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Limestone Prospects in the Vicinity of Crowsnest Pass: A Preliminary Assessment

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Chapter 1

Summary

1.1 Background

This study was commissioned for Summit Lime Works Limited by Alberta Energy and Natural Resources. Summit Lime Works requires new reserves of high-grade limestone for its Crowsnest Pass lime plant. Reserves in the existing quarry will last only 11 years with the company's proposed plant expansion, projected for 3 or 4 years from now. The company currently quarries 135,000 tonnes of limestone annually; with expansion, its production will almost double. Plant expansion and modernization are necessary for the company to maintain a competitive market position.

1.2 Prospective Localities

Prospective limestone-bearing formations in the Crowsnest Pass region are the Devonian Palliser and the Mississippian Livingstone Formations. The two formations crop out extensively in the vicinity of the Pass and present quarriable situations in several localities with existing access. Summit Lime Works Limited has determined its economic haul limit to be 24 km (15 mi), which limits prospects to two localities for detailed field geological study and evaluation. These are in Phillipps and Deadman Passes, both lying to the north of Crowsnest Pass about

2 km and 8 km respectively. Both are readily accessible by existing roads.

Localities south of Crowsnest Pass that could have potential limestone exploitaility lie in the Prime Protection Zone (Eastern Slopes Land Use Management Policy) and are closed to mineral development.

1.3 Study Methods

Six sites within the two localities selected for field study, and one site between the two, are herein evaluated for limestone exploitability. Sections of the Palliser and Livingstone Formations were measured and sampled systematically and the samples subjected to detailed chemical analyses. These data, along with field geological observations afford a preliminary evaluation of the limestone quality, extent, and quarriability at the sites.

Consideration of the feasibility of underground mining at existing quarry sites is based on cursory site observations and a review of the company's internal documentation.

1.4 Results

Study results are summarized in table 1 of the text. At Phillipps Pass, the Palliser Formation has three limestone zones of 95% or greater $CaCO_3$, with thicknesses of 86, 23, and 72 m. Two of the zones present favorable dipslope quarrying situations on the north side of the Pass, with reserves of 2.8 million and 10 million tonnes. The three zones are present but less easily quarriable on the south side of the Pass. The Livingstone Formation was not sampled at Phillipps Pass; it is indicated to have the same properties and unfavorable quarrying conditions here as in the company's operations on the south slope of Crowsnest Ridge.

At Deadman Pass, the Palliser Formation generally has lower quality limestone, with three zones averaging 91 to 94 percent $CaCO_3$. However, the uppermost zone is upgraded to 98 percent $CaCO_3$ if a single 3-m dolomitic bed is removed. This zone, 27 m thick, has reserves of 2.4 million tonnes in a favorable dipslope quarrying situation. The Livingstone Formation presents no quarriable sites on the Alberta side of Deadman Pass, but it has a limestone zone averaging 97 percent $CaCO_3$ that may be quarriable on the British Columbia side. The zone is near the top of the formation and is 42 m thick.

Between Phillipps and Deadman Passes, a site exists where the Palliser Formation forms an isolated knoll just east of the mountain range. The site (Site 7) lacks road access and was not sampled, but appears to present the upper and middle high-grade zones in a favorable quarrying situation. Reserves of nearly 2 million tonnes are indicated, with projected grades of 93 to 94% $CaCO_3$.

Underground mining at an existing quarry site appeared not to be economical feasible when evaluated in 1974. Re-evaluation may now show it as a viable option. Mining by a room-and-pillar method at the Quarry 1 site appears technical feasible but many factors remain to be studied.

1.5 Recommendations

Detailed site-specific geological mapping and structural studies are recommended for the prospects favorably appraised, particularly those in Deadman Pass where no land use zoning constraints or mineral dispositions exist. A follow-up test drilling program, designed on the basis of these studies, is recommended to fully evaluate the limestone quality and reserves at sites with confirmed quarrying potential.

Detailed structural analysis of the Quarry 1 site is recommended, to aid the current quarrying operation and to better define the reserves. In regard to underground mining, it is proposed that an economic feasibility review be carried out following the final evaluation of the quarry prospects.

Chapter 2

Introduction

2.1 General Remarks

Summit Lime Works Limited quarries limestone in the Crowsnest Pass for use in lime manufacture at its Crowsnest plant and also for sale as crushed limestone. Reserves of high-grade limestone at the operating quarry site are adequate for only 13 years at the present rate of production, about 135,000 tonnes per year. The company proposes to expand its lime plant, and accordingly to about double its kiln feed production, in order to remain competitive. With the proposed expansion, projected for 3 or 4 years from now, reserves exist for only 11 years. Clearly, the company requires additional reserves before plant expansion can proceed.

Additional reserves have been identified in a deposit six miles south of the plant, near the head of Ptolemy Creek. However, the deposit is situated in Zone 1 of the Eastern Slopes Land Use Management Policy, that is, the Prime Protection Zone, in which mineral development is prohibited. Moreover, it lies in proximity to a classical alpine karst area, the preservation of which has been strongly lobbied for by speleologists. The company's application for a quarrying lease in the area was disallowed, but the Alberta Government agreed to assist Summit Lime Works Limited in finding alternative sources of high-grade limestone.

The Alberta Research Council was commissioned by Alberta Energy and Natural Resources to study and evaluate limestone deposits in the vicinity of Crowsnest Pass, for the purpose of locating new reserves for the company. A preliminary review of the geology was made and prospective areas were identified. The company had determined that its economical haul limit was 24 km (15 mi), which indicated two potential localities for detailed field examination. Field work was carried out in September 1980; analytical work was completed in February, 1981. This report presents the results of the study and makes recommendations for follow-up exploration.

2.2 Location, Geography and Access

The area of study is in the vicinity of Crowsnest Pass in southwestern Alberta, in the Rocky Mountain Front Ranges, extending for about 10 km on either side (north and south) of the Pass.

Specific localities of field investigation in this study are in Phillipps and Deadman Passes, both lying to the north of Crowsnest Pass about 2 km and 8 km respectively. Both passes cut through the High Rock Range, which is the easternmost range of the Front Ranges north of Crowsnest Pass. The High Rock Range forms the Continental Divide here, and thus also the Alberta-British Columbia boundary. Its continuance southward from the Crowsnest Pass is called the Flathead Range. The High Rock Range trends approximately in a north-south direction and forms rugged topography with many spectacular cliffs along its eastern scarp slopes. Elevations along the range average 2,300 m, and in the two passes 1,600 m, for an average local relief of 700 m. Crowsnest Pass is much lower, with an elevation of only 1,350 m. The highest elevation in the area is 2,800 m, on Mount Ptolemy in the Flathead Range.

Crowsnest Pass is serviced by Alberta and British Columbia Highway No. 3 and by the southern mainline of the Canadian Pacific Railway. Secondary roads run north from Highway No. 3 along Allison Creek in Alberta and along Alexander Creek in British Columbia. A truck trail through Deadman Pass connects with both roads, to provide some difficult access to this area. Phillipps Pass has easy access directly from Highway No. 3 by a secondary road. The only access to the area south of Crowsnest Pass (apart from Summit's quarry haul road) is provided by a road to the abandoned Tent Mountain coal mine. A truck trail up to the head of Ptolemy Creek is no longer open to use.

Summit Lime Works Limited operations are located mainly on the north side of Crowsnest Pass about 1.5 km east of the British Columbia border. The plant is at Hazell, a siding on the CPR, and the main quarrying operations are just above the plant on the slope of Crowsnest Ridge (Fig. 1), where only the easternmost quarry is presently active. Quarries have been operated on the south side of the Pass, but are presently in disuse.

2.3 Previous Work

The geology of Crowsnest Pass and vicinity has been mapped by the Geological Survey of Canada in the course of regional geological mapping (Price, 1962).

Summit Lime Works Limited has had at least five geological investigations undertaken by private consultants since 1966 (Crabb, 1966; Van Raalte, 1969; Pelletier, 1973; Brasher, 1974; and Pool, 1974). All of the resulting reports deal with the Livingstone Formation around the existing quarries (north and south of the Crowsnest River) or in the Ptolemy Creek area. Limestone within the Livingstone Formation has been sampled also in Phillipps Pass by Summit Lime Works, but only on a preliminary basis.

Holter (1976) studied limestones in the Alexo Formation, the Fairholme Group, and the Palliser, Exshaw, Banff, Livingstone and Mount Head Formations in the Crowsnest Pass valley (Fig. 1).

2.4 Method of Study

Prospective localities for high-grade limestone were identified on the basis of regional geological mapping (Price, 1962), and previous work by Holter (1976) which indicates that high calcium limestones in this region are confined essentially to the Palliser and Livingstone Formations. Summit's defined economic haul limit of 24 km restricts the possibilities to narrow outcrop bands of Palliser and Livingstone that run through or nearby the plant site, northward along the High Rock Range, and southward along the Flathead Range. The Flathead Range in Alberta falls entirely within the Prime Protection Zone, which rules out this area for mineral development. This leaves only the High Rock Range north of Crowsnest Pass as prospective ground.

Phillipps and Deadman Passes provide the only accessible sites in the High Rock Range where the limestone formations are exposed at low and potentially quarriable elevations. Both are within the haul limits and are unencumbered by land use zoning constraints. These localities were selected for detailed geological examination and sampling of the limestone formations.

The sampling procedure followed was to take chip samples at average intervals of 1.5 m (some at 3 m) through the limestone sections, the sample spacing depending on the thickness of the section and degree of lithologic variation. The chip samples were combined to form composite samples representing stratigraphic intervals of uniform lithology. Samples were subjected to standard wet chemical analyses and these data were used together with field-derived geological information to obtain an assessment of the quality, extent and quarriability of limestones.

The study also included a geological review of the company's existing quarry sites, to determine the possibilities for extension of existing quarries, and as well, to gain some appreciation of the feasibility of underground mining. This involved site investigations plus a thorough review of the company's internal documentation.

Chapter 3

General Geology

The geology of the study area is mapped in detail in figure 1. The succession of formations is given in a generalized stratigraphic column for the Crowsnest Pass region in figure 2. Dominant lithologies of each rock unit are indicated graphically in the column. The principal limestone formations that crop out in the study area are the Devonian Palliser and the Mississippian Livingstone Formations.

