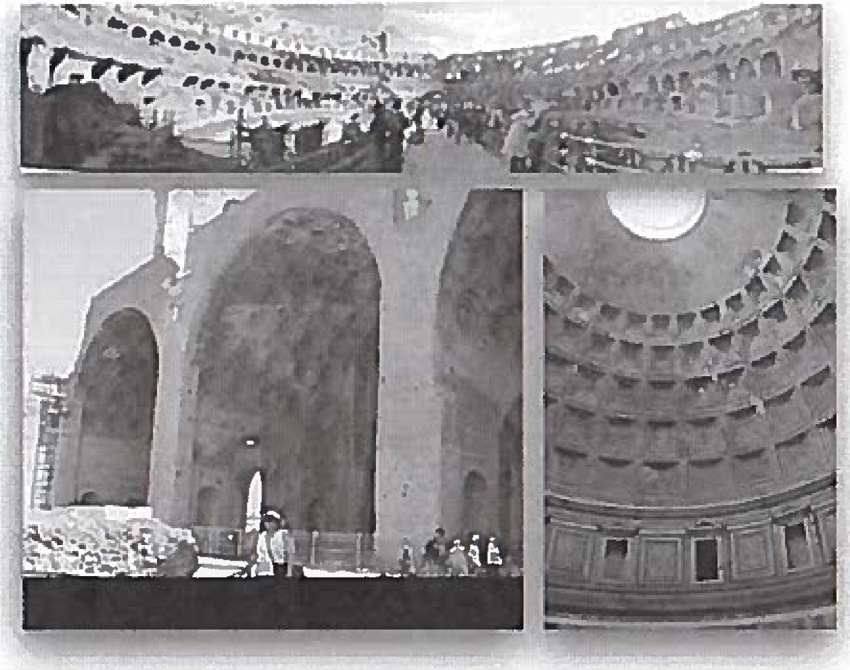
Concrete's global appeal is not accidental - the ubiquitous, stone-like material is produced from some of the world's most abundant resources, as is cement.

Early History and Development of Portland Cement

Ever since civilizations first started to build, we've sought a material that would bind stones into a solid, formed mass. The Assyrians and Babylonians used clay for this purpose, and the Egyptians advanced to the discovery of lime and gypsum mortar as a binding agent for building such structures as the Pyramids.

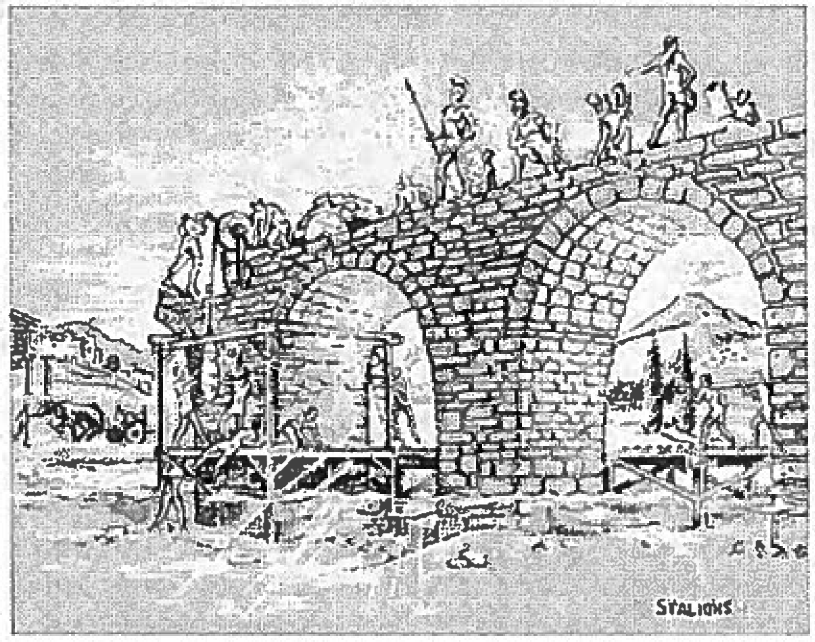
The Greeks made further improvements and finally the Romans developed a cement that produced structures of remarkable durability.

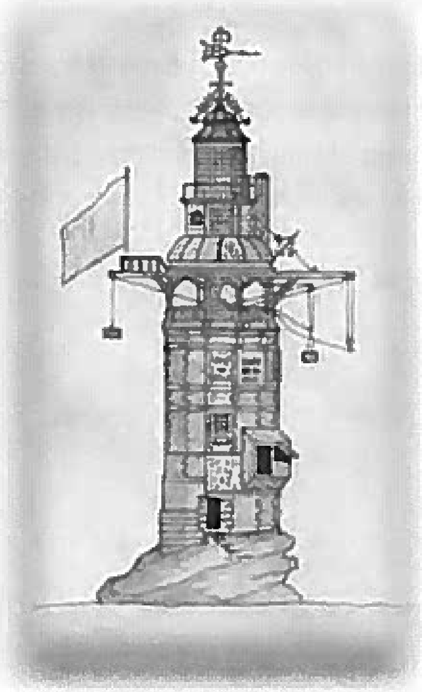
Most of the building foundations in the Roman Forum were constructed of a form of concrete, placed in some locations to a depth of 12 feet. The great Roman baths built about 27 B.C., the Coliseum, and the huge Basilica of Constantine are examples of early Roman architecture in which cement mortar was used.



Roman Formula

The secret of Roman success in making cement was traced to the mixing of slaked lime with pozzolana, a volcanic ash from Mount Vesuvius. This process produced a cement capable of hardening under water. During the Middle Ages this art was lost and it was not until the scientific spirit of inquiry revived that we rediscovered the secret of hydraulic cement -- cement that will harden under water.





Repeated structural failure of the Eddystone Lighthouse off the coast of Cornwall, England, led John Smeaton, a British engineer, to conduct experiments with mortars in both fresh and salt water. In 1756, these tests led to the discovery that cement made from limestone containing a considerable proportion of clay would harden under water.

Making use of this discovery, he rebuilt the Eddystone Lighthouse in 1759. It stood for 126 years before replacement was necessary.

Other men experimenting in the field of cement during the period from 1756 to 1830 include L. J. Vicat and Lesage in France and Joseph Parker and James Frost in England.

Before portland cement was discovered and for some years after its discovery, large quantities of natural cement were used. Natural cement was produced by burning a naturally occurring mixture of lime and clay. Because the ingredients of natural cement were mixed by nature, its properties varied as widely as the natural resources from which it was made.

Aspdin Obtains Patent

In 1824, Joseph Aspdin, a bricklayer and mason in Leeds, England, took out a patent on a hydraulic cement that he called portland cement because its color resembled the stone quarried on the Isle of Portland off the British coast. Aspdin's method involved the careful proportioning of limestone and clay, pulverizing them, and burning the mixture into clinker, which was then ground into finished cement.

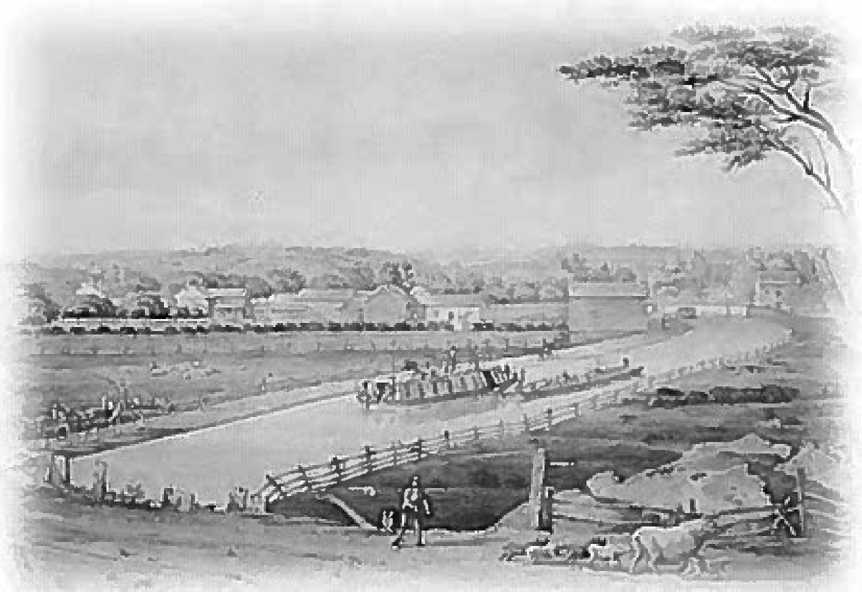
Portland cement today, as in Aspdin's day, is a predetermined and carefully proportioned chemical combination of calcium, silicon, iron, and aluminum. Natural cement gave way to portland cement, which is a predictable, known product of consistently high quality.

Today, about 98 percent of the cement produced in the United States is portland cement. In Aspdin's day, however, this new product caught on slowly. Aspdin established a plant in Wakefield to manufacture portland cement, some of which was used in 1828 in the construction of the Thames River Tunnel.

