UNIVERSITY OF ALBERTA

AN EVALUATION OF ALBERTA OIL SANDS RESOURCES FOR ROAD PURPOSES

by

AYODELE A. OLAGOKE

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July 9, 1991

Dr. Ken Anderson
Dept. of Civil Engineering
University of Alberta
Edmonton, Alberta

Dear Dr Anderson;

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The data sheet containing bitumen data will give you an idea of the variations in viscosity data we have found historically in Athabasca bitumen. I have also included a report we made on Nigerian oil sands which were analysed in 1981.

If you require any further information contact me at (403)464-9204.

Yours truly,

Deborah Henry
Oil Sands Sample Bank

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Satellite data before enhancement show central California: night (red) and daytime (blue) thermal-infrared and daylight-visible-light (green) bands. North is to the left; San Francisco Bay appears in red at bottom, right of center. The same data enhanced by image processing appear in the story beginning on Page 2211. Photo courtesy DeAnza Div., Gould Inc.

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UNIVERSITY OF ALBERTA

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ABSTRACT

The Province of Alberta is endowed with vast reserves of oil sands resources. Presently, most of the development of these resources is directed towards exploitation as an alternative source of energy in the light of continuing global depletion of conventional oil reserves. However, due to significant benefits that could be derived, it is worth investigating the potential for utilizing these resources for road building purposes as well.

A study to evaluate Alberta oil sands resources for road purposes was embarked upon in this thesis. For this purpose, the properties of oil sands affecting paving use are examined; the historical and current paving uses of Alberta oil sands resources are reviewed; and conditions for utilizing oil sands resources for paving today are identified and discussed. Furthermore, a review of studies conducted to date with the aim of evaluating the paving-use potential of asphalts obtainable from the oil sands was carried out, and the suitability of oil sand asphalts for paving was evaluated with respect to current CGSB specifications for use of asphalt cements for road purposes.

It is concluded that bitumen from Alberta oil sands is very good material for producing paving grade asphalts as it can be refined to yield Group A asphalt cements, i.e. asphalts of superior temperature susceptibility property

offering high resistance to low temperature transverse cracking of pavements.

Preliminary laboratory mix design testing using the Marshall Method was also carried out to investigate properties of oil sand-aggregate mixtures relevant to pavement performance.

The results show that while the oil sand-aggregate mixtures prepared in this study appear inadequate for heavy and medium trafficked road pavements, Alberta oil sands used in conjunction with graded aggregates would be quite satisfactory for light traffic or low volume roads.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Background

Oil sands (also known as tar sands or bituminous sands) occur in nature generally as a four-phase material comprising in order of increasing proportion, gas (free or dissolved), water, bitumen and mineral grains (sand and fines*).

All over the world, there has continued to be a marked increase in the amount of attention being paid to oil sands, notable occurrences of which exist in several locations across the globe as illustrated in Figure 1.1.

Most of this attention and related efforts, are aimed at developing oil sands resources as an alternative source of energy in the light of continuing depletion of conventional oil reserves. It is however also deemed worthwhile to investigate the potential for utilizing oil sands resources for road paving purposes today. The main attractiveness is cost savings expected in the production of paving mixtures as incorporating oil sands in paving mixtures would amount to substantial reductions in asphalt cement and fine aggregate requirements. There are other potential benefits such as conservation of resources and of the environment as the tendency presently is for the most part to discard large

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* silt- and clay-sized particles --finer than 44 microns

quantities of lean oil sands* encountered in ongoing mining operations as worthless or uneconomic to exploit for oil.

Utilization of oil sands in road paving could take the form of incorporating oil sands in base course and/or surface wearing course mixes. That is provided the resultant paving mixtures are not excessively rich in bitumen (as to pose the risk of pavement bleeding during hot weather), and that they conform reasonably to conventional specification requirements, otherwise pertinent mixture properties would need to be modified before use.

Also, bitumen from the oil sands could be refined to obtain paving grade asphalt cement for producing asphalt concrete mixtures or bituminous surface treatments for road surfacing and other paving applications.

1.2 Objectives of Thesis

To achieve the overall objective of this thesis, specific objectives were to:

- examine properties of the oil sands relevant to paving use as is necessary to adequately assess the potential for paving utilization;
- review the historical and current paving uses of Alberta oil sands resources;

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* bitumen content less than 6% by weight

- identify conditions for utilizing oil sands resources as paving materials;
- review studies that have been conducted to date to evaluate the paving-use potential of Alberta oil sands bitumen;
- evaluate the suitability of Alberta oil sand asphalts for paving using CAN/CGSB-16.3-M90 which is the current CGSB standard for asphalt cements for road purposes.
- conduct preliminary laboratory mix design testing on oil sand-aggregate mixtures using the Marshall test method.

1.3 Organization of Thesis

Chapter 1 presents background to study, as well as objectives and organization of the thesis.

Oil sands properties relevant to paving use are examined in Chapter 2 which also contains a review of the geology of the Alberta oil sands and provides estimates of resources in place.

In Chapter 3, the historical and current paving uses of Alberta oil sands resources are reviewed and the conditions for utilizing oil sands resources for paving today are identified and discussed. Previous studies on Alberta oil sand asphalts are reviewed, and Alberta oil sand asphalt cements are evaluated with respect to current CGSB specifications.

The laboratory mix design testing conducted is reported in Chapter 4 while Chapter 5 presents the summary, conclusions and recommendations of this study.

Figure 1.1 Worldwide distribution of tar-sand deposits (Carrigy, 1983)

CHAPTER 2

THE OIL SANDS RESOURCES OF ALBERTA

2.1 The Principal Oil Sands Deposits

The oil sands deposits of Alberta collectively represent one of the largest such resources in the world (Alberta ERCB, 1985). The deposits are currently grouped by the Alberta Energy Resources Conservation Board into three geographic areas namely Athabasca, Cold Lake and Peace River oil sands areas as illustrated in Figure 2.1.

2.1.1 Athabasca Oil Sands Deposits

Athabasca oil sands area comprises the McMurray, Wabiskaw and Grand Rapids oil sands deposits. The McMurray Formation ranges between 40 and 80 m in thickness (MacGillivray et al., 1988) and is subdivided into three informal stratigraphic units (lower, middle, and upper McMurray). Where it lies close to the present-day surface, the McMurray Formation constitutes the orebody being exploited by the Syncrude and Suncor surface mining operations (Wightman et al., 1989).

As compared to the other oil sands deposits, the sediments of the McMurray Formation in the Athabasca area have a very uniform mineralogy (Mossop et al., 1981). The sediments consist of uncemented, very fine to coarse-grained quartz sand with subordinate associated shale, silt, and thin coal beds.

The Wabiskaw Member sediments generally consist of lower to upper shoreface   offshore sands, silts, and shales. The uncemented quartz sands are generally fine to very fine grained and occur as laterally persistent, though relatively thin reservoirs. In contrast to the McMurray Formation sands in the Athabasca area, the Grand Rapids Formation sands are mineralogically complex, with quartz, chert, feldspar, and rock fragments of mainly volcanic and sedimentary origin as framework grain components (Wightman et al., 1989).

2.1.2 Cold Lake Oil Sands Deposits

Deposits in the Cold Lake oil sands area are distributed through four main stratigraphic intervals over a depth range of 275 to 600 m, the principal deposits being the McMurray-Wabiskaw, Clearwater, Lower and Upper Grand Rapids deposits.

The McMurray-Wabiskaw deposit holds the smallest bitumen reserves in the Cold Lake area and the bulk of the bitumen in this interval is in the thinner (5 to 10 m) sands at the top, the thick (10 to 50 m) channel deposits in the underlying continental McMurray Formation being predominantly water bearing (*ibid.*).

The Clearwater deposit holds the second largest bitumen reserves in the Cold Lake area even though it is the smallest in areal extent. The relatively large reserves are due to the greater thickness of oil sands (up to 60 m of net pay thickness) and this, along with good lateral reservoir continuity, has resulted in the Clearwater deposit being the focus of extensive thermal recovery activity.

Although the Lower Grand Rapids deposit is not as areally extensive as the Upper Grand Rapids deposit, it holds the largest bitumen reserves in the Cold Lake area. As explained by Wightman et al.(1989), this is because the oil sands of the Lower Grand Rapids are more continuous, while the oil sands of the Upper Grand Rapids are relatively discontinuous and thin in many parts of the deposit.

2.1.3 Peace River Oil Sands Deposit

Within the Peace River deposit area, bitumen is trapped in an updip pinchout of the Cretaceous Gething and Bluesky formations against Mississippian carbonates which form a high on the sub-Cretaceous unconformity (Rottenfusser, 1985). Furthermore, the thickest and most continuous oil sands in the Peace River deposit are found in tidal channel complexes, although high oil saturations (77% pore volume) can also be found in widespread shoreline and shallow marine sands. The reservoir is relatively deep (460 to 760 m) with zones of net pay up to 30 m thick. The reservoir sands have a mixed mineralogy, dominated by quartz, chert, rock fragments, carbonate grains, and minor feldspar (Wightman et al., 1989).

2.2 Reserves Estimates for Alberta Oil Sands.

Together, the three major oil sands areas of Alberta have an areal extent of about 91,860 square km and hold an estimated reserve of about 1250 billion barrels of bitumen in place (Wightman et al., 1989). A summary of in-place bitumen reserves for each deposit area as designated by the Alberta Energy Resources Conservation Board is provided in Table 2.1.

2.3 Characteristics of Alberta Oil Sands Resources

2.3.1 Deposit Characteristics

There are two main characteristics of oil sands deposits which have important bearing on the economic exploitation and development of the resources. These are, accessibility of the resource (which is usually measured in terms of depth of overburden), and percentage bitumen saturation of the oil sands (Camp, 1976).

2.3.1.1 Depth of Overburden

The oil sands occur in layers at different depths in each deposit as illustrated by Figure 2.2. The overburden depth is important as it influences the method employed for exploiting the oil sands. For example, surface mining methods such as presently used in the Athabasca oil sands area by Suncor Inc. and Syncrude Canada Ltd., are only economically practical where the oil sands are overlain by not more than 50 m overburden (McRory, 1982).

The overburden in the Athabasca oil sands area varies from 0 m along the Athabasca River valley where the McMurray Formation outcrops, to approximately 600 m in the southwest portion of the deposit (Wallace et al., 1988). The range of overburden thicknesses is about 300 to 600m in the Cold Lake oil sands area and 450 to 800m in the Peace River oil sands area as illustrated in Figure 2.3 which further indicates that, of all the deposits, it is the approximately 10 percent of the Athabasca oil sands lying below overburden thickness of 50m or less that are shallow enough to be exploited by surface mining methods. Deeper-lying deposits may be recovered by *in-situ* methods such as cyclic steam stimulation (huff and puff), steam drive and fire flooding, while those lying at intermediate depths (50-150 m overburden) can be recovered by Mine Assisted In Situ Production (M.A.I.S.P.), a recently proposed concept also known as "Shaft And Tunnel Access Concept" (SATAC) which employs underground drilling tunnels to gain access to oil sand formations not accessible by surface mining techniques (AOSTRA, 1984).

2.3.1.2 Bitumen Saturation

In the Athabasca oil sands area, bitumen saturation of the sands is up to 18 weight percent, with 14 to 16 weight percent being common in the channel sands, while the average bitumen saturation is about 9 weight percent (Wallace et al., 1988). Bitumen saturations in the main Clearwater reservoir of the Cold Lake oil sands area vary between 14 and 16 weight percent while the maximum bitumen saturation in the Peace River oil sands area is 12 weight percent (Reddy et al., 1982). It is worth noting that at present, oil sands with bitumen contents less than about 6 weight percent are generally considered lean and uneconomic to exploit.

2.3.2 Oil Sands Characteristics

Alberta oil sands characteristics are well documented in the literature (e.g., Dusseault, 1977; Scott and Kosar 1984; Camp 1976; Energy, Mines and Resources Canada 1977, and others). Therefore, only those characteristics, namely composition, grain size distribution, and bitumen content which affect paving usage are discussed.

2.3.2.1 Composition

Oil sands are known to be a mixture of sand, bitumen and water. The sand component is predominantly quartz, in the form of rounded or subangular particles, each wet with a thin film of water (Deston, 1976). Surrounding the wetted sand grains, and somewhat filling the void volume between them, is bitumen. The balance of the void volume is filled with water and sometimes a small volume of gas which is usually air but may also be methane (*ibid.*). According to Scott and Kosar (1984), the water and bitumen each form a continuous phase throughout the oil sand structure with gases dissolved in both phases, or occurring occasionally as free gas depending on in-situ temperatures and pressures.

2.3.2.2 Grain Size Distribution

From the viewpoint of possible utilization in paving mixes, Alberta oil sands as they occur in nature are rather fine and uniformly graded, being deficient in the larger particle sizes. The oil sands tend to consist predominantly of smaller-sized particles (approximately 100% finer than 1.25mm sieve size). This is further illustrated by Figure 2.4 which shows plots of oil sands particle size distribution (obtained by sieve analysis of test samples, and as derived from data accompanying samples supplied by Alberta Research Council), in comparison with Alberta Transportation and Utilities' grading specifications for granular and asphalt stabilized base courses.

It is therefore necessary to blend in suitable coarse aggregate with the oil sands in order to achieve a well graded total aggregat suitable for a paving mix.

2.3.2.3 Bitumen Content

Ordinarily, if richly-impregnated oil sands (10% bitumen by weight and higher) were to be used directly for paving without blending in additional aggregate, the bitumen content would be more than required, with unacceptable risk of pavement bleeding under warm weather conditions. When coarse aggregate is blended in with the oil sands however, the bitumen content of the total mixture falls, albeit desirably, by an amount depending on the proportions of oil sands and other aggregate in the mix.

As selecting the right asphalt content is of vital importance to the performance of a paving mixture, a primary factor in preparing oil sand-aggregate mixtures for paving purposes would be to determine an optimum asphalt content that would yield oil sand-aggregate mixes having sufficiently well-coated aggregate particles with good cohesion, stability and durability characteristics.

Table 2.1. Summary of reserves estimates for Alberta oil sands

Area	Deposit	Areal Extent	Mean Pay Thickness	Bitumen - in place	
		(10^3 ha)	(m)	(10^9 m^3)	(10^9 bbl)
Athabasca	Mcmurray / Wabiskaw	4680	34	144	906
	Grand Rapids	689	7	7	44
				151	950
Cold Lake	Grand Rapids	1603	7	20	126
	Clearwater	561	12	11	69
	Mcmurray / Wabiskaw	666	5	4	25
				35	220
Peace River	Bluesky / Gething	987	14	12	76

(modified from Wightman et al., 1989)

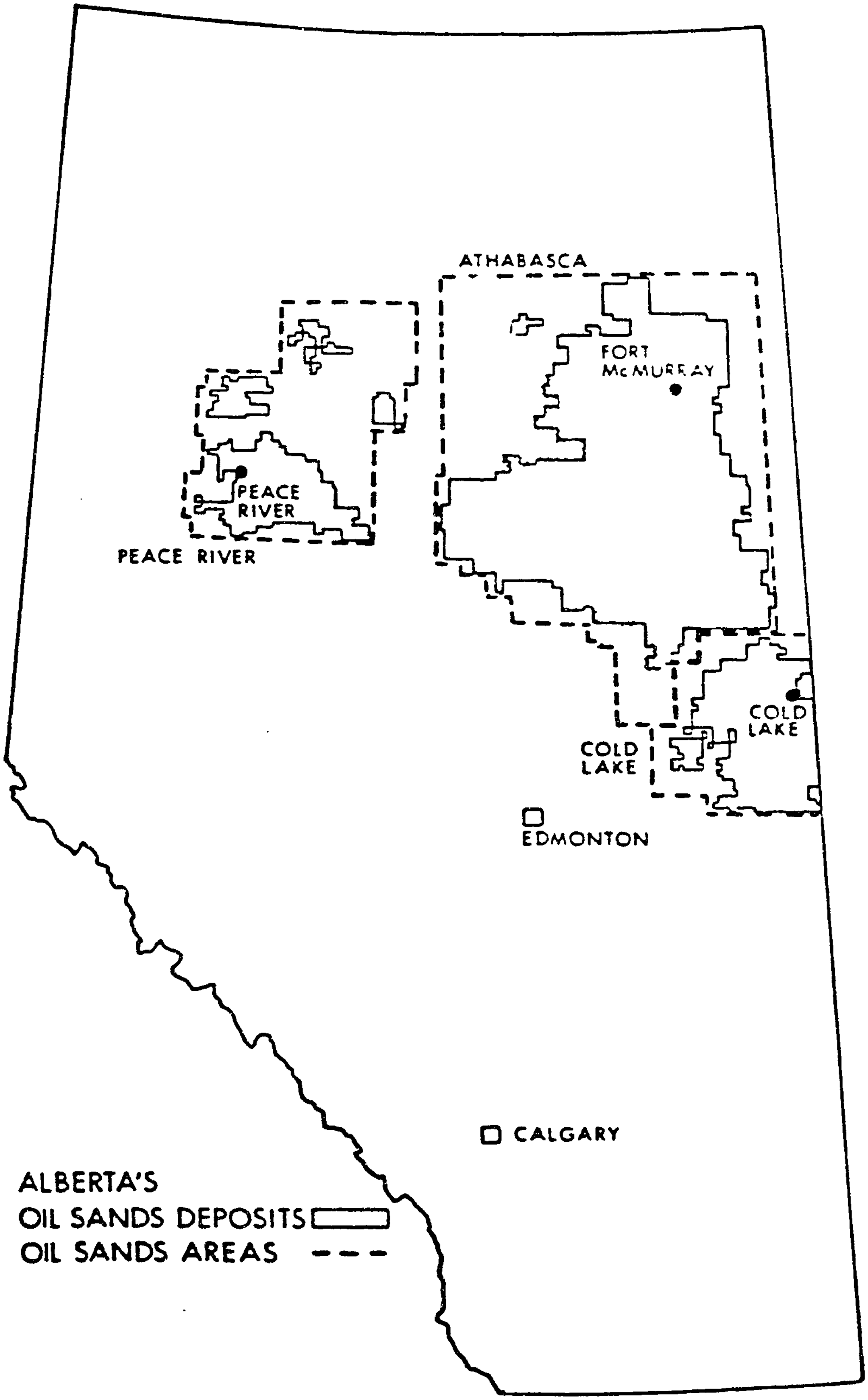

Figure 2.1 Oil Sands Areas of Alberta
(modified from Alberta ERCB, 1985)