The Palliser Formation consists typically of dark gray, finely crystalline limestone, massively bedded, and in part mottled with brownish gray, medium crystalline dolomite. It is 200 to 220 m thick and is a prominent cliff-forming unit that forms many of the precipitous eastern faces on High Rock and Flathead Ranges. The Livingstone Formation forms the basal unit of the Rundle Group and consists of light gray, medium-grained bioclastic limestone and finely crystalline limestone, with interbeds of finely crystalline dolomite commonly in the upper half of the unit. The succession is medium to thick bedded, and moderately resistant. Its thickness in the study area is about 350 m, although the section along High Rock and Flathead Ranges is much thickened by fault repetition.

Other limestones indicated in the lithologic column (Fig. 2) generally are too dolomitic, siliceous, or argillaceous to have potential as sources of high-grade limestone. The Mount Head

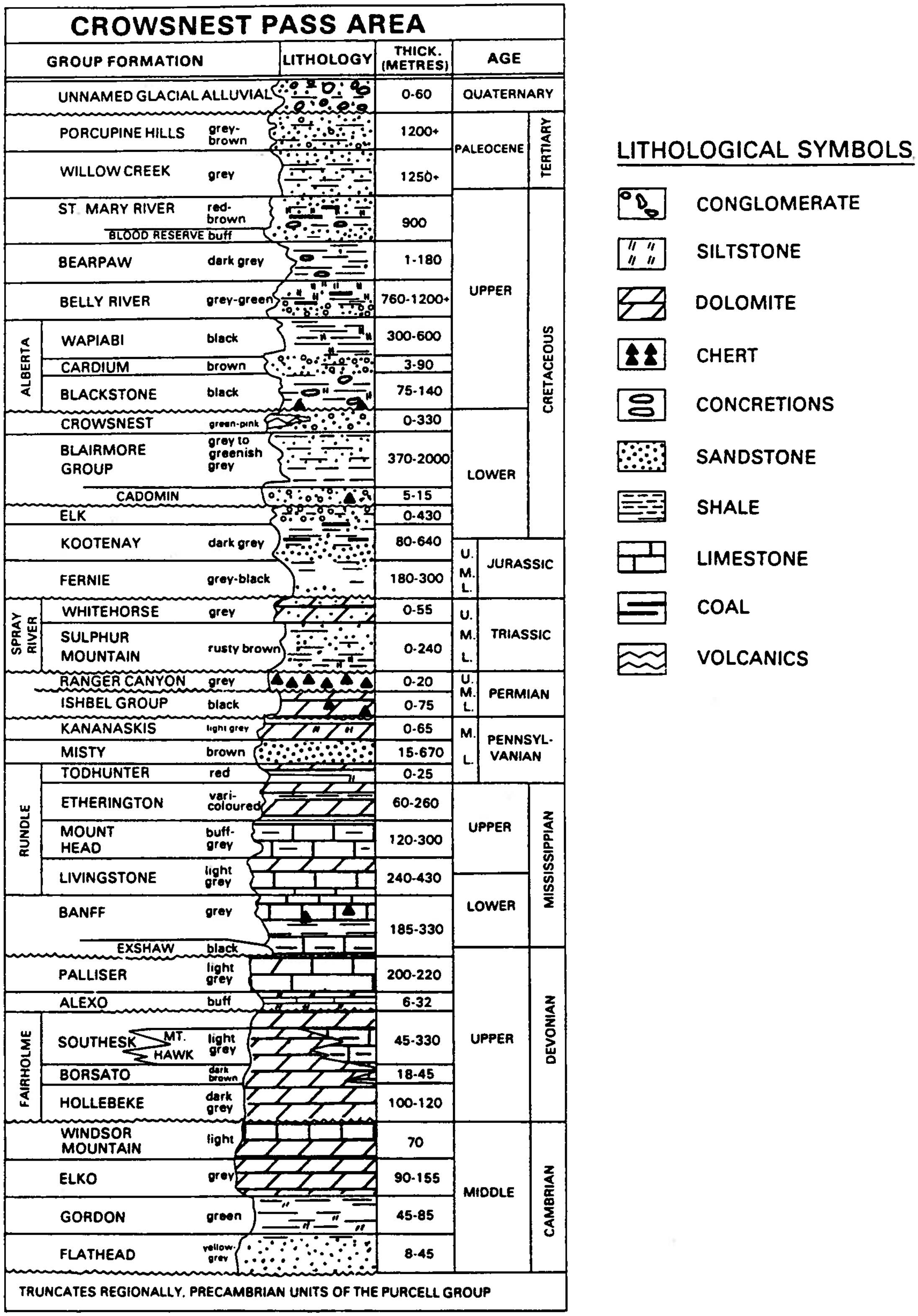

Figure 2. Generalized stratigraphic column, Crowsnest Pass Area.(after Jackson, 1975)

Formation has some high-grade beds similar to those in the underlying Livingstone but is much more variably interbedded with cherty and dolomitic beds (Holter, 1976).

Structurally, the study area can be discussed in terms of a major structural unit, the Lewis Thrust Sheet. The surface trace of the Lewis thrust fault marks the eastern boundary of the Front Ranges and extends for more than 100 km north and south of Crowsnest Pass. Paleozoic rocks of the Lewis Thrust Sheet are faulted over Upper Cretaceous strata along the east flank of the High Rock and Flathead Ranges (Fig. 1). In over-all aspect, the thrust sheet forms a west-dipping homoclinal succession cut by several lesser thrust faults. In the High Rock Range, Palliser, Banff, Livingstone and Mount Head strata are repeated along a series of west-dipping faults that extend from Deadman Pass southward through the Flathead Range (Price, 1962). These faults commonly follow the bedding, so that their position can be established only through detailed mapping or stratigraphic sampling.

Chapter 4

Study Localities

4.1 Phillipps Pass

4.1.1 Location and Physiographic Setting

Phillipps Pass is located 1.7 Km due north of the Crowsnest Pass (Fig. 1). It has a pass elevation of 1,570 m (5,150 ft). An unmaintained gravel road starts from Highway 3 in Alberta and runs through Phillipps Pass into British Columbia. At least one pipeline and one power transmission line also run through Phillipps Pass. The total haul length from the Phillipps Pass sites to the presently operated crushing plant is 7.6 km (4.7 mi).

4.1.2 Geologic Setting

The north-south trending Lewis Thrust fault has exposed strata of Cambrian to Permian ages along the High Rock Range through which Phillipps Pass cuts (Fig. 2). At least seven other thrust faults within this sequence have been identified, three of which occur in the Livingstone Formation (Fig.1). Most of the formations along the pass dip at between 37 and 47 degrees to the southwest. The Livingstone and Palliser Formations were the only rock units deemed to have potential for high quality, thick sections of exploitable limestone (Fig. 1).

The Livingstone Formation is described lithologically as consisting of:

> "...light gray skeletal (echinoderm-bryozoa) calcarenites and calcarenitic fine-crystalline limestones. Cherty-limestone interbeds are common in the lower part of the formation and interbeds of light gray, fine-crystalline dolomite, commonly silty, occur within the upper half (Price, 1962).

The formation is 357 m (1,170 ft) thick at Tornado Pass, which is located approximately 35 km (22 mi) to the north along the High Rock Range (Price, 1962). The calculated thickness of the formation at Phillipps Pass is 1,306 m (4285 ft); here, the formation has been thickened by faulting to at least three times its normal thickness. This formation is the one presently being quarried on the south side of Crowsnest Ridge, by Summit Lime Works.

The Palliser Formation is described as consisting of;

> "...dark gray, fine-crystalline limestone that is commonly mottled with brownish gray, medium-crystalline dolomite" (Price, 1962).

The formation is 198 to 219 m (650 to 720 ft) thick (Price, 1962). Faulting has increased its thickness at Phillipps Pass to approximately 280 m (918 ft).

4.1.3 Site 1

Sampling

This site is located within the Palliser Formation on the north side of Phillipps Pass (Fig. 1, Plate 1). A stratigraphic section measured at this site (Section P1, Fig.3) begins near the Palliser/Alexo contact and terminates in a covered interval near the presumed Banff Formation contact. At least one, and possibly two, thrust faults are present in the section. Part of the Palliser is therefore repeated in the section shown on Fig. 3. The section was sampled at regular 1.5 m intervals.

Analytical Results

Results of all the chemical analyses are given in Appendix 1. The calculated $CaCO_3$% values are plotted beside the stratigraphic column in figure 3.

Three stratigraphic zones of high quality limestone are identified in the Palliser Formation at this site. These zones, in general, average 95% or greater $CaCO_3$ and have less than 10% dolomitic or cherty impurities in any bed within the zone.

The easternmost outcropping zone (Zone 1, Figs. 1 and 3) contains an average of 96% $CaCO_3$ over 86 m of strata. $MgCO_3$ contents are less than 2%, except for one 1-m interval that contains 10% $MgCO_3$.

The central zone (Zone 2, Figs. 1 and 3) is located immediately east of the small creek that runs into Phillipps Pass (Plate 1). This zone is in a dipslope quarrying situation and the limestone averages 96% $CaCO_3$ over 23 m. $MgCO_3$ content is less than 1.5% over this interval.

The westernmost zone (Zone 3, Figs. 1 and 3) is located at the top of the Palliser Formation and also forms a dipslope. This limestone zone is 72 m thick, averages 95% $CaCO_3$ and contains less than 2% $MgCO_3$. A covered interval about 1 m thick is located midway through this zone and may be dolomitic.

Quarriability

Two potential quarry sites, 1A and 1B, exist at Site 1 on both sides of a small creek that drains into Phillipps Pass (Plate 1). The Palliser Formation dips moderately (24 to 35 degrees) to the southwest and erosion has produced two 30 to 60 m (100 to 200 ft) high shoulders of limestone (Zones 2 and 3) with overburden-free dip slopes.

Zones 2 and 3 are the most easily exploited, due to their dipslope situation. Exploiting limestone from Zone 1 would have to be done similar to the way the existing Summit Lime Works quarry operates, i.e., by slot trenching into and benching up the mountain. No dipslope expression of Zone 1 limestone is apparent.

Local jointing within the rock is N80E, 77 degrees SE. The present road gradient from the railway line to this site is 7%, but steepens to 9.5% where the road enters Phillipps Pass proper.