But it was almost 20 years later when J. D. White and Sons set up a prosperous factory in Kent that the portland cement industry saw its greatest period of early expansion, not only in England, but also in Belgium and Germany. Portland cement was used to build the London sewer system in 1859-1867.

The first recorded shipment of portland cement to the United States was in 1868, when European manufacturers began shipping cement as ballast in tramp steamers at very low freight rates.

History and Development of Portland Cement in the North America



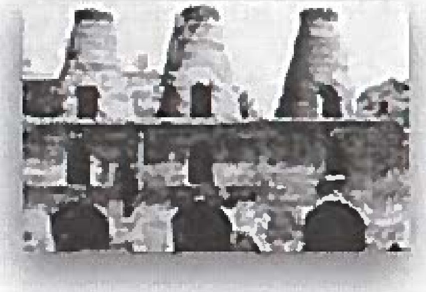
Construction of a system of canals in the first half of the 19th Century created the first large-scale demand for cement in this country. In 1818, a year after the Erie Canal was started, Canvass White, an engineer, discovered rock deposits in Madison County, NY, from which natural hydraulic cement could be made with little additional processing. He produced large amounts of this cement for use in the Erie Canal.

Other deposits were found, principally in the Rosendale district of New York, the Louisville district of Indiana and Kentucky, and the Lehigh Valley of Pennsylvania. By 1899, nearly 10 million bbl. of natural cement was produced annually in the US and Canada.

Although portland cement had been gaining in popularity in Europe since 1850, it was not manufactured in the US until the 1870s. Probably the first plant to start production was that of David O. Saylor at Coplay, Pa. In 1871, Saylor tried his hand at selecting and mixing different kinds of rock from his quarries to produce portland cement.

After initial difficulties, he succeeded, and at the Centennial Exhibition in Philadelphia in 1876, samples of Saylor's product and that made by John K. Shinn at Wampum, Pa., compared favorably with the best imported portland cements. While Saylor was perfecting his product in Pennsylvania, Thomas Millen and his two sons were experimenting with the manufacture of portland cement in South Bend, Ind. Their first portland cement was burned in a piece of sewer pipe (perhaps the first experimental rotary kiln used in America) and the resulting clinker was ground in a coffee mill.

A notable pioneer in the industry in America was Robert W. Lesley. In 1874, he founded the firm of Lesley &Trinkle, cement brokers, dealing in both natural and portland cements. This led to his entering the manufacturing business for himself in Egypt, Pa. From his previous sales contacts, he picked up some ideas for time- and labor-saving devices for manufacturing portland cement, most notable of which was a method for pressing the pulverized raw materials into "eggettes" for burning in the kiln.



In 1880, about 42,000 bbl. of portland cement was produced in the United States; a decade later, the amount had increased to 335,000 bbl. One factor in this tremendous increase was the development of the rotary kiln. In the early days, vertical stationary kilns were used and wastefully allowed to cool after each burning.

In 1885, an English engineer, F. Ransome, patented a slightly tilted horizontal kiln which could be rotated so that material moved gradually from one end to the other. Because this new type of kiln had much greater capacity and burned more thoroughly and uniformly, it rapidly displaced the older type.

Thomas A. Edison was a pioneer in the further development of the rotary kiln. In 1902, in his Edison Portland Cement Works in New Village, NJ, he introduced the first long kilns used in the industry-150 feet long in contrast to the customary 60 to 80 feet. Today, some kilns are more than 500 feet long. Parallel improvements in crushing and grinding equipment also influenced the rapid increase in production.

APPENDIX 2

Types of Portland Cement - Cement Association of Canada

The right mix for the job

Typical uses for General Use cement include highways, floors, bridges and buildings.

Portland cements are hydraulic cements – in other words, cements that set and harden by reacting chemically with water – and are composed primarily of hydraulic calcium silicates. The reaction process, called hydration, combines cement and water to form a stone-like mass.

Various types of portland cement are manufactured to meet different physical and chemical requirements for specific purposes. In Canada, the Canadian Standards Association (CSA) recognizes six types of portland cement under Standard A3001, as follows.

General Use Hydraulic Cement (GU) is a general-purpose cement suitable wherever the special properties of other types are not required. Its uses in concrete include pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipe, masonry units and various concrete products.

Moderate Sulphate Resistant Hydraulic Cement (MS) is used where precaution against moderate sulphate attack is important. It is used in normal structures or parts of structures that are exposed to soil or ground waters where sulphate concentrations are higher than normal but not unusually severe.

When sulphates in moist soil or water enter concrete, they cause chemical reactions that result in expansion, scaling and cracking. Wetting and drying in a sulphate environment aggravates the formation of sulphate salts or compounds that have sufficient crystallization pressure to disrupt cement paste.

Concrete exposed to seawater is often made with Moderate Sulphate Resistant cement. Seawater contains significant amounts of sulphates and chlorides. Although sulphates in seawater are capable of attacking concrete, the presence of chlorides reduces the expansive reaction that is characteristic of sulphate attack.

High-Early-Strength Cements are used where early concrete strength is required, as in cold weather concreting, fast paving to minimize congestion and rapid form removal situations.

Moderate and Low-Heat-of-Hydration Cements minimize heat generation in massive structures, such as bridge supports and dams.
Moderate Heat of Hydration Hydraulic Cement (MH) is specially manufactured to generate less heat, at a slower rate than General Use hydraulic cement. Heat of hydration is the heat generated by the chemical reaction when cement is initially mixed with water. The requirement of moderate heat of hydration can be specified at the option of the purchaser. This type of cement can be used in structures of considerable mass, such as large piers, foundations and thick retaining walls, in which temperature-related cracking may be a problem, especially when concrete is placed in warm weather.

High Early Strength Hydraulic Cement (HE) provides high strength relatively quickly, usually in a week or less. It is chemically and physically similar to General Use hydraulic cement, except that its particles are more finely ground. It is used when forms need to be removed promptly or when the structure must be put into service quickly. In cold weather, its use reduces the length of the curing period.

Moderate and High-Sulphate-Resistant Cements are used in situations where concrete is exposed to soils high in sulphate content, for example slabs on the ground, pipe and concrete posts.

White portland cement is used for white and light-coloured architectural applications.
Low Heat of Hydration Hydraulic Cement (LH) is used where the rate and amount of heat from hydration must be minimized. It develops strength at a slower rate than other cement types. This type of cement is intended for use in massive concrete structures, such as large gravity dams, where the temperature rise resulting from heat of hydration must be minimized. It is generally only available by specific request for large projects.

High Sulphate Resistant Hydraulic Cement (HS) is used in concrete exposed to severe sulphate action, principally where soils or ground waters have high sulphate content. It gains strength more slowly than General Use hydraulic cement. Use of a low water-to-cementing-materials ratio and low permeability are critical to the performance of any concrete exposed to severe sulphate attacks. Like other portland cements, it is not resistant to acids and other highly corrosive substances.

White portland cement differs from the usual gray cement chiefly in colour. It is made to conform to CSA specifications, usually General Use or High Early Strength hydraulic cement. The manufacturing process is controlled so that the finished product will be white. It is made of selected raw materials containing negligible amounts of iron and magnesium oxides, the substances that give cement its gray colour. White portland cement is used primarily for architectural purposes, such as precast curtain walls and facing panels, terrazzo surfaces, stucco, cement paint, tile grout and decorative concrete. Its use is recommended wherever white or coloured concrete, grout, or mortar is desired.

APPENDIX 3

VILLENEUVE AREA
(PREGLACIAL FLUVIAL DEPOSIT)

Geology:

The Villeneuve gravels are one type of preglacial gravel, described as 'Saskatchewan Sands and Gravels', (originally named 'South Saskatchewan Gravels' by McConnell in 1886) or more recently as Empress Formation (Shaw, 1993). The term Saskatchewan Sands and Gravels or Empress Formation refers solely to sand and gravel deposited in preglacial valleys (as valley fill or terraces) (Edwards, 1983). These gravels occupy an extensive network of preglacial bedrock channels in the Edmonton region (Figure 9, Shaw, 1993). Edwards and Scafe (1996) describe the Villeneuve formation as a Unit 1, Group 4 preglacial deposit.

