OIL SAND OVERBURDEN CHARACTERIZATION
WITHIN THE MINE AREA OF SYNCRUDE LEASE NO. 17
FOR RECLAMATION OF SPENT OIL SAND

A REPORT SUBMITTED TO THE DEPARTMENT OF
SOIL SCIENCE, FACULTY OF AGRICULTURE AND
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ABSTRACT

For the establishment and growth of plants, spent oil sand lacks Ca, K, NO_3-N, available P, Zn, CEC and available water storage capacity. Cu, Mn and possibly SO_4-S are marginally adequate in spent sand.

Oil sand overburden materials within the mine area of Syncrude Lease No. 17 were sampled and analyzed with the intent of isolating mineral materials overlying lean oil sand which may be useful in the amelioration and reclamation of spent oil sand.

Overburden materials were broadly identified.

Physical properties analyzed and discussed include: saturation percent, particle size distribution, soil moisture storage capacity, and specific surface and Atterberg limits on selected samples. Chemical properties analyzed and discussed include: pH, EC, SAR, major water soluble cations and anions, major extractable cations, CEC, NO_3-N, total N, available P and DTPA-extractable Cu, Fe, Mn and Zn.

Fine-textured materials within the mine area of Syncrude Lease No. 17 have a limited distribution. Heavy clay materials, particularilly, have sufficient levels of Ca, K, Zn, Cu, Mn and SO_4-S and a sufficiently high CEC and available water storage capacity to contribute substantially in the amelioration and reclamation of spent oil sand.

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INTRODUCTION

During its projected 25-year life span, the Syncrude Canada Ltd. oil sand extraction project, located within Alberta Bituminous Sands Lease No. 17*, will open pit mine a 2,800-ha area. Tailings** from the hot water bitumen extraction process will be disposed over a 4,300-ha area, 1,400 of which will be within the mine pit (Syncrude Canada Ltd. 1973). Although the mine pit could at a future date accommodate all of the oil sand tailings (Syncrude Canada Ltd. 1973), placement of all of the tailings into the mine area does not seem likely (Laycock 1975). In total, then, the mine and tailings disposal will generate a 5,700-ha area requiring reclamation.

It is accepted that the disturbed areas be reclaimed (Syncrude Canada Ltd. 1973). The establishment of a permanent self-sustaining plant community, particularily within the spent sand, is, however, difficult (Lesko 1974; Massey 1972). Spent sand has no structure, is erosive, lacks nitrogen, phosphorus and potassium, and has a low cation exchange capacity (CEC) and low available moisture storage (Lesko 1974; Massey 1970, 1972; McCoy et al. 1976).

Spent sand can be ameliorated for plant growth through the addition of peat, fine-textured soil materials or a combination thereof (Lesko 1974; Massey 1970, 1972; McCoy et al. 1976). Although the long term ameliorative effect of peat on spent sand has not been assessed, it seems the addition of textural fines to a spent sand-peat mixture would enhance and contribute to the permanent amelioration of spent sand. Both organic matter and clay contribute significantly to CEC, available moisture storage, fertility, and soil aggregate formation and stability (Baver et al. 1972; Hallsworth and Wilkinson 1958; Nuttal 1970; Toogood and Lynch 1959; Wilding and Rutledge 1966). Within the soil, the presence of clay and silt decreases the rate of organic matter decay and increases the amount of hydrolyzable organic substances (Martel and Paul 1974; Sorensen 1972, 1975). Hydrolyzable organic substances are relatively easily degraded and hence contribute to fertility. Additionally, clay increases the amount of nonhydrolyzable organic substances within the soil. Such substances are relatively inert and are considered important in such processes as cation exchange, formation of stable soil aggregates and water adsorption (Campbell et al. 1967). Physically, the addition of fine-textured material to spent sand would create a stratified soil. Such soil comprised of a relatively fine-textured material overlying coarser material could retain additional moisture within the fine-textured stratum without developing a water table (Baver et al. 1972). Finally, from an economic point-of-view, the addition of fine-textured material to spent sand may reduce reclamation costs. The bulk density of peat is approximately 10 to 20% that of inorganic soil materials‡.

* Hereafter referred to as Syncrude Lease No. 17.

** Oil sand tailings are also referred to as spent sand.

‡ Personal communication; D. N. Graveland, Alberta Environment, Lethbridge.

Substituting a portion of the peat to be added to spent sand with fine-textured material would reduce the volume of ameliorative material handled, thereby seemingly reducing reclamation costs.

In response to a need outlined by the Alberta Conservation and Utilization Committee (1974), overburden materials within the mine area of Syncrude Lease No. 17 were sampled and characterized with the intent of isolating materials which may be useful in reclaiming oil sand tailings. Overburden materials were described and sampled at an exploratory level of study and may not be totally representative of the oil sand overburden materials within the mine area of Syncrude Lease No. 17.

