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Information Series No. 33

ALBERTA SUBBITUMINOUS COALS AS DRILLING FLUID THINNERS

by

E. J. Jensen



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CONTENTS

	Page
Summary	5
Introduction	5
Humic acids	6
Selection of samples	7
Experimental work	8
Procedures for measurements of mud properties	8
Results	9
Discussion	10
Acknowledgments	12
References	13

TABLES

Table I.	Description of coal samples	15
Table II.	Analyses of coal samples	16
Table III.	Exchangeable cations, total exchange-capacity and pH	17
Table IV (a) - (e).	Effect of additions of coal on the properties of an 8% bentonite suspension	18-19
Table V.	Comparison of Coal No. 2 with Lignite B	20
Table VI.	pH Adjusted, 8% bentonite suspension tested with selected coals and other additives	21
Table VII.	pH Adjusted, 8% bentonite suspensions tested with selected coals	22

FIGURES

Figure 1.	Map of central Alberta showing sample localities	23
Figure 2.	Columnar sections through coal seams	25

ALBERTA SUBBITUMINOUS COALS AS DRILLING FLUID THINNERS

SUMMARY

From laboratory studies of the mud-thinning qualities of several weathered (i.e. naturally oxidized) Alberta sub-bituminous coals, it is concluded that:

(a) Deposits of suitable subbituminous coals, requiring little or no treatment beyond appropriate pulverization, occur abundantly within the Province;

(b) Alberta coals possessing good thinning qualities are characterized by high cation-exchange capacities and fixed-carbon: volatile-matter ratios of less than unity;

(c) The amount of coal required for maximum thinning is of the order of 2 - 4 per cent by weight of the drilling mud.

The fact that coals of poor thinning ability can exist in close proximity to highly effective ones suggests, however, that controlled oxidation of mined subbituminous coals might, from a practical standpoint, be preferable to reliance on random and necessarily incomplete weathering. It is reasonable to assume that weathering can only rarely (and accidentally) yield thinners of predetermined and controlled quality.

INTRODUCTION

Modern drilling practice involves the injection into boreholes of a heavy fluid commonly known as 'mud'. Except in a few instances where suitable substitutes are locally available, this material is made from carefully specified bentonites and serves to counteract hole pressures, to lubricate drill bits, to remove cuttings, and to seal borehole walls.

In order to ensure smooth drilling operations and to compensate for the natural and progressive contamination of the mud, it is also standard practice to introduce additives, of which so-called thinners are examples. The particular function of a thinner is to control the rheological properties of the mud and, in this way, to maintain normal mud flow without excessive power consumption.

Chemically, thinners can vary widely. But one of the most common types, accounting for as much as 40 per cent of the total 1952 thinner consumption in the

United States*, is a complex mixture marketed under the common name "Lignite"**. The active components in this type of thinner are known as humic acids. Since these materials occur in naturally weathered, or artificially oxidized, coals -- from which they can, if desired, be extracted with aqueous alkali solution -- and since several Alberta coals are known to be particularly rich in humic acids, it was thought pertinent to explore the direct use of such coals as thinners. The investigations reported in the following pages accordingly deal with attempts to survey and characterize some potentially suitable coals and to compare them with two well-established, commercially marketed lignite thinners.

It might, in this connection, be observed that as much as 500 tons per year of these lignites have been imported into Alberta (1958) for use in oil-exploration programs, and that the material sold at approximately 10 cents per pound. When bentonite mining and purification was started in Alberta (1), the company responsible for these operations reportedly acquired a small coal deposit for thinner production, but lignite importation is believed to be still fairly substantial.

Humic Acids

Humic acids - believed to be the active ingredient in the materials investigated in the present study - are still of uncertain chemical composition and structure. The coal chemist labels as humic acids that part of a coal which can be extracted with aqueous alkalis and recovered to yield dark-brown to black solids possessing weakly acidic properties. Molecular weights of humic acids are likewise uncertain, but a method recently developed at the Research Council of Alberta (2), and seemingly capable of yielding much more significant data than have previously been reported in the literature (see for example reference 3), has given number-average values of ca. 1,500 for the humic acids involved in this test series.

In principle, humic acids form in (and on) coals exposed to air and will, when thus generated, occur in quantities varying with coal rank as well as with the intensity and duration of exposure. Lignites and many subbituminous coals form humic acids very readily, while the more mature coals do so only slightly or not at all. But while humic acids are essentially degradation products formed by the combined effects of air and moisture, they can also be obtained by artificial oxidation of coal (for example, by heating coal in air at temperatures between 100° and 250°C.). As far as is known, such artificially produced humic acids do not significantly differ from their 'natural' counterparts, and it may therefore be presumed that thinning properties of naturally weathered coals can be reproduced (and probably improved upon) by controlled oxidation.

* Later consumption figures are not available, but there is no indication that the use of humic acids has declined.

** This designation may be synonymous with the term "lignite" used in coal classifications, but is not necessarily so.

The origin of the two imported lignites used as comparison materials is not known with certainty, but they are either North Dakota lignites or New Mexico lignites. It is equally uncertain whether or not they have been artificially oxidized after mining; however, no attempt has been made to establish this point since it has no direct relevance to the present investigation. They were chosen as 'standards' simply because they are widely accepted as thinners in the drilling industry.

Until quite recently, humic acids appear to have figured only in academic studies, particularly those concerned with coal constitution. However, during the past few years they have attracted wider, and more 'practical' attention. For example, humic acids have been or are being studied as hydrogenation raw materials, as starting substances in the manufacture of cheap plastics, as possible soil amendment agents, and as source materials of novel insecticides. Certain of these areas are currently under study at the Research Council and will form the subject matter of future reports.