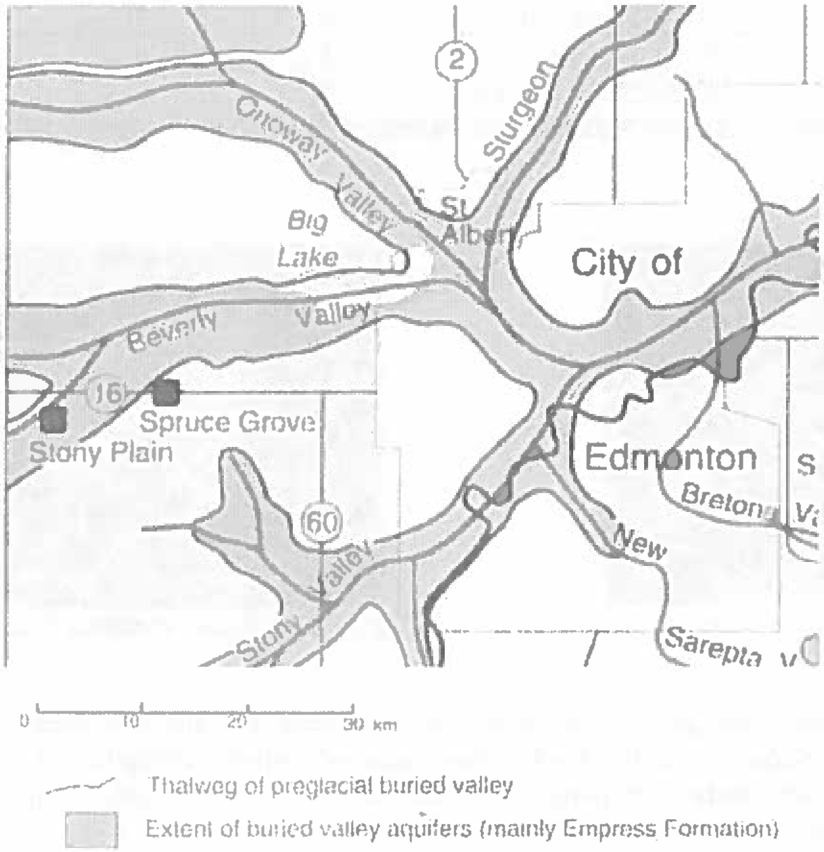


Figure 9: Preglacial valleys in the Edmonton region (Shaw, 1993).

These gravels were deposited just prior to continental glaciation: they show evidence of periglacial conditions (Photo 3) and contain cold climate fossils (Photo 4) (Burns, 1993). Dates on fossil materials recovered from the Villeneuve deposit (youngest preglacial unit) range from ~27,000 to 40,000 years before present (Edwards et al., 1994 and Edwards, 1998b).

The preglacial deposits generally are gravelly or even cobbly(Table 5). The coarse nature of these sediments is the result of their fluvial deposition in high energy systems and results in attractive deposits for the production of coarse aggregate. The Villeneuve deposit is not nearly as coarse as many other preglacial gravels (Table 6) with most of the gravel less than cobble size.

Table 5: Summary of geological properties of gravel from selected sites in the Edmonton region. (Edwards, 1983)

Origin	% Passing							Petrography (% wt)						Degree (%) of Fracturing
	3"	1"	#4	#10	#40	#100	#200	A	B	C	D	E	F	
Recent N. Sask. R. Terrace Gravel	94	64	31	25	12	2	1	56	15	24	-	-	5	<1
Saskatchewan Gravels (Villeneuve)	97	82	37	29	22	2	1	-	-	-	-	-	-	<1
Glacial Thrust Preglacial Gravel	93	60	27	24	16	3	2	96	3	-	1	<1	-	64
Outwash	81	48	29	20	5	2	1	69	6	24	-	1	-	<1
Preglacial Upland Gravel	95	60	24	20	12	2	1	96	3	-	1	<1	-	<1

A) quartzite, B) sandstone, C) granite and gneiss, D) conglomerate, E) carbonate, F) shale and ironstone

Photo 3: Fossil ice wedge

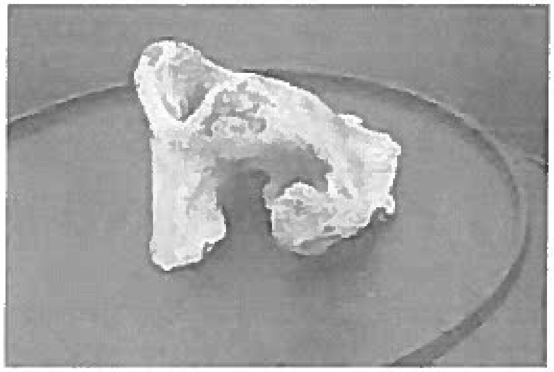


Photo 4: Fossil vertebrae (mammoth?)

The coarse sediments are derived primarily from sandstone and quartzite formations presently found in British Columbia or the Rocky Mountains of British Columbia and Alberta. Plains bedrock such as soft sandstones, shale, and ironstone forms a minor, deleterious component of most preglacial deposits (Table 7, Edwards, 1998b).

Table 6: General grain size distribution for samples collected at ten preglacial deposits (Edwards et al. 1985, 1994) (Edwards, 1998b)

Size Fractions		Preglacial Deposits* (value as %)									
		1	2	3	4	5	**6**	7	8	9	10
Gravel		58	66	75	78	70	**63**	81	80	77	70
	Boulders	0	0	0	3	0	**0**	2	0	0	0
	Cobbles	1	0	5	20	10	**3**	24	10	7	3
	Pebbles	57	66	70	55	60	**60**	55	70	70	67
Sand		41	33	23	19	28	**36**	17	19	21	29
	Coarse	17	9	2	4	3	**8**	1	3	5	10
	Medium	15	8	5	5	7	**7**	2	4	4	8
	Fine	9	16	16	10	18	**21**	14	12	12	11
Fines		1	1	2	3	2	**1**	2	1	2	1

* deposits located on or near: 1. Halverson Ridge, 2. Grimshaw, 3. Watino. 4. Swan Hills, 5. Pelican Mountains, **6. Villeneuve**, 7. Lacombe, 8. Wintering Hills, 9. Cluny, 10. Del bonita Uplands. Data for all sites except deposit 6 from (Edwards et al. 1994), data for deposit 6 from (Edwards et al. 1985).

Table 7: Rock types in the gravel (19 - 38 mm) fraction of preglacial deposits. (Edwards, 1998b)

Rock Type	Preglacial Deposits* (percentage of rock type)									
	1	2	3	4	5	6	7	8	9	10
Quartzite	33	23	24	54	31	10	35	26	57	29
Sandstone	37	28	68	35	59	67	49	42	9	32
Conglomerate	0	6	4	11	1	6	1	1	6	14
Shale**	0	0	<1	<1	7	3	3	3	0	1
Chert	4	5	2	<1	2	12	12	4	6	<1
Carbonate	0	0	0	0	0	0	0	8	20	0
Argillite	1	1	0	0	0	0	0	<1	0	23
Igneous**	0	11	<1	0	0	0	0	0	0	1
Quartz	25	14	2	0	0	2	2	0	2	0
Other Metamorphic***	0	13	0	0	0	<1	<1	0	0	0

* Deposits located on or near: 1. Halverson Ridge, 2. Grimshaw, 3. Watino, 4. Swan Hills, 5. Pelican Mountains, **6. Villeneuve**, 7. Lacombe, 8. Wintering Hills, 9. Cluny, 10. Del bonita Uplands, ** Includes mudstone and ironstone, *** Igneous and metamorphic rocks of mountain origin, not Canadian Shield origin.

Preglacial deposits at Villeneuve and Onoway contain some of the highest gold values in Alberta (Table 8, Edwards et al, 1994). Panning recovers up to 45 flakes (colours) per pan and consistently averages 25 colours. One gravel operator in the early 1990's reported a grade of 100 oz. gold per 100,000 tons of sand and gravel (Edwards et al, 1994). Panning for heavy minerals (gold, platinum, magnetite, garnet, diamonds) is a standard mapping technique during our sand and gravel mapping (Photo 5).

Table 8: Summary of placer gold results for preglacial groups (Edwards, 1994)

		Volumetric Results (g gold/m^3)	Results by oz. (gold/100 000 tons)	Panning (colours/pan)
Group 1				<2
	Range	0.0001 - 0.0017	0.84 - 1.62	
	Average	0.0012	1.32	
Group 2				<5
	Range	0.0001 - 0.0017	0.04 - 2.02	
	Average	0.0007	0.73	
Group 3/4 (includes Villeneuve)				<45
	Range	0.0013 - 0.0687	1.02 - 52.06	
	Average	0.0166	18.04	
Group 5				<25
	Range	0.0004 - 0.0061	0.38 - 7.98	
	Average	0.0025	3.31	
Group 6				<50
	Range	0.0028 - 0.1723	0.99 - 57.62	
	Average	0.0102	13.97	
Group 7				
	Range			
	Average	0.0009	0.52	

Photo 5: AGS geologist tests deposit for heavy minerals.

The postulated formation of the gravels is not only determined by the rock composition but by the structure of the beds. By analyzing the cross (Photo 6) and trough beds (Photo 7, 8) in the deposit and the imbrication (angle) of flat pebbles an idea of the direction of flow of the river that deposited the gravel can be estimated. Overall the flow direction was basically west to east as represented in the map of streamflow indicators (Figure 10, Edwards, 1996).