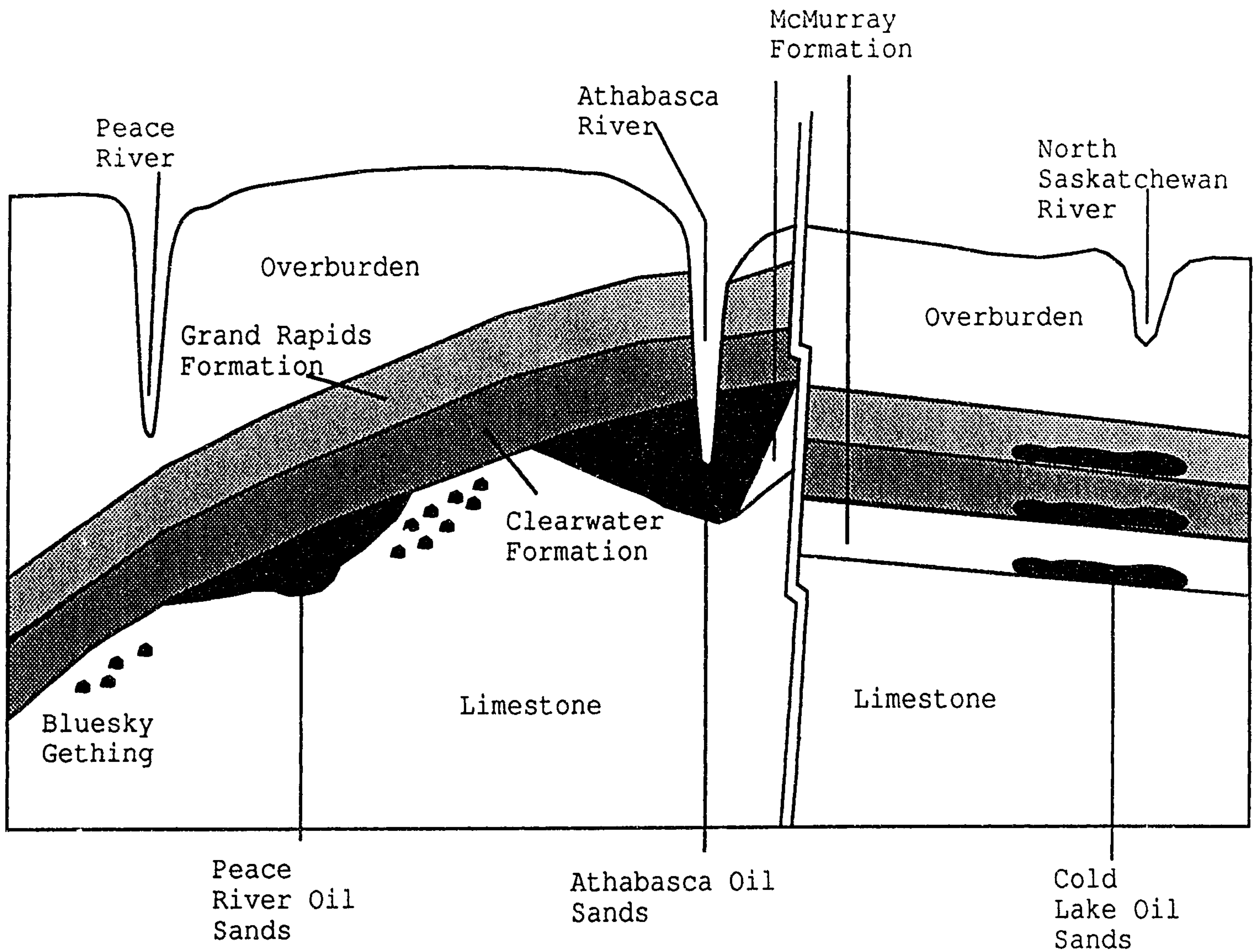

Figure 2.2. Schematic of Geological Location of Major Oil Sands Deposits (modified from McRory, 1982)

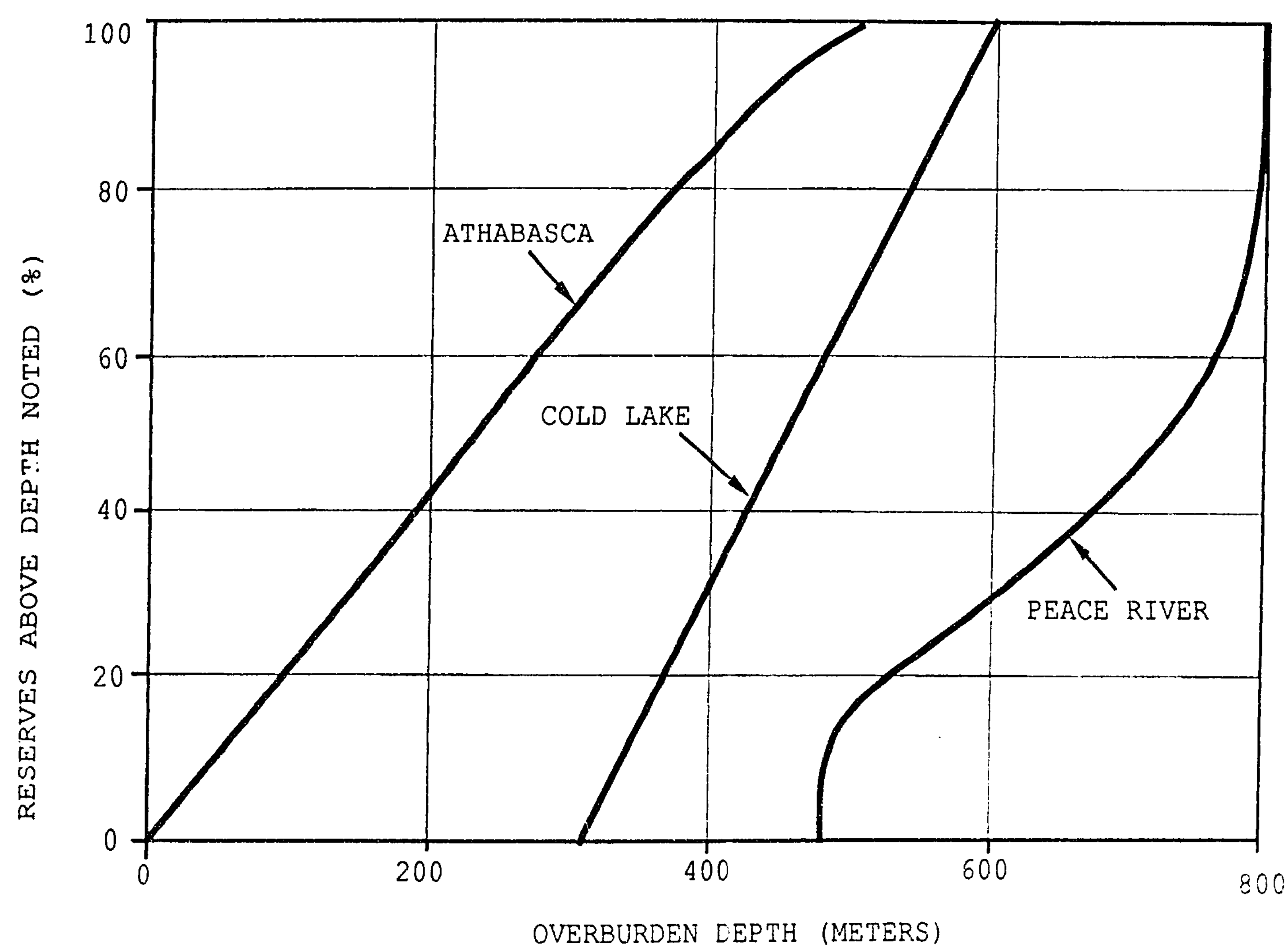

Figure 2.3. Overburden Thickness Estimates for Alberta Oil Sands

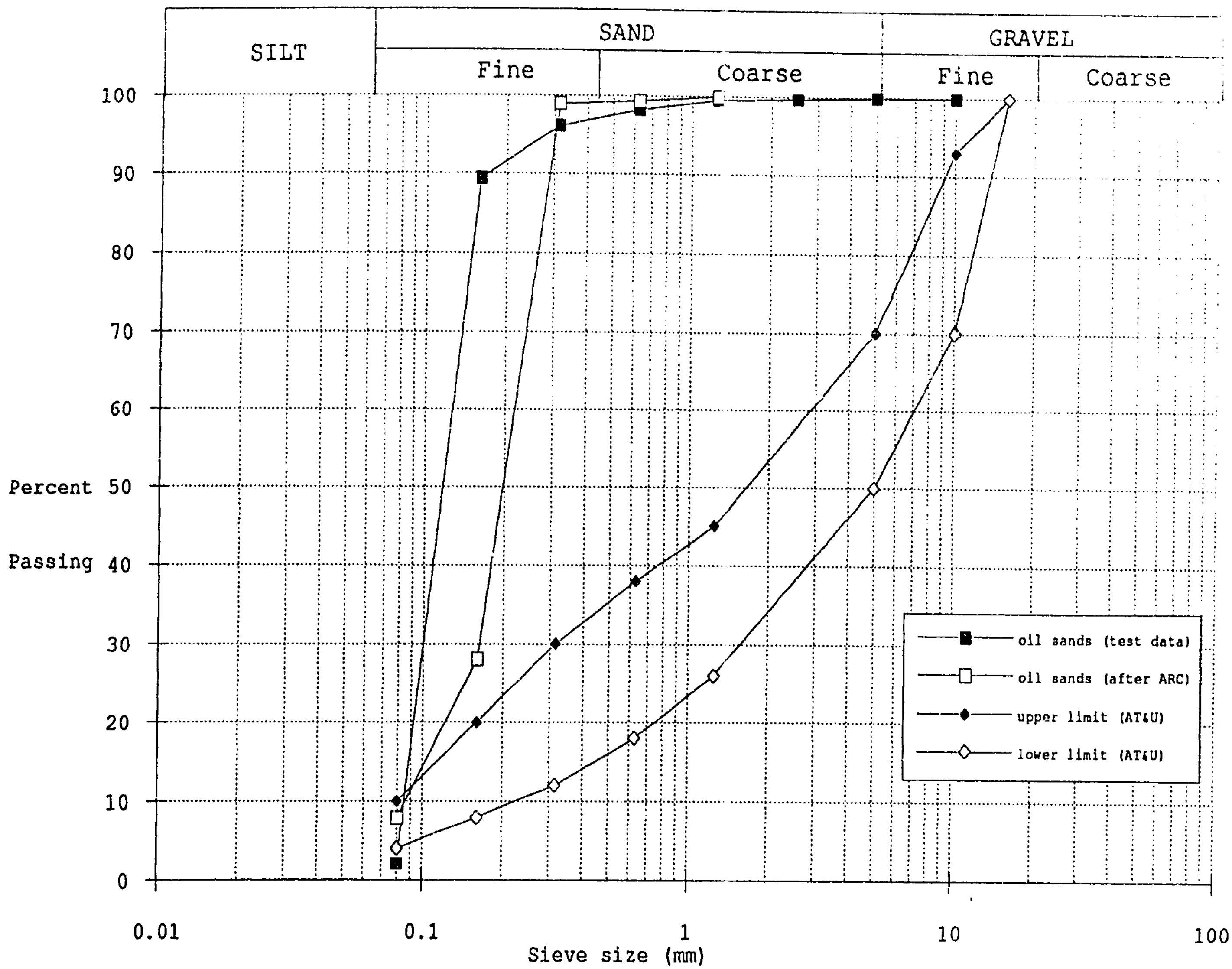

Figure 2.4 Comparison of natural gradation of oil sands with Alberta Transportation and Utilities grading for granular and asphalt stabilized base courses (Designation 2-16).

CHAPTER 3

THE POTENTIAL OF UTILIZING ALBERTA OIL SAND RESOURCES IN PAVING

3.1 Preamble

While most of the attention and related efforts being directed at oil sands is with a view to developing oil sands resources as an alternative source of energy in the light of continuing depletion of conventional oil reserves, it is also worth investigating the potential for utilizing oil sands resources for road purposes. In this regard, it is noted that blending in suitable coarse aggregate with the oil sands is necessary in order to achieve a well graded total aggregate suitable for road paving.

The objective of this chapter is to assess the potential for utilizing Alberta oil sands resources for paving purposes. Towards this end, the historical and current paving uses of Alberta oil sands resources are reviewed, the conditions for utilizing oil sands resources in paving are identified, and a review of studies conducted to date with the aim of evaluating the paving-use potential of Alberta oil sand asphalts is undertaken. The suitability of oil sand asphalts for paving is also evaluated with respect to current CGSB specifications for use of asphalt cements for road purposes.

3.2 Historical Use of Alberta Oil Sand Resources

3.2.1 Use of Oil Sands as Surfacing Material

Bituminous sands have been extensively used as road surfacing materials in the United States, in England and in other parts of Europe with satisfactory results when properly applied (Ells, 1962). Alberta oil sands have also been successfully used for this purpose, with the pioneering work of Ells (1924;1926;1927;1962) being the most notable efforts in previous paving attempts with the Alberta oil sands. Each relevant aspect of Ells' work, in the form of attempts made to demonstrate the practicability of using Alberta oil sands for road surfacing, is reviewed under separate headings in the following sub-sections.

3.2.1.1 Oil Sands Pavement in Edmonton (1915)

The oil sands pavement laid in Edmonton in 1915 by Ells and his co-workers on Kinnaird Street, south of Alberta Avenue* comprised three surfacing mix types incorporating oil sands, namely sheet asphalt, bitulithic mix and bituminous concrete (Ells, 1926; 1962).

Pertinent data provided by analyses of the raw bituminous sands prior to use in the 1915 surface mixes are presented in Appendix A as reported by Ells (1926). From this data, the grain size distribution of the coarse- and

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* now 82nd Street, 118 Avenue

fine-grained bituminous sands used were derived as shown in Tables 3.1a and b. This is useful for arriving at the total aggregate gradations of the sheet asphalt, bitulithic and bituminous concrete mixes laid for the 1915 oil sands pavement. The three mixes incorporated the coarse- and fine-grained bituminous sands in differing proportions with additional aggregate introduced to modify the uniform gradation of the raw oil sands. Average weights and composition of the mixes were reported by Ells (1926) as given also in Appendix A. The total aggregate gradations of the three paving mixes were derived as shown in Tables 3.2 through 3.4, while Figures 3.1 through 3.3, show the derived total aggregate gradations plotted in comparison with present-day grading specifications. (Relevant comments regarding the comparison are given in Section 3.3).

The uniform gradation of the coarse and fine bituminous sands was in 1915 partly corrected by combining the two in a proportion of two fine to one of coarse for the sheet asphalt and bitulithic mixes. In addition, some fresh sand was incorporated in the sheet asphalt mix as indicated in Table 3.2. The bitulithic mix also had fresh aggregate comprising sand and crushed gravel blended with the oil sands mixture (Table 3.3) while for the bituminous concrete mix, the gradation of the fine-grained bituminous sand was improved by adding crushed gravel and sand (Table 3.4). These manipulations also simultaneously served to bring about desirable reduction in the high percentage of bitumen present in the original material.

A heated rotary mixer was used for heating and mixing the materials. This mixer consisted essentially of a revolving drum connected to the engine by shaft and gears. The inner surface of the mixer drum was fitted with baffles so arranged as to ensure thorough mixing of charged materials. Prior to charging, the drum was usually pre-heated to a temperature of 250 to 300 F (120-150 C), whereupon the bituminous sand was wheeled in barrows to the loading platform and the drum charged. During the first period of heating, the charging opening of the drum was kept closed by means of a damper. When, however, the bituminous sand had reached the desired temperature, the heat was turned off and the damper removed. The mix was then allowed to remain in the drum for a further period of about 8 to 10 minutes, during which time the lighter hydrocarbons passed off freely as vapor.

In adding crushed rock, as in the case of the bitulithic and bituminous concrete mixes, it was found that a better bond resulted when the drum was charged at a drum temperature not exceeding 300 F (150 C). In adding new sand however, as in the case of the sheet asphalt mix, the sand was usually added after the crude bituminous sand had attained a temperature of 380 to 400 F (193-205 C). In either case it was found that a period of ten minutes was sufficient to allow all materials to be thoroughly mixed.

The reports by Ells (1926; 1962) further indicate that in each case, i.e. for each surface mix type, the raw bituminous sand was first heated alone for a period of from 20 to 30 minutes before adding sand, or sand and crushed gravel. This addition caused mix temperature to fall 20 to 30 degrees Fahrenheit, with 5 to 8 minutes usually required for the mix to regain its former temperature. Thereupon, the damper was usually removed from mixer drum and vaporization of lighter hydrocarbons, indicated by volumes of oil vapor, proceeded freely. While to some extent, the color of the vapor indicated the progress of distillation, after a period not exceeding ten minutes the contents of the drum were discharged into a wagon. The temperature of the mix when discharged into wagons usually ranged from 380 to 410 F (193-210 C), reaching the street at an average temperature of 325 F (163 C).

Upon being sent to the street, the sheet asphalt mix was laid with a compacted thickness of 2 1/4 inches (57 mm) on an open graded binder course compacted to 1 1/2 inches (38 mm). The bitulithic and bituminous concrete mixes were laid directly on a 6-inch concrete base composed of 1 part Portland cement, 3 parts sharp sand, and 6 parts crushed gravel, and both mixes given a compacted thickness of 3 inches (76 mm) (Ells, 1926; 1962).

This first trial paving effort with the Alberta oil sands proved quite successful, given the resulting satisfactory performance the pavement provided under the decidedly heavy traffic it served at the time. As reflected in the written assessment of the then City Engineer of Edmonton ten years after laying, the pavement was still in excellent condition, having showed no signs of defect or deterioration, and at that point in time still appeared good for many more years of satisfactory service. Subsequent to this remarkably positive assessment by the City Engineer was the following assessment by the same officer *thirty-five years* after the pavement was laid by Ells and his team of workers:

"The work ... laid in Edmonton in 1915 has stood up very well and is in good condition, having only had the usual minor repairs that all flesh and pavements are heir to" (Ells, 1962).

It is worth noting that Clark and Blair (1927) also affirmed quite positively to the short- and long-term performance of this pavement in satisfactorily carrying the decidedly heavy traffic it was subject to from the time it was laid.

Thus, the initial experience of surfacing with Alberta oil sands gave positive indication of good potential for utilizing the oil sands in pavement surfacing.