Reserves

Site 1A contains Zones 1 and 2 (Fig. 3). Zone 2 is calculated to contain 2.8 million tonnes of 96% $CaCO_3$ limestone.[1] No estimate for Zone 1 within Site 1A is made at this time, but the 86 m of good quality limestone indicates considerable reserve potential, provided a benching quarry is established.

Site 1B, Zone 3 is also in a dipslope situation and is estimated to contain 10 million tonnes of 95% $CaCO_3$ limestone.[2] Approximately 11 m (stratigraphically) of overburden is present, consisting of 86% $CaCO_3$ limestone.

4.1.4 Site 2

Sampling

Site 2 is located on the south side of Phillipps Pass (Fig. 1), directly opposite Site 1 and also within the Palliser Formation (Plate 2). The strata at Site 2 are assumed to be very similar compositionally to strata at Site

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[1]This assumes a rectangular body 23 m(thick) by 116 m(along the dipslope) by 400 m(strike length)

[2] Based on a rectangle; 72 m(thick) by 450 m (strike length) by 116 m(along the dipslope).

1, thus no sampling was done. Figure 1 shows the main rock types within the Palliser extrapolated to Site 2. Faulting has also likely repeated the Palliser section at Site 2.

Quarriability

Quarrying could take place within Zones 1 and 2 at Site 2, using the method presently employed at Summit Lime Works main quarry. This would mean quarrying by slot trenching along strike southward, and benching up the side of the northwest facing slope of Crowsnest Ridge. One quarriable dip slope topographic situation may exist, near Zone 3. This would require surface sampling to confirm. Stratal dip and road gradients are the same as for Site 1. No reserve estimates have been made for Site 2.

4.1.5 Site 3

Sampling

Sites 3A and 3B are located on the north and south sides of Phillipps Pass (Fig. 1) within strata of the Livingstone Formation. Most of the potentially quarriable sites are within British Columbia. No sampling was done in the Livingstone Formation at Sites 3A and 3B. It is presumed that the same lithologic succession found on the south side of Crowsnest Ridge (i.e. at the Summit Lime quarries) would also be found on the north side of the ridge and on the north wall of Phillipps Pass. Several low angle thrust faults continue within the Livingstone Formation at Sites 3A and 3B (Fig. 1). Locating an economically thick, high-grade limestone bed at either Site 3A or 3B would require very detailed structural mapping and surface sampling.

Quarriability and Reserves

Quarrying at Sites 3A and 3B would have to be done in a manner identical to that which is presently being done at the Summit Lime Works quarry, i.e., by benching up the mountain, following a thick, high-grade bed along strike. Stratal dips are on the order of 37 to 47 degrees southwest. The road gradients to Sites 3A and 3B, via Alberta, are roughly the same as to Sites 1 and 2 (i.e. 7 to 9.5%). The road gradient from Highway No. 3 in British Columbia to Sites 3A and 3B is about 8.7% over 2.5 km (1.5 mi).

Reserve estimates are not possible at this time, as no specific quarriable sites have been identified. The prospects for locating substantial new reserves at these sites appear to be limited.

4.2 Deadman Pass

4.2.1 Location and Physiographic Setting

Deadman Pass is located 7.2 km (4.5 mi) north-northeast of the Summit Lime Works operation (Fig. 1). The distance to Deadman

Pass from the plant, via Highway 3, a secondary road, and an unmaintained truck trail is approximately 17 km (10.5 mi).

Deadman Pass forms a gap in the High Rock Range with a pass elevation of approximately 1615 m (5300 ft).

4.2.2 Geologic Setting

The Lewis Thrust is the major fault that has exposed strata of Devonian to Permian ages at Deadman Pass (Fig. 2). Two other minor thrust faults are known in the Mississippian (Banff Formation) and more are suspected in the Livingstone Formation. The formations in Deadman Pass dip to the southwest at 29 to 52 degrees. The Livingstone and Palliser Formations were each evaluated for their limestone potential.

The description of the Livingstone Formation at Deadman Pass is essentially the same as that described for the Phillipps Pass area. At Tornado Pass, 28 km north along the High Rock Range, Price (1962) found the formation to be 357 m (1170 ft) thick. At Section D2 (Fig. 1) the formation was measured to be 391 m thick, however, the Livingstone Formation section exposed over the border in British Columbia is calculated to be nearly 767 m thick. Thus it seems that the formation has been nearly doubled in thickness by faulting in British Columbia, but has not been thickened in Alberta.

The Palliser Formation description is also essentially the same as described in Phillipps Pass. Price (1962) found the formation to be 198 to 279 m (650 to 720 ft) thick in the Crowsnest Pass region. At Deadman Pass (Section D1-Site 4) it measured 286 m (938 ft) in thickness. No evidence of thickening due to faulting could be found in the field to account for the somewhat abnormally thick section.

4.2.3 Site 4

Sampling

Site 4 is on the north side of Deadman Pass near its eastern entrance. Sampling of the Palliser Formation at Site 4 (Section D1) was done at regular 1.5 m intervals (Fig. 3). The section begins at the lowest outcrop of exposed Palliser and terminates in the highest (stratigraphically) outcrop observed. Covered intervals conceal both the upper and lower contacts.

Analytical Results

Three zones are identified in the Palliser succession (Section D1) as containing potentially quarriable limestone (Figs. 1 and 3). Results of all chemical analyses appear in Appendix 2. All calculated $CaCO_3$ values for this section appear in figure 3.

The lowest zone (Zone 4) contains an average of 91% $CaCO_3$, 3-6% $MgCO_3$ and 1% Fe_2O_3 over 66 m (Fig. 1).

The central zone (Zone 5) is 34 m thick and contains an average of 93% $CaCO_3$ and 2% $MgCO_3$. One 1.5-m thick bed of 86% dolomitic limestone exists in the lower part of this zone (Fig.3).

The upper zone (Zone 6, Fig.1) is 27 m thick and contains one 3-m thick, 84% $CaCO_3$, dolomitic limestone/dolomite sequence. This zone averages 94% $CaCO_3$, including the low-grade horizon. It also contains 1 to 3% $MgCO_3$ (excluding the low-grade zone, that contains up to 13% $MgCO_3$).

Quarriability

Site 4 presents an ideal dipslope quarrying situation (Plate 3). The overlying Banff Formation has been eroded off in part leaving a 500 m (1524 ft) long, N.E.-S.W. trending ridge of Palliser Formation (Fig. 1). The lowest (in elevation) outcrops that could be quarried in a dipslope situation are approximately 30 to 45 m (100 to 150 ft) above the present road. The truck trail that goes from the secondary road into Deadman Pass is presently passable only by four wheel drive and would therefore require extensive upgrading to be used as a haul road. The average road gradient along this truck trail, from the secondary highway to the provincial boundary in Deadman Pass, is approximately 1%.

Reserves

As can be seen on figure 1, there is much rock type variability within the Palliser at this site. The lower Palliser (Zone 4) consists of 66 m (201 ft) of uniform, moderately high quality (91% $CaCO_3$) limestone (Fig.1). One quarriable site within this lower zone exists at the southern most exposure of rock type "L" (Fig. 1). An overburden-free shoulder of this strata could yield approximately 8.8 million tonnes[3] without removing much overburden.

Zone 5 is in the upper part of the Palliser, and is exposed in a dipslope situation starting at the top of a prominent knoll approximately 200 m above the valley floor (Plate 3). It is calculated to contain approximately 1.5 million tonnes of 91-93% $CaCO_3$ limestone[4]

Zone 6 in the uppermost Palliser is also exposed in a dipslope situation (Fig. 3, Plate 3). This zone is calculated to contain 2.7 million tonnes of 94% $CaCO_3$,[5] or, excluding the low-grade horizon, 2.4 million tonnes of 98% $CaCO_3$ limestone.

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[3]Assuming a rectangular body 434 m x 66 m x 116 m, and a quarrying height of about 91 m (300 ft) above the valley floor.
[4] This assumes a triangle with dimensions; 200 m (base) by 85 m (height) by 34 m (thick)
[5] Based on a rectangle; 27 m (thick) by 434 m (base) by 173 m (height)

4.2.4 Sites 5 and 6

Sampling

Sites 5 and 6 are both in British Columbia, on the north valley wall, and are in the Livingstone Formation (Fig. 1). No sampling was done at these sites because of suspected faulting and repetition of the section to at least double its thickness. One complete, presumably unfaulted stratigraphic section of the Livingstone was measured in Alberta on the south wall of Deadman Pass (Figs. 1 and 3, Section D2, Appendix 2). Although Section D2 is in an impossible quarrying situation, it will provide some idea of the lithologies present at Sites 5 and 6 in British Columbia. Sampling at Section D2 was done at regular 1.5 m intervals except for the upper 60 m (183 ft) where sampling was done every 3 m.

Quarriability

In Section D2 (Plate 4) the base of the formation is 183 m (500 ft) above the valley floor. The individual beds run roughly parallel to the topographic contours and the strata dip into the side of the mountain. All of these factors make for an unfavorable quarrying site. Sites 5 and 6 in British Columbia are chosen for their dipslope setting and favorable quarriability as well as on the basis of the geology. As previously stated, several thrust faults have thickened the Livingstone in British Columbia, and the position of these faults is not known.

Analytical Results and Reserves

The Livingstone formation at this locality contains two thick zones of relatively high-grade limestone. The lower zone, Zone 7, is 70 m (213 ft) thick, averages 94% $CaCO_3$, ranges from 2 to 8% $MgCO_3$, and contains one 14-m covered interval. Zone 8, near the top of the formation, averages 97% $CaCO_3$, 1 to 4% $MgCO_3$, and is 42 m (128 ft) thick.[6]

Sites 5 and 6 would require very detailed examination and structural mapping to see if one or both of these high-grade limestone zones (as found in Section D2) is present and quarriable.

4.2.5 Site 7

Site 7 is a small isolated knob of Palliser Formation that lies 2.1 km (1.3 mi) south of Deadman Pass (Fig. 1). No sampling was done at this site due to lack of access and extensive vegetative cover. Results from Site 4, Section D1 could be extrapolated to this site with reasonable assurance.