Photo 6: Cross beds here are ~one metre thick, bedding is emphasized by manganese staining, the flow direction would be from right to left.

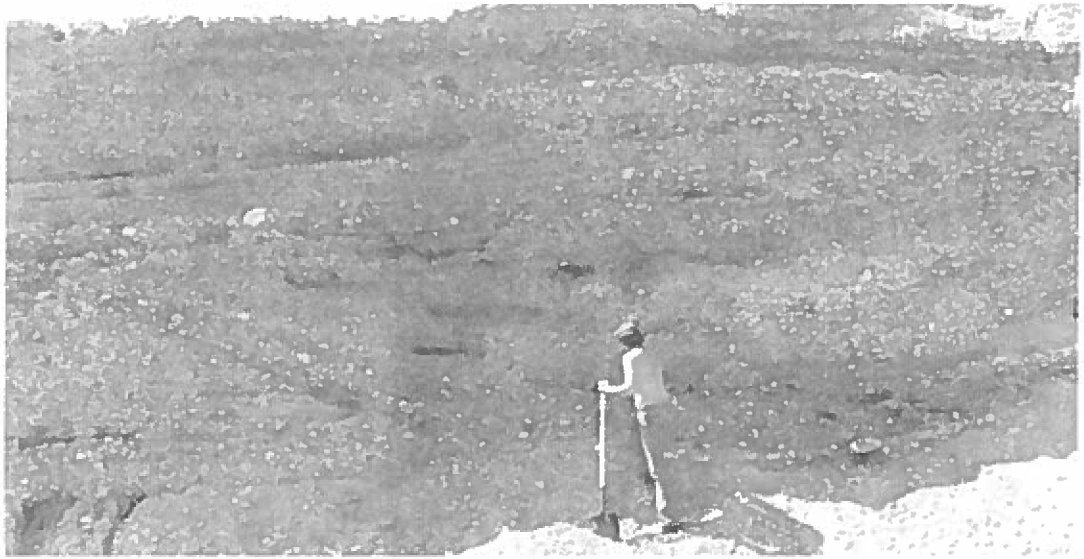


Photo 7: Large trough cross bed, direction of flow was out of bed towards geologist.

Workings in the Villeneuve area usually expose black soil on 1 to 4 m of glaciolacustrine fine sand-silt-clay over 4 to 8 m of clay till (Photo 9). At some locations two till units divided by glacial sand and gravel 3 to 5 m thick are seen (Figure 11). At the fieldtrip site there is 9 to 10 m of combined overburden (glaciolacustrine fine sand-silt plus clay till). The glaciolacustrine sediment was deposited in Glacial Lake Edmonton, is light in colour and has thin horizontal beds (Photo 9). The till is massive, medium brown in colour and may have a vertical blocky appearance due to joints (Photo 10). The till often forms a step vertical face. Overall the preglacial sand and gravel beds are 10 to 15 m thick. The beds appear as planar (horizontal) layers up to a metre thick (Photo 11) when viewed parallel to the original flow direction.

Photo 8: These sand beds have small troughs, flow was out of the photo at an oblique angle.

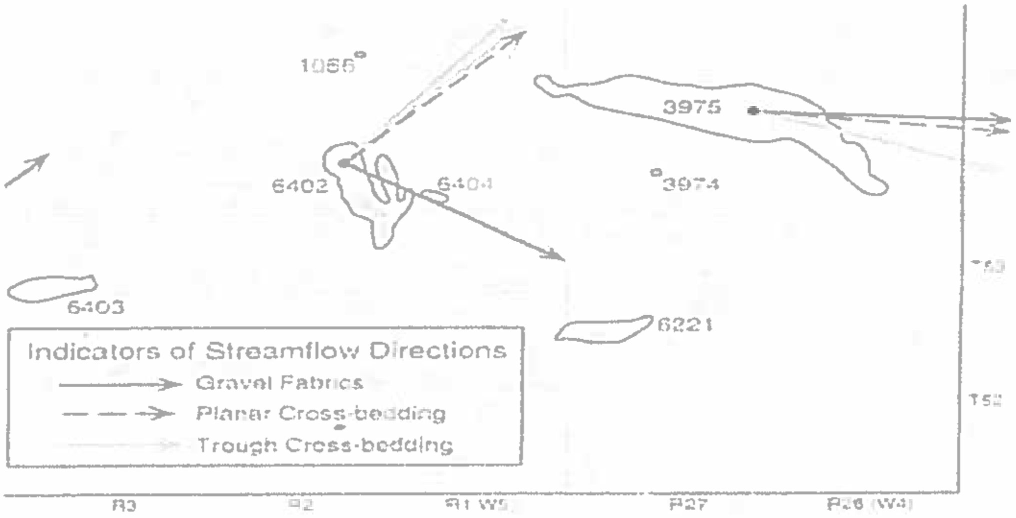


Figure 10: Summary streamflow vectors for indicators measured in the Entwistle-Villeneuv area. Villeneuve is deposit # 3975. (Edwards, 1994)

Photo 9: View of operating face that shows faint, thin beds of glaciolacustrine silt and clay over massive, blocky brown till.

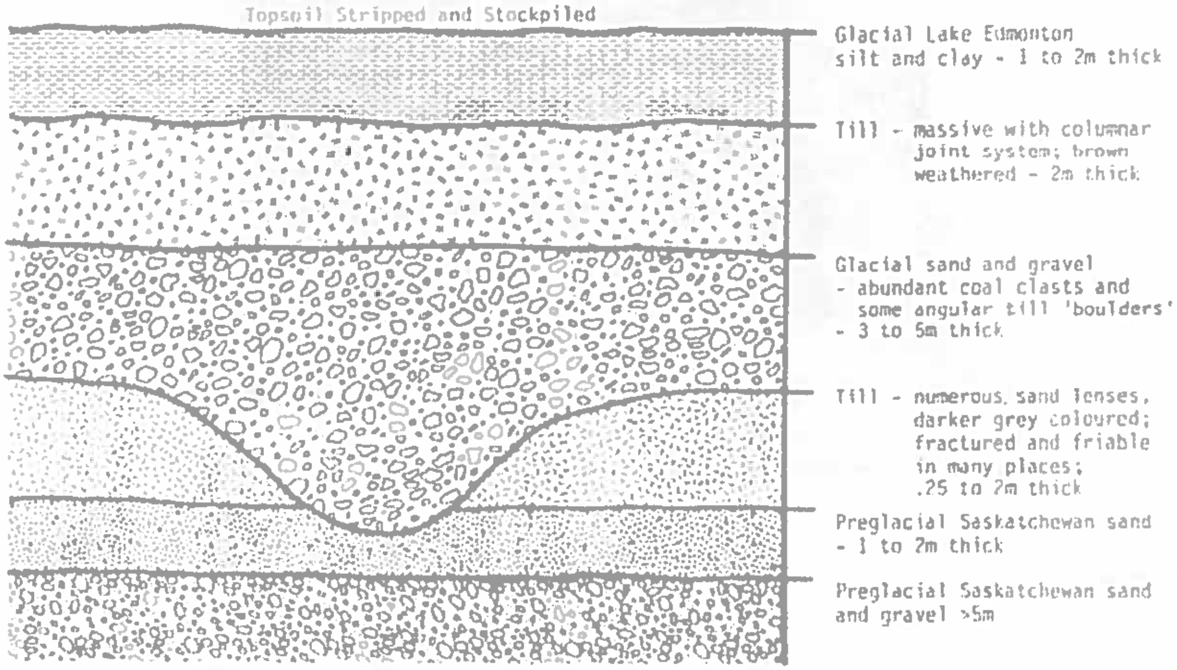


Figure 11: Generalized geologic section in Villeneuve deposit

Photo 10: Blocky, brown till over a glacial sand and gravel bed.

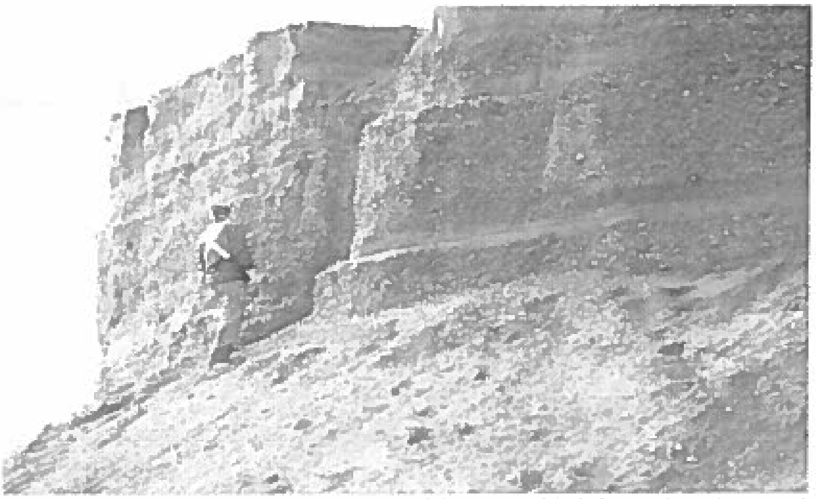


Photo 11: Horizontally (planar) bedded preglacial sand and gravel beds.