Selection of Samples

Because this study was conceived as an exploratory investigation, it was deemed adequate to undertake a somewhat random and incomplete sampling program. The absence of particular coals from the list of coals actually investigated must therefore not be construed as meaning that such coals are necessarily likely to be less useful as drilling mud additives. Nor should it be thought that the coals here studied are necessarily the most promising.

However, in selecting coals for more detailed study, a simple criterion was used; since humic acids are known to form during the weathering of coal, emphasis was placed on sampling locations containing well-exposed coal outcrops and seams likely to have been fairly thoroughly oxidized by air or by percolating surface waters. In these locations samples were also taken in places that showed no visible signs of having been oxidized. Since humic acids are also soluble in alkalis, a further guide to potentially useful sampling areas was provided by previously published data on alkali solubility of Alberta coals contained in Research Council of Alberta Report 35 (4). Because data in that report relate to solubility in fused alkali and may, therefore, reflect not only humic acid contents, a rough field test involving solubility in aqueous alkalis was also used in selecting samples.

As shown later, the sampling criteria were not the best, and it is now thought that they might, under certain conditions, actually prove to be misleading. In the discussion, therefore, an empirical but more helpful criterion has accordingly been suggested. On the other hand, even the admittedly inadequate sampling program produced a series of coals among which several very promising materials were found.

A list of the samples tested in the laboratory is shown in table I. The mines from which these samples were collected form an arc stretching north and north-west across central Alberta, and lie closely above the geological boundary between the top of the marine Bearpaw shale and the bottom of the nonmarine Edmonton formation. Figure 1 shows the geographic position of the eight general localities in which sampling was done, while figure 2 reproduces typical seam-logs from five of these localities.

EXPERIMENTAL WORK

Procedures for Measurements of Mud Properties

The mechanism by which thinners control the consistency of a drilling mud is still uncertain, and the application of thinners is therefore an art rather than a definite technology. However, because mud control is today a quite essential phase of work at a drill site, analytical procedures and specifications have been standardized by the American Petroleum Institute (5). Discussions of the many factors involved in drilling mud formulation and behavior are given in text books of which one of the most authoritative is by Rogers (6). Some of the more important terms and properties are discussed briefly:

Mud, in this work, designates an aqueous suspension of Wyoming drilling-grade bentonite which has been allowed to swell and mature for a considerable period of time prior to use.

The weight of a mud is its density expressed in pounds per U.S. gallon.

Rheological properties of bentonite muds are complex and must therefore be described by several functions (6). Two of these are:

- (a) So-called plastic viscosity, and
- (b) Yield value.

These qualities vary with the previous history of the sample and are customarily determined on suspensions which have been well stirred prior to testing.

A third relevant rheological parameter which depends strongly on the previous history of the suspension, is the gel strength. This is the force necessary to initiate a specific small degree of flow. It can be regarded as a measure of the solidity which a mud will attain when allowed to stand undisturbed for some time. In practice, this solidity has certain advantages; for example, it prevents cuttings from settling at the hole bottom when drilling is temporarily discontinued. But since an excessively strong gel may resist 'breaking' with available pump capacity, gel strength must be kept under control. In the laboratory, gel strength is measured on thoroughly stirred muds after allowing them to stand for 10 seconds and for 10 minutes.

Actual values obtained for these quantities are dependent on the type of measuring instrument used. The measurements given in this report were obtained with a Fann V.G. 35 viscosimeter calibrated with oils of known viscosity.

In addition to plastic viscosity, yield value, and gel strength, considerable importance is attached to fluid loss. This is a measure of the rate at which a mud gives up water to the surrounding formation and thereby forms a bentonite 'wall' which prevents further loss of circulating mud to the formation. Experimentally, fluid loss is measured in a filter press by applying 100 pounds per square inch pressure, and

determining the thickness of the filter cake and the quantity of filtrate during a 30-minute period. (Because of the difficulty encountered in accurately measuring filter-cake thicknesses, these data are omitted from the tables summarizing the experimental results).

Results

The test series summarized in the following pages comprised (a) proximate analysis of all coal samples and of the two lignites used for comparison; (b) determination of the ion-exchange capacities; and (c) measurements of weight, plastic viscosity, yield value, fluid loss, and gel strength of laboratory muds before and after addition of varying quantities of coal or imported lignite thinners.

Table II shows the proximate analyses and fixed-carbon: volatile-matter (FC:VM) ratios, as well as B.t.u. values, of all test samples. The coal analyses were carried out in conformity with A.S.T.M. Standards with such modifications as have been adopted by the Research Council of Alberta coal analytical laboratory.

Table III lists the corresponding pH values, total cation-exchange capacities, and concentration of individual exchangeable cations. Exchangeable cations other than hydrogen were extracted with 1N ammonium acetate adjusted to pH = 7. Exchangeable calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) were then determined in a Beckman DU flame photometer. Exchangeable hydrogen was determined by leaching the test sample with 0.5N barium acetate buffered to pH = 7, and titrating an aliquot of the extract with 0.1N sodium hydroxide. (For essential experimental details, see reference 7).

The total exchange capacity was determined by replacing ammonium ions introduced via ammonium acetate with sodium (from 1N sodium chloride), and measuring nitrogen contents by the macro-Kjeldahl method. The soil-paste technique (7) was used for pH measurements.

Laboratory muds were prepared by suspending 8 g. of Wyoming drilling-grade bentonite in 100 g. of water. The plastic viscosity of these muds, as measured with a Fann V.G. 35 viscosimeter, varied between 25 and 30 centipoises and remained variable within these limits even after aging for one week. Some uncertainty accordingly attaches to a direct comparison of data relating to different samples, but the general conclusions derived from the tests are thought not to be seriously affected by it.

Additions of 0.5, 1.0, 2.0, 4.0, and 8.0 per cent of finely ground coal (100% through -200 mesh Tyler) were in each case made under vigorous stirring. The treated muds were then left to mature for two days and again thoroughly agitated before being submitted to testing.