3.2.1.2 Surfacing at Jasper Park, Alberta (1927-28)

Following the success of the oil sands pavement laid in Edmonton in 1915, and the ensuing wide notice it received, the suggestion was made to Ells by the then Director of Canadian National Parks that a section of highway at Jasper, Alberta be similarly surfaced (Ells, 1962). Consequently, the oil sands quarry at Ft. McMurray was further extended and a new and larger mixing plant than that used in Edmonton, was designed and built for use in Jasper. The essential components of this mixing plant included two revolving steel mixing drums fitted with an effective arrangement of heavy mixing baffles, two oil-fired combustion chambers, as well as loading and discharging chutes.

According to Ells (1962), the heated mixture delivered from the drums of the mixing plant could best be described as a stone-filled sheet asphalt. This heated mixture was delivered into five-ton trucks, and a two-inch compacted surface was laid directly on the gravel road which had previously been in use. Additional aggregate blended with the bituminous sand consisted of crushed limestone and gravel. The limestone used was crusher-run rock broken to pass a one-inch ring. Gravel and crushed rock were both passed through a rock screen with material passing $^{1}/_{4}$ -inch mesh (6.25mm), and material exceeding one inch (25mm) diameter removed. Immediately after spreading and raking, the bituminous sand mixture was compacted by means of a hand roller weighing 300 pounds (136kg), and after the wearing surface had cooled to some extent, final compression was effected by the use of a 7-ton tandem roller (Ells, 1927).

The section of highway surfaced was from the town of Jasper, Alberta to Jasper Lodge, a summer tourist hotel that was operated by the Canadian National Railway System, and traffic using the road was described by Ells (1927) as fairly heavy, particularly during summer months. Commenting on the above pavement in July of 1928, Mr J.B. Snape, then Resident Engineer at Jasper Park wrote in part as reported by Ells (1962) as follows: "The road from Jasper to the Lodge, which was paved with McMurray bituminous sand last year, has come through the winter in excellent shape, and in fact the general appearance is better than last Fall. It is quite dustless, gives excellent trackage normally and also during wet weather, and there is no danger of skidding and side-slipping. In fact it seems to be the ideal road surfacing material". Ten years after this assessment of the surfacing work done with bituminous sands at Jasper Park, Ells himself had occasion to drive over the pavement and found it to be in excellent condition as well. He further testified to Mr Snape's reference to the non-skid qualities of the surface, based on positive comments and inquiries from operators of motor vehicles including trucks, cars and motorcycles that were using the road (Ells, 1962). It is worth noting too that Clark (1929) also commented favorably regarding the performance of this pavement surfaced with bituminous sands at Jasper Park.

3.2.2 Use of Oil Sands as Base Course Material

In a comprehensive literature search at the AOSTRA Library and Information Services (ALIS) located in Edmonton, Alberta, it was found that nowhere has the use of Alberta oil sands as pavement base course material been reported. However, given an understanding of the grain size distribution of the raw oil sands material as exists in nature with its fine, uniform gradation, the gradation can be appropriately modified by blending with coarse aggregates such as crushed gravel in order to attain a combined aggregate gradation conforming with whatever is adopted as the standard composition for a base course mix.

An example of such standard as being referred to above is the Alberta Transportation and Utilities recommended grading for asphalt stabilized base courses (ASBC).

3.2.3 Paving Uses of Bitumen from Alberta Oil Sands

Use of the raw oil sands with a modified or improved gradation for building pavements is only one of the possibilities of oil sands utilization in paving. The bitumen component can be separated from the associated sand by available means, with potential for use in the construction of a wide range of bituminous roads. To this category belongs the use of separated and subsequently refined bitumen as an asphaltic oil in road-mix operations, as a stabilizing agent in earth and gravel road construction, and in the form of asphalt cement for binding aggregates in pavement surface and/or base courses.

Clark (1927; 1929) gives details of relevant work done by the Scientific and Industrial Research Council of Alberta (then under the University of Alberta), which used bitumen produced by its experimental bituminous sand separation plant to successfully treat a stretch of earth road surface. The work involved loosening the earth road surface to depths varying from two to six inches (50-150mm) in the different sections treated, and spraying the heated bitumen on in a number of applications to provide a bitumen content of about 10%, while ensuring thorough mixing of earth and bitumen. The bituminized earth would then be properly distributed with a grader, then allowed to compact under traffic, and as a final operation, a seal coat of bitumen and sand sprinkling was applied onto the surface. The reports (*ibid.*) indicated that the final mixture compacted readily, giving a good surface, that the separated bitumen had a very marked stabilizing effect.

According to Clark (1945), the results obtained with this and other works undertaken later, demonstrated that the asphalt cement derived from the separated bitumen is of excellent quality for road-building purposes. In fact, as further stated by Clark (*ibid.*), this asphalt was once the subject of a joint laboratory study by Imperial Oil Company technologists and the Fuels Division of the Federal Department of Mines and Resources, in respect of which findings indicated that the oil sand asphalt compared favorably with other paving asphalts whose road-building suitability was known from practical use. Other successful practical demonstrations of the value of the asphalt cement derived from the bituminous sands can be cited (Ells, 1927), and the only conclusion that can be drawn from this evidence is that the asphalt cement derivable from the Alberta oil sands is a good road-building material.

3.2.4 Other Historical Paving Uses

Also reported in the literature are other related forms of use to which the Alberta oil sands had been successfully put in the past which do not fall directly under the above designated categories. To this belongs the use of the oil sands in the construction of driveways and city sidewalks. For example, it is reported that in 1927, a driveway on the grounds of the government buildings in Edmonton was surfaced with good results by the McMurray Asphaltum and Oils Co. Ltd. using asphalt aggregate mixes utilizing bituminous sands (Clark, 1929).

It is also reported (*ibid.*) that the City of Edmonton ordered twenty tons of bituminous sands from the McMurray Asphaltum and Oils Co. Ltd. of Waterways, Alberta in order to undertake sidewalk surface construction during the construction season of 1922. Representative samples of the shipment were taken during unloading and submitted to the

Scientific and Industrial Research Council of Alberta* for examination, whereupon tests showed the material contained 20% bitumen on the average. The results of the tests further showed that the sand constituent was rather fine, consisting of about 15% particles passing a 200-mesh (0.08mm) sieve, and approximately equal parts of sand particles retained on the 100 and 200-mesh (0.15 and 0.08mm) sieves.

Making use of the results of tests performed on samples of the shipment, and of sieve analyses on stocks of sand available at the paving plant, a combination of the bituminous sands and sand used for concrete was deduced which gave a mixture that fairly well approached a standard sheet asphalt mixture. Some portland cement was also added as filler, and the same heated rotary mixer that was used for mixing materials for the oil sands pavement of 1915 was again secured and used for preparing the mix for this bituminous sands sidewalks surfacing project. Batches of about 1000 pounds (450 kg) were handled at a time, and were heated and mixed during periods ranging from 30 to 60 minutes, which operation caused the evaporation of about 10% of the bitumen contained in the mixtures. Upon completion of the mixing and heating, the bituminous sand mixtures were hauled to the sidewalks, spread and rolled. Two stretches of bituminous sand sidewalks were so built, one on the north side of 102nd Avenue between 99th and 100th Streets, and the other on the

* now Alberta Research Council

north side of the same avenue between 96th and 97th Streets. Both sidewalk surfaces were laid on old, compacted cinder foundations and according to Clark (1923) the finished sidewalks showed good prospects for giving satisfactory performance.

3.3 Comparison of 1915 Oil Sands Pavement Surfacing Mixes With Current Grading Specifications

The total aggregate gradations of surfacing mixes for the 1915 oil sands pavement are compared with relevant present-day grading specifications as shown in Figures 3.1 through 3.3. From these plots, it is seen that while the total aggregate gradation of the 1915 sheet asphalt mix approximately conforms with current grading, those for the bitulithic and bituminous concrete mixes do not.

It is worth noting that the evidence of good performance in respect of these mixes laid for the 1915 oil sands pavement, gives indication that much better results can be expected today with the use of oil sands for paving purposes, given today's improved mix design standards and practice, and related to these, improved construction control testing and monitoring.

3.4 Current Usage of Alberta Oil Sand Resources

3.4.1 Cold Lake Oily Sand Road Application Practices (Price and Holland, 1989).

This is one remarkable case reported in recent times in respect of present-day utilization of Alberta oil sands resources for paving purposes. Esso Resources Canada Limited produces oily sand as a byproduct with bitumen recovered at the commercial scale Cold Lake cyclic steam stimulation project. Various options are available for utilizing this oily sand byproduct. These include processes to extract residual oil followed by disposal to landfill sites, incineration, re-injection into the ground or use as a dust suppressant on roads.

Price and Holland (1989) report that Esso Resources has developed a technology, including guidelines and work methods to utilize the oily sand as a road surfacing material giving smooth all-weather road surfaces supporting high traffic volumes and loads (> 400 vehicles per day, < 35 tonnes axle weight). The oily sand byproduct is used on roads in a manner which is beneficial for accessing ongoing operations at Cold Lake as well as providing a good quality road for public use while not representing an environmental hazard. Furthermore, the road surfacing methods employed use commonly available road building and maintenance equipment, and adapt techniques used for laying asphalt paving mixtures to achieve a road surface closely approaching conventional asphalt pavements in appearance and performance.

This oily sand generated at Cold Lake as a byproduct of bitumen production from the Clearwater reservoir, is characterized as a liquid sludge composed of bitumen, fine sand and water. The sand is moved into the sand pits during the annual plant turnarounds, and a typical drained analyses of the oily sand found in the sand pits is 13% bitumen, 7% water and 80% solids by weight.

Essentially, the process of using this oily sand material for road paving starts by carefully controlling, monitoring, and recording on a continuous basis all-year round, the materials that are thrown into the sand pits which would later serve as the source of material for the road surfacing work.

All of the free fluids (bitumen and water) contained in the sand pit are drained and pumped out on a continuous basis and recycled back to the plants. To enable the material to be utilized for road building, coarse aggregate is introduced by dumping gravel into the sand pit and mixing with a front end loader. The desired composition is dependent on the road bed and pit contents, usually being close to a 1:1 mixture by volume of oily sand to gravel. Using a front end loader, the mixture is lifted out of the pits into trucks and hauled to where it is placed on the roads, ensuring trucks do not drip enroute.

Windrows are developed on the road surface by blading loose material to the center of the road and adding gravel, while ensuring not to include topsoil, weed clumps, hard clay etc, the objective being to lay out parallel windrows so that a trench is formed in the road center. As material arrives from the sand pit, it is laid in the trench between the windrows, and if bitumen is applied, this is done by using a vacuum truck with spreader bars to minimize splashing, with application rates depending on the specific characteristics of the road bed and the oily sand/gravel mixture.

The mixture is graded, mixed and dried, the amount of drying required being dependent on the initial water content of the pit material and prevailing weather conditions. Grading and mixing take place directly behind the unloading truck. Grader blade is set flat and low to the road surface while the operator grades the windrows in towards each other until both have been combined into one large windrow. Then the windrow is rolled across the road a number of times to ensure consistent mix and to remove moisture. It was noted that drying the mixture while developing the proper consistency requires experience on the part of the grader operator as well as warm, dry weather conditions.

On the other hand, if it rains and the mixture becomes very wet, the rolling and mixing may require a number of days. When this happens, precautions to prevent runoff at sensitive areas have to be taken. Windrows are doubled, and also placed at the high side of elevated curves to provide runoff control in the event of rain, this having to be done before leaving the worksite overnight. The windrow placement is illustrated as shown in Figures 3.4a and 3.4b. According to Price and Holland (1989), experience gained provided indications that negligible or no 'sheen' on the surface of standing water along ditch lines, and no vegetation stress from dissolved chloride would be expected given proper implementation of the precautions.

Upon achieving the desired consistency, the mixture is laid out on the road bed as soon as possible. The mixture is windrowed to one side of the road surface by the grader, and the windrow material is pushed across the road in small lifts (maximum 50 cm high) to the road surface elevation. Immediately following the grader would be a wobbly wheel roller, proper compaction at this stage being essential. Local traffic would also be let through to help compact the mixture if traffic can be readily controlled. To achieve best results, compaction is kept continuous for several days in between lifts, and continued for several days after the last lift. A sheep's foot roller is used to ensure sufficient compaction at the edges, a good and simple test for proper compaction being to try to grind the heel of a boot into the road surface to see that no indent is made by the applied pressure.

Final compaction is effected by means of a grader 'tight blading' (the blade is made close to horizontal to the road surface causing surface compression) followed closely by a smooth drum vibrating roller, new blades being put on for this crucial final step.

Road surfacing in the Cold Lake area using the oily sand has been administered by Esso Resources as a project and guidelines have been developed in the process to ensure best results.

3.4.2 Asphalt Cement from Cold Lake Deposits

The Cold Lake oil sands area currently provides material for producing paving grade asphalt on a commercial scale at the Esso Refinery in Strathcona, Edmonton. The resource is exploited by means of the cyclic steam stimulation recovery technique (huff and puff process), and upon being made sufficiently fluid through the addition of pipeline diluent, it is pipelined to Edmonton for refining (Canadian Research, 1985).

It is worth noting that this asphalt cement is a superior quality product classifying as a Group A asphalt cement when its consistency properties (Table 3.5) are plotted on the CGSB Classification Chart (Figure 3.5). It is a well-known product exported to other countries such as the United States.

3.5 Conditions for Utilizing Oil Sand Resources as Road Paving Materials

3.5.1 Oil Sand Mixture

The technical problem of building pavements with the oil sands basically resolves itself into that of modifying the composition of the raw material in such a way as to make it conform with whatever is the required composition of aggregate for the particular paving use. Such standards usually developed from experience in a specific region would call for a combined aggregate falling within certain limitations with regards to grading, properly mixed with a definite proportion of asphalt of specified consistency.

Raw oil sands will vary with respect to these points of definition of the standard aggregate, and since the raw oil sands would more often than not be expected to contain more bitumen than required, additional aggregate must be blended with the oil sands. This can be so chosen as to modify the total aggregate of the final mixture towards the desired grading.

Also crucial to the utilization of oil sands in road paving mixtures is the availability of appropriate construction equipment for processing oil sand-aggregate mixtures. Of particular importance in this regard is suitable mixing equipment and methodology for producing hot-mixed oil sand-aggregate mixtures for road paving without violating present-day environmental standards for emissions and opacity. This was not considered a problem in the early part of the century when oil sand-aggregate paving mixes were first prepared by Ells. As the general level of environmental awareness then was still low compared to currently, mixing equipment fabricated simply discharged hot-mix exhaust products freely into the air.

Alberta Environment's regulations as stipulated in the Clean Air Act currently limit the concentration of particulates in an effluent stream to the atmosphere to 0.2 kg per 1000 kg of effluent, while the opacity of emissions is limited to 40% (Millions et al., 1985). Thus there is need for a much more controlled approach to oil sand-aggregate mixture preparation today.

To meet the need for mixing equipment capable of producing oil sand-aggregate paving mixtures within these constraints, newly developed equipment in current use on hot-mix asphalt recycling projects in Alberta can possibly be adapted for processing oil sand-aggregate mixtures. Several dryer-drum type asphalt plants with a center-feed system and an air heater system are being used presently in pavement recycling in the Province, to handle bitumen coated aggregate in the form of reclaimed asphalt pavement (RAP). For achieving good quality mixes in the process of heating and mixing RAP with virgin asphalt and aggregate, the two plant types employ different approaches to control emissions satisfactorily.

One approach used is not to expose the RAP directly to the burner flame or hot gases issuing therefrom, but rather to heat up the RAP by the transfer of heat from heated aggregates. This is the method employed by the centre-feed style drum-mix plants presently in common use for recycling in the Province of Alberta. As the name suggests, the RAP is fed in at about the mid-point of the drum, and uses the virgin aggregate introduced at the burner end of the drum, to shield the RAP from high temperature gases and to transfer heat into the RAP materials (Anderson et al., 1988). This means of shielding the RAP from high temperature gases can be adopted for processing oil sand-aggregate mixtures by replacing the RAP with oil sands. The indirect heating approach thus employed would help prevent loss of mix durability that can result from aging of the oil sand bitumen during the heating and mixing process, and would also minimize emission and opacity problems as may otherwise result from hydrocarbon vapors if the oil sands were heated directly to high temperatures as was done by Ells (1926).

The other approach is provided by air heater style drum-mix plants which introduce the RAP and virgin materials together at the burner end of the drum, and rely on higher gas volumes to transfer the heat energy without requiring high temperatures (*ibid.*). As with the centre-feed plant option, it is also expected that the air heater style plants designed for recycling in the Province can be adapted for processing oil sand-aggregate paving mixtures on the same basis of replacing RAP with oil sands in the mix production process.

Furthermore, it is desirable to use longer drums for mix production as higher drum lengths provide a simple and effective method of increasing heat transfer without using higher gas temperatures (Millions et al., 1985). This is particularly important from the point of view of meeting the requirements of the Alberta Clean Air Act, as it is necessary to ensure that gas and mixing temperatures at the point of introduction of the oil sands do not exceed the temperature at which distillation vaporization begins to occur in the oil sands. According to simulated distillation data on Alberta oil sands available from Alberta Research Council (Appendix C), no significant distillation is expected to take place in the oil sands up to about 343 C, which gives good operating margin for drum mixing, as plant mixing temperatures are typically around 145 C or thereabout.

A demonstration project could possibly be initiated to examine the feasibility of processing oil sand-aggregate mixtures in a drum-mix plant. The use of longer drums would also allow additional asphalt cement to be introduced further away from the burner end of the drum, if there is need to raise the binder content of the oil sand-aggregate mixture as in the case of using lean oil sands.

3.5.2 Oil Sand Asphalt Cements

The suitability of asphalt cements from Alberta oil sands, for pavement construction can be evaluated with respect to the requirements of the current Canadian General Standards Board (CGSB) specification for use of asphalt cements for road purposes. This is done in section 3.7.

3.6 Review of Previous Studies Conducted to Evaluate Alberta Oil Sand Asphalt Cements.

A number of different organizations have made significant efforts in the past to have the quality or "acceptability" of asphalt cements obtainable from Alberta oil sands evaluated. The basis of such evaluation has usually been the conduction of a program of tests required by relevant specifications prevailing at the time of the investigation.

Studies conducted to date with the objective of evaluating the paving-use suitability of Alberta oil sand asphalt cements are reviewed in this section.

3.6.1 Tests Performed by Hignell (1965)

Following a request in 1965 by the British American Research and Development Company that a report be prepared based on the determination of the quality of grades of paving asphalts that can be prepared from the Athabasca tar sands, samples of the required products prepared from Athabasca tar sands and termed 'Abasand Bitumen' were subsequently examined with respect to the requirements of the CGSB specifications current at the time, as well as future anticipated specification requirements. On the basis of the results of the investigation, Hignell concluded that Abasand Bitumen represented a source of paving material that would meet specifications current at the time, and went further to indicate that the material was expected to meet future anticipated specifications having more rigorous requirements.