Quarriability and Reserves

This site appears to be a favorable one for quarrying. Much of the Palliser is completely overburden-free, exposed

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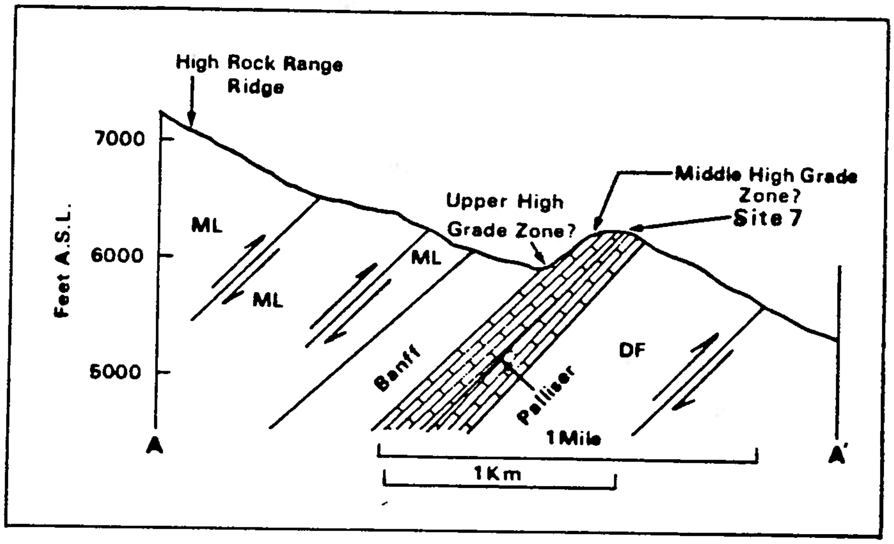
[6] The upper 60 m of the formation, including part of Zone 8, was sampled on a 3 m interval, not 1.5 m.

on a small plateau that lies just east of the Front Ranges (see sketch below).

Cross Section Through Site 7



This site would lend itself well to an open-pit or dipslope operation. There is a 328 m (1000 ft) rise in elevation from the Deadman Pass truck trail to this site. A certain amount of overburden (lower grade limestone) would have to be removed in designing an open pit for this site (see sketch).

No accurate reserve estimates can be made until surface sampling or drilling is undertaken. However, if it is assumed that the upper and central high-grade zones of the Palliser at Deadman Pass are present here, a crude estimate can be made for this site. The central high-grade zone appears to be in a dipslope quarrying situation and contain about 1 million tonnes of 93% $CaCO_3$ (2% $MgCO_3$) limestone.[7] The upper high-grade zone appears to be in a relatively flat, open-pit quarrying situation and contains about 800,000 tonnes of 94% $CaCO_3$ limestone.[8]

4.3 Summit Lime Works Quarry Sites

4.3.1 Location and Geological Setting

The locations of the Summit Lime quarries in the Crowsnest Pass are confined essentially to the Livingstone Formation on the north and south sides of the Pass (Fig. 1). These quarry sites have had extensive geological investigations (Crabb, 1966; Van Raalte, 1969; Pelletier, 1973; Brasher, 1974; Berman, 1975). The following is a summary of the current status of these quarries.

4.3.2 Quarry 1

At the present time, Quarry 1 is the only quarry operated by Summit Lime Works. The company is concentrating all of its efforts into this one location (Plate 5), as suggested in 1973 by a consultant's report (Pelletier, 1973). This same report suggested quarrying by benching at Quarry 1, which is also now being done. At the present, six benches have been cut above the original quarry site.

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[7] Based on a rectangle; 34 m (thick) by 640 m (strike length) by 20 m (along the dipslope).

[8] This assumes a rectangle; 640 m (strike length) by 27 m (thick) by 17 m (along the dipslope). It also assumes a vertical quarrying depth of 10 m with stratal dips of 35 degrees.

The quarry consists of two 37 m (120 ft) thick high-grade limestone units, separated by a 11 m (35 ft) thick dolomitic limestone unit, all horizontally measured. The high-grade limestone units are said to average 98% $CaCO3$. These two units are being followed along strike and up the mountain side. Some difficulty in following these units has been experienced on the upper benches, and it is suspected that a thrust fault cuts through the quarry site and has consequently displaced the two high-grade units.

Quarry 1 is estimated to contain 1.2 million tonnes (1.3 tons) of high purity limestone. At the present rate of extraction (135,000 tonnes/year) the quarry has another 13 years of production available. The company has proposed to almost double its production rate in its plans for plant expansion in order to remain competitive. This would reduce the quarry lifetime to about 11 years, if the expansion takes place 3 or 4 years from now.

Even for Quarry 1 to provide for the next 3 or 4 years, it may be necessary to undertake more detailed geological and structural mapping at the site. This need is indicated by the difficulty in following the high purity beds on the upper benches. Having to look for high-grade rock on a hit-miss basis as the quarrying proceeds leads to decreased production, increased operating costs, and uncertainty of reserves.

4.3.3 Quarries 2 to 7

Quarries 2 through to 7 (Plate 5) are all inactive at the present time . Quarries 2 to 4 were abandoned due to high unsafe pitwalls and only moderate thicknesses of high-grade limestone. In Quarries 5 and 6, the high-grade bed itself is fairly thin and reserves were soon exhausted. Quarry 7, which was only abandoned in the last 5 years, is located in a favorable dipslope situation along the west end of Crowsnest Ridge (Plate 5). Dolomitic limestone overburdens the high-grade beds here, and as quarrying proceeded northward, this overburden became thicker to the point where the quarry was no longer economical.

4.3.4 Quarries 10 and 11

Quarries 10 and 11 are located along Crowsnest Creek south of the Summit Lime plant site. Both quarries are in favorable dipslope situations, and both are in the upper part of the Livingstone Formation.

Quarry 10 was abandoned because of structural problems and road gradients to the quarry that were eventually considered to be too steep. Construction of a new road was not economically feasable given the low average grade of the limestone (Brasher, 1974).

Quarry 11 was abandoned for similar reasons, plus the fact that reserves are small and there was no place to dump waste rock. A number of consultants reports were done in evaluating

Quarry 11 (Crabb, 1966; Van Raalte, 1969; Pelletier, 1973; Brasher, 1974; Berman, 1975).

Study Localities

Chapter 5

Underground Mining

Previous work on the feasibility of underground mining at the Summit Lime Works site dealt mainly with economics (Berman, 1975; Pool, 1974) and the results were not encouraging. They indicated that underground mining would be feasible only if production and sales of pulverized limestone and lime products were increased to double the then current (1973) level and if prices were increased by 10% relative to costs (Berman, 1975). However, the preliminary cost analysis figures were based on unsupported assumptions regarding mining costs, and gave little consideration to the offsetting benefits that would accrue from underground mining. Moreover, at the time of those studies, the company's reserves position appeared to be somewhat better. A more rigorous economic analysis in the light of current conditions might now show underground mining as a viable option.

Generally, the cost of underground mining of limestone is higher than for surface quarrying by at least 50%. Nevertheless, conditions can exist where underground mining is economical, even in conjunction with quarrying. Some of these conditions are given below (Carr and Rooney, 1975), all of which seem to fit Summit Lime Works' present situation.

1. Lack of nearby surface deposits. If the alternative sources involve high haulage costs, these may offset the additional costs of underground mining.

2. Unfavorable geologic structure. Moderately to steeply dipping beds that strike into the hillslope present limited quarriability, but could be mined extensively by underground methods.

3. Efficient utilization of reserves. Where quarriable reserves have been exhausted, new reserves can be established by tunnelling. Quarrying and tunnelling can be carried on side by side to extend the life of the quarry.

4. Selective mining. Premium-grade limestone in a particular bed or zone can be extracted to the exclusion of lower-grade material.

5. All-weather mining and uniform production. Underground mining is not affected by inclement weather. Uniform production gives more stable employment for the crews and reduces the need for large stockpiles.

6. Environmental problems. Underground mining is less conspicuous and involves less surface disturbance. Dust and noise are confined below ground.

7. Underground storage and waste disposal. If the mine is dry, the space created can have subsequent valuable storage potential.

The site previously considered for underground mining is Quarry 1, where two very high-purity limestone beds exist with horizontal thicknesses of 37 m (120 feet) each. The beds dip westerly at 40 to 60 degrees. In the present study, no detailed investigation of this site was made, but preliminary observations support generally the proposal by Pool (1974) for a room-and-pillar method of mining as the most practical and economical for this deposit. However, many factors remain to be evaluated in determining the applicability of the method at this site.

Further study in this regard would best await the final evaluation of quarry prospects. An economic review of underground mining feasibility could then be undertaken more rigorously, with concrete data on the alternatives against which to compare. Should an economic review give encouraging results, then detailed site-specific studies would be in order. These would include geological mapping and structural analysis on a very detailed scale, along with extensive test-drilling, and a thorough study of the competency of the limestone beds (rock strengths and nature of jointing and fracturing), to determine the support problems that may be encounered. Measurement of the mineable reserves would be an integral part of the studies.

Chapter 6

Conclusions

The results of this study of limestones in the Crowsnest Pass region are summarized in table 1. At Phillipps Pass, three limestone zones of 95% or greater $CaCO_3$ exist within the Palliser Formation. These zones are 86, 23, and 72 m thick. The 23-m and 72-m thick zones on the north side of the Pass are in a dipslope quarrying situation. These same three zones are very likely present on the south side within the Palliser, but not in easily quarriable dipslope exposures. The 23-m zone is believed to contain 2.8 million tonnes, the 72-m zone 10 million tonnes.

The Livingstone Formation was not sampled along Phillipps Pass, as it was expected that similar thicknesses and qualities of limestone would be found here as at the Summit Lime Works quarry sites.

A small overburden-free knob of Palliser Formation lies between Phillipps and Deadman Passes along the eastern most exposure of the Front Ranges. This site was not examined due to lack of access, but is indicated to have potential. Approximately 1.8 million tonnes of 93 to 94% $CaCO_3$ limestone may be available at this site.

At Deadman Pass, the Palliser Formation contains three zones of potentially exploitable limestone, however the quality is generally poorer than at Phillipps Pass. The lowest zone is 66 m thick and averages 91% $CaCO_3$. An overburden-free shoulder may yield 8.8 million tonnes. The middle zone is 34 m thick, averages 93% $CaCO_3$ and has 1.5 million tonnes of limestone that could be exploited in a dipslope quarrying situation. The uppermost zone is 27 m thick and contains 2.7 million tonnes of 94% $CaCO_3$ limestone in a dipslope quarrying situation. At this same location the quality is upgraded to 98% $CaCO_3$, for reserves of 2.4 million tonnes, if a single low-grade bed is removed.