While physical parameters characterizing drilling muds have been reported to change with time (6), preliminary tests failed to show such 'drift', and the results

set out in tables IV (a) - (e) can therefore be regarded as firm measures of the relevant mud properties. (Gel-strength measurements have been confined to selected coals at the 2%- and 4%-concentration levels).

A direct comparison of the effects of Coal No. 2 (one of the better coals tested in this study) and Lignite B on mud properties is shown in table V*. The measurements relate to treated 10 per cent bentonite suspensions at variable pH.

Since changes in pH are known to influence the viscosity and other physical characteristics of a drilling mud quite markedly, and to cause minimum viscosities in the range pH = 7 - 10, parallel tests were also conducted at constant pH. For these, 400 g. of a 12 per cent bentonite suspension, containing 48 g. of bentonite, was adjusted with alkali to pH = 9, mixed with an aqueous suspension of 12 g. of coal adjusted to the same pH, and finally brought to a total volume of 600 cc. with water. The treated mud therefore corresponded to an 8 per cent bentonite suspension containing 2 per cent coal. (Total addition of other chemicals needed for pH control, e.g. NaOH, did not exceed 0.5%). Coals chosen for testing in this series include one (No. 1) that had shown little thinning ability in the preceding experiments, and two (Nos. 3 and 6) that had shown marked thinning properties. Control tests were conducted with Lignite B and with samples of Quebracho**. The results are tabulated in table VI.

Table VII contains results of a similar series in which the pH of the coal suspensions was not adjusted prior to their addition to the mud. In this case, measurements were made on two muds originally brought to a pH of 9 and 10 respectively.

DISCUSSION

The evaluation of a thinner is based upon its ability to lower the gel strength and yield value of a mud. The fluid loss should be maintained or lowered, whereas the plastic viscosity, though preferably kept low, may vary slightly one way or the other. The evaluation is best made at constant pH. Where this is not possible, allowance must be made for the fact that optimum values are attained in the pH range 7 - 10.

* Because Lignite D performed in much the same manner as Lignite B, it has been omitted from tables in which coals are compared with the lignite thinners. Lignite D is included in table II to show additional composition data for satisfactory thinners.

** Quebracho is usually an extract of a tree belonging to the genus Schinopsis principally found in the Argentine. The extract contains 60 - 70% tannin. Quebracho, sold under this name, is obtainable from oil well supply companies and is generally regarded as the most effective thinner currently available (6).

Against this background, the experimental results shown in tables I - VII leave little doubt that several of the coals tested in the present study compare very favorably with the two lignite thinners used as 'standards', and that these coals offer good substitutes for them. The most satisfactory samples are:

- (a) No. 2, 3, 6 (Sheerness),
- (b) No. 11, 13, 16 (Battle River),
- (c) No. 21 (Round Hill),

which are described in table I. As shown in table IV (and the following tables), all these samples, when added to a laboratory mud, resulted in significant lowering of the plastic viscosity and/or the yield value - and exerted no deleterious effects on the gel strength and fluid loss. (In certain respects, indeed, some of these samples were actually superior to the imported lignites used as standards - compare table V (2% and 4%); table VI, coals No. 3 and 6, last column; table VII, coals No. 3 and 6. However, the present tests are not sufficiently definitive, and the practical performance of a thinner depends upon too many factors to permit more than a qualitative judgment at this time).

Other coal samples tested in the present series appear to be more or less unsuitable for use as thinners, although it may reasonably be assumed that they could be converted into satisfactory thinning agents by further oxidation. It is also likely, as pointed out earlier, that adequately weathered coals with good thinning qualities exist elsewhere in the Province, and that they could be located quite easily if demand warrants further search. However, in view of the fact that only three out of the seven most promising coals mentioned above were derived from freshly exposed faces, it is evident that such a search should not exclusively concentrate on outcrops or long-exposed seams.

It was stated earlier that humic acids are recovered by extraction with aqueous solutions of alkali. It would be very convenient if alkali solubility of the humic acids could be used as a simple field test. However, this is not the case. It can, at best, be used as a negative test, that is, lack of solubility rules out a coal as a mud thinner whereas pronounced solubility does not automatically imply that it is a good thinner.

None of this means that association of thinning properties with humic acid contents is untenable: in principle, humic acids can form by oxidation processes that do not entail prolonged exposure of the coal to the atmosphere*, and solubility in

* For example, oxidation of a near-surface seam can be brought about by percolation of oxygenated surface waters (especially alkaline waters) - some chemists also consider that the humic acid molecules may be a direct precursor of the coal molecule; if this view should be substantiated, a high humic acid content in an immature coal may be due to the particular conditions of formation and maturation, rather than to subsequent exposure and oxidation.

alkalis - in a field test judged by color intensity - can arise from coal components more or less unrelated to humic acids per se. But it does imply that there is no simple direct field test by which the probable performance of a coal as a mud thinner can be estimated, and that reliance can therefore only be placed on quite detailed laboratory evaluation.

It is noteworthy that Alberta coals possessing good thinning abilities comparable to those of imported lignites are characterised by:

1. High total ion-exchange capacity,
2. A high content of exchangeable hydrogen ions,
3. A fixed-carbon: volatile-matter ratio of less than 1.

The latter parameter offers an especially convenient, but purely empirical, datum for selecting potentially useful samples for further study and, incidentally, emphasizes the direct connection between thinning properties and the degree of coal oxidation.

One other notable feature emerging from the results is that the maximum thinning effects accruing from additions of oxidized coal appear to coincide with concentrations in the range 2 to 4 per cent. Further additions of coal generally produce detrimental effects and imply that overdosing (a common practice on drill sites when using thinners of the type here considered) must be avoided.