Of the asphalt cement products laboratory-refined from the oil sands for the purpose of the investigation, three were designed to meet the three principal use penetration grades specified in CGSB specification 16-GP-3A of July 1964 namely, 60-70 pen., 85-100 pen. and 150-200 pen.. It is shown in Figure 3.5 that all three samples (consistency parameters shown in Table 3.5) classify as 'Group A' asphalt cements on the 'absolute viscosity vs. penetration' chart of the current CGSB specification (CAN/CGSB-16.3-M90). This implies a low temperature susceptibility asphalt cement which is a desirable quality as such asphalts are known to offer better resistance to low temperature transverse cracking, a problem of major concern in cold weather conditions as experienced in Canadian winters.

Furthermore, results obtained from this investigation for other important specification test requirements such as Flash Point and Thin Film Oven tests were quite satisfactory. The results showed the material readily meeting the 1964 CGSB specification requirements as well as those of the current 1990 CGSB specification. This is of remarkable importance because, while the Flash Point test is essentially a safety requirement test, the purpose of the Thin Film Oven Test requirements (usually expressed in terms of percent weight loss and percentage of retained penetration), is to ensure that the long-term durability of the asphalt is not lost during the hot mixing with aggregate. Therefore, results comparing favorably with Thin Film Oven Test requirements represent a positive indication of good durability characteristics. The only requirement that was not quite met was the solubility-in-solvent requirement meant to assure purity. Whereas the specifications require 99% minimum solubility (obviously with conventional petroleum asphalt cements in mind), the range of solubility values reported by Hignell was 97.1 to 97.8. This is but a slight shortfall readily explained by recognizing that asphalts extracted from oil sands and subsequently refined would yet contain a tiny proportion of particles of clay or other fine mineral matter in suspension. Therefore, given that all other vital requirements are adequately met, the use of asphalt cements from Athabasca oil sands for road purposes should not be precluded on just this account.

3.6.2 Tests Performed at the University of Alberta

Tests were conducted in 1967 at the University of Alberta on asphalt cement samples refined from Athabasca Bitumen produced by the G.C.O.S.* plant at Ft. McMurray. The purpose was to evaluate the suitability of the material for paving construction. The report prepared in respect of this investigation (Anderson, 1967), and submitted to Stanley Associates Engineering Ltd. of Edmonton, Alberta indicated the tests were performed on two asphalt cement samples A and B, respectively of 100 and 150 penetration grading which were produced by Sun Oil Company on a small laboratory scale.

The durability characteristics were established to be quite good on the basis of the Thin Film Oven Test results. Results obtained for other relevant characteristics such as consistency properties (penetration, viscosity) compared very favorably with the specification requirements in existence at the time. However, as with the findings of Hignell (1965), the solubility test property reported as 97.6 also falls a little short of the 99 % minimum typically required by specifications.

Relevant parameters for the two samples were taken from the aforementioned report as shown in Table 3.5, and plotted on the absolute viscosity - penetration chart of the current CGSB specification (Figure 3.5). The position of both samples on the chart also indicates the material classifies

* now Suncor

as a Group A asphalt cement implying low temperature susceptibility property which is highly desirable as already explained.

3.6.3 Tests at the Alberta Research Council (ARC)

A study to investigate the preparation of paving asphalt from Athabasca bitumen was also conducted by Moschopedis and Speight (1976) of the Alberta Research Council.

Bitumen obtained from Athabasca oil sands by the hot water extraction process and subsequently dried, was supplied to the investigators by Syncrude Canada Ltd.. Laboratory-refined asphalt cement was produced from the supplied material by vacuum distillation under 15 ± 3 mm Hg pressure, heating being done to desired temperatures (by means of an oil bath containing wax of high flash point) until distillation of light fractions ceased. Under conditions of 350 C temperature and 15 ± 3 mm Hg pressure, this process yielded a 75% asphalt residue, relevant consistency parameters of which are taken from the published results (as shown in Table 3.5) and plotted on the CAN/CGSB-16.3-M90 Classification Chart. From the plot (Figure 3.5), the refined material classifies as a Group A asphalt cement which is indicative of superior temperature susceptibility characteristics as already explained.

Other vacuum distillation products were similarly prepared, and upon comparing the physical properties of these products with those of three commercial asphalt cements, th investigators concluded that choice of a suitable distillation temperature and distillation cut, would undoubtedly yield an asphalt residue with properties comparable to those of the commercial asphalt cements.

Several other products were also obtained by air blowing of the vacuum residua and air blowing of the natural bitumen. The results of the tests performed showed that while air blowing of the natural bitumen at different temperatures also resulted in products with properties comparing well with those of the commercial asphalts, air blowing of the vacuum residua yielded products having higher softening points and lower penetrations than the commercial asphalts, characteristics which seem more desirable from the perspective of combatting pavement cracking.

3.7 Evaluation of Alberta Oil Sand Asphalt Cements With Respect to CAN/CGSB-16.3-M90

The Canadian General Standards Board (CGSB) is the government agency responsible for producing standards for a wide range of subject areas, doing so through the media of standards committees and the consensus process. These standards committees are composed of representatives of relevant interests including producers, consumers and other users, retailers, governments, educational institutions, technical, professional and trade societies, and research and testing organizations. The standards are developed on the consensus of views expressed by such representatives while the Minister's Advisory Council on CGSB reviews the results of the consensus process.

The latest specification for use of asphalt cements for road purposes is issued by the CGSB as CAN/CGSB-16.3-M90 which replaces 16-GP-3M. Deme and Palsat (1989) have described the evolutionary development of the Canadian standard for paving asphalts. The current standard classifies asphalt cements into three groups in terms of their temperature susceptibility property, which may be considered as a measure of the resistance an asphalt cement offers against low temperature transverse pavement cracking, a major design consideration for cold climatic conditions as in Western Canada. The best resistance is expected to be offered by asphalt cements falling into Group A, which comprises asphalts having a *high* viscosity at 60 C and 135 C for a given penetration at 25 C. Asphalt cements which have a *medium* viscosity at 60 C and 135 C (for a given penetration at 25 C) are classed as Group B asphalt cements while those having a *low* viscosity at 60 C and 135 C (for a given penetration at 25 C) fall into Group C. Asphalt cements can be readily classified by means of charts which the CGSB specification provides on the basis of penetration at 25 C and absolute viscosity at 60 C (or alternatively, kinematic viscosity at 135 C).

In addition to temperature susceptibility characteristic as explained above, the CGSB specification also prescribes other test requirements such as Flash Point, Thin Film Oven Test (for assessing durability characteristics), and test of solubility in trichloroethylene. These requirements are prescribed according to penetration grading and are reproduced with permission in Appendix B.

For the purpose of evaluating the oil sand asphalt cements using CAN/CGSB-16.3-M90, test property values required for plotting them on the CGSB Chart were adopted from the reports of the different organizations that have done relevant testing on the oil sand asphalts. The reported values have been presented in Table 3.5 which also includes consistency parameters reported for asphalt cements produced from Cold Lake oil sands. For the purpose of comparison, values are included as well for asphalt cements produced from a well-known and long used Western Canadian heavy crude, namely Lloydminster.

The plots are shown in Figure 3.6 on which basis the asphalt cements prepared from Athabasca and Cold Lake oil sands are classified as Group A asphalt cements while the Lloydminster asphalt cements also classify as Group A materials.

It is also noted that the results of previous test programs on Alberta oil sand asphalt cements indicate asphalt cements can be prepared from the oil sands which would meet all the requirements of CAN/CGSB-16.3-M90 (Appendix B) except the required 99% minimum solubility in trichloroethylene. This is because of small amounts of particles of clay or other suspended fine mineral matter usually present in oil sand asphalts (Anderson, 1967). For this reason, it should not be insisted upon that oil sand asphalt cements satisfy the 99% minimum requirement, especially as other unconventional asphalt sources noted for higher mineral contents such as Trinidad Lake asphalt, have been widely used for paving purposes with satisfactory results. Hence, to enable asphalt cements from Alberta oil sands to be used in paving, permission for non-compliance to this particular requirement could be given for oil sand asphalt cements, i.e. with respect to permissible mineral matter content. This is necessary as processing to the point of achieving products sufficiently free of native sands and clays (as to be considered equal to petroleum asphalt cements in terms of purity) could increase production costs and render oil sand asphalt cements uncompetitive with conventional asphalt cements costwise.

3.8 Conclusions

On the basis of the foregoing evaluation as well as the preceding review of previous studies on oil sand asphalt cements, the conclusion is drawn that bitumen extracted from the oil sands is very good material for producing asphalt cements as it can be refined to a paving grade asphalt meeting the CGSB requirements for Group A asphalt cements. That is, paving asphalts of superior temperature susceptibility property offering high resistance to low temperature transverse cracking of pavements.

Furthermore, the review of historical and current paving uses of Alberta oil sands carried out in this chapter gives positive indications of good potential for utilizing Alberta oil sands in road paving mixes, that is, in conjunction with graded aggregates.

Also, recent developments in pavement recycling provide a solution to the vital requirement for suitable equipment and methods for producing oil sand-aggregate paving mixtures within the constraints on emission levels in effect today. Newly available recycling equipment in the form of centre-feed and air heater style drum-mix plants developed for handling bitumen coated aggregate, can be adapted to process oil sand-aggregate mixtures on the basis of substituting oil sands for RAP in the hot-mix production process.

To further ensure conformance with Alberta Environment's particulate emission and opacity limits of 0.2 kg/1000 kg effluent and 40% respectively, longer drums are recommended for mix production as this enhances heat transfer without the use of higher gas temperatures. It need also be ensured that gas and mixing temperatures at the point of introduction of the oil sands do not exceed about 343 C, which is the temperature horizon beyond which the oil sands would smoke significantly.

Table 3.1 Grain size distribution derived for bituminous sands used in preparing 1915 surfacing mixes.

(a) Coarser-grained bituminous sands

Sieve size	% retained	% passing
2.36mm (#8)		100
2.00mm (#10)	1.6	98.1
0.80mm (#20)	27.2	70.9
0.60mm (#30)	34.2	36.7
0.30mm (#50)	22.0	14.7
0.175mm (#80)	6.8	7.9
0.150mm (#100)	0.7	7.2
0.075mm (#200)	4.5	2.7
pan	2.7	
	99.7	

(b) Finer-grained bituminous sands

Sieve size	% retained	% passing
2.36mm (#8)		100
2.00mm (#10)		100
0.80mm (#20)		100
0.60mm (#30)		99.8
0.30mm (#50)	0.6	99.2
0.175mm (#80)	23.0	76.2
0.150mm (#100)	15.6	60.6
0.075mm (#200)	54.6	6.0
pan	6.0	
	99.8	

Table 3.2 Total aggregate gradation derived for sheet asphalt mix of 1915 oil sands pavement

% used	Aggregate Fraction	Particle size -- Percent Passing							
		2.36 mm	2.0	0.8	0.6	0.3	0.18	0.15	0.08
52.5	fine grained bit. sand	52.5	52.5	52.5	52.4	52.1	40	31.8	3.15
26.5	coarse grained bit. sand	26.5	26.0	18.8	9.73	3.9	2.1	1.9	0.72
8.2	sand < 0.6 mm	8.2	8.2	8.2	8.2	2.1	0.82	0.8	0.1
5.6	sand < 0.3 mm	5.6	5.6	5.6	5.6	5.6	1.4	1.1	-
7.2	filler < 0.08 mm (Portland cement)	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
100		100	99.5	92.3	83.1	70.9	51.5	36.3	11.2

Table 3.3 Total aggregate gradation derived for bitulithic mix of 1915 oil sands pavement

% used	Aggregate Fraction	Particle size -- Percent Passing										
		25 mm	20	16	12.5	6.25	2.0	0.6	0.3	0.	15	0.08
35.0	fine grained bit. sand	35	35	35	35	35	35	34.9	34.7	26.7	21.2	2.1
17.5	coarse grained bit. sand	17.5	17.5	17.5	17.5	17.5	17.2	6.4	2.6	1.4	1.3	0.5
1.9	sand < 2 mm	1.9	1.9	1.9	1.9	1.9	1.9	1	1	1	1	0.1
1.9	filler < 0.08 mm (Portland cement)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
7.8	crushed gravel (19.0 - 25 mm)	7.8	0.1	-	-	-	-	-	-	-	-	-
18.1	crushed gravel (12.5 - 19 mm)	18.1	18.1	9.1	-	-	-	-	-	-	-	-
11.4	crushed gravel (6.25 - 12.5 mm)	11.4	11.4	11.4	11.4	-	-	-	-	-	-	-
5.1	crushed gravel (3.1 - 6.25 mm)	5.1	5.1	5.1	5.1	5.1	-	-	-	-	-	-
1.2	crushed gravel (2.5 - 3.1 mm)	1.2	1.2	1.2	1.2	1.2	-	-	-	-	-	-
100		100	92.2	83.1	74	62.6	56	44.2	40.2	31	25.4	4.6

Table 3.4 Total aggregate gradation derived for bituminous concrete mix of 1915 oil sand pavement

% used	Aggregate Fraction	Particle size -- Percent Passing							
		12.5 mm	6.25	2.0	0.6	0.3	0.18	0.15	0.08
58.0	fine grained bit. sand	58	58	58	57.9	57.5	44.2	35.1	3.5
4.0	sand < 2 mm	4	4	4	1	1	1	1	0.1
29.8	crushed gravel, 12.5 mm	29.8	-	-	-	-	-	-	-
8.2	crushed gravel (6.25 - 12.5 mm)	8.2	-	-	-	-	-	-	-
100		100	62	62	58.9	58.5	45.2	36.1	3.6

Table 3.5. Consistency Properties Required To Plot Alberta Oil Sand Asphalts On CGSB Classification Chart.

	Pen. @ 25 C, mm x 0.1	Viscosity @ 60 C, Pa.s.
Abasand* sample #B-18-61-4	64	319 **
Abasand sample #B-18-61-3	96	173
Abasand sample #B-18-61-2	158	81
Sun Oil Co./U of A Tests: Sample A (Anderson 1967)	109	137
Sun Oil Co./U of A Tests: Sample B (Anderson 1967)	149	87
A.R.C.: A.C. Produced by Vacuum distillation under 15 ± 3mm Hg pressure and heating to 350 C to obtain 75% residual asphalt (Moschopedis and Speight, 1976)	143	92
A.C.s Refined from Cold Lake Oil Sands (Leung, 1986)	96 242	177.5 47
Lloydminster A.C. from Husky Oil Refinery (Leung, 1986)	87 257	196.8 47.1

* asphalt cement laboratory refined from Athabasca oil sands (Hignell, 1965)
** plotted as 300 on CGSB Classification Chart due to limited vertical axis range

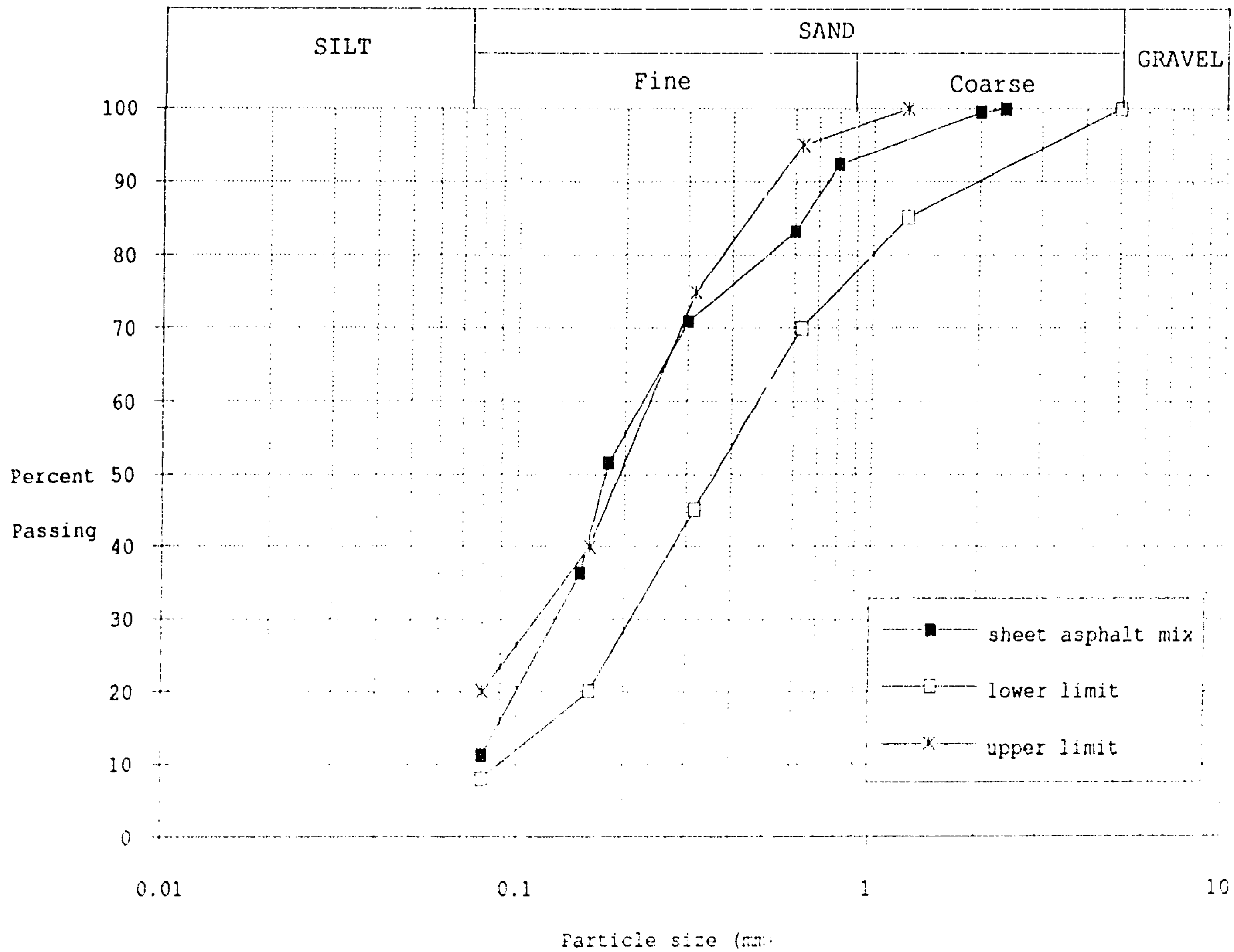

Figure 3.1 Total aggregate gradation of sheet asphalt mix laid for 1915 oil sands pavement compared with Asphalt Institute grading specification for sheet asphalt (Mix Designation 8A, Asphalt Institute, 1975)