MATERIALS AND METHODS

Field sampling

Oil sand overburden materials within the mine area of Syncrude Lease No. 17 were described and sampled at cut-face sites along the constructed open drainages which traverse the mine area. Much of the mine area was traversed along the open drainages so as to allow a somewhat representative sampling of overburden materials. Sampling was, however, somewhat restricted to the finer-textured materials. Mineral materials were sampled in 45-cm depth increments or more frequently if warranted by lithological change. Overlying peat, if present, was sampled at random depths. When not restricted by drain depth, overburden materials were sampled up to and occasionally into lean oil sand (materials which distinctly smelled of bitumen). Each sample of mineral material was described with respect to depth, kind of geological material, dominant color (moist) and texture. Only the depth and dominant color (moist) of peat were described. General characteristics such as stratification, sorting, lithology and landscape relationships were applied in identifying geological deposits. Glacial drift was broadly classified according to Thwaites (1963).

Analytical procedures

Particle size distributions were determined by a hydrometer procedure (USDI 1951). Soil moisture contents at tensions of 1/5, 1/3 and 15 bar were determined gravimetrically (Salinity Laboratory Staff 1954). Atterberg limits (ASTM 1975) and specific surface by ethylene glycol monoethyl ether sorption (Heilman et al. 1965) were determined on selected samples. Specific surface was determined on both the soil and clay fraction. Clay was separated by sedimentation as outlined by Day (1965).

Saturated soil pastes and extracts were prepared as described by Bower and Wilcox (1965). The soil saturation percentage was determined (Salinity Laboratory Staff 1954). Soil pH and electrical conductivity (EC) were determined on the soil pastes and extracts, respectively.

Soluble Ca and Mg were determined by atomic absorption spectrophotometry; soluble Na and K were determined by atomic emission spectrophotometry. Saturation extracts in which the EC exceeded 0.8 mmhos/cm were analyzed for anions: HCO_3 by H_2SO_4 titration (Bower and Wilcox 1965); Cl by $AgNO_3$ titration (Bower and Wilcox 1965); NO_3-N with phenoldisulfonic acid (Cameron and Toogood 1970); and SO_4-S by $BaCl_2$ titration (Rasnick and Nakayama 1973). Cation exchange capacities were determined by Na acetate saturation and NH_4 acetate displacement; exchangeable cations were determined by NH_4 acetate extraction (Salinity Laboratory Staff 1954). Total soil Kjeldahl N (TKN) was determined as described by Bremner (1965), soil NO_3-N with phenoldisulfonic acid (Cameron and Toogood 1970), and available soil P by an extracting solution of 0.03 N NH_4F in 0.03 N H_2SO_4 (Miller and Axley 1956). Soil micronutrients, DTPA-extractable Cu, Fe, Mn and Zn (Lindsay and Norvell 1969) were determined by atomic absorption. A manometric procedure modified by Gold was used to determine $CaCO_3$ equivalent*.

Statistical analyses

Overburden materials were categorized into textural classes and one organic (peat) class. The physical and chemical soil characteristics were determined for each class. Soil samples with EC values greater than 2 mmhos/cm and SAR values greater than 6 were excluded from the characterization. Soil characteristics are based upon approximately 80% of the samples within each class if the sample population exceeded three - otherwise the characteristics are based upon the entire sample population for each class. Mean and standard deviation values were determined.

RESULTS AND DISCUSSION

Overburden geology

Description of oil sand overburden deposits within the study area are outlined in Table 1; the study area and location plan of sampling sites are shown in Figure 1. The study area is located approximately 40 km north from Fort McMurray, Alberta.

Geological materials overlying lean oil sand (approximately 6% or less bitumen content by weight) within the study area were broadly identified as alluvial (Recent), aeolian, glaciofluvial, glaciolacustrine and glacial (till). The aforementioned deposits vary considerably in both their horizontal and vertical distribution, particularily within the area east from Beaver River.

Surficial deposits overlying lean oil sand are often shallow. At approximately one-half of the sites sampled, lean oil sand occurred within 1 to 2 m of the uppermost surface of the mineral materials. Peat often overlies the mineral materials to a depth of approximately 1 m. The depth and distribution of peat within the mine area has been delineated by Syncrude Canada Ltd. (1973).

* Calcium carbonate equivalent was determined by C. Gold, Geology Department, University of Alberta, Edmonton, Alberta.

Much of the overburden material is coarse-textured*. Medium and fine-textured deposits, primarily glaciofluvial and glaciolacustrine, respectively, have a seemingly shallow localized distribution. These deposits may, however, be sufficiently large as source materials for reclamation purposes, and as such should be delineated.

Physical characteristics

Physical characteristics of oil sand overburden materials are outlined in Table 2.

Overburden materials within the study area are predominantly coarse-textured. Fine-textured materials seem restricted to the south-east portion of the study area.

Specific surface values for selected samples range from 5 m^2/g for a sand-textured sample to 92 m^2/g for a sandy clay-textured sample. Specific surface values seem not closely correlated to total percent clay. For example, a clay material at site 1 sampled from a depth of 45 to 105 cm has approximately the same surface area as a loam-textured material sampled from a similar depth at site 5 (73 and 74 m^2/g, respectively).