As a final comment, it should be noted that while oxidized coals are generally less efficient thinners than several chemically more closely defined materials (such as Quebracho) available for mud control programs, they are economically most attractive. For this reason they may prove useful in wider areas than are afforded by drilling muds. Control of the flow properties of slurries, such as are encountered in cement manufacture, is a typical example of these areas.

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Table I. Description of Coal Samples.

Sample No.	Locality	Description
1	Sheerness	Strip pit, face of mined seam, exposed 1 month
2	"	" " , upper (not mined) seam, freshly exposed
3	"	" " , upper (not mined) seam, freshly exposed
4	"	" " , base of mined seam, exposed 3 years
5	"	" " , centre of mined seam, exposed 3 years
6	"	" " , upper seam, exposed 3 years
7	Castor	Underground workings, fresh run-of-mine coal
8	Paintearth Creek	Strip pit, run-of-mine coal, freshly exposed
9	" "	" " , coal exposed several years
10	" "	Underground workings, stockpiled several years
11	Battle River	Strip pit, 0.5-ft. seam 40 feet above mined seam, freshly exposed
12	" "	" " , bone directly above mined seam
13	" "	" " , in or near mined seam, heavily weathered
14	" "	" " , mined seam, partly weathered
15	" "	" " , fresh run-of-mine coal
16	" "	Outcrop, heavily weathered
17	Camrose	Strip pit, face of mined seam, exposed 1 year
18	"	" " , fresh run-of-mine coal
19	Round Hill	Strip pit, fresh run-of-mine coal
20	" "	" " , mined seam, abandoned part of pit
21	" "	" " , weathered mined-seam, abandoned part of pit
22	Dodds	Strip pit, fresh run-of-mine coal
23	Tofield	Abandoned strip pit, upper half-foot of mined seam, exposed several years
24	"	" " " " , mined seam, not exposed
	Imported Lignite B	Commercially marketed drilling-mud thinner
	Imported Lignite D	Commercially marketed drilling-mud thinner

Table II. Analyses of Coal Samples

Sample No.	"As received" basis					Dry basis				
	% Moisture	% Ash	% VM	% FC	B.t.u./lb.	% Ash	% VM	% FC	B.t.u./lb.	FC/VM
1	26.8	4.9	28.3	40.0	8,510	6.7	38.7	54.6	11,640	1.41
2	35.7	7.1	28.6	28.6	5,720	11.1	44.5	44.4	8,890	1.00
3	30.9	14.1	28.6	26.4	5,570	20.4	41.4	38.2	8,060	0.92
4	26.7	4.7	29.7	38.9	-	6.4	40.5	53.1	-	1.31
5	18.8	18.6	28.1	34.5	7,240	22.8	34.6	42.6	8,920	1.23
6	15.2	12.1	36.7	36.0	7,370	14.2	43.3	42.5	8,690	0.98
7	14.7	6.6	34.6	44.1	9,230	7.7	40.5	51.8	10,810	1.28
8	15.0	8.5	32.5	44.0	9,210	10.0	38.2	51.8	10,840	1.35
9	10.1	22.5	29.4	38.0	8,000	25.0	32.8	42.2	8,910	1.32
10	11.3	12.0	33.8	42.9	8,850	13.5	38.1	48.4	9,970	1.27
11	25.4	21.4	29.6	23.6	5,180	28.7	39.7	31.6	6,940	0.80
12	7.9	43.3	23.6	25.2	5,690	47.0	25.6	27.4	6,180	1.07
13	18.8	6.3	35.2	39.7	7,830	7.7	43.4	48.9	9,640	1.12
14	9.8	6.7	35.4	48.1	10,130	7.4	39.3	53.3	11,230	1.35
15	13.4	5.4	33.8	47.4	9,740	6.3	39.0	54.7	11,250	1.40
16	16.2	12.5	36.0	35.3	7,220	14.9	43.0	42.1	8,610	0.98
17	13.3	9.9	32.6	44.2	9,160	11.5	37.6	50.9	10,570	1.35
18	21.2	5.8	30.3	42.7	9,080	7.4	38.5	54.1	11,520	1.44
19	23.5	6.6	29.4	40.5	8,420	8.6	38.5	52.9	11,020	1.37
20	13.5	6.5	35.3	44.7	9,430	7.5	40.8	51.7	10,890	1.26
21	24.9	8.8	30.9	35.4	7,400	11.8	41.1	47.1	9,850	1.14
22	22.1	6.2	30.4	41.3	8,830	8.0	39.0	53.0	11,340	1.36
23	13.7	12.1	32.5	41.7	8,510	14.0	37.7	48.3	9,860	1.28
24	10.8	6.3	34.8	48.1	10,030	7.1	39.0	53.9	11,240	1.38
Lignite B	15.1	18.3	38.0	28.6	6,570	21.6	44.8	33.6	7,950	0.75
Lignite D	18.0	18.6	38.0	25.4	-	22.6	46.4	31.0	-	0.67

Table III. Exchangeable Cations, Total Exchange-Capacity, and pH
(reported in milliequivalents per 100 grams)