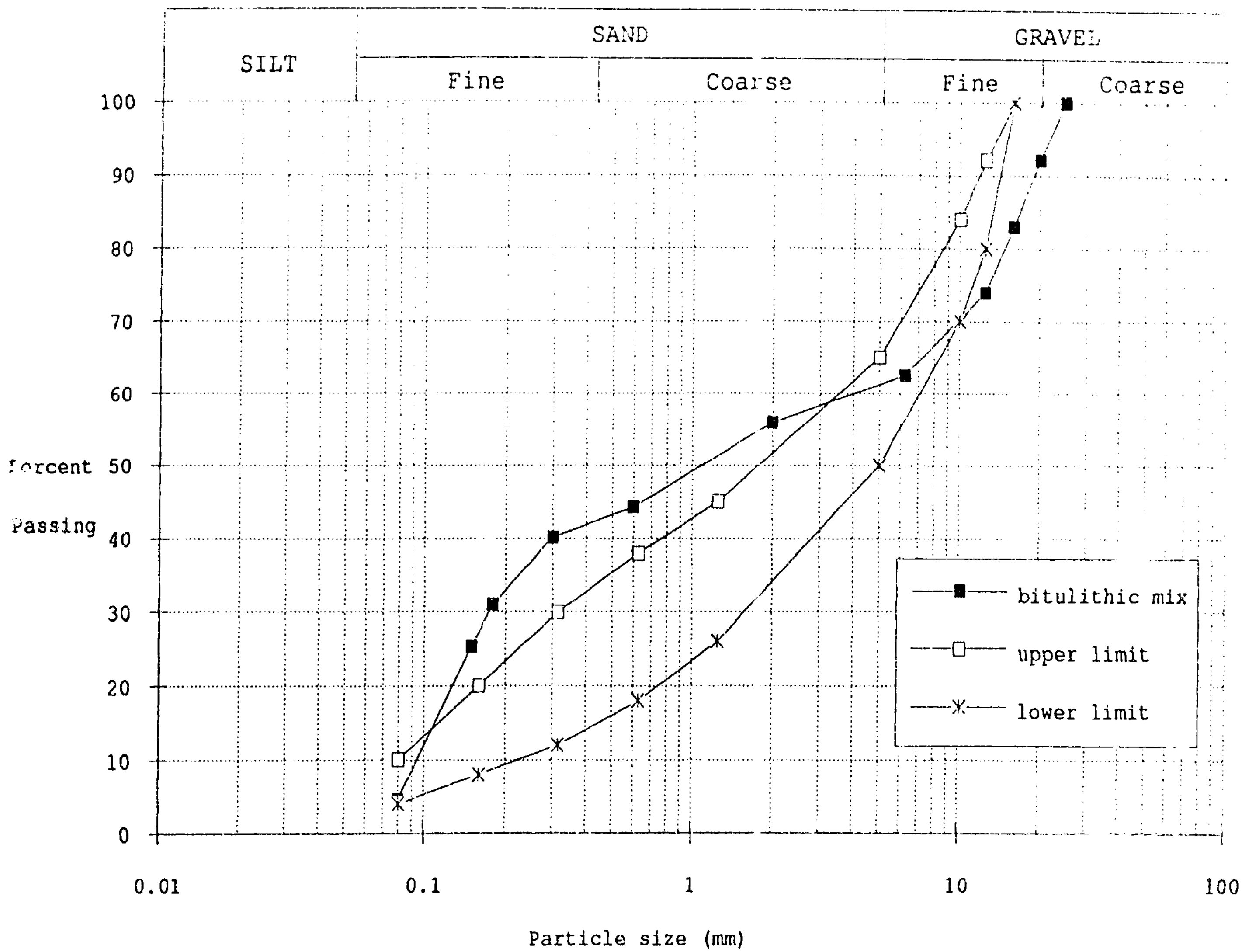

Figure 3.2 Total aggregate gradation of bitulithic mix laid for 1915 oil sands pavement compared with Alberta Transportation and Utilities grading for asphalt concrete (Designation 1-16).

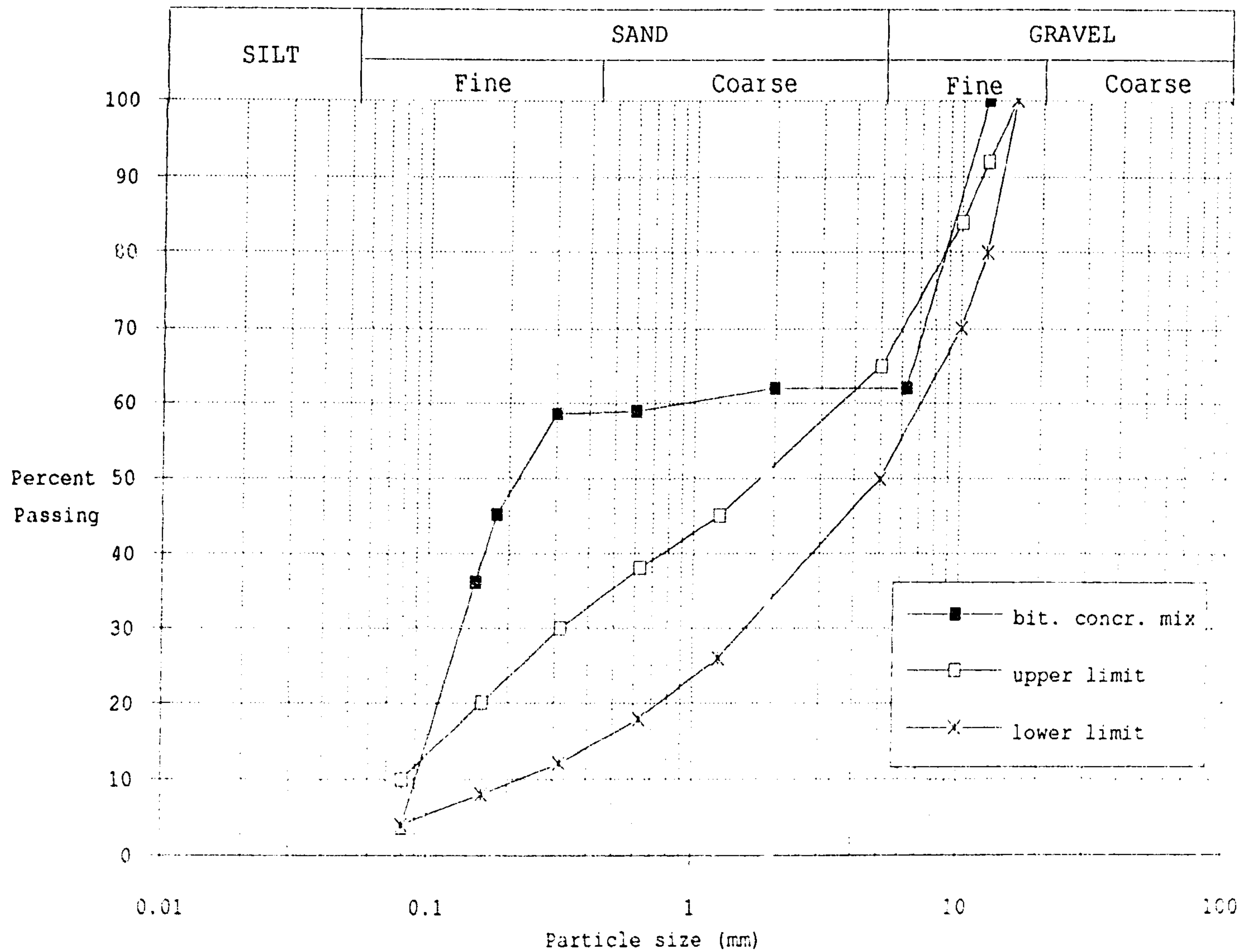

Figure 3.3 Total aggregate gradation of bituminous concrete mix laid for 1915 oil sands pavement compared with Alberta Transportation and Utilities grading for asphalt concrete (Designation 1-16).

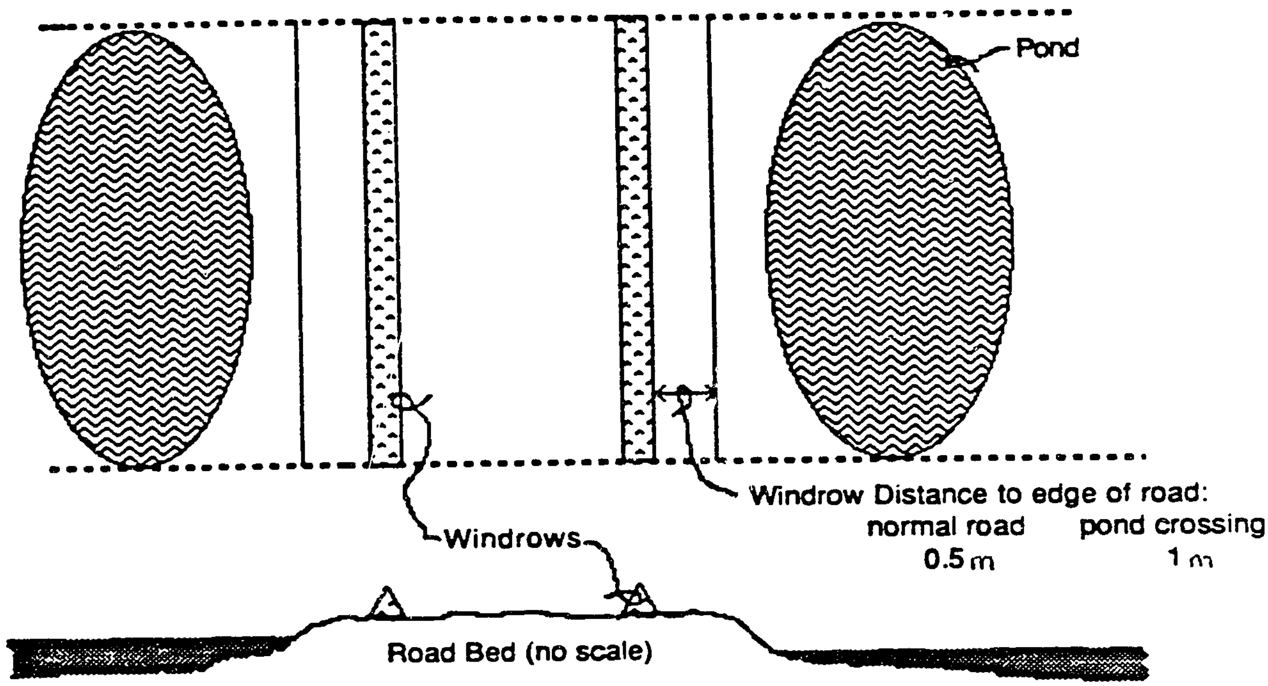

Figure 3.4a Windrow placement at ponds

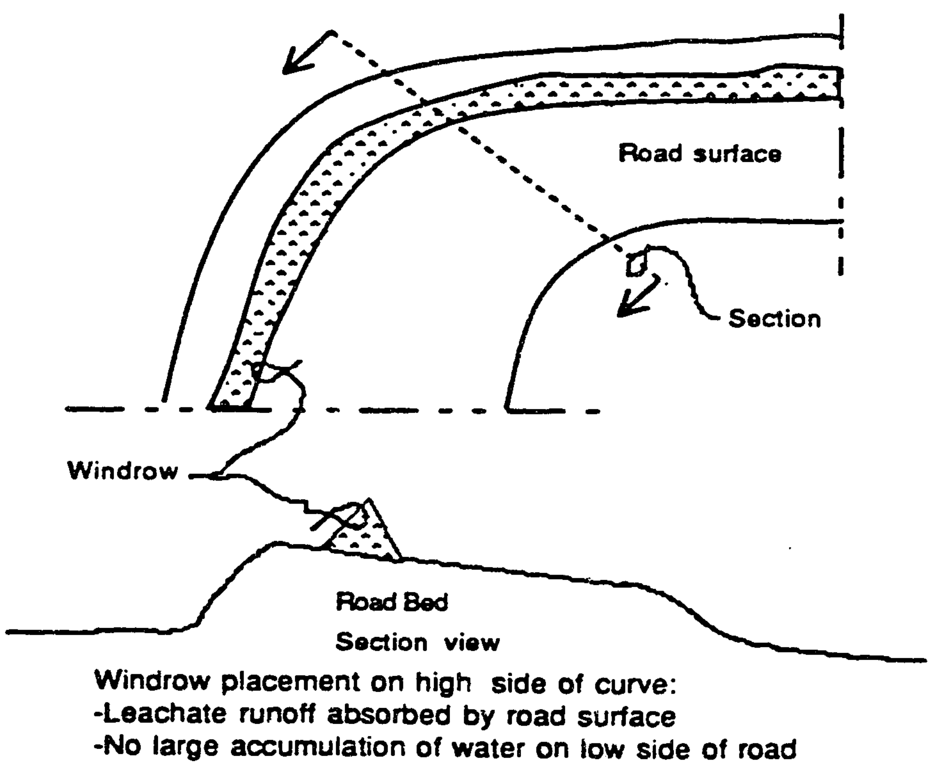

Figure 3.4b Windrow placement on banked road surfaces (modified from Price and Holland, 1989)

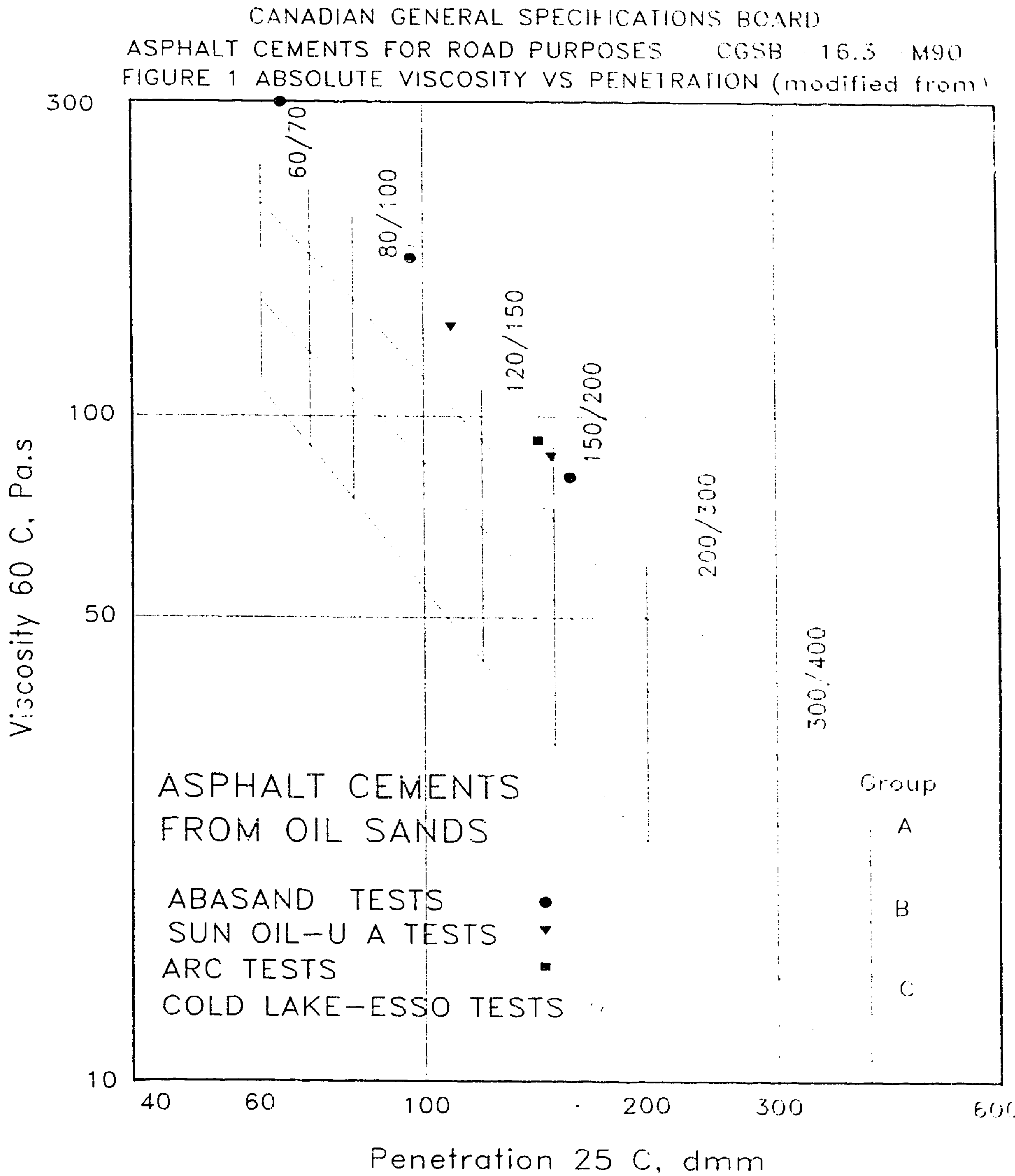

Figure 3.5 Classification of Asphalt Cements Refined from Athabasca and Cold Lake Oil Sands