Exploration:

API

The Villeneuve deposit appears as a flat clay plain. Vegetation reflects the surface materials (now farmed). API would not pick this area as highly prospective for gravel.

Geological Model

Based on what we know about preglacial deposits the Villeneuve deposit is a classical Unit 1 preglacial deposit. The model suggests the deposit could be buried and identifies the approximate elevation at which the deposit would occur. In preglacial deposits in central and northern Alberta we routinely test the material for gold and diamonds.

Drilling

Nine auger holes were completed in the Villeneuve area (see round dots on aggregate map, Edwards, 1979). These test holes were very valuable in testing our hypothesis for the area and assigning a boundary for the potential deposit.

EM-31

The Villeneuve deposit is buried under ~10 m of glaciolacustrine silt-clay and till. The EM-31 does not register sand and gravel under this amount of cover. The resistivity readings at Villeneuve are:

o glaciolacustrine silt and clay	~25 mS/m
o clay till	~35 mS/m
o sand and gravel	<5 mS/m

Resources:

Preglacial deposits are critical resources supplying both the Calgary and Edmonton markets. Deposits northwest of Calgary (Bearspaw area) and Edmonton (Villeneuve) have become land use battlefields (Edwards, 1995). The Villeneuve deposit, using the 1979 AGS estimates from the St. Albert (83H/12) Aggregate Resources map (Edwards, 1979), is large in area (4836 hectares), contains extensive reserves (over 150 million m^3), and is thick (up to 15 m). Constituent rocks are hard and tough and the coarse aggregate yields some of the highest quality mineral aggregate produced in Alberta (Edwards, 1998b). The deposit requires significant overburden removal (up to 15 m). Extraction may require dredging or pumping water from the pit. This is an ideal deposit for hosting large operations and supplying the major Edmonton market.

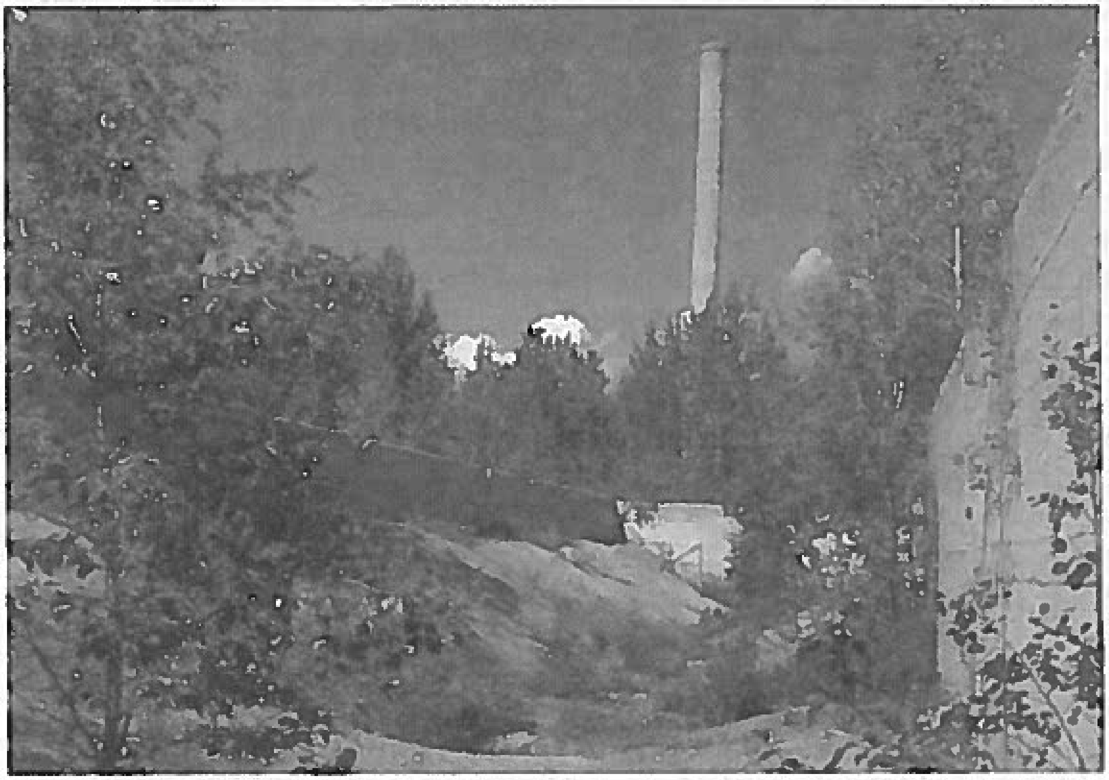
The massive gravel deposits at Villeneuve, fifty-km northwest of Edmonton and in an adjoining municipality, were developed in the late 1960's to service the Edmonton market (see the air photo history fold out). Information from the Alberta Research Council groundwater group in the 1970's and later the AGS Aggregate Inventory helped to identify and confirm the Villeneuve area as the premier source of aggregate for the Edmonton region. In 1970 the Alberta government commissioned a major study on gravel extraction in this area. A comprehensive report identified the problems that would result from lowering the elevation of such a large area by 10 to 15 meters and recommended prohibition of residential development to ensure proper management and reclamation.

A review is underway in the Calahoo area to assess continued gravel extraction. The review resulted from a challenge by local residents. The reason for conflict is the juxtaposition of the residents and mining. This relationship is similar to the situation that excluded Edmonton valley deposits 30 years earlier. An Environmental Impact Assessment at >$500,000 will be required before operations can continue through extension of pits that have been in existence for 30 years (Walls, 2001).

Other preglacial deposits in the Edmonton region are found north of Lake Wabamun, south of Onoway, protruding into the North Saskatchewan River valley upstream from the Alberta Provincial Museum and paralleling the North Saskatchewan River east of Edmonton.

APPENDIX 4

MARLBORO: Lonely Chimney in the Muskeg
From Mussieux, R. and Nelson, N.(1998) A Traveller's Guide to the Geological Wonders of Alberta. The Provincial Museum of Alberta. 254 p.



Ron Mussieux – Provincial Museum of Alberta

The chimney stands above the ruins of the Marlboro Cement Plant.

HIGHLIGHTS

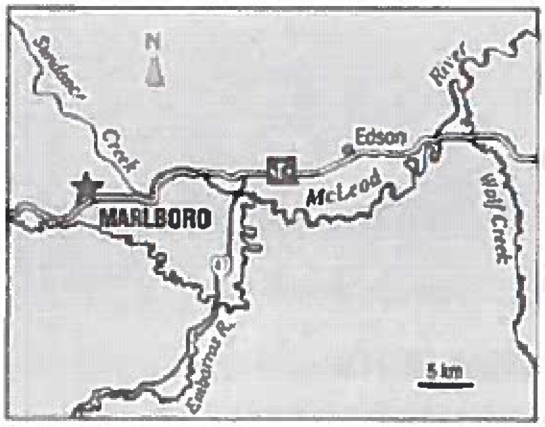
Many motorists travelling the Yellowhead Highway (Highway 16) have pondered why a lonely chimney rises 56 metres above the muskeg near Marlboro, 35 kilometres west of Edson. This is the site of Alberta's first cement plant and the smokestack is a reminder of a dream that fell far short of its goals. The plant was built in 1913 by the Edmonton Portland Cement Company. This site was chosen because of the nearby extensive marl and clay deposits and its closeness to the Grand Trunk Pacific Railway. Marl was once used as a major constituent in cement.

THE STORY

Marl is a soft, crumbly, fine-grained limestone (calcium carbonate) that forms only in fresh waters. The Marlboro region has areas of high relief, and as groundwater moves through these higher hills it dissolves limestone fragments in the glacial deposits. This lime-rich water trickles out as springs near the sloughs and ponds adjacent to the plant. As the spring water warms, it can not hold as much carbon dioxide and calcium carbonate (marl) is precipitated. The precipitation of marl is further increased by animal and plant activities that change the carbon dioxide and calcium concentration in the water.

Marl can be used as a livestock feed supplement, as a treatment for acidic soils, or in cement. Cement is composed of calcium carbonate and silica. At very high temperatures, these two fuse together to form solid blocks. The blocks are then crushed into a fine powder that we call cement. This is mixed with water, sand, and gravel to form concrete.