No quarriable limestone exists in the Livingstone Formation at Deadman Pass in Alberta. However, at least two potential sites do exist just over the border in British Columbia. These British Columbia sites were not investigated, but sampling in Alberta indicates that two zones of moderately high-grade limestone are present within the Livingstone in this area. The middle Livingstone zone is 70 m thick and averages 94% $CaCO_3$; the upper Livingstone zone is 42 m thick and averages 97% $CaCO_3$.

The limestone prospects considered in this study all lie outside restricted development zones of the Eastern Slopes Land Use Management Policy. In this respect, they are free of development constraints. However, the Phillipps Pass prospects are all held under quarrying leases by competitors of Summit Lime Works. No quarrying leases exist in Deadman Pass, but here the location of the Alberta-British Columbia border is a matter of dispute, which could affect the granting of leases.

Field examination of Summit Lime Works' past quarrying operations confirms that no possibilities exist for extension of Quarries 2 to 7. Quarry 1, the only quarry presently operating, would benefit from rigorous structural analysis, to determine the cause of discontinuities in the upslope projection of the high-grade beds. This would assist the quarrying operation and afford a better indication of the reserves. A re-design of quarrying methods in Quarries 10 and 11 may enlarge the company's reserve of lower grade rock, though it probably would not augment reserves of high-grade rock.

Chapter 7

Recommendations

The results of the study are based only on surface sampling and must therefore be considered preliminary. Nevertheless, they offer sufficent encouragement to recommend further exploration on some of the prospects. The recommendations depend on the minimum quality limitations that the company, Summit Lime Works Limited, can tolerate.

If the minimum limestone quality is 97% $CaCO_3$, then only one prospect identified in this study could potentially yield limestone of such quality. This is the Palliser Formation at Deadman Pass (Site 4), in the upper zone (Zone 6) which is indicated to have 2.4 million tonnes of quarriable limestone grading 98% $CaCO_3$. Accordingly, it is recommended that this site be further investigated in a detailed geological study and drilling program.

Also, it is recommended that the Livingstone Formation at Deadman Pass be thoroughly investigated on the British Columbia side (Sites 5 and 6). This would be an attempt to locate the high-purity limestone in Zone 8 of the Livingstone, in what would be a quarriable situation. This zone grades 97% $CaCO_3$ over a 42-m interval. Some thinner high-grade intervals in the Livingstone may also be found. Sites 5 and 6 require detailed geological mapping and structural analysis to sort out the succession of rock strata exposed there.

A further recommendation is that a preliminary investigation be made of the Palliser Formation on Site 7. This site has no existing road access, but based on geological projection it seems to present the upper and middle high-purity zones in a favorable quarrying situation. The feasibility of constructing a road to the site should be examined.

If Summit Lime Works Limited can accept a lesser limestone quality of 95 to 96% $CaCO_3$, then the more accessible prospects in Phillipps Pass enter consideration. In this case, it is recommended that Sites 1 and 2 be included for detailed geological mapping and structural analysis. These studies would be with respect to the high-purity zones in the Palliser Formation (Zones 1, 2 and 3), to outline more accurately their quarriable expressions, and would be followed by a drilling program to test the most favorable, or perhaps all the prospects. In these three zones, potential exists for at least 15 million tonnes of quarriable limestone at Site 1. No reserve estimates are made for Site 2.

The Livingstone Formation in Phillipps Pass is not recommended for study at this time, although it should not be discounted entirely. Undoubtedly some high-grade quarriable beds exist on Crowsnest Ridge and on the opposite side of the Pass, but they would present the same quarrying difficulties that the company now experiences in its existing quarries on the south side of Crowsnest Ridge.

This study included a brief examination of the potential for underground mining at the existing quarry site. No further work is recommended in this regard before the quarry prospects outlined above have been fully evaluated. At that time, an economic review of underground mining feasibility should be carried out in rigorous comparison with the quarry alternatives. However, it is recommended that a detailed structural analysis of the Quarry 1 site be undertaken directly as an aid to the current quarrying operation, to better define and perhaps to extend the quarriable reserves. This would also provide useful data for subsequent evaluation of underground mining potential.

References

Berman, B.L. (1975): Report on Operations of Summit Lime Works Ltd. at Crowsnest Pass, Alberta; David S. Robertson and Associates, Denver, Colorado, 33p.

Brasher, G.K. (1974): Preliminary Report on the Geology of Properties Controlled by Summit Lime Works Ltd. Crowsnest Pass Area, Alberta; David S. Robertson and Associates, Inc., Denver, Colorado, 18 p.

Carr, D.D. and L.F. Rooney (1975): Limestone and Dolomite,chapter in Industrial Minerals and Rocks; American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., p. 757-789.

Crabb, J.J. (1966): Summit Lime Works Ltd. Quarry No. 11; Consultants Report, 10p.

Holter, M.E. (1976): Limestone Resources of Alberta; Alberta Research Council, Economic Geology Report 4, 91p.

Jackson, P.C. (1975): Geological Highway Map of Alberta, Canadian Society of Petroleum Geologists.

Pelletier, J.D. (1973): Report on Quarry Operations and Development of Limestone Reserve for Summit Lime Works Limited; Equity Mining Capital Limited, Vancouver.

Pool, T.C. (1974): Preliminary Analysis Proposed Underground Limestone Mine Near Crowsnest Pass, Alberta; David S.

Robertson and Associates, Inc., Denver, Colorado, 7p.

Price, R.A. (1962): Fernie Map-Area, East Half, Alberta and British Columbia 82G E1/2; Geological Survey of Canada, Paper 61-24, 65p.

Van Raalte, A. (1969): Report on Investigation of Property Controlled by Summit Lime Works Ltd.; Van Raalte Engineering Ltd., Calgary, Alberta, 14p.

APPENDIX I

Chemical Analyses - Phillipps Pass Area

Sample Number	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	K_2O	S	Insol.	L.O.I.	H_2O	Total	$CaCO_3$	$MgCO_3$
Section P1														
DM80 - P1- 1	48.41	2.34	3.78	1.34	0.75	0.04	0.45	0.05	4.55	41.55	0.04	98.70	86.4	4.9
- P1- 2	52.91	0.89	0.72	0.68	0.21	0.02	0.20	<0.01	1.11	43.28	0.02	98.93	94.4	1.9
- P1- 3	53.02	0.86	0.66	0.38	0.13	0.01	0.12	0.04	1.12	43.32	0.02	98.52	94.6	1.8
- P1- 4	53.39	0.88	0.74	0.26	0.13	0.02	0.11	<0.01	1.15	44.46	0.03	100.02	95.3	1.8
- P1- 5	54.36	0.62	0.76	0.48	0.11	0.01	0.11	0.25	1.01	43.11	0.02	99.58	97.0	1.3
- P1- 6	54.28	0.51	0.75	0.65	0.12	0.01	0.13	0.05	1.14	43.18	0.03	99.66	96.9	1.1
- P1- 7	48.60	5.05	0.59	0.66	0.70	0.02	0.12	0.03	1.13	43.99	0.03	99.76	86.8	10.6
- P1- 8	47.15	6.59	0.66	0.38	0.19	0.02	0.13	<0.01	1.29	44.11	0.03	99.26	84.2	13.8
- P1- 9	54.25	0.46	0.74	0.54	0.12	0.01	0.12	<0.01	1.18	43.23	0.03	99.50	96.8	1.0
- P1-10	53.47	0.69	0.26	0.16	0.33	0.02	0.05	<0.01	0.60	43.64	0.02	98.64	95.4	1.4
- P1-11	50.49	3.29	0.50	0.56	0.52	0.01	0.08	<0.01	0.83	43.90	0.03	99.38	90.2	6.9
- P1-12	51.08	2.50	0.51	0.40	0.12	0.01	0.08	<0.01	0.88	43.66	0.02	98.38	91.2	5.2
- P1-13	51.43	2.17	0.62	0.40	0.15	0.01	0.13	<0.01	1.25	43.35	0.02	98.28	91.8	4.5
- P1-14	50.50	2.54	0.63	0.31	0.15	0.01	0.12	0.01	1.39	43.40	0.01	97.67	90.1	5.3
- P1-15	54.50	0.54	0.74	0.51	0.15	0.01	0.11	0.02	1.48	42.94	0.03	99.53	97.3	1.1
- P1-16	54.23	0.70	0.82	0.46	0.19	0.02	0.14	0.01	1.66	42.92	0.02	99.50	96.8	1.5
- P1-17	53.60	0.71	0.81	0.52	0.18	0.01	0.14	0.05	1.44	43.30	0.03	99.50	95.7	1.5
- P1-18	53.83	0.77	0.30	0.22	0.08	0.01	0.02	0.04	0.57	43.69	0.01	98.93	96.1	1.6
- P1-19	49.72	4.55	0.12	0.22	0.04	0.02	0.03	0.04	0.50	44.45	0.02	99.17	88.8	9.5
- P1-20	54.21	0.72	0.37	0.33	0.10	0.01	0.08	0.06	0.70	43.58	0.02	99.42	96.8	1.5
- P1-21	53.59	0.71	0.22	0.91	0.09	0.01	0.08	0.06	0.70	43.63	0.04	99.28	95.7	1.5
- P1-22	53.69	0.95	0.13	0.38	0.07	0.01	0.06	0.05	0.01	43.66	0.04	98.99	95.8	2.0
- P1-23	49.10	6.15	0.06	0.27	0.06	0.01	0.08	0.04	0.36	44.76	0.03	100.52	87.6	12.9
- P1-24	50.55	3.29	0.14	0.26	0.09	0.00	0.05	0.06	0.51	44.18	0.02	98.58	90.2	6.9
- P1-25	53.49	1.42	0.11	0.35	0.05	0.01	0.03	<0.01	0.34	43.91	0.03	99.40	95.4	3.0
- P1-26	51.41	3.19	0.20	0.37	0.04	0.01	0.03	0.01	0.43	44.11	0.05	99.41	91.8	6.7