Sample	Na	K	Ca	Mg	H	Total Cations	Total Exchange Capacity*	pH
1	4.3	0.3	35.0	5.3	22.4	67.3	57.5	6.6
2	22.1	0.5	55.0	11.7	149.3	238.6	217.4	4.4
3	19.0	1.1	47.7	10.7	130.9	209.4	201.9	4.5
4	4.0	0.3	39.3	7.3	25.6	76.5	68.6	6.6
5	3.1	0.8	39.3	8.3	61.2	112.7	100.9	5.2
6	16.1	0.8	46.7	11.3	141.3	216.2	203.8	4.3
7	17.5	-	44.2	2.5	44.6	108.8	108.0	5.9
8	15.0	-	26.6	-	38.3	79.9	81.2	5.9
9	15.8	-	28.3	0.8	34.9	79.8	78.9	6.0
10	15.8	-	29.1	0.8	65.6	111.3	109.0	5.4
11	21.6	0.8	39.1	12.5	103.0	177.0	164.0	3.9
12	25.8	2.5	32.4	3.3	18.5	82.5	83.2	6.2
13	19.1	-	23.3	1.7	150.0	184.1	189.0	3.6
14	16.7	-	30.8	1.7	38.8	91.0	84.6	6.2
15	16.7	-	25.8	1.7	43.8	88.0	81.4	5.9
16	4.2	0.8	41.6	12.5	149.0	208.1	208.0	3.3
17	1.7	-	35.0	7.5	40.3	84.5	85.2	5.0
18	2.5	-	28.3	6.7	39.4	76.9	72.1	5.1
19	8.3	-	26.6	4.2	38.4	77.5	75.0	5.2
20	10.0	-	54.9	10.0	38.4	113.3	110.0	6.1
21	12.5	-	75.8	15.0	29.1	132.4	131.0	6.2
22	10.0	-	30.0	5.8	26.8	72.6	70.3	6.3
23	0.8	-	19.9	5.8	63.8	90.3	96.3	4.6
24	5.0	-	22.5	5.0	49.5	82.0	80.9	5.1
Lignite B	2.5	-	54.9	15.8	121.0	194.2	163.0	3.3

* In a number of cases, the total exchange capacity was found to be less than the total cations. This is due to inadequacies in the analytical procedures employed (cf. page 9).

Table IV (a) - (c). Effect of Additions of Coal on the Properties of an 8% Bentonite Suspension

Sample No.	(a)						(b)						(c)					
	Plastic Viscosity, cPs.						Yield Value, lbs./100 sq. ft.						Fluid Loss, cc. in 30 min. at 100 lbs./sq. in.					
	0%	1/2%	1%	2%	4%	8%	0%	1/2%	1%	2%	4%	8%	0%	1/2%	1%	2%	4%	8%
1	25.0	25.5	23.0	24.0	25.0	29.5	37.0	39.0	40.0	37.5	36.0	41.5	9.5	9.8	10.0	10.1	9.9	8.2
2	25.5	23.0	23.5	24.0	25.5	32.5	34.5	22.5	23.0	24.0	26.5	29.0	12.4	11.2	11.0	10.4	10.8	10.5
3	23.5	26.0	25.5	26.5	29.0	35.0	35.5	28.0	26.5	25.5	27.0	33.5	10.0	10.0	10.5	10.2	10.0	9.0
4	27.0	24.5	24.0	24.5	27.5	33.0	31.0	40.5	40.0	37.0	39.0	46.0	10.6	10.0	9.9	10.4	10.2	7.2
5	26.0	25.0	26.0	26.5	29.0	32.0	33.0	34.5	34.0	33.5	34.0	42.0	10.4	9.3	9.0	8.9	9.3	9.1
6	27.0	27.5	28.0	29.0	31.0	35.5	35.0	31.5	30.0	29.0	32.0	37.5	10.0	8.9	9.0	9.1	8.4	8.2
7	25.5	25.0	27.0	27.0	29.5	34.5	36.0	44.0	38.0	38.0	38.5	41.0	9.9	8.7	9.0	8.2	8.6	8.2
8	26.0	25.5	26.0	26.0	29.0	38.5	38.0	44.5	38.0	39.0	35.5	41.0	9.6	9.5	9.4	10.2	10.3	8.5
9	26.0	27.0	26.5	28.0	32.0	38.0	41.0	39.0	40.0	39.5	37.0	43.0	9.2	9.8	9.2	8.8	8.8	8.7
10	26.0	26.5	27.5	28.0	33.0	38.0	40.0	41.5	37.0	36.0	38.5	42.0	10.0	8.8	9.4	8.6	8.8	8.8
11	27.5	28.5	29.5	30.5	30.5	31.5	43.5	40.5	36.0	38.5	42.0	46.5	8.9	8.9	8.9	8.6	9.0	8.0
12	32.0	29.5	31.0	32.0	38.5	51.0	43.0	44.5	44.0	45.0	48.5	64.0	8.8	9.0	8.5	9.5	8.4	8.0
13	32.0	31.5	33.5	34.0	35.0	37.0	45.0	39.5	37.5	36.0	39.0	43.0	9.1	9.2	8.0	9.0	9.0	8.8
14	33.5	30.5	31.0	33.0	35.0	41.0	48.5	47.5	47.0	50.0	45.0	52.0	9.5	8.9	8.9	9.0	8.2	8.7
15	35.0	33.0	34.0	34.5	37.0	45.0	48.0	49.0	48.0	46.0	49.0	52.0	9.2	9.0	8.0	8.5	7.6	7.8
16	23.0	34.0	35.5	36.0	35.5	36.0	42.0	43.0	40.5	41.0	44.5	49.0	8.8	8.6	8.6	8.6	8.6	8.9
17	36.5	33.0	32.0	32.5	35.0	38.0	52.0	48.0	48.0	47.5	48.0	52.5	9.3	9.8	9.8	9.6	9.6	8.8
18	35.5	33.0	32.0	33.0	35.0	37.5	52.5	50.0	52.0	52.0	53.0	56.5	9.2	8.8	8.9	8.8	8.7	8.5
19	29.0	26.5	24.5	25.0	27.0	29.0	35.0	37.0	37.5	39.0	37.0	43.0	11.2	10.0	10.4	10.0	10.0	10.0
20	30.0	26.0	26.5	27.0	29.0	32.0	33.0	37.0	36.5	35.0	36.0	41.0	10.5	10.2	10.0	10.0	10.0	9.9
21	28.0	26.0	27.0	27.5	28.5	30.5	36.0	40.5	39.0	34.5	37.5	40.5	10.6	10.0	9.4	10.6	9.6	9.2
22	31.0	28.0	28.5	28.0	31.0	32.5	36.0	31.0	30.5	40.0	38.0	44.0	10.0	9.9	9.8	9.1	9.7	9.6
23	31.0	28.0	27.0	28.0	30.0	33.0	37.0	38.0	39.0	38.0	38.0	42.0	9.8	9.6	9.5	9.5	8.6	8.4
24	30.5	29.0	29.5	27.5	29.0	34.0	37.5	40.0	38.5	40.5	42.0	44.0	10.0	9.0	9.5	9.8	8.9	9.1