At the beginning of this century, Edmonton was going through a major development boom. Projects like the High Level Bridge and the Legislature Building required large amounts of cement, which had to be shipped in from Ontario at high cost. When marl was discovered by railway workers at the Marlboro site in 1910, the people of Edmonton thought they had found an inexpensive alternative to the Ontario cement. With a large deposit of marl and nearby silica and coal to heat the kilns, the plant was expected to be a great success. Well known and wealthy Edmonton businessmen, like George Bulyea and Henry Marshall Tory, invested a total of three quarters of a million dollars in the cement plant. Unfortunately, the plant never did as well as expected because the nearby silica was unsuitable and there was too much competition from other cement plants. The plant was closed in 1931 and today all that remains are the towering smokestack and the foundation walls of the old buildings that are now being overgrown by trees. The marl, which gives the nearby town of Marlboro its name, still forms and can be seen clearly from the edge of the highway.



B.1370 – Provincial Archives of Alberta

The Edmonton Portland Cement Company Plant at Marlboro in the 1920s.

APPENDIX 5

Holter, M.E. (1975): Limestone resources of Alberta; Alberta Research Council, ARC/AGS Economic Geology Report 4, 100 p.

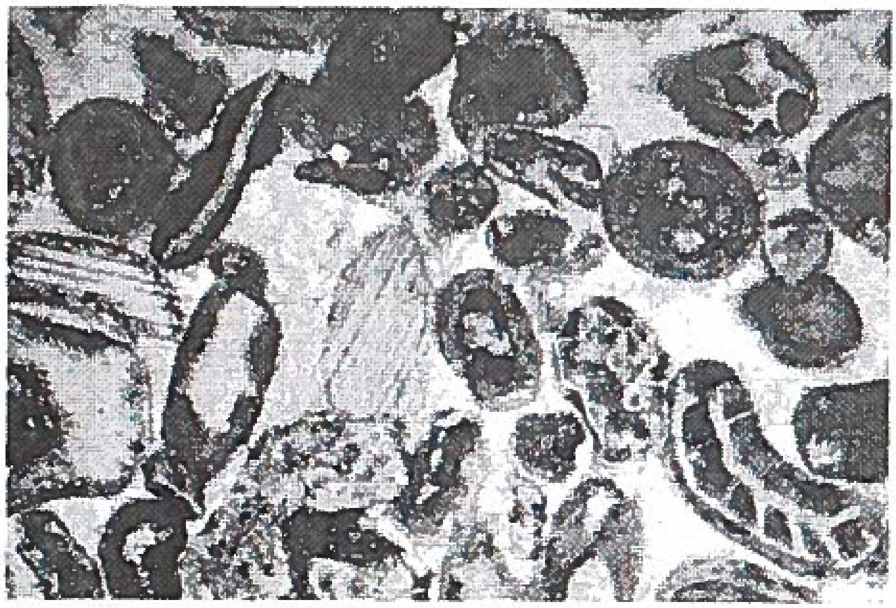


PLATE 8. Photomicrograph of limestone, Pekisko Formation, Nordegg area (sample 146, 400X).

CADOMIN AREA

LOCATION AND ACCESSIBILITY

The Cadomin area, 60 miles (97 km) southwest of Edson, is reached by Highway No. 47 and a branch of Canadian National Railways. Cadomin is the only community in the area with the exception of the nearby station of Leyland, the local railway servicing point. Inland Cement Company operates a large quarry south of Cadomin which supplies limestone to the company's cement plant in Edmonton, 190 miles (306 km) to the east (Plate 9).

Relief in the area ranges from rolling foothills with elevations near 5,000 feet (1500 m) to the rugged topography of the Nikanassin Range where elevations may exceed 8,000 feet (2400 m) (Fig. 16). The Mcleod River flows through a ½ mile (0.8 km) wide gap in the range at Cadomin.

GEOLOGY

The geology of the area is presented on two maps by MacKay (1929): the Cadomin and Mountain Park sheets (compilation given in figure 16). Paleozoic and early Mesozoic strata are thrust north over Jurassic and Cretaceous strata. The regional strike is west-northwest. Formations north of the main thrust are folded with the amplitudes of the structures decreasing northeastward away from the Nikanassin Range. Devonian and Mississippian strata southwest of the front of the range dip south at angles averaging approximately 25 degrees. They have been repeated at least twice by secondary thrusts or splays. A few folds and minor thrusts have been mapped in these beds.

The Palliser Formation is composed of thick-bedded, grey, fine-grained limestone and interbedded dolomitic limestones (Plate 10) with minor chert in part. Gotts (1966) reported that at least three magnesian limestone beds are continuous through the main Inland Cement deposit: one near the top, about 100 feet (30 m) below the Exshaw shale contact, one in the center, and one near the base. He further states that these high-magnesian beds vary in thickness from 10 to 40 feet (3 to 12 m) and, on fresh surfaces, are not distinguishable by eye from the high-calcium beds. On weathered surfaces, however, the dolomite has an irregular brownish grey mottling. The upper dolomitic band is thicker in the abandoned Inland Cement quarry (Fig. 16, Plate 11), otherwise the formation exhibits similar bedding characteristics within the southern thrust slice.

Seven feet (2 m) of dark brown shale comprising the Exshaw Formation overlie the Palliser. The Banff Formation, above the Exshaw, has been subdivided into three units by Macqueen (1966). The lowest is a recessive unit, 352 feet (107 m) thick, consisting of dark brown, calcareous shales and minor interbedded shaly, very fine-grained limestones at the base. The middle is a resistant 63-foot (19-m) thick unit, composed of medium-to thin-bedded, grey, very fine-grained limestones,

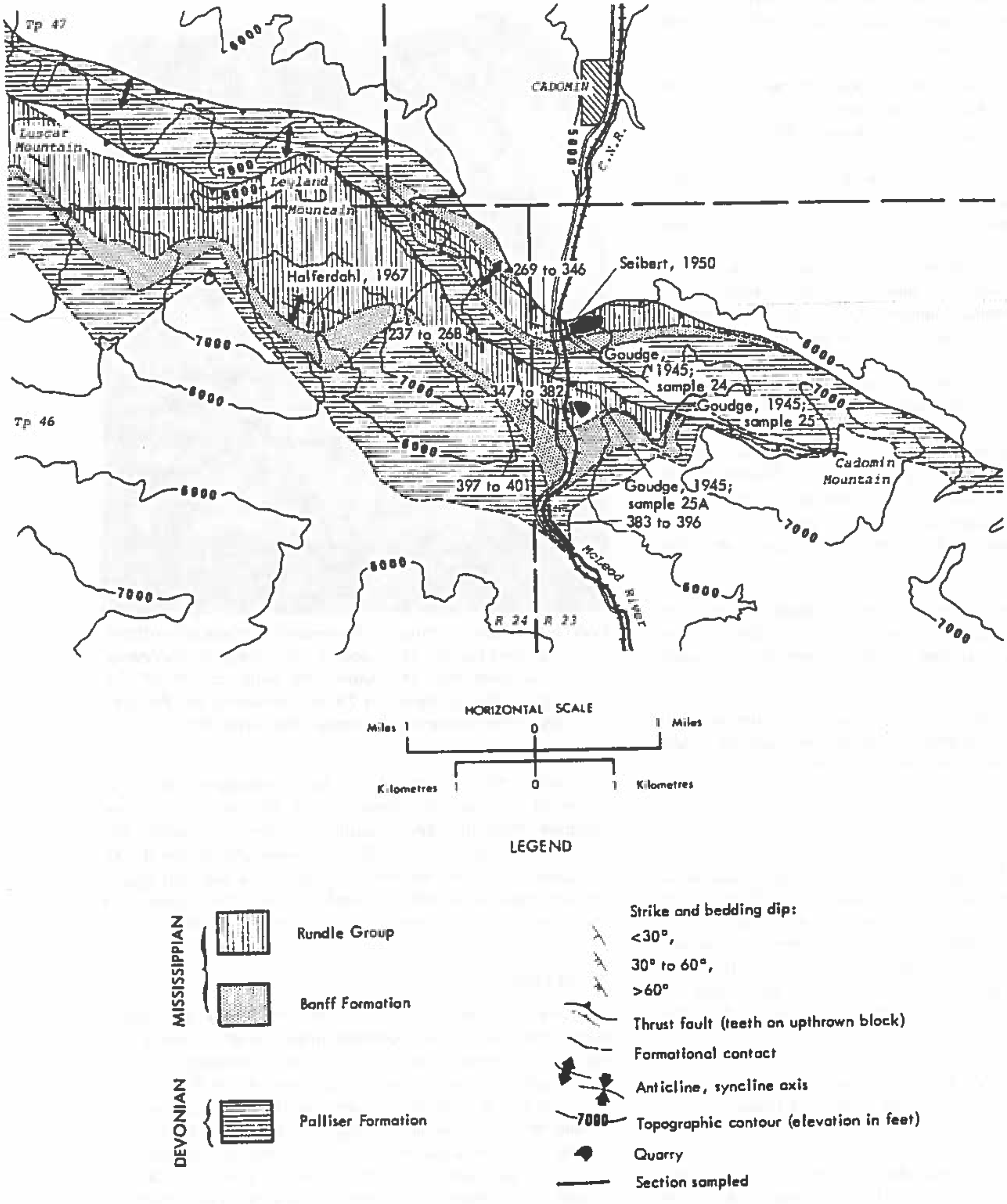


Figure 16. Geology of the Cadomin area (after MacKay, 1929)

dolomitized in part, with calcareous shale interbeds. At the top is 100 feet (30 m) of microcrystalline to very finely crystalline, yellowish brown silty dolomites with minor interbeds of very fine-grained limestones.