APPENDIX 2

Chemical Analyses - Deadman Pass Area

Sample Number	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	K_2O	S	Insol.	L.O.I.	H_2O	Total	$CaCO_3$	$MgCO_3$
Section D1														
DM80 - D1- 1C	50.36	2.57	1.45	0.62	0.89	0.15	0.21	<0.01	2.03	43.24	0.02	99.51	89.9	5.4
- D1- 2C	51.74	1.80	0.56	0.33	0.84	0.16	0.26	<0.01	1.18	43.82	0.08	99.52	92.4	3.8
- D1- 3C	50.53	2.66	0.56	0.23	0.87	0.14	0.26	<0.01	1.12	43.92	0.08	99.25	90.2	5.6
- D1- 4C	50.80	2.42	0.70	0.31	0.90	0.16	0.17	<0.01	1.25	43.80	0.03	99.29	90.7	5.1
- D1 -5C	52.36	1.32	0.54	0.22	0.92	0.16	0.11	<0.01	1.01	43.72	0.02	99.37	93.5	2.8
- D1- 6C	47.44	4.73	1.40	0.50	0.98	0.17	0.25	<0.01	2.03	43.70	0.03	99.20	84.7	9.9
- D1- 7C	48.76	4.58	0.55	0.20	0.98	0.15	0.12	<0.01	1.02	44.30	0.03	99.67	87.0	9.6
- D1- 8C	52.04	2.28	0.53	0.24	0.88	0.15	0.17	<0.01	1.00	44.28	0.01	100.58	92.9	4.8
- D1- 9C	51.47	0.63	0.40	0.18	0.85	0.17	0.13	<0.01	0.81	43.36	0.04	97.23	91.9	1.3
- D1-10C	54.35	1.06	0.31	0.33	0.87	0.15	0.14	<0.01	0.78	43.28	0.02	100.51	97.0	2.2
- D1-11C	51.35	0.91	0.75	0.21	0.84	0.14	0.10	<0.01	1.32	44.10	0.02	98.42	91.6	1.9
- D1-12C	46.67	7.86	0.55	0.26	0.90	0.17	0.13	<0.01	0.98	43.15	0.04	99.73	83.3	16.4
- D1-13C	46.99	5.66	0.93	0.48	0.99	0.14	0.15	<0.01	1.43	43.48	0.04	98.86	83.9	11.8
- D1-14C	37.88	13.94	0.70	0.35	1.59	0.16	0.11	<0.01	1.32	44.96	0.03	99.72	67.6	29.1
- D1-15C	51.74	0.89	0.46	0.38	0.86	0.16	0.08	<0.01	1.14	42.81	0.04	97.42	92.4	1.9
- D1-16C	48.31	6.23	0.61	0.28	0.92	0.15	0.11	<0.01	1.23	43.68	0.03	100.32	86.2	13.0
- D1-17C	53.70	0.90	0.24	0.12	0.88	0.15	0.09	<0.01	0.78	43.47	0.02	99.57	95.9	1.9
- D1-18C	51.23	0.85	0.39	0.17	0.92	0.15	0.12	<0.01	1.33	42.94	0.06	98.16	91.4	1.8
- D1-19C	38.84	13.07	0.55	0.29	0.92	0.16	0.20	<0.01	1.69	44.86	0.11	99.00	69.3	27.3
- D1-20C	45.10	8.41	0.72	0.25	0.87	0.31	0.15	<0.01	1.47	44.16	0.13	100.10	80.5	17.6
- D1-21C	53.51	1.34	0.62	0.18	0.77	0.15	0.10	<0.01	1.19	43.61	0.04	101.51	95.5	2.8
- D1-22C	46.99	6.10	0.38	0.16	0.89	0.15	0.12	<0.01	0.86	44.29	0.03	99.11	83.9	12.8
- D1-23C	55.30	0.82	0.46	0.18	0.87	0.16	0.13	<0.01	1.12	43.43	0.03	101.38	98.7	1.7
- D1-24C	54.60	0.44	0.25	0.04	0.88	0.16	0.10	<0.01	1.09	43.46	0.03	99.96	97.5	0.9

APPENDIX 2 (continued)

Chemical Analyses - Deadman Pass Area

Sample Number	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	K_2O	S	Insol.	L.O.I.	H_2O	Total	$CaCO_3$	$MgCO_3$
Section D2														
DM80 - D2- 1	22.86	16.15	19.32	1.65	1.07	0.18	0.78	<0.01	21.75	36.07	0.20	98.28	40.8	33.8
- D2- 2	28.85	12.23	24.05	1.03	0.98	0.21	0.38	0.04	25.16	34.01	0.14	101.88	51.5	25.6
- D2- 3	46.74	3.88	4.63	0.58	1.02	0.19	0.27	0.13	6.16	41.20	0.16	98.67	83.4	8.1
- D2- 4	53.64	0.88	0.24	0.09	0.89	0.17	0.06	<0.01	1.32	43.36	0.07	99.40	95.7	1.8
- D2- 5	54.85	0.69	0.10	0.02	0.75	0.17	0.03	<0.01	0.31	43.81	0.06	100.48	97.9	1.4
- D2- 6	54.10	1.25	0.22	0.05	0.77	0.16	0.05	<0.01	0.53	43.66	0.07	100.33	96.6	2.6
- D2- 7	53.60	1.73	0.35	0.34	0.78	0.20	0.12	<0.01	0.67	43.59	0.07	100.78	95.7	3.6
- D2- 8	30.16	10.99	18.11	1.42	1.10	0.21	0.96	<0.01	22.15	35.53	0.04	98.52	53.8	22.9
- D2- 9	48.05	5.33	0.56	0.19	0.81	0.19	0.10	<0.01	1.70	43.81	0.03	99.07	85.8	11.1
- D2-10	47.97	5.74	0.38	0.15	0.80	0.18	0.03	<0.01	0.72	44.26	0.05	99.56	85.6	12.0
- D2-11	48.18	4.95	0.70	0.21	0.79	0.22	0.06	<0.01	1.68	41.56	0.07	96.74	86.0	10.3
- D2-12	17.85	9.47	41.00	1.80	1.18	0.23	1.53	<0.01	47.97	24.04	0.08	97.18	31.9	19.8
- D2-13	38.98	12.24	0.20	0.14	0.75	0.20	0.06	<0.01	1.19	45.63	0.06	98.26	69.6	25.6
- D2-14	50.69	4.21	0.09	0.24	0.79	0.22	0.05	<0.01	0.44	44.05	0.06	100.40	90.5	8.8
- D2-15	40.82	11.96	0.15	0.16	0.77	0.18	0.06	<0.01	0.45	45.52	0.08	99.70	72.9	25.0
- D2-16	49.32	6.00	0.08	0.23	0.38	0.14	0.05	0.02	0.40	44.69	0.05	100.94	88.0	12.6
- D2-17	50.63	2.44	0.30	0.17	0.72	0.20	0.04	0.01	0.70	43.86	0.04	98.40	90.4	5.1
- D2-18	33.78	14.19	7.10	0.66	0.16	0.08	0.46	0.01	8.59	42.27	0.07	98.77	60.3	29.7
- D2-19	51.65	2.89	0.08	0.07	0.03	0.08	0.05	0.01	0.39	44.14	0.07	99.06	92.2	6.0
- D2-20	37.95	5.19	19.22	0.46	0.10	0.10	0.38	0.01	20.94	35.33	0.06	98.79	67.7	10.9
- D2-21	47.17	2.11	5.54	1.00	0.32	0.08	0.47	0.08	6.40	40.99	0.07	97.75	84.2	4.4
- D2-22	45.12	4.65	6.55	0.76	0.32	0.09	0.56	0.08	7.88	40.60	0.06	98.71	80.5	9.7
- D2-23	46.15	2.77	8.55	0.33	0.13	0.08	0.19	0.03	9.67	40.11	0.06	98.37	80.6	5.8
- D2-24	29.38	0.51	43.05	0.04	0.04	0.06	0.02	0.01	44.48	23.72	0.04	96.86	52.4	1.1
- D2-25	53.78	2.00	2.68	0.26	0.03	0.07	0.11	0.01	2.96	42.24	0.04	101.21	96.0	4.2

APPENDIX 2 (continued)

Chemical Analyses - Deadman Pass Area

Sample Number	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	K_2O	S	Insol.	L.O.I.	H_2O	Total	$CaCO_3$	$MgCO_3$
Section D2 (cont'd.)														
DM80 - D2-26	52.81	1.49	0.42	0.20	0.04	0.05	0.02	0.01	0.73	43.27	0.04	98.34	94.3	3.1
D2-27	52.38	2.20	0.15	0.05	0.04	0.06	0.01	0.02	0.45	43.43	0.04	98.33	93.4	4.6
D2-28	50.71	3.60	0.14	0.07	0.03	0.05	0.02	0.01	0.42	43.80	0.06	98.48	90.5	7.5
D2-29	54.76	0.74	0.01	0.14	0.02	0.06	0.03	<0.01	0.33	43.41	0.04	99.21	97.7	1.5
D2-30	46.10	8.07	0.15	0.45	0.05	0.07	0.06	<0.01	0.54	44.37	0.03	99.35	82.3	16.9
D2-31	41.90	13.31	0.24	0.52	0.04	0.08	0.18	<0.01	0.64	44.90	0.05	101.22	74.8	27.8
D2-32	44.67	9.61	0.10	0.11	0.04	0.06	0.02	0.01	0.31	45.22	0.01	99.84	79.1	20.1
D2-33	39.39	3.45	19.94	0.47	0.11	0.09	0.26	0.01	21.28	34.20	0.02	97.93	70.3	7.2
D2-34	39.70	6.99	10.05	1.36	0.36	0.09	1.11	0.01	12.94	38.12	0.04	97.82	70.9	14.6
D2-35	54.89	0.67	0.01	0.03	0.01	0.08	0.03	0.01	0.30	43.22	0.02	98.96	98.0	1.4
D2-36	50.28	1.14	5.44	0.14	0.02	0.09	0.04	0.01	5.83	41.55	0.02	98.72	89.8	2.4
D2-37	37.89	0.57	28.50	0.05	0.03	0.07	0.06	0.01	29.09	31.00	0.02	98.19	67.6	1.2
D2-38	40.39	3.10	17.54	0.12	0.03	0.08	0.01	0.01	18.14	36.51	0.06	97.84	72.1	6.5
D2-39	45.79	7.57	6.90	0.42	0.04	0.12	0.11	0.01	7.16	41.44	0.01	102.40	81.7	15.8
D2-40	50.20	3.78	0.44	0.14	0.02	0.09	0.02	0.01	0.67	44.11	0.04	98.84	89.6	7.9
D2-41	39.03	4.12	19.24	0.14	0.03	0.07	0.03	0.01	19.66	35.75	0.01	98.42	69.7	8.6
D2-42	40.39	4.07	17.75	0.10	0.03	0.07	0.03	-	18.23	36.32	0.04	98.80	72.1	8.5
D2-43	32.20	1.89	35.93	0.29	0.03	0.05	0.03	0.01	36.53	28.09	0.03	98.54	57.5	4.0
D2-44	50.16	2.24	4.26	0.23	0.04	0.07	0.03	0.01	4.46	42.13	0.03	99.19	89.6	4.7
D2-45	51.22	2.23	2.37	0.31	0.05	0.07	0.07	0.01	2.70	42.87	0.02	99.21	91.4	4.7