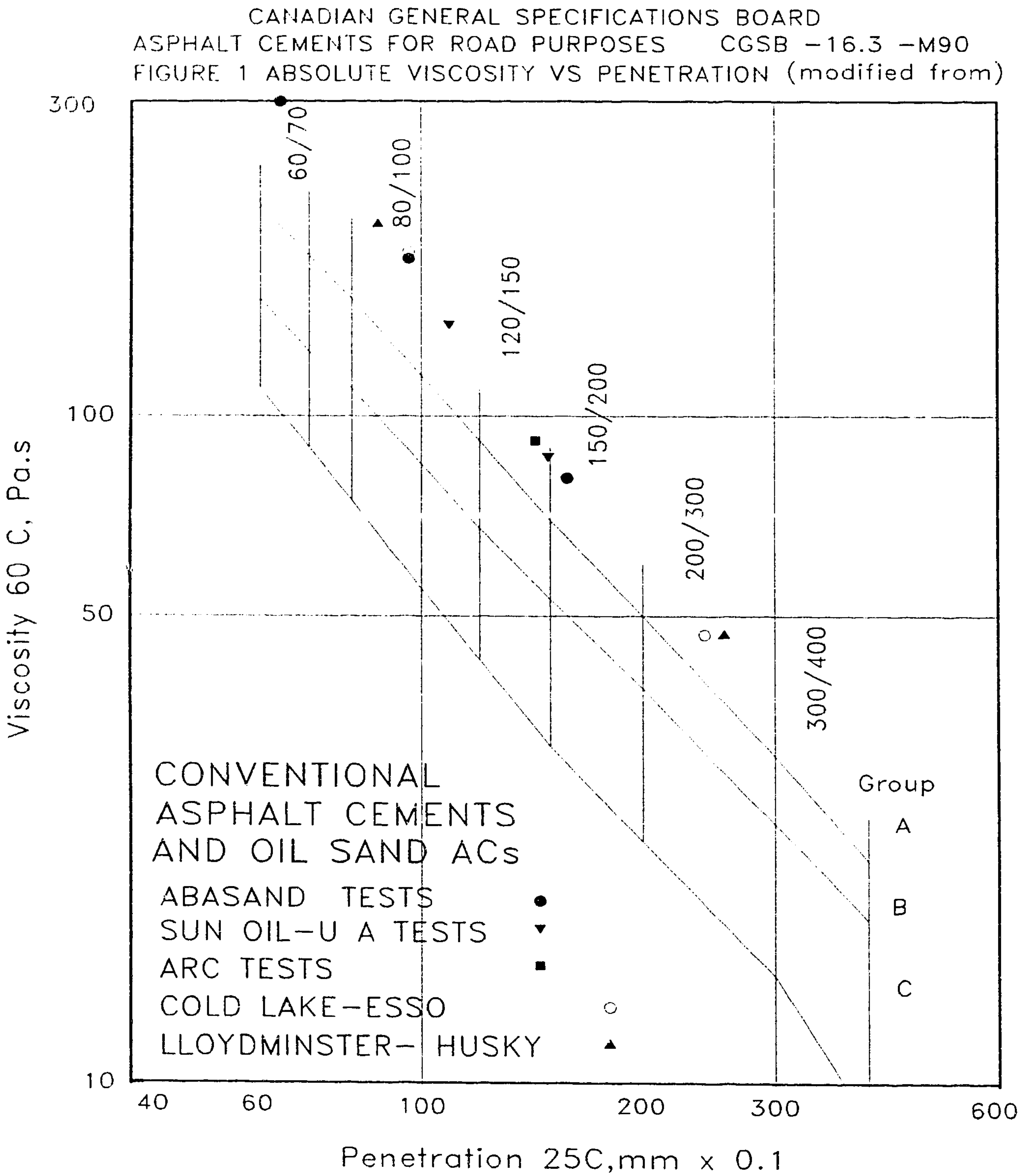

Figure 3.6 Conventional Lloydminster ACs Compared with Alberta Oil Sand Asphalt Cements

CHAPTER 4

LABORATORY EVALUATION OF PROPERTIES OF OIL SAND-AGGREGATE MIXTURES

4.1 Introduction

A preliminary laboratory investigation was undertaken with the objective of evaluating the properties of oil sand-aggregate mixtures that are relevant to mixture and pavement performance. For this purpose, conventional mix design testing involving Marshall stability and flow testing, and density-voids analysis was embarked upon after appropriate preparatory tests had been carried out.

The preparatory tests comprised :

- bitumen extraction tests using available extraction apparatus with toluene as solvent. This enabled the bitumen content and moisture content of the oil sands samples to be ascertained simultaneously;

- sieve analysis of extracted oil sands in order to determine the gradation of test samples as required for aggregate blending calculations. (The gradations of coarse aggregates used were already pre-determined and results of washed sieve analysis made available for determining blend proportions);

- bulk specific gravity determinations for extracted oil sands and manufactured sand aggregate C. Bulk specific gravities for coarse aggregates from the same source were available from a previous study (Dawley et al., 1990).

4.2 Test Materials

Samples of Athabasca oil sands mined by Suncor (rich oil sands variety) were obtained from the Oil Sands Sample Bank of the Alberta Research Council while coarse aggregates blended with the oil sands are commercially available aggregates obtained from Tollestrop Construction Ltd., Lethbridge, Alberta.

Specifically, three aggregate fractions were used in this investigation namely aggregate A (crushed gravel aggregate of 16mm nominal maximum size), aggregate B (crushed gravel of 12.5mm nominal maximum size), and manufactured sand aggregate C. Their respective gradations are shown in Table 4.1 together with that of the extracted oil sands.

Extraction tests performed on representative samples of the oil sands showed average bitumen content of 13.65 per cent by weight of total mixture, average sand content of 84.38 weight per cent, and moisture content of 1.97 weight per cent. The bulk specific gravity of oil sand solids was obtained as 2.664, and sieve analysis results showed the oil sands to be classifiable as Group I oil sands (after Carrigy, 1959), i.e Coarse-Medium Sands defined by a maximum grain size larger than 1 mm, median diameter greater than 0.13 mm, and more than 80 per cent by weight of sample larger than 0.074 mm.

Summaries of the properties of materials used are presented in Tables 4.2a and 4.2b.

4.3 Preparation of Marshall Test Specimens

For preparing test oil sand-aggregate mixes, blend proportions were derived using a Lotus 1-2-3 based computer program to select oil sand and aggregate blend proportions at settings of 20%, 25%, 30%, 35% and 40% oil sands by weight of total aggregate. Blend proportions for mixes tested are as shown in Table 4.3, while Figures 4.1 and 4.2 show the combined aggregate gradations of test mixes in comparison with Alberta Transportation gradations for asphalt concrete and asphalt stabilized base courses respectively. Figure 4.1 goes further to illustrate the improvement achieved with the test mixes, on the historical bituminous concrete mix of 1915. It is also noted that the combined gradations achieved represent the closest to the Alberta Transportation grading bands that could be obtained with the oil sands and the aggregates used. This is as a result of the fine, uniform grading of the raw oil sands as they consist of so much of the finer-grained particles (as much as 96.1 and 89.4 % passing the 0.315 and 0.16mm sieves respectively for samples of oil sands tested). From a comparison of Figures 4.1 and 4.2 with Figure 2.4, it is seen that the total aggregate gradations of test mixes improve substantially on the fine, uniform gradation of the raw oil sands as test mixes conform more closely to the Alberta Transportation grading bands even though still outside the recommended limits.

Batch weights were computed as outlined in Manual Series #2 published by the Asphalt Institute (1984) and constituent materials for desired mix combinations weighed out accordingly. It is worth noting that in arriving at appropriate batch weights for the oil sands, due allowance (approximately 2 per cent) was made for the moisture content that vaporizes during heating.

In preparation for mixing, aggregates were heated overnight at an oven temperature of 160 C. As a precaution against unduly inducing aging of the asphalt in the oil sands, it was decided not to heat the oil sands at high temperatures for prolonged periods. Therefore, immediately preceding mixing, weighed oil sand materials were heated until an oven temperature of about 150 C was attained. This took about 50 minutes on the average. Mixing was then begun and had to be done quickly once the materials were taken out of the oven in order to avoid excessive temperature fall. It was found that, of the mixtures obtained, the best (in terms of stability, homogeneity and visual appearance of mixture) were obtained when mixture temperatures were not allowed to fall below about 135-140 C and 125-130 C for mixing and compaction respectively. A lower stability mixture, non-homogeneous and honeycombed in appearance usually resulted whenever mixing and/or compaction temperatures fell below these ranges. To ensure adequate mixing and compaction temperatures, relevant apparatus such as specimen mold, spading spatula, mixing spoon and bowl were heated simultaneously with the oil sands, while the compaction hammer face was heated on a hot plate.

Three specimens were prepared for each aggregate combination and 50 compaction blows were applied to each end of specimen as recommended in Marshall Criteria for medium traffic category design (Asphalt Institute, 1984).

Compacted specimens were allowed to cool overnight in air. Prior to stability and flow testing, their bulk specific gravities were determined according to ASTM Method D2726, and specimens submerged afterwards in 60 C water bath for about 35 minutes as recommended. When retrieved from the water bath, the compacted specimens were tested quickly for stability and flow in accordance with ASTM D1559.

4.4 Results of Tests and Density-Voids Analysis

Average values were computed for results obtained from the stability and flow testing of individual oil sand-aggregate mixture specimens. These are presented in summary form in Table 4.4 together with the density-voids analysis results*. Corresponding test property curves are presented in Figure 4.3 in which regard it is worth noting that the oil sand proportions of 20, 25, 30, 35 and 40% by weight of total aggregate are respectively equivalent to 3.3, 4.1, 4.9, 5.7, 6.5% asphalt content by weight of total aggregate.

4.5 Discussion of Results

Marshall Mixture Design Criteria (Table 4.5 a and b) recommended by the Asphalt Institute (1984; 1975) represent a

* Sample density-voids analysis calculations are shown in Appendix D

basis for evaluating the results of mix design testing performed using the Marshall Method. These criteria are generally relied upon for indications of expected quality of performance of test mixtures in actual pavement service.

4.5.1 Results Compared With Criteria for Asphalt Concrete Surface and Base Courses (Table 4.5a)

As results and test property curve plots of Figure 4.3 indicate, stability values obtained for test mixes are low in comparison with the minimum stability requirements for heavily and medium trafficked mixes. However, oil sand-aggregate mixtures appear satisfactory for use in light-trafficked pavements as the average stability values for the 25 and 30% oil sands mixes surpass the minimum stability requirement for light trafficked mixes.

Since stability is not the only criterion or mixture characteristic to be considered in meaningful mix design testing, other mixture characteristics must as well be duly considered as indicators of potential performance in an actual paving mix. In this regard, the following is noted :

- Flow values obtained range from 1.52 to 2.04 mm as against the 2 to 4.5 mm range recommended for Light Traffic Category Design;
- values obtained for percent Voids in Mineral Aggregate (VMA) are satisfactory, all exceeding the minimum of 15;

- values for percent voids in total mix are high, being above the recommended range of 3 to 5% for surface course mixes;
- values for the percentage of voids filled with asphalt appear generally low for the oil sand-aggregate mixtures tested, even though this property is not an Asphalt Institute requirement.

4.5.2 Results Compared With Criteria for Hot-Mix Sand Asphalt Base Mixes (Table 4.5b)

On the other hand, the results obtained for test mixture characteristics compare favorably with the Asphalt Institute criteria for test limits on hot-mix sand asphalt base mixes in which regard the following is worth noting:

- Average stability values obtained for all test mixes well exceed the minimum stability requirement of 890N;
- none of the flow values obtained exceeds the recommended maximum flow of 5 mm, and,
- all percent air voids values obtained fall within the recommended range of 3 to 18.

4.6 Conclusions and Recommendations

On the basis of information provided by this laboratory investigation, oil sand-aggregate mixtures appear inadequate for heavy and medium trafficked road pavements, while there is very good potential for using them for light traffic or low volume roads. Furthermore, oil sand-aggregate mixtures appear usable as sand asphalt base mixes as results compare well with the Asphalt Institute criteria for hot-mix sand asphalt bases (Table 4.5b).

It is noted that two parameters, namely, percent air voids and percent voids filled presently give indications of possible problems with water intruding into paving mixture matrix as values obtained for air voids content were relatively high and percent voids filled with asphalt somewhat low. Normally, for conventional asphalt-aggregate mixtures, such conditions would be expected to pose a threat to pavement durability. Therefore, a more elaborate testing program is required to provide further insight regarding these two parameters.

In addition, while high air voids may not adversely affect the performance of oil sand-aggregate mixtures (as Walker and Hicks (1976) report high air voids as a characteristic of sand asphalt mixes with indication that experience with sand asphalt pavements in the U.S. show they have provided good service despite excessive air voids), low percent voids filled may be detrimental to performance through encouraging water intrusion. Thus, further testing is needed to evaluate the effect of water on oil sand-aggregate mixtures as can be ascertained by performing retained stability tests on compacted specimens soaked for 24 hours.

Future test programs forming part of additional studies required, should also include the evaluation of the elastic, permanent deformation and fatigue characteristics of oil sand-aggregate mixtures.

A recommended preliminary mixture design procedure could evolve from the results of these additional studies that would enable investigations to be extended to pavement test sections constructed to conform with the recommended design mix, modifications to design being made on the basis of actual field performance of the test sections.

Table 4.1 Gradation of aggregate fractions and oil sands used

Sieve size (mm)	Percent Passing			
	A	B	C	Oil Sands
16	100	100	100	100
12.5	82.2	99.2	100	100
10	41.1	73.8	100	100
5	5	11.2	86.5	99.9
2.5	2.9	5.5	61.7	99.7
1.25	2.6	4.4	46.3	99.5
0.63	2.5	3.7	36.3	98.2
0.315	2.3	3	27.1	96.1
0.16	2	2.5	18.9	89.4
0.08	1.5	1.9	12.2	2.1

Table 4.2 a. Summary of Pertinent Oil Sands Properties

Supplier - Alberta Research Council
(also provided basic data with samples supplied as given in Appendix C)
Source - Athabasca Oil Sands Deposit, McMurray Stratigraphic Unit
Grain Size Distribution - gradation shown in Table 4.[illegible]
Composition - as determined from extraction tests performed
13.65 % bitumen
84.38 % solids (sand)
1.97 % water
Specific Gravity of oil sand solids = 2.6643
Specific Gravity of oil sand asphalt = 1.0266 (by supplier)

Table 4.2 b. Summary of Aggregate Properties

Supply Pit - Tollestrop Construction Ltd.
Location - City of Lethbridge, Alberta
Gradation of Aggregate Fractions - washed sieve analysis results shown in Table 4.1
Specific Gravity of aggregate A = 2.6212
Specific Gravity of aggregate B = 2.6088
Specific Gravity of aggregate C = 2.6793

Combined Aggregate Gradations for Test Mixes

Mix Designation	Percent Passing									
	16mm	12.5	10	5	2.5	1.25	0.63	0.315	0.16	0.08
40% Oil Sands	100	89.3	64.7	43.0	41.6	41.4	40.8	39.8	37.0	1.7
35% Oil Sands	100	92.9	70.2	39.8	37.5	37.0	36.3	35.3	32.7	1.8
30% Oil Sands	100	99.4	81.7	37.8	33.8	32.9	32.1	30.9	28.6	2.0
25% Oil Sands	100	99.5	83.0	40.9	34.7	32.4	30.6	26.7	25.9	3.0
20% Oil Sands	100	99.5	84.3	44.0	35.6	31.8	29.1	26.4	23.2	4.0
Alberta Transportation & Utilities' Recommended Gradings										
Designation 1-16*	[illegible]	80-92	70-84	50-65		26-45	18-38	12-30	8-20	4-[illegible]
Designation 2-16**	[illegible]		70-93	50-70		[illegible]-45	[illegible]	12-30	8-20	4-[illegible]

* Asphalt Concrete aggregate, 16mm nominal maximum size

** Asphalt Stabilized Base Course (ASBC), 16mm nominal maximum size

Table 4.3 Blend proportions for test oil sand-aggregate mixes

A	B	C	Oil Sands
60%	-	-	40%
39%	26%	-	35%
-	70%	-	30%
-	65%	10%	25%
-	60%	20%	20%

Table 4.4 Summary of Marshall Test Results and Density-Voids Analysis

Asphalt Content by wt. agg. % (Oil Sands Proportion)	3.3 (20% OS)	4.1 (25% OS)	4.9 (30% OS)	5.7 (35% OS)	6.5 (40% OS)
Stability N	2970	3642	4408	2751	1454
Flow mm	2.04	1.92	1 75	1.87	1.52
Bulk Density kg/m3	2248	2253	2219	2242	2240
Voids in Mineral Aggregate, VMA %	17.4	17.7	19.5	19.4	20.3
Air Voids Content of Mix %	10.6	9.5	10.8	10.0	10.0
Voids Filled with asphalt %	39.0	46.3	44.2	48.5	50.8

Table 4.5 Marshall Mixture Design Criteria

(a) Asphalt Concrete Mixtures for Surface and Base Courses

Traffic Category	Heavy		Medium		Light	
No. of Compaction Blow (each end of specimen)	75		50		35	
Test Property	Min.	Max.	Min.	Max.	Min.	Max.
Stability, N	8006	-	5338	-	3336	-
Flow, mm	2	3.5	2	4.0	2	4.5
Air Voids Content, %	3	5	3	5	3	5
VMA*, % (16mm max. size)	15	-	15	-	15	-

* Voids in Mineral Aggregate. Source : Asphalt Institute (1984) (MS-2)

(b) *Hot-Mix Sand Asphalt Base Course*
(Compacted with 50 blows on each end).

Test Property	Minimum	Maximum
Stability, N	890	-
Flow, mm	-	5
Air Voids Content, %	3	18

Source : Asphalt Institute (1975) (SS-1).