The Rundle Group is well exposed along the railway opposite the mouth of Whitehorse Creek. Stratigraphy of the beds has been described in detail by Macqueen (1966).

The Pekisko is mainly massively bedded, very fine- to very coarse-grained, light grey limestone. The limestone is dolomitized in places and grey chert bands occur near the top.

Macqueen (1966) recognized four units within the Shunda Formation. The lowest is 66 feet (20 m) of recessive, thickly bedded, finely crystalline dolomite. Overlying this is 134 feet (40 m) of cyclically bedded carbonates with individual cycles varying between 3 and 5 feet (1 to 1.5 m) in thickness. A single cycle consists of very fine-grained limestones passing upwards into tan, microcrystalline to very finely crystalline dolomite. This cycle may be immediately repeated or may be overlain by shaly dolomite beds or finely crystalline dolomite. The third unit includes 38 feet (11 m) of microcrystalline dolomite and shaly dolomite. The upper part of the Shunda is composed of 94 feet (28 m) of breccias, brown microcrystalline dolomites, shaly dolomites, and grey, very fine-grained limestones.

The Turner Valley Formation contains finely to medium-crystalline, brown, porous, and resistant dolomite. The upper part is finely crystalline and less porous than the lower part.

Microcrystalline to finely crystalline dolomite interbedded with green dolomitic shale or shaly dolomite makes up the Mount Head Formation. The formation is 200 feet (60 m) thick in the Cadomin area.

SAMPLING

The entire Palliser Formation was sampled by the author at the presently active Inland Cement quarry (see figure 17 for sampling intervals and stratigraphy). Exposures sampled in the company's abandoned quarry 1 mile (2 km) to the south represent beds near the middle of the formation. One section measured and sampled across the valley and above the Cadomin caves (samples 237 to 268) is also of strata from the middle of the formation.

A brief account of sampling carried out on the site of the main Inland Cement quarry before operations began is given by Seibert (1950).

Halferdahl (1967) tested two sections on Leyland Mountain 3 miles (5 km) west of the main Inland Cement quarry. The beds outcrop along a small tributary of Whitehorse Creek and are from the top of the Palliser Formation.

PLATE 9. Palliser limestone exposed at the main Inland Cement Quarry at Cadomin. Quarrying is underway at a level near the upper left hand corner of the photo. The Nikanassin Thrust, thrusting the Palliser over the Fernie is exposed at the lower left.

The author did not sample the Banff Formation. However, overlying Mississippian beds of the Rundle Group were sampled along the railway south of Cadomin opposite the mouth of Whitehorse Creek. Samples were also obtained from the basal part of the Pekisko Formation at a low cliff above the campgrounds on Whitehorse Creek. Goudge's account of investigations in the Cadomin area is included in Appendix C.

ANALYSES

Samples taken in the Palliser Formation, along the railway below the main Inland Cement quarry, were divided into successive 100-foot (30-m) intervals and analysed (Fig. 17). The results are documented in analyses 81 to 87 inclusive (samples 270 to 346) and indicate $CaCO_3$ grades of between 86 and 96 percent. A similar range of values was determined for the abandoned quarry using similar procedures (analyses 88 to 91, samples 347 to 382). Goudge's sample 24 was probably from mottled beds in the middle or lower part of the formation whereas sample 25 was from strata near the top. Analyses of the former reflect the presence of dolomite mottling (6 percent $MgCO_3$); the latter proved the deposit's economic potential (96 percent $CaCO_3$). Seibert (1950) provided one analysis of the upper part of the Palliser, on beds outcropping on the face above the railway (98 percent $CaCO_3$). The top of the mountain above the quarry yielded samples with not less than 96 percent $CaCO_3$. Samples from the middle of the Palliser taken by the author across the valley from the plant showed relatively low $CaCO_3$ (87 to 92 percent) and high $MgCO_3$ (6 percent to 11 percent). The results are given in analyses 78 to 80 (samples 237 to 268A).

Quality of upper strata of the Palliser Formation was determined by Halferdahl (1967) farther west on Leyland Mountain. Calcium carbonate contents vary from 87 to 97 percent and only one sample exceeds 5 percent $MgCO_3$ (analysis 12-20). Silica values tend to be relatively high and are commonly greater than 2 percent.

The basal beds of the Mississippian Pekisko Formation sampled above the campgrounds on Whitehorse Creek, are of very low industrial quality (analysis no. 96, samples 397 to 401, 79 percent $CaCO_3$). The formation was also tested along the railway south of Whitehorse Creek and low grades were verified (analysis no. 92, samples 383 to 384, 54 percent $CaCO_3$). The remainder of the Mississippian succession above the Pekisko, also examined along the railroad, consists of highly dolomitic material (analyses 92 to 95, samples 385 to 395).

Results of X-ray fluorescence analyses of individual samples are given in Appendix B.

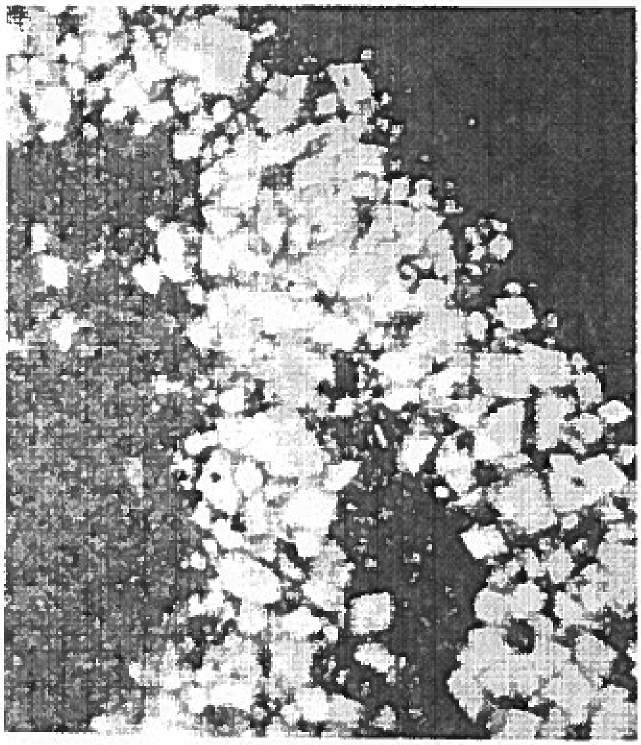


PLATE 10. Photomicrograph of mottled limestone showing dolomite rhombs comprising the mottled zones and very finely crystalline limestone of the main rock mass (sample 339, 400X).

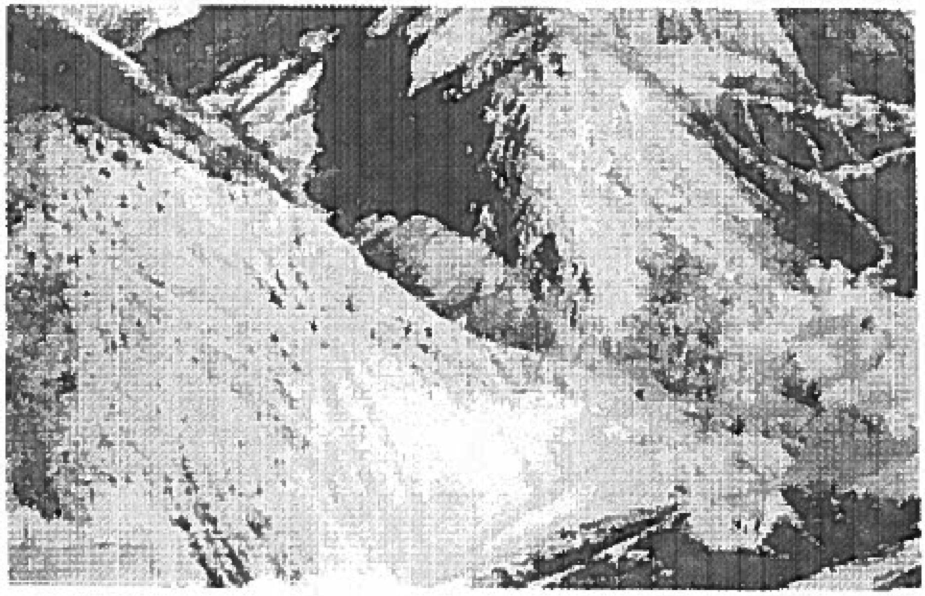


PLATE 11. Abandoned Inland Cement quarry in Palliser strata at Cadomin, situated approximately one mile south of the main quarry. The Palliser overlies the Rundle Group (to the left) along a thrust demarked by Cadomin Creek (center of photo).