Table 1: Summary of Results of the Crowsnest Pass Limestone Study

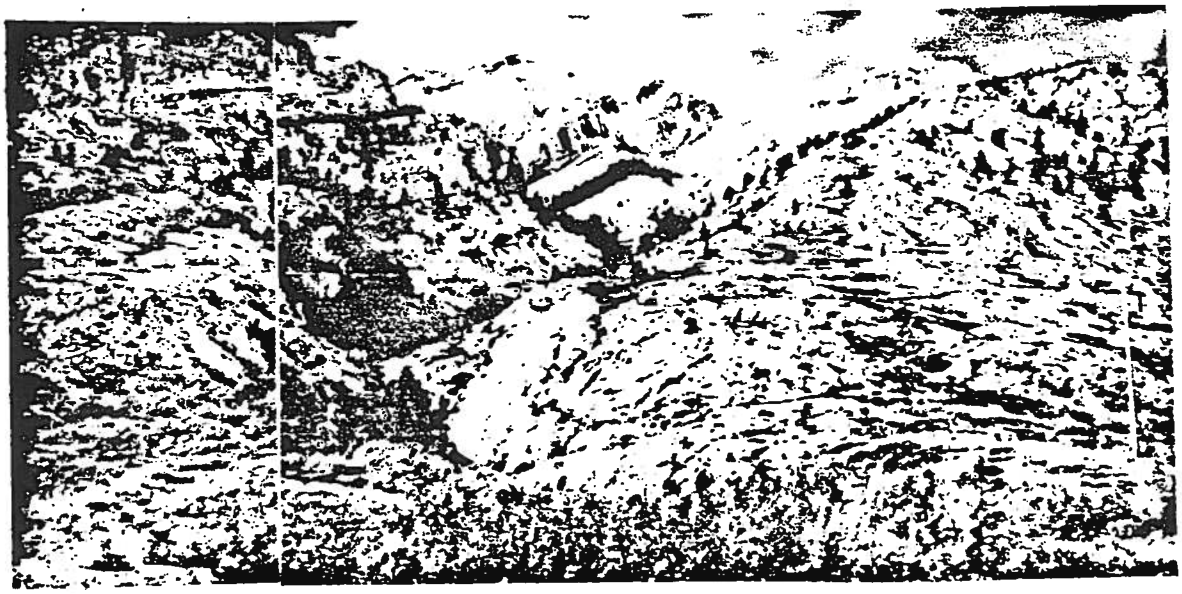
Locality	Formation	Site	Zone	Average $CaCO_3$ %	Average $MgCO_3$ %	Thickness (metres)	Reserves (tonnes $X10^6$)	Quarriability
Phillipps Pass	Livingstone	3A & 3B*	-					Fair; slot-trenching by benching along strike
	Palliser	1B	3	95	<2	72	10	Good; dipslope
		1A	2 1	96 96	<1.5 <2	23 86	2.8 -	Good; dipslope
Between Phillipps and Deadman Passes	Palliser	7**	6 5	94 93	1-3 2	27 34	0.8 1.0	Fair to good; open pit Good; dipslope
Deadman Pass	Livingstone	Section D2 5 & 6*	8 7 -	97 94	1-4 2-8	42 70	- -	nil nil Good; dipslope
	Palliser	4	6 5 4	94 or 98+ 93 91	1-3 2 3-6	27 or 24 34 66	2.7 or 2.4 1.5 8.8	Good; dipslope Good; dipslope Fair to good; dipslope or slot-trenching by benching along strike

*Sites not sampled
**Not sampled - data for Zones 5 and 6 extrapolated from Site 4
+Excluding one 3-m dolomitic bed in the interval

PLATES

Plate 1. Site 1 - Phillipps Pass. View looking northward up small creek. Zone 2 limestone within the Palliser Formation in center foreground, in dip slope quarrying situation. Zone 3 limestone appears at the extreme left.

Plate 2. Site 2 - Phillipps Pass. View looking south at the extreme east end of Crowsnest Ridge. Zones 2 and 3 within the Palliser Formation lie somewhere to the right of center of the photo. Roadcut to the left of center, bottom of photo, approximately marks the position of the base of the Palliser Formation (and base of zone 1). Top of formation marked by rock/tree contact to the right of the peak on Crowsnest Ridge.



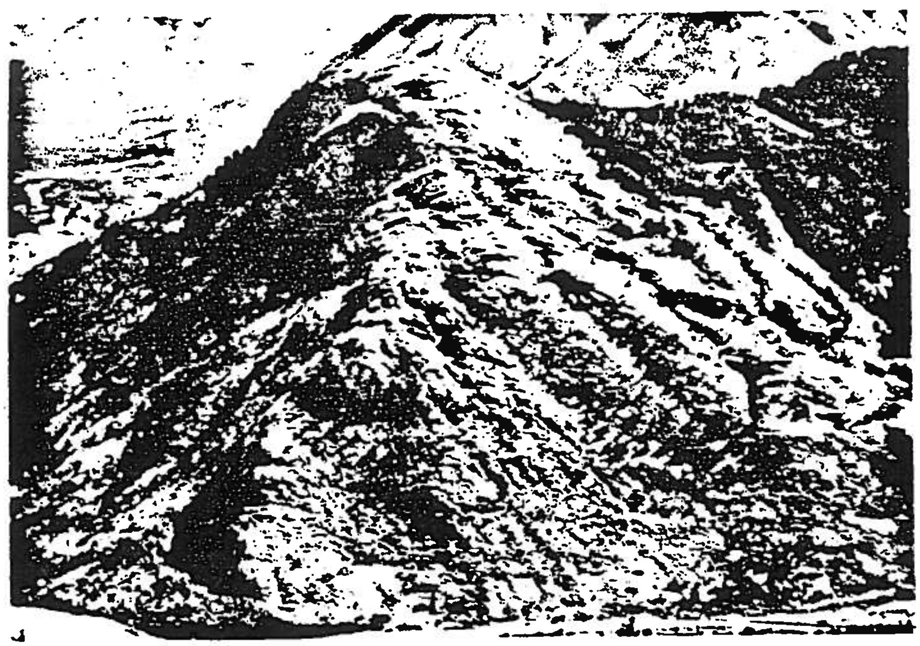
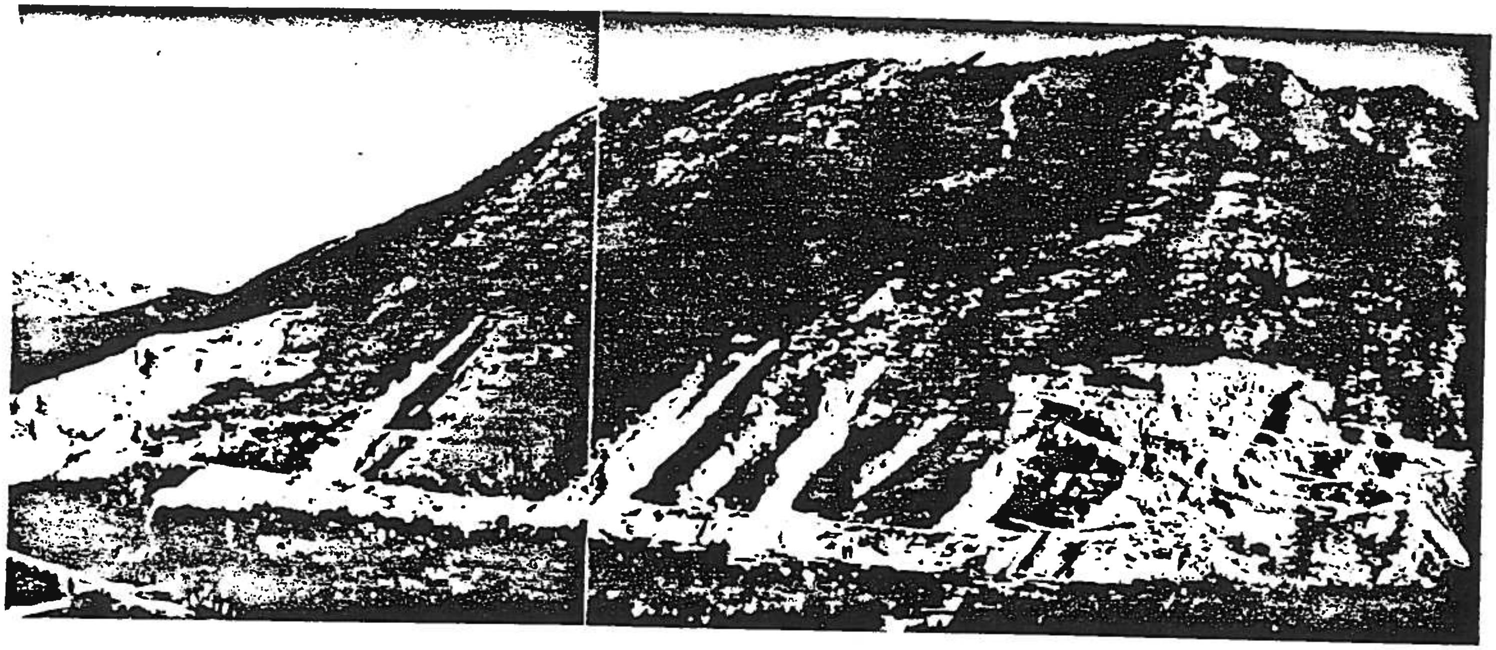


Plate 3. Site 4. Deadman Pass. View looking northeast. Crowsnest Mountain in the background. Section D1 measured along this north-northeast trending spur of Palliser Formation. Strata along this spur are dipping toward the reader. Zone 6 limestone outcrops in lower triangular shaped dip slope, center foreground. Zone 5 is exposed at first prominent knob to the north of zone 6 along this spur (at about dead center of photo). Zone 4 is off the photo to the center-right.