Table IV (d) - (e). Effect of Additions of Coal on the Properties of an 8% Bentonite Suspension

Sample No.	(d) Gel Strength, lbs./100 sq. ft.						(e) pH					
	0%		2%		4%		0%	1/2%	1%	2%	4%	8%
	10 sec.	10 min.	10 sec.	10 min.	10 sec.	10 min.						
1	50	69	53	75	50	69	8.6	7.5	7.4	7.0	6.7	6.4
2	50	69	39	60	37	60	8.4	7.1	6.1	5.3	5.2	5.2
3							8.0	6.9	6.2	5.3	4.8	4.5
4							8.2	7.5	7.1	6.8	6.4	6.1
5							7.8	7.4	7.0	6.1	5.8	5.4
6							7.7	6.6	5.8	5.2	4.8	4.4
7	50	69	48	67	44	65	7.7	7.3	7.2	6.6	6.4	6.1
8	50	69	49	66	43	58	7.6	7.2	7.0	6.8	6.3	6.0
9							7.5	7.4	6.9	6.8	6.5	6.2
10							8.2	7.9	7.4	6.4	5.9	5.4
11							7.8	6.5	6.1	5.5	5.0	4.5
12							7.8	7.5	7.3	7.0	7.0	6.8
13	50	69	37	50	38	60	8.3	6.5	5.8	5.0	4.4	4.1
14							7.9	7.1	6.8	6.7	6.2	6.1
15	50	69	48	66	45	65	7.5	7.0	6.8	6.4	6.1	5.8
16	50	69	38	59	42	59	7.7	6.5	5.4	4.7	4.2	3.9
17	50	69	49	63	48	63	7.6	7.5	7.4	6.8	6.4	5.9
18							7.7	7.5	7.2	7.0	6.8	6.4
19							8.4	7.8	7.4	7.1	6.7	6.4
20	50	69	49	63	48	67	8.2	7.6	7.2	6.8	6.5	6.2
21							8.2	7.6	7.3	6.9	6.6	6.5
22	50	69	50	78	49	67	8.2	7.7	7.5	7.3	6.9	6.8
23	50	69	48	68	50	70	8.0	7.2	6.8	6.3	5.8	5.3
24							7.9	7.2	6.8	6.3	6.0	5.6

Table V. Comparison of Coal No. 2 with Lignite B
(10% bentonite suspension)

Additive	Additive %	PV	YV	FL	Gel St.		pH
					10 sec.	10 min.	
None	0	45	70	8.3	57	83	7.4
Coal No. 2	0.5	33	78	9.5	47	68	6.2
	1	47	56	8.2	43	69	5.8
	2	50	58	8.0	40	64	5.3
	4	54	63	8.0	42	68	4.9
	8	64	80	8.1	43	73	4.7
Lignite B	0.5	41	62	8.5	56	79	6.2
	1	43	62	8.0	55	78	5.4
	2	40	68	8.5	54	83	4.8
	4	36	74	8.8	56	84	4.3
	8	25	86	12.7	35	56	3.9

PV = Plastic viscosity, centipoise

YV = Yield value, lbs./100 sq. ft.

FL = Fluid loss, cc. at 100 lbs./sq. in.

Gel St. = Gel strength, lbs./100 sq. ft.

Table VI. pH Adjusted, 8% Bentonite Suspension Tested with Selected Coals and other Additives Adjusted to Match the pH of the Bentonite