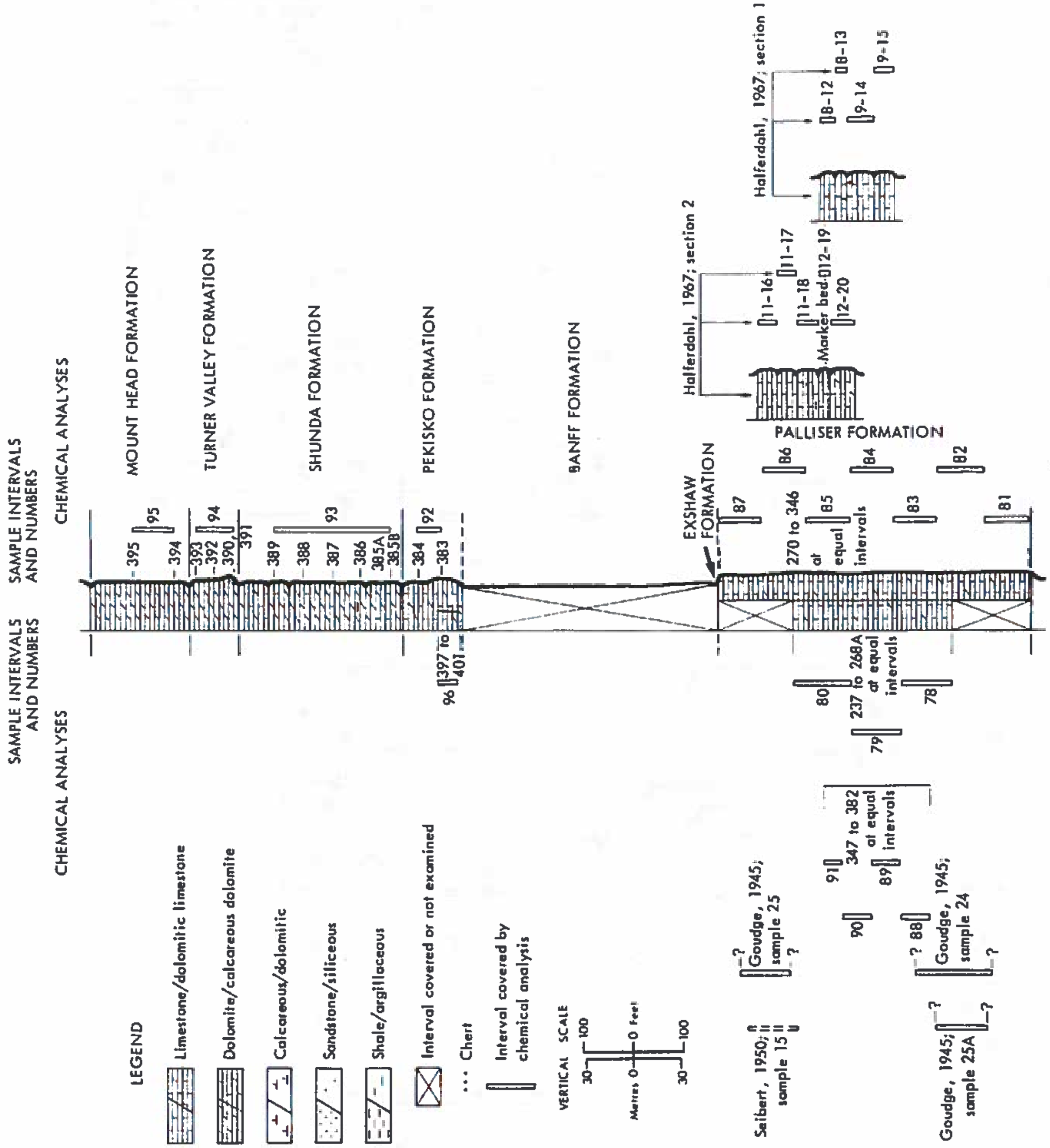


Figure 17. Composite section, limestone-bearing strata, Cadomin area

PRODUCTION AND RESERVES

Palliser limestones were first quarried for lime production close to the present site of the main Inland Cement quarry. For a brief time, after quarrying operations began to supply the cement plant in Edmonton, Inland Cement also produced limestone from the south quarry. This quarry was later abandoned in favor of production from the top of the north deposit. Details of history and development and reserves of the area are provided by Gotts (1966).

The Alberta Lime Company has recently done evaluation work on Leyland Mountain on their property west of that of Inland Cement. The Palliser sections described by Halferdahl occur on the company's property.

The Palliser appears to be the only formation in the area containing high-calcium limestones. Reserves and development potential hinge on the distribution and accessibility of this one unit.

BRÛLÉ AREA

LOCATION AND ACCESSIBILITY

The Brûlé area is located 15 miles (24 km) west of Hinton and 200 miles (320 km) west of Edmonton. Highway No. 16 passes through the area as does the main line of Canadian National Railways. Brûlé, on the west side of Brûlé Lake, is the only community in the area and provides minimal commercial services (Fig. 18).

The Athabasca River flows from a wide mountain valley in the west into the adjacent foothills where it immediately broadens out to form Brûlé Lake. The nearby northwest-southeast trending mountain ranges are up to 7,000 feet (2100 m) in elevation in contrast to the valley floor which lies at about 3,300 feet (1000 m). The eastern boundary of Jasper National Park at Brûlé is shown in figure 18. Investigations for limestones were confined to occurrences outside the Park.

GEOLOGY

The Brûlé area was mapped by Lang (1947) and Mountjoy (1959); the results are compiled in figure 18. Typical Rocky Mountain structural features are observed in the area. Paleozoic strata are thrust east over Mesozoic beds along the main fault, the Boule Thrust. A second major thrust, the Perdrix Fault, has repeated the Paleozoic rocks within a distance of less than 1 mile (2 km) across the strike. Folding Mountain, on the east side of the area, is an anticlinal outlier of Paleozoic rocks 1 mile (2 km) beyond the mountain front. The east limb of anticlinal structures, dip southwest at angles of between 30 and 60 degrees. Due to thrusting, beds in the Brûlé area are more contorted than in the other areas of the Foothills and Front Ranges which were examined in this study.

The lowest stratigraphic unit present, the Mount Hawk Formation, is dark grey, argillaceous, thin-bedded, finely crystalline limestone with some calcareous shale. It may be up to 600 feet (180 m) thick.

Above the Mount Hawk is the Alexo Formation which includes less than 100 feet (30 m) of yellowish grey, calcareous

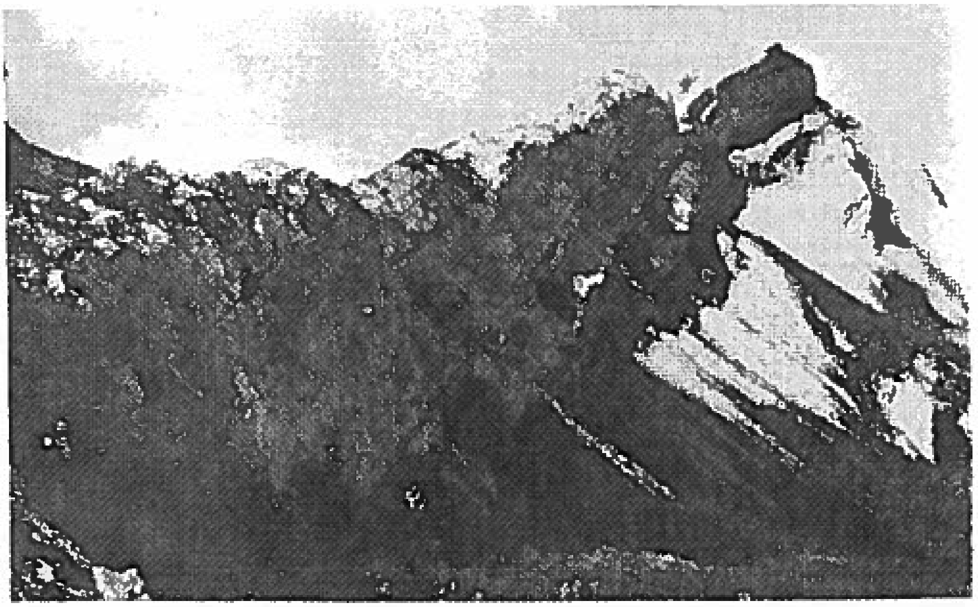


PLATE 12. Cliff-forming Palliser Formation exposed on Boule Range, Brule area. Photo taken from top of ridge ½ mile (0.8 km) south of Ogre Canyon, looking north.