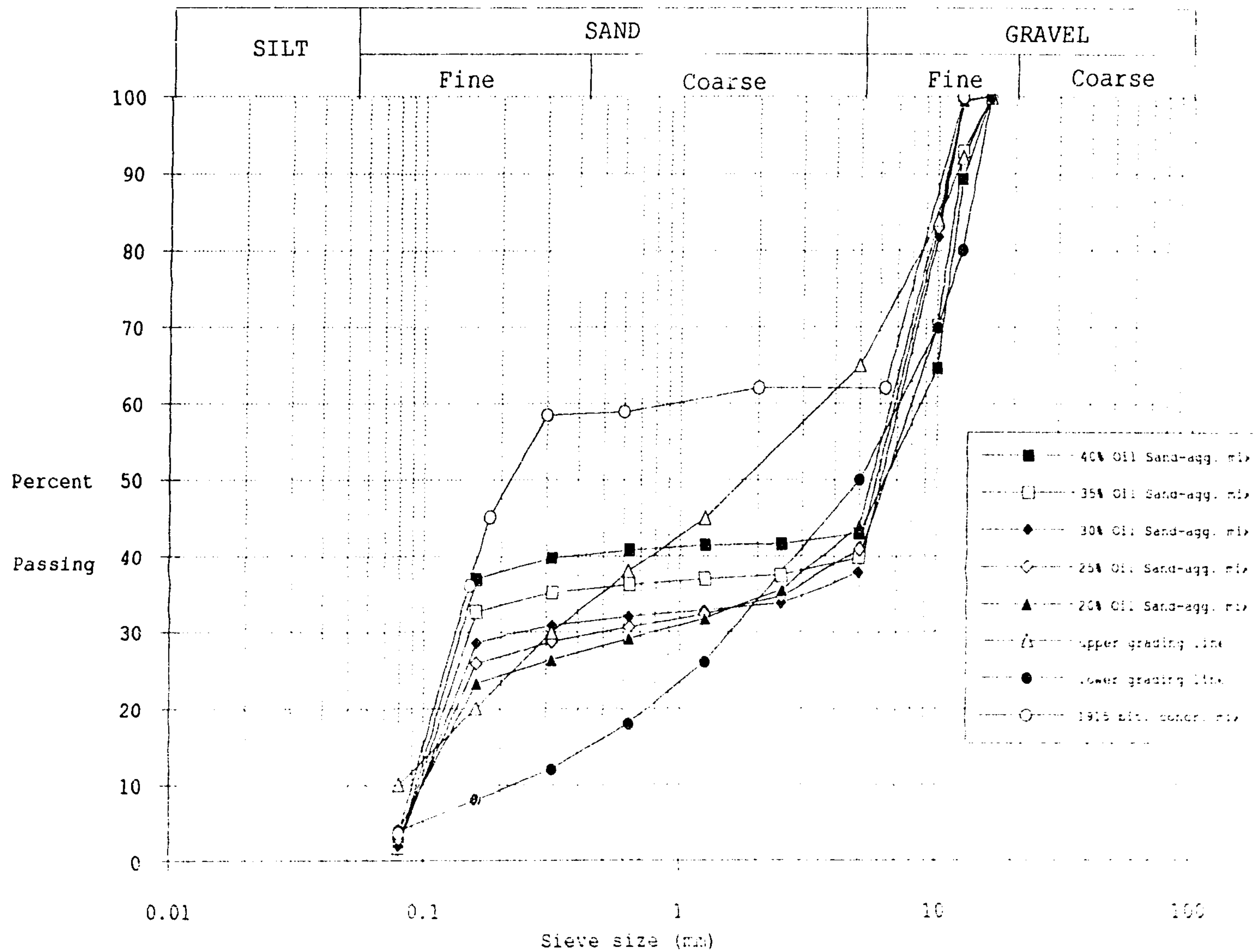

Figure 4.1 Combined aggregate gradations for test mixes compared with Alberta Transportation and Utilities grading for asphalt concrete (Designation 1-16) (1915 bituminous concrete mix plotted to show improvement on historical mix).

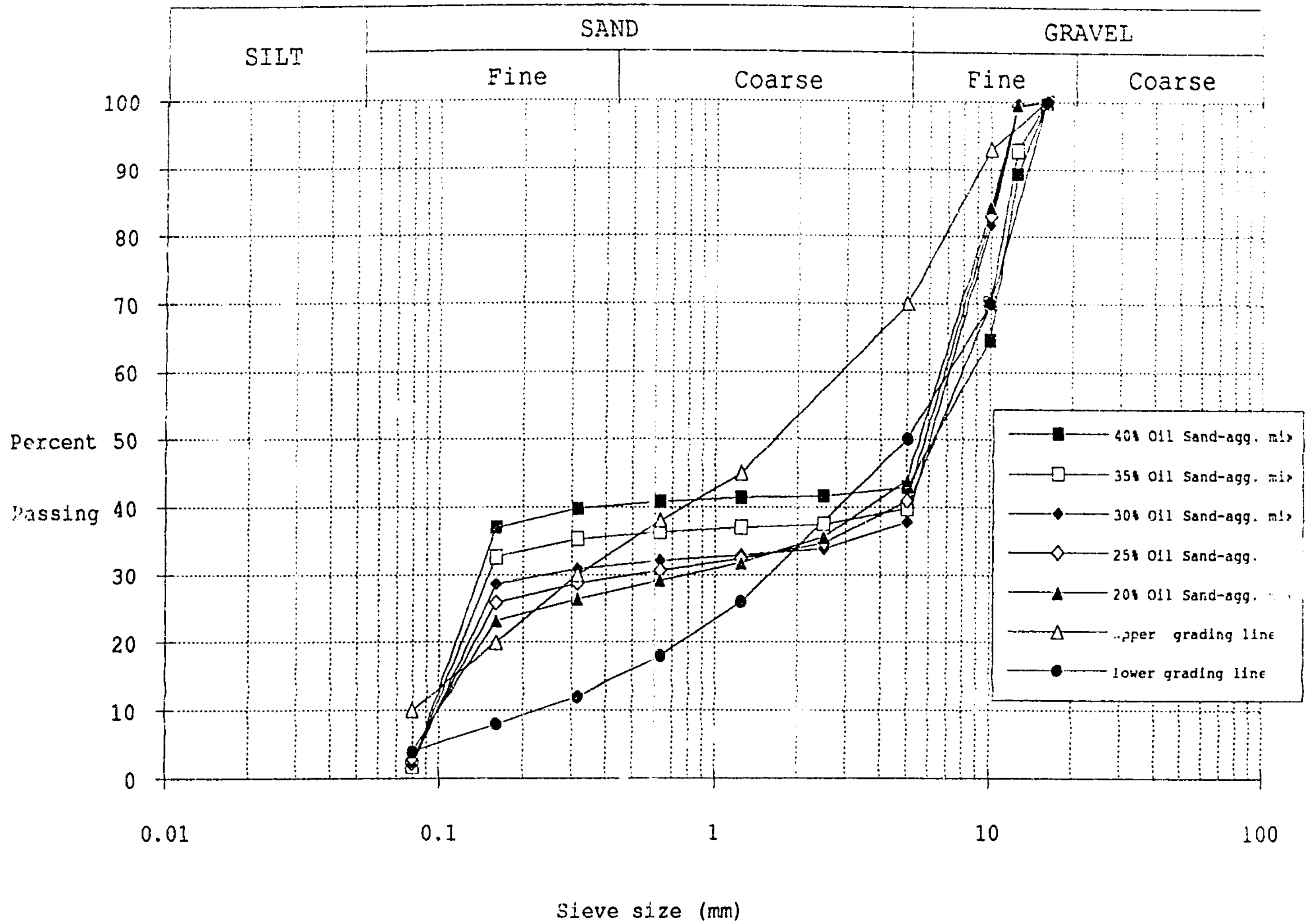

Figure 4.2 Combined aggregate gradations for test mixes compared with Alberta Transportation and Utilities grading for asphalt stabilized base course (ASBC) (Designation 2-16).

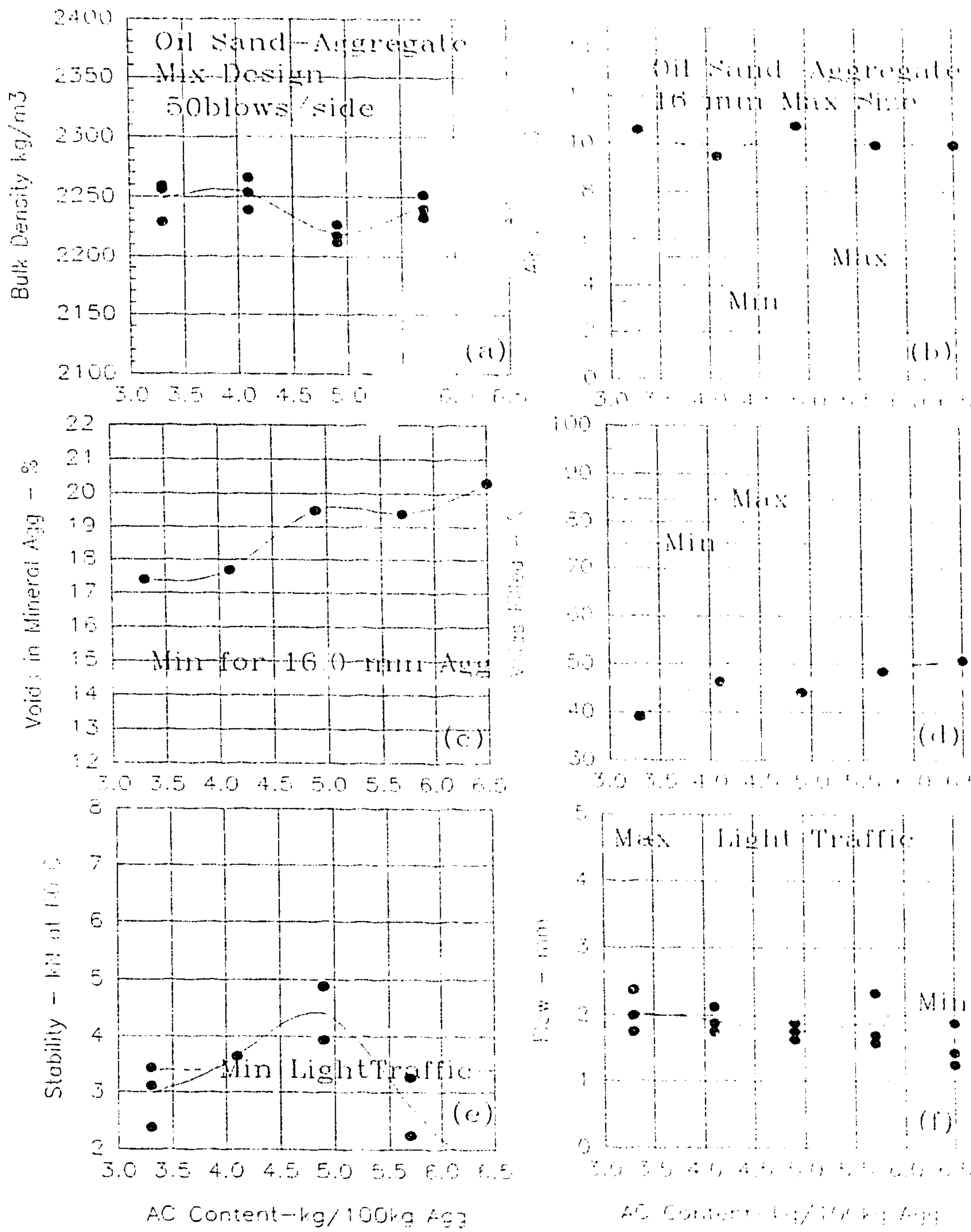

Figure 4.3 Test Property Curves for Oil Sand-Aggregate Mixtures Prepared by Marshall Method -ASTM D1559

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Alberta oil sands comprising the Athabasca, Cold Lak and Peace River oil sands areas, represent one of the larg such resources in the world, collectively spanning a total area of about 91,860 square km and holding an estimated reserve of about 1250 billion barrels of bitumen in place (Wightman et al., 1989).

Approximately 10% of the Athabasca oil sands (amount to about 5369 square km in areal extent) is amenable to surface mining, being overlain by not more than 50m of overburden. Suitable methods have evolved (and are being further developed) to provide access to the deeper lying o sands. These include the Mine Assisted In Situ Production (M.A.I.S.P.) method recently developed for the recovery of resources occurring at intermediate depths (50-150 m overburden), and a number of *in-situ* recovery methods such cyclic steam stimulation ('huff and puff'), steam drive ar fire flooding, for oil sands occurring deeper than 150m.

While the main thrust of the various oil sands developments is towards exploiting oil sands as an alternative energy resource in the light of continuing depletion of conventional oil reserves, there is good potential for utilizing oil sands for road building purposes as well. Such utilization offers economic advantages in the form of:

- savings in the cost of road paving mixtures resulting from reduced asphalt cement and fine aggregate requirements;
- conservation of resources as well as of the environment, if large quantities of lean oil sands being encountered in mining operations were to be utilized for road purposes as against the present tendency to discard such material as worthless or uneconomic to exploit for oil;
- an expanded revenue generation base as bitumen from the Athabasca oil sands can be refined to obtain paving grade asphalts meeting the CGSB requirements for Group A asphalt cements, so that, like the Cold Lake oil sands currently providing bitumen for commercial scale production of asphalt cement at the Esso Refinery in Strathcona, the Athabasca oil sands also represent a good source of material for producing paving asphalts for export and internal use.

5.2 Conclusions

The findings of this study indicate good potential for utilizing Alberta oil sands resources in paving. Test sample properties for Alberta oil sand asphalt cements reported by various testing organizations in connection with past studies were evaluated with respect to current CGSB specification requirements for asphalt cements for road purposes.

Based on this evaluation, it was concluded that bitumen from Alberta oil sands is very good material for producing asphalt cements for road building purposes. The oil sands bitumen can be refined to yield paving grade asphalts meeting all but one of the CGSB requirements for Group A asphalt cements. That is, paving asphalts of superior temperature susceptibility property offering high resistance to low temperature transverse pavement cracking.

While test oil sand-aggregate mixtures prepared in this study appear inadequate for heavy and medium trafficked roads, Alberta oil sands can be used in conjunction with graded aggregates for the construction of pavements for light trafficked roads. Such road types include roads carrying residential traffic in city streets, as well as low volume rural roads.

5.3 Recommendations

In the laboratory investigation of oil sand-aggregate mixtures conducted in this study, two mixture parameters--percent air voids content and percent voids filled with asphalt gave indications of possibly detrimental water intrusion into mix matrix as air voids values obtained were high and percent voids filled lower than usual. Therefore, a more elaborate testing program is required to provide further insight into oil sand-aggregate mixture properties.

Future test programs should also include the evaluation of the elastic, permanent deformation and fatigue characteristics of oil sand-aggregate mixtures. A preliminary mixture design procedure could evolve from the results of these additional studies, which may then enable investigations to be extended to pavement test sections constructed to conform with the recommended design mix. Modifications can then be made to the design on the basis of actual field performance of the test sections.

It was shown in this study that the uniform, fine gradation of the raw oil sands makes it necessary to blend with graded crushed gravel, stone chips or other suitable coarse aggregate in order to achieve a well graded total aggregate conforming with gradation requirements for paving mixes. While the combined gradations achieved with the test mixes of this study represent the closest to the Alberta Transportation grading band that could be obtained with the oil sands and the aggregates used, it is recommended that the possibility of getting better mixes be explored by trying other aggregates.

To meet the vital need for suitable equipment and methods to produce oil sand-aggregate mixtures within present-day constraints on emission levels, it is recommended that advantage be taken of recent developments in pavement recycling through which newly available equipment in the form of centre-feed and air heater style drum-mix plants developed for handling bitumen coated aggregate, can be adapted to process oil sand-aggregate mixtures on the basis of substituting oil sands for RAP in the hot-mix production process.

And, to further ensure conformance with Alberta Environment's particulate emission and opacity limits of 0.2 kg/1000 kg effluent and 40% respectively, the use of longer drums is advocated for mix production as this enhances heat transfer without the use of higher gas temperatures in the drum mixer. It must also be ensured that gas and mixing temperatures at the point of introduction of the oil sands do not exceed about 343 C. This temperature horizon beyond which the oil sands would smoke significantly, gives ample margin for drum mixing operations as plant mixing temperatures are usually in the proximity of 145 C. A demonstration project could possibly be initiated to examine the feasibility of processing oil sand-aggregate mixtures in a drum-mix plant.

Large quantities of lean oil sands encountered in ongoing mining operations are currently regarded as uneconomic to exploit for oil, and the general tendency is to discard such material as worthless. However, the findings of this study indicate such material can be used in building light-trafficked or low-volume road pavements if coarse aggregate is blended with the lean oil sands, and additional asphalt cement introduced to raise the mix binder content as required to ensure adequate coating of aggregates.

The only CGSB requirement that was not quite met by the oil sand asphalt cements was the solubility-in-solvent requirement. Whereas the specifications require 99% minimum solubility (obviously with conventional petroleum asphalt cements in mind), the solubility test values reported by the testing organizations show a slight shortfall, being in the range 97.1 to 97.8. This shortfall is explained by recognizing that bitumens extracted from oil sands and subsequently refined usually still contain a tiny proportion of particles of clay or other fine mineral matter in suspension. For this reason, it should not be insisted upon that oil sand asphalt cements satisfy the 99% minimum requirement. Other unconventional asphalt sources noted for higher mineral contents, such as Trinidad Lake asphalts, are known to have been widely used for paving with satisfactory results. Therefore, given that all other vital requirements are adequately met, the use of oil sand asphalt cements for road purposes should not be precluded on just this account. Hence, to enable asphalt cements from Alberta oil sands to be utilized in paving, permission for non-compliance to the solubility requirement could be given.

Finally, as this thesis did not involve an investigation of the economic factors influencing use of the oil sands for pavement construction, a survey of the economic factors involved with using Alberta oil sands in road construction, is recommended. Such a study would also compare the costs for an oil sand-aggregate mixture (cost of components, hauling, mixture preparation etc) with costs for conventional paving mixtures.

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Appendix A.

Pertinent Data Reported in Respect of 1915 Oil Sands Pavement in Edmonton

Table A.1. Analysis of raw bituminous sands prior to use in 1915 oil sands pavement as reported by Ells (1926).