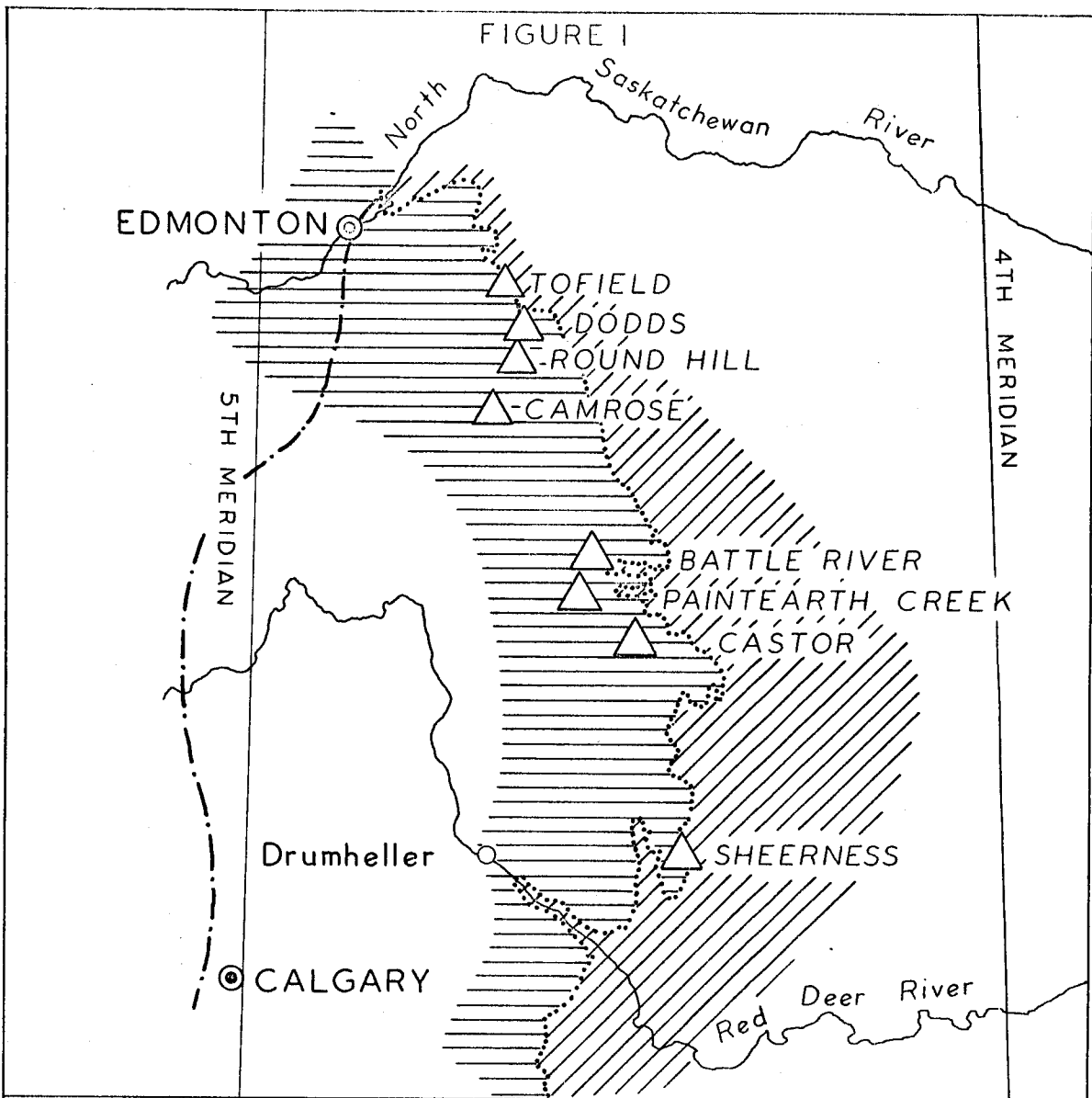
Additive	Additive %	PV	YV	FL	W	pH	Gel St.	
							10 sec.	10 min.
None	0	25	30	10.0	8.75	8.6	33	62
Coal No. 1	2	40	34	9.8	8.78	8.6	22	63
Coal No. 3	2	41	28	6.8	8.78	8.3	8	13
Coal No. 6	2	41	28	7.0	8.72	8.8	7	14
Lignite B	2	36	20	6.0	8.76	8.4	5	23
Quebracho	2	29	14	6.5	8.82	8.1	7	35

PV = Plastic viscosity, centipoise
 YV = Yield value, lbs./100 sq. ft.
 FL = Fluid loss, cc. at 100 lbs./sq. in.
 W = Weight, lbs./U.S. gal.
 Gel St. = Gel strength, lbs./100 sq. ft.

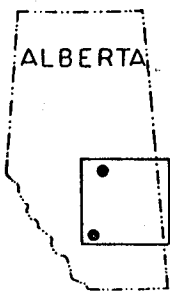
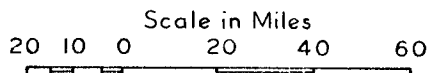
Table VII. pH Adjusted, 8% Bentonite Suspensions Tested with Selected Coals
 The bentonite suspensions were adjusted to pH 9 and pH 10
 The additives were not adjusted to match the pH of the bentonite suspensions

Set No.	Additive	Additive %	PV	YV	FL	W	pH	Gel St.	
								10 sec.	10 min.
I	None	0	16	23	12.0	8.79	9.0	27	43
	Coal No. 3	2	24	8	8.5	8.82	8.2	1	4
	Coal No. 6	2	18	10	10.6	8.78	7.3	10	28
	Coal No. 11	2	18	8	10.0	8.79	7.6	3	25
	Coal No. 13	2	14	20	10.8	8.75	7.0	21	30
	Coal No. 16	2	17	11	10.5	8.76	7.3	13	29
	Coal No. 23	2	14	25	9.8	8.76	7.7	25	35
	Lignite B	2	25	14	10.6	8.80	6.9	15	29
II	None	0	14	34	11.1	8.80	10.0	39	74
	Coal No. 3	2	19	9	7.5	8.82	8.6	1	4
	Coal No. 6	2	17	9	7.5	8.80	8.5	2	6
	Coal No. 11	2	16.5	9	8.8	8.78	8.8	3	4
	Coal No. 13	2	16	8	10.5	8.80	8.7	3	28
	Coal No. 16	2	18	7	8.0	8.79	8.5	2	5
	Coal No. 23	2	14	19	10.2	8.78	9.3	20	40
	Lignite B	2	18	8	8.4	8.78	8.7	2	9