Plate 4. Section D2. Deadman Pass. View looking southwest from site 4 (see plate 3). Livingstone Formation strata dipping into the mountain. Section measured along central spur that runs up the mountain. Top of formation marked by uppermost dark brown bed of dolomite seen along this spur, approximately three-quarters of the way up the mountain. No quarriable sites exist within the Livingstone at this locality.

Plate 5. Summit Lime Works Ltd. quarries. View looking north. All quarries are in the Livingstone Formation. Main quarry, Quarry 1, is on the extreme right. Quarry 2 comprises the two converging cuts at the center of the photo. Quarry 3 is a small cut immediately to the left of Quarry 2. Quarry 4 is the first cut to the left of Quarry 3. Quarry 5 is left of center of the photo and first cut left of Quarry 4. Quarries 6 and 7 appear at the far left of the photo.



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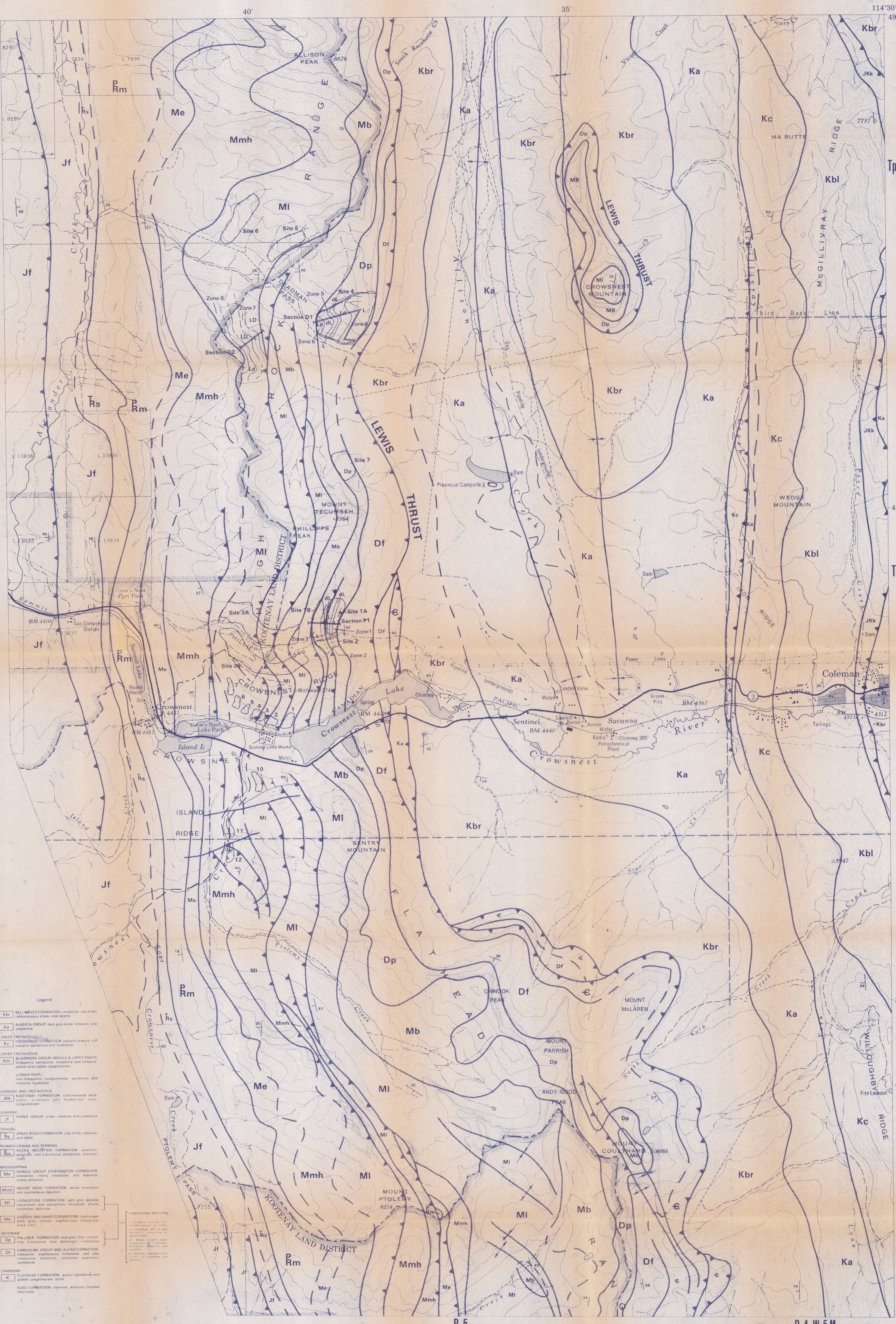

GEOLOGY OF THE CROWSNEST PASS AREA

Scale: 1:25 000

Miles 1 ¼ ½ ¾ 0 1 2 3 4 5

Km 1 ½ 0 1 2 3 4 5 6 7 8

Topographic base from Department of Mines and Technical Surveys Map "Crowsnest 82G 10 E" (1973)

Geology modified from Price, 1962; Brasher, 1974

Syncline
Anticline
Anticline, plunging
Strike and dip
Geological Contact (defined, approximate)
Thrust Fault (teeth in direction of dip)

High Angle Fault
Quarry Site and Number
Summit Lime Works Ltd.
Stratigraphic Section Measured
Adit
Potential Quarrying Site

Main Highway
Secondary Roads
Truck Trails or cutlines
Railway
Power Line
Township Boundary (surveyed)
Township Boundary (unsurveyed)

Provincial Boundary
Creek
Intermittent Stream
Contours (interval 100 ft.)
Depression Contour
Height in feet above sea-level
Building(s)

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Figure 1.

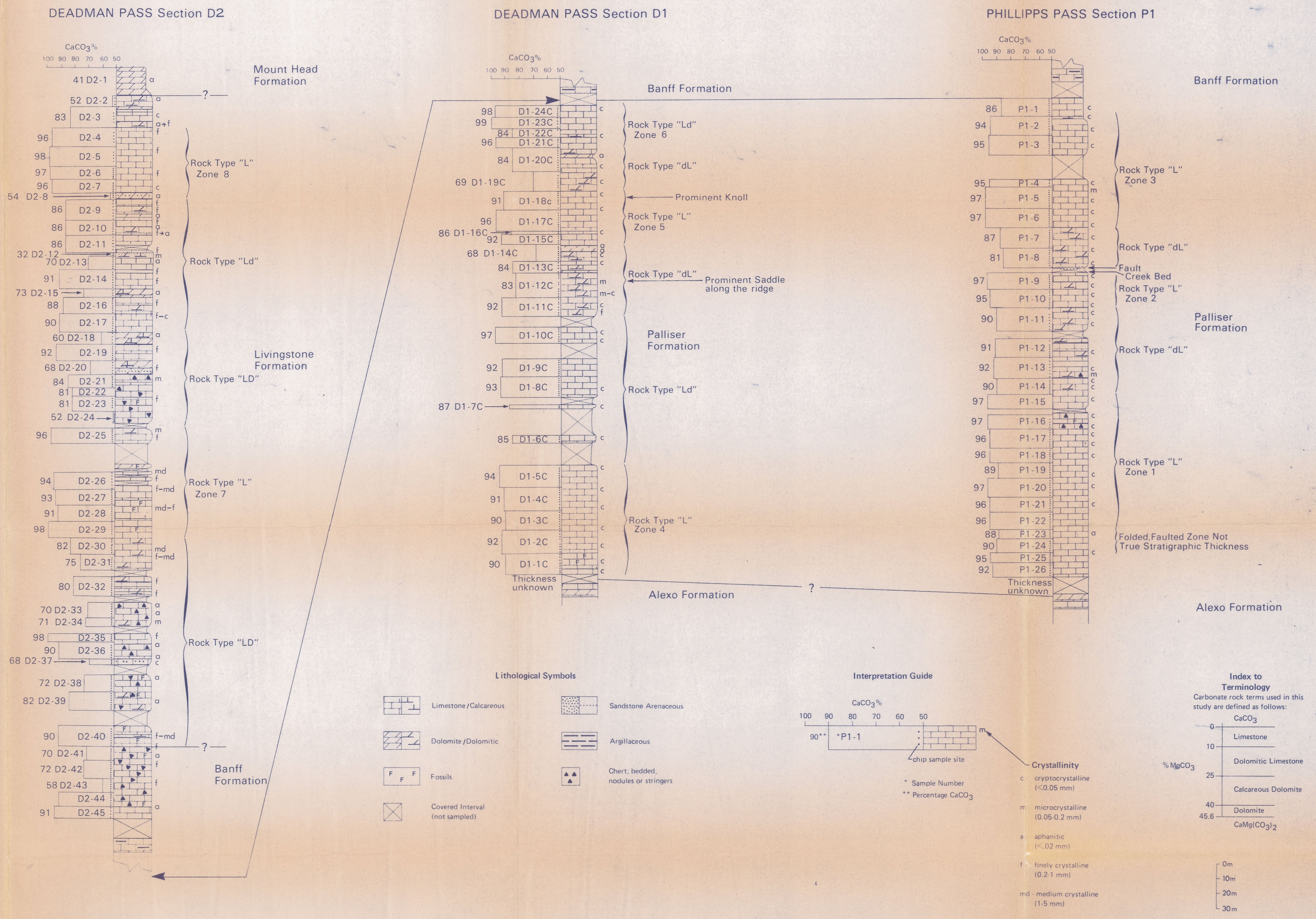

Figure 3. Stratigraphic Sections, Devonian and Mississippian Limestone Strata, Phillipps and Deadmans Pass Area.

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