					Coarse Bituminous Sand %	Fine Bituminous Sand %
Asphalt Content					12.0	16.0
Passing	#10 (2.0mm),	retained on	#20 (0.8mm)		27.2	
"	#20 (0.8mm),	"	#30 (0.6mm)		34.2	
"	#30 (0.6mm),	"	#50 (0.3mm)		22.0	0.6
"	#50 (0.3mm),	"	#80 (0.175mm)		6.8	23.0
"	#80 (0.175mm),	"	#100 (0.15mm)		0.7	15.6
"	#100 (0.15mm),	"	#200 (0.075mm)		4.5	54.6
"	#200 (0.075mm),				2.7	6.0
Oversize					1.6	

Table A.2. Average weights and compositions of mixes used for 1915 oil sands pavements (Ells, 1926)

Charge	Sheet asphalt lbs	Sheet asphalt %	Bituminous concrete lbs	Bituminous concrete %	Bitulithic concrete lbs	Bitulithic concrete %
Fine-grained bituminous sand	726	52.5	755	58	480	35
Coarse-grained bituminous sand	363	26.5	-	-	240	17.5
10/20 clean sand	-	-	52	4	26	1.9
30/50 clean sand	114	8.2	-	-	-	-
50/80 clean sand	77	5.6	-	-	-	-
Dust (Portland cement)	100	7.2	-	-	26	1.9
Crushed Gravel, 3/4 - 1 inch	-	-	-	-	108	7.8
" " 1/2 - 3/4 "	-	-	-	-	248	18.1
" " 1/4 - 1/2 "	-	-	107	8.2	156	11.4
" " 1/8 - 1/4 "	-	-	-	-	70	5.1
" " 1/10 - 1/8 "	-	-	-	-	16	1.2
" " max. 1/2 "	-	-	388	29.8	-	-
Total weight in charge	1380	-	1302	-	1370	-

Appendix B

Requirements for Paving Grade Asphalt Cements Stipulated by CAN/CGSB-16.3-M90

TABLE I / **TABLEAU I**

Grades of Asphalt Cement
Classes des liants bitumineux

Grades	60-70		80-100		120-150		150-200		200-300		300-400		Test Method Méthode d'essai ASTM	Classe
Requirements	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max	Min	Max.	Min.	Max.		Exigences
Penetration at 25°C 100 g and 5 s, 0.1 mm	60	70	80	100	120	150	150	200	200	300	300	400	D 5	Pénétration à 25°C 100 g, 5 s, 0.1 mm
*Viscosity at 60°C, Pa·s or *Viscosity at 135°C, mm²/s													**D 2171** **D 2170**	*Viscosité à 60°C, Pa·s ou *Viscosité à 135°C, mm²/s
*Group A *Group B *Group C	User must specify <u>either</u> Figure 1 or Figure 2 for all asphalt grades. Both Figures shall not be used simultaneously. L'usager doit indiquer l'emploi <u>soit</u> de la figure 1 ou de la figure 2 pour toutes les classes de liants bitumineux. Il est interdit d'utiliser les deux figures simultanément.													*Groupe A *Groupe B *Groupe C
Flash point (Cleveland Open Cup), °C	230	–	230	–	220	–	220	–	175	–	175	–	D 92	Point d'éclair (Cleveland à vase ouvert), °C
Thin-film oven test, % loss in mass	–	0.8	–	0.85	–	1.3	–	1.3	–	1.5	–	1.5	D 1754	Essai d'étuvage en couche mince, perte de masse
Penetration of residue at 25°C, 100 g, 5 s, 0.1 mm, % of original penetration	52	–	47	–	42	–	40	–	37	–	35	–		Pénétration du résidu à 25°C, 100 g, 5 s, 0.1 mm, % de la pénétration initiale
Solubility in trichloroethylene, % by mass	99.0	–	99.0	–	99.0	–	99.0	–	99.0	–	99.0	–	D 2042	Solubilité dans le trichloroéthylène, % en masse

*All requirements, except for viscosity at 60°C *or at 135°C, are the same for Group A, B and C. Minimum viscosity is defined by the bottom line of each group as shown in Figure 1 or 2.*

**Toutes les exigences, sauf celles concernant la viscosité à 60°C ou à 135°C, sont identiques pour les groupes A, B et C. La viscosité minimale est indiquée par la ligne du bas de la figure 1 ou 2 pour chaque groupe*

Penetration 25°C	60	70	80	100	120	150	200	300	400	Pénétration à 25°C
Minimum Viscosity at 60°C, Pa s Viscosité minimale à 60°C, Pa s										
Group A	210	175	150	115	92	70	50	31	21.5	Groupe A
Group B	150	125	110	85	68	53	39	24.5	17.5	Groupe B
Group C	110	90	75	55	43	32	23	14.5	8.8	Groupe C

Note: *Minimum viscosities at 60°C for other penetrations within each group can be read from the corresponding straight line on the chart.*

Remarque: *Les viscosités minimales à 60°C pour d'autres pénétrations au sein de chaque groupe peuvent être lues à partir de la droite correspondante du graphique.*

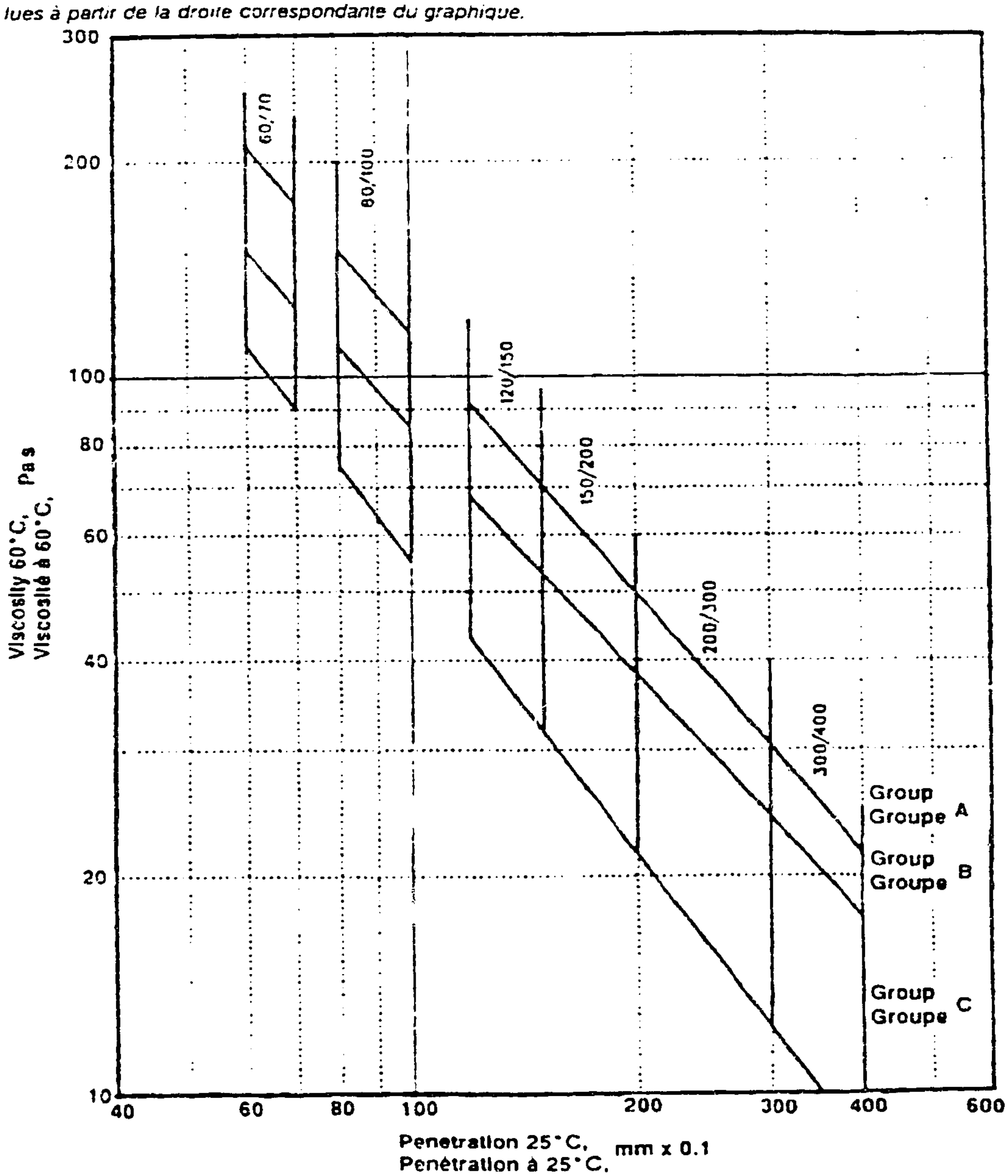

FIGURE 1

Absolute Viscosity vs. Penetration
Viscosité absolue en fonction de la pénétration

Penetration 25°C	60	70	80	100	120	150	200	300	400	Pénétration à 25°C
Minimum Viscosity at 135°C, Viscosité minimale à 135°C, mm^2/s										
Group A	400	360	330	290	255	225	185	145	120	Groupe A
Group B	310	280	260	225	200	175	145	115	95	Groupe B
Group C	235	205	185	150	130	107	84	60	46	Groupe C

Note: *Minimum viscosities at 135°C for other penetrations within each group can be read from the corresponding straight line on the chart.*

Remarque: *Les viscosités minimales à 135°C pour d'autres pénétrations au sein de chaque groupe peuvent être lues à partir de la droite correspondante du graphique.*

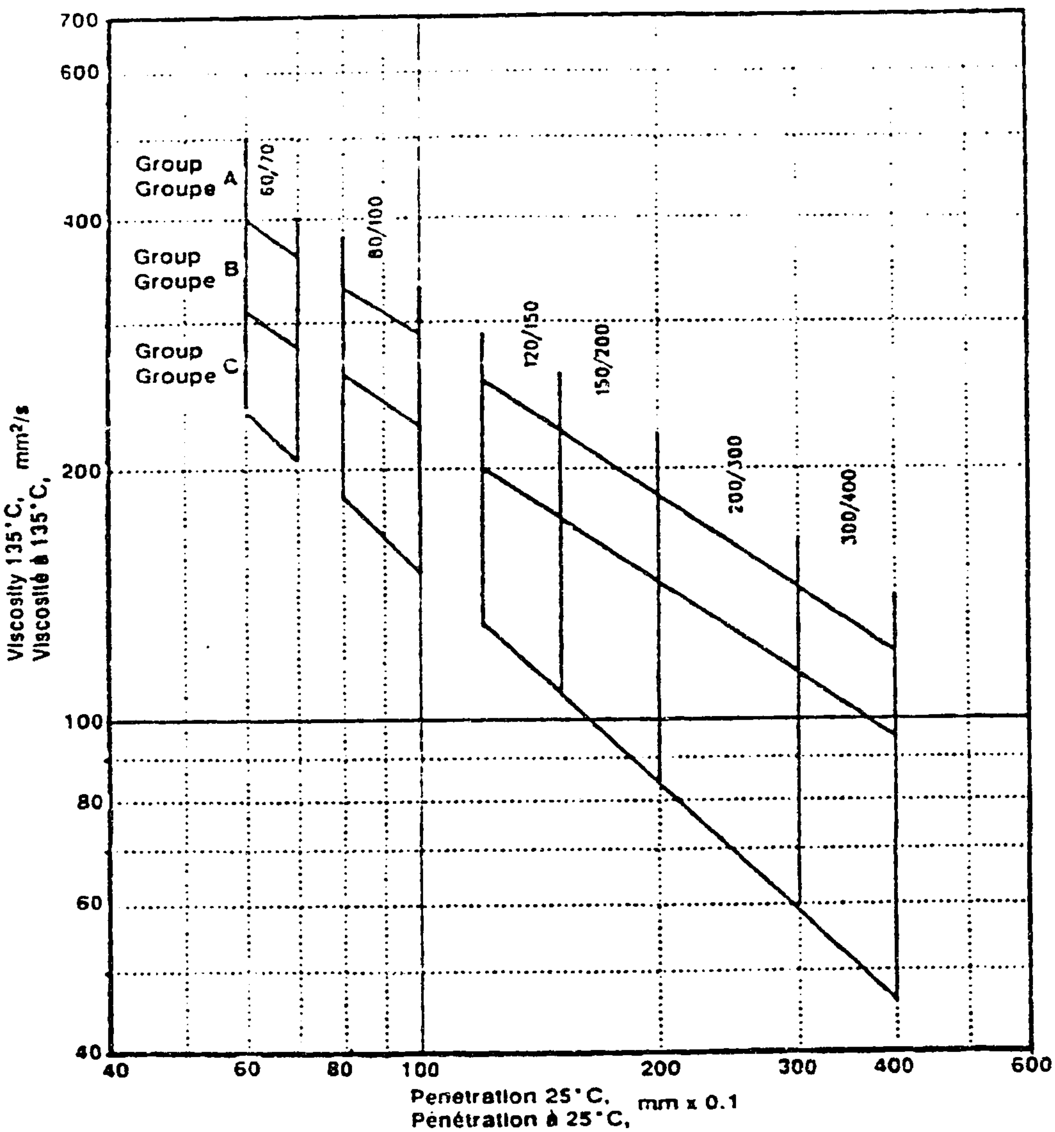

FIGURE 2

Kinematic Viscosity vs. Penetration
Viscosité cinématique en fonction de la pénétration

Appendix C

Basic Data Provided by Alberta Research Council in Accompaniment to Oil Sands Samples

DATA SHEET - OIL SAND

Sample number:	82-14%	
Field:	Athabasca	
Stratigraphic unit:	McMurray	
Location:	23-92-10-W4M	
Depth:	Middle mining bench	
Source:	Suncor Canada Ltd.	
Date sampled:	1982	
	sample 1	sample 2
Bitumen (wt.%):	13.9	12.8
Water (wt%):	1.5	2.6
Solids (wt%):	83.8	83.9

Particle size distribution:

Phi	Mesh	Microns	Cumulative Percent sample 1
0.0	18	1000.0	0.3
0.5	25	710.0	0.6
1.0	35	500.0	0.9
1.5	45	350.0	1.1
2.0	60	250.0	17.2
2.5	80	177.0	70.3
3.0	120	125.0	87.7
3.5	170	88.0	92.1
4.0	230	62.5	94.4
4.5	325	44.0	95.9
4.75	400	37.0	96.2
	<400		100.0

Statistical parameters for particle size distribution:

	sample 1
Median (Phi):	2.309
Graphic mean (Phi):	2.389
Graphic standard deviation (Phi):	0.465
Inclusive standard deviation (Phi):	0.623
Graphic skewness:	0.256
Inclusive graphic skewness:	0.361
Graphic kurtosis:	1.883

Bitumen Data Sheet

Sample number	90-01
Field:	Athabasca
Stratigraphic unit:	McMurray
Location:	10-93-10-W4M
Method of production:	Hot water process
Date sampled:	March 1990
Depth:	from Mined oil sand
Source	Syncrude Canada Ltd.
Sample description:	Coker feed bitumen

	Historical data		90-01
	Max	Min	
API gravity:	9.0	7.7	6.2
Density:	1.006	1.016	1.0266
Viscosity 15°C	>700000	19000	-
(cp) 25°C	300000	53200	374000
60°C	4350	3630	5030
100°	303	160	[illegible]
Ramsbottom Carbon residue(wt%):	14.5	11.5	-
Ash (wt%):	1.03	0.70	1.01
Carbon (wt%):	83.95	82.41	83.04
Hydrogen (wt%):	10.63	10.16	9.76
Nitrogen (wt%):	0.92	0.44	0.55
Sulphur (wt%):	5.44	4.41	7.07
Oxygen (wt%):	1.38	0.76	1.26
Vanadium (ppm wt.)	218	81	235
Nickel (ppm wt.)	85.2	69	83.6
Asphaltenes (wt%):	17.1	15.1	-
Acid number	2.58	1.57	3.59

Simulated distillation:

IBP: 391

Cut Temp(C)	Cumulative Volume %	Cut temp(C)	Cumulative Volume %
150:	---	175:	---
195:	---	225:	---
250:	---	275:	---
300:	---	325:	---
343:	---	375:	---
400:	2	425:	7
450:	12	475:	18
500:	24	524:	29
Residue:	100		

Appendix D

Sample Density-Voids Analysis Calculations

Sample Calculations for Specimen 30-2 (30% oil sands by weight of aggregate, serial no.2):

From record of measurements made during specimen preparation,

wt. of heated coarse aggregate B = 840.40g
wt. of heated oil sands = 426.00g
1266.40g

=> percent coarse aggregate by weight of total mix

$$= \frac{840.40}{1266.40} \times 100\% = 66.36\% = P_1$$

The average composition of the oil sands as determined from bitumen extraction tests was 13.65% bitumen, 1.97% water and 84.38 % sand. Upon heating the oil sands to about 150 C prior to mixing with coarse aggregate, moisture is eliminated and composition becomes 13.92 % bitumen and 86.08 % sand. Therefore,

wt. of total aggregate in mix = 840.4 + 0.8608(426)
= 1207.1 g

and, percent coarse aggregate B by weight of total aggregate

$$= \frac{840.40}{1207.1} \times 100\% = 69.62 \simeq 70\ \%$$

Similarly, percent oil sand solids by wt. of total aggregate

$$= \frac{0.8608(426)}{1207.1} \times 100\% = 30.38 \simeq 30\ \%$$

and percent oil sand solids by weight of total mix

$$= \frac{0.8608(426)}{1266.4} \times 100\% = 28.96\ \% = P_2$$

By subtraction, percent bitumen content by wt. of total mix

$= 100 - (66.36 + 28.96) = 4.68\%$

Check: by direct calculation, percent bitumen content by wt. of mix

$$= \frac{0.1392(426)}{1266.4} \times 100\% = 4.68\ \%$$

(Percent asphalt content by wt. aggregate

$$= \frac{0.1392(426)}{1207.1} \times 100\% = 4.91\ \%)$$

Bulk Specific Gravity of aggregate B = 2.6088 = G_1

Bulk Specific Gravity of oil sand solids = 2.6643 = G_2

=> Bulk Specific Gravity of combined aggregate, G_{sb}

$$= \frac{P_1 + P_2}{P_1/G_1 + P_2/G_2} = 2.6254$$

Theoretical maximum specific gravity of mixture, G_{STM} = 2.489 (ASTM D 2041)

Specific gravity of oil sand asphalt, G_A* = 1.0266

To calculate asphalt absorption, assume 100cc of mixture :

wt. of voidless mixture = 100 x G_{STM} = 248.9 g

wt. of asphalt = 4.68% x 248.9 = 11.65 g

=> wt. of aggregate = wt. of mixture - wt. of asphalt
= 248.9 - 11.65 = 237.25 g

vol. of asphalt = wt./sp. gr. = 11.65/1.0266 = 11.35 cc

vol. of aggr. = wt. agg./G_{sb} = 237.25/2.6254 = 90.37 cc

Corresponding total volume of mixture = 101.72 cc

However since maximum volume = 100 cc, 1.72 cc of asphalt must be absorbed in aggregate.

=> wt. asphalt absorbed = 1.72 x 1.0266 = 1.77 g

=> % asphalt absorption by wt. agg.= 1.77/237.25 x 100%
= 0.75 = P_{ba}

---

* Data provided with samples by Alberta Research Council (Appendix C)

With asphalt absorption determined, voids calculations can then be performed for the mixture as follows:

Bulk specific gravity of ...acted specimen, G_{mb} = 2.2180

Assuming 100cc volume of mixture,

wt. of mixture = 100 x G_{mb} = 221.8

wt. of asphalt = 4.68% x 221.8 = 10.38

=> wt. of aggregate = 221.8 - 10.38 = 211.42 g

=> wt. of absorbed asphalt = 0.75 % x 211.42 = 1.59 g

=> wt. effective asphalt = wt.asphalt - wt.absorbed asphalt
= 8.79 g

=> vol. effective asphalt = wt/sp.gr = 8.79/1.0266 = 8.56cc

vol. of aggregate = wt. agg./G_{sb} = 211.42/2.6254 = 80.53cc

=> Voids in Mineral Aggregate, VMA = total vol.- vol. of agg
= 100 - 80.53 = 19.47 cc
≃ 19.5 %

Air voids = VMA - vol. of effective asphalt
= 19.47 - 8.56 = 10.91 ≃ 10.9 %

% Voids filled with asphalt = $\frac{\text{vol. effective asphalt}}{\text{VMA}}$ x 100%
= 8.56/19.47 x 100% ≃ 44 %