FIGURE 1



MAP OF
CENTRAL ALBERTA
SHOWING
SAMPLE LOCALITIES
EASTERN EDMONTON FORMATION



INDEX MAP

LEGEND






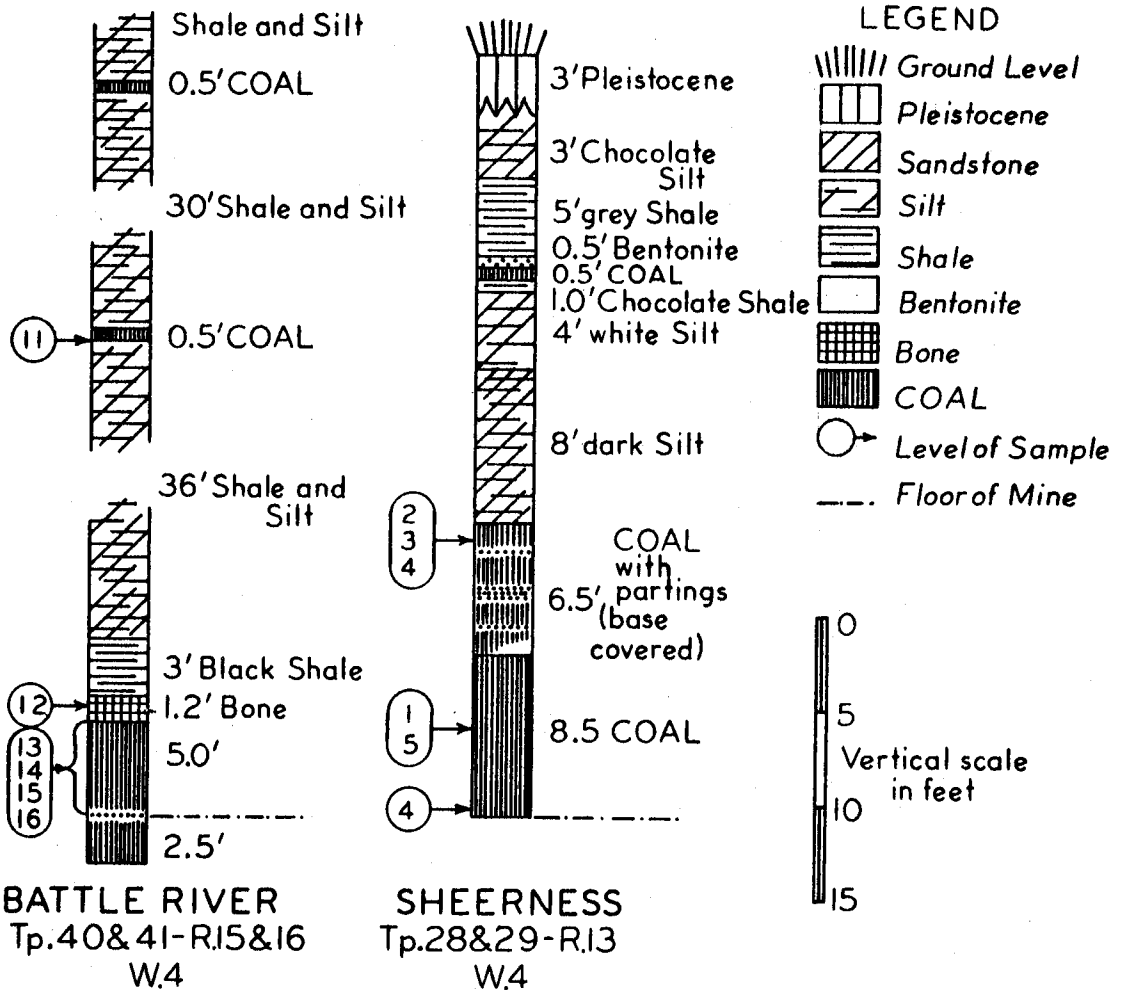
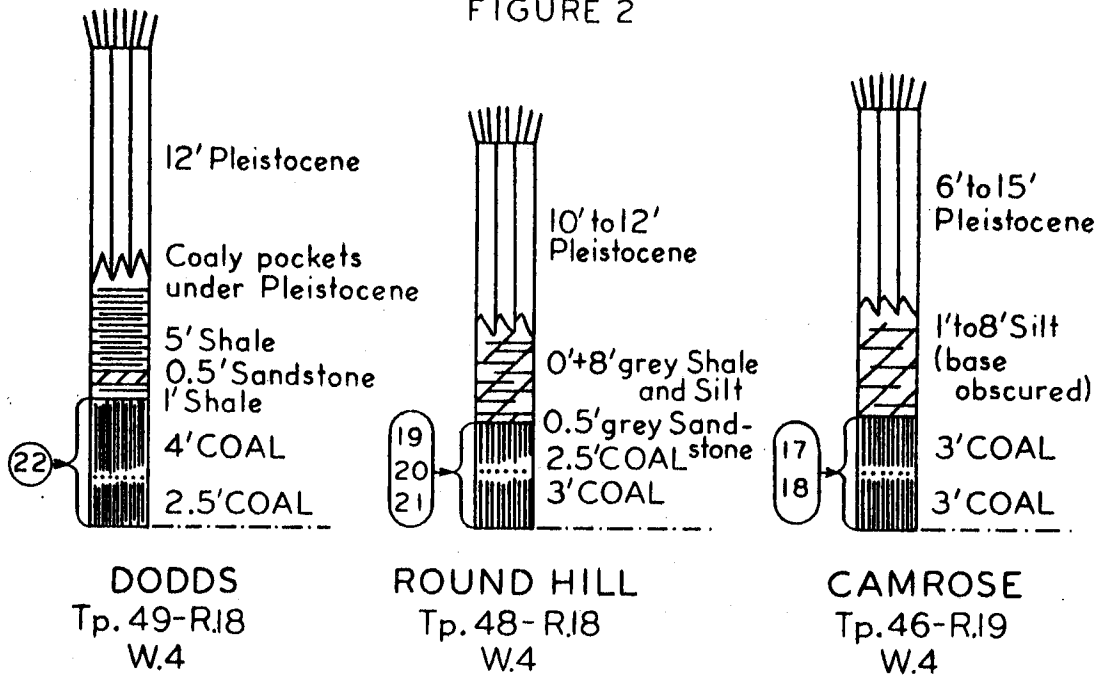
-  Sample Locality
-  Edmonton Formation Outcrop Area
-  Bearpaw Formation Outcrop Area
-  Edmonton Bearpaw Boundary Outcrop
-  Western Limit Bearpaw Formation Subsurface

FIGURE 2



COLUMNAR SECTIONS THROUGH COAL SEAMS
EASTERN EDMONTON FORMATION SAMPLE LOCALITIES