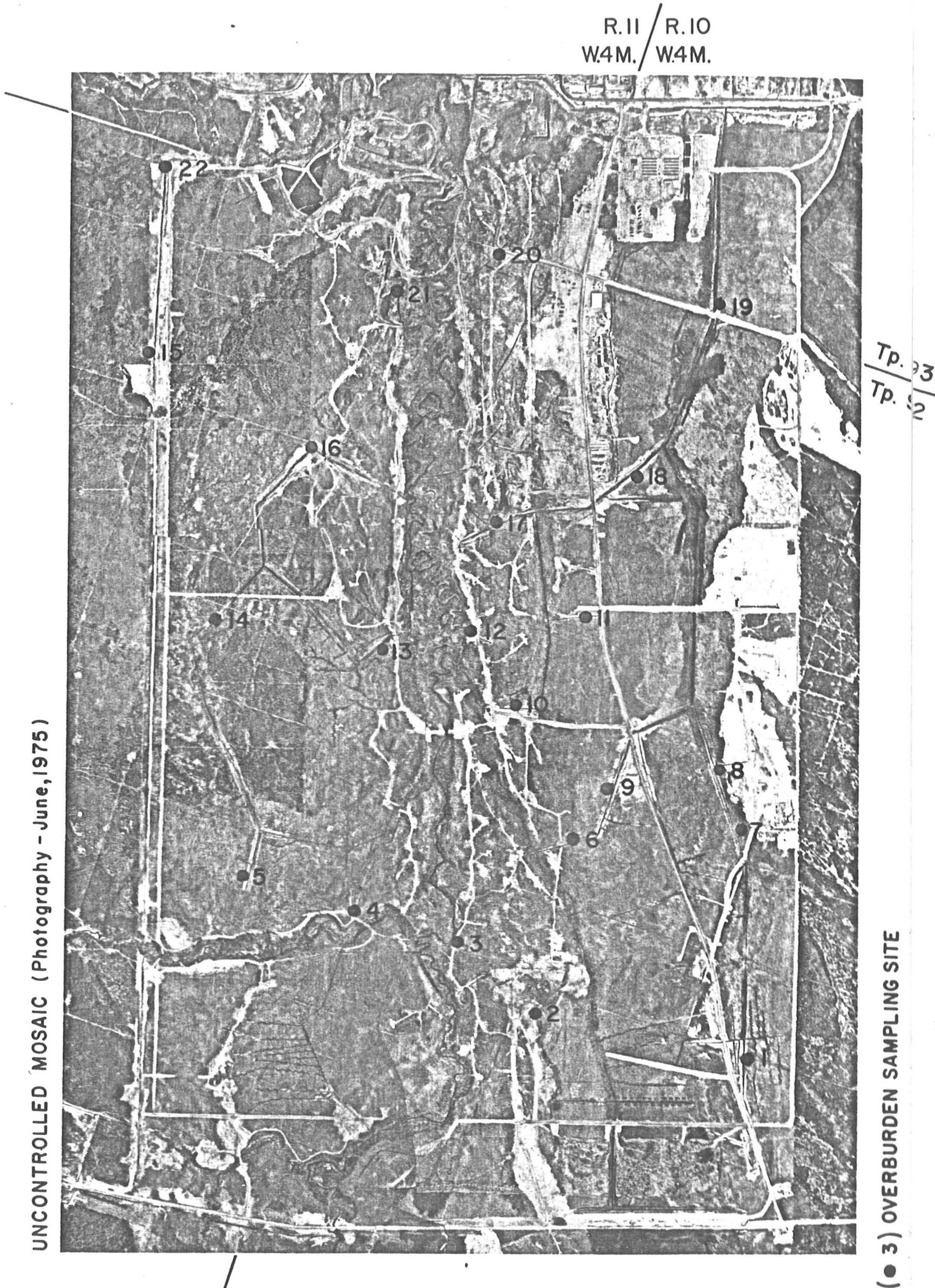
The specific surface values for the clay fraction of the selected samples range from 33 to 330 m^2/g, with a mean value of 170 m^2/g. The range is likely due to dissimilarily distributed clay sizes within the respective clay fractions, and possibly due to mineralogical differences. The data suggest varying amounts of expanding and nonexpanding clay minerals. Specific surface values of approximately 300 m^2/g suggest approximately equal amounts of hydrous mica and montmorillonite, whereas decreasing specific surface values suggest increasing amounts of hydrous mica and decreasing amounts of montmorillonite (Pawluk and Bayrock 1969).

Available moisture percent was determined by the difference in moisture content between 1/3-bar and 15-bar tensions. For inorganic materials, available moisture ranges from 2% for a sand to 20% for a clay. Available moisture values for peat were not determined. The tensions at which available moisture is held in peat have not been established.

Plastic limits for medium-textured materials range from 14 to 21 (mean 17), whereas plastic limits for fine-textured materials range from 15 to 32 (mean 20). Liquid limits range from 20 to 29 (mean 25) and 21 to 70 (mean 43) for medium and fine-textured materials, respectively. Values for plasticity index, an indirect measure of the force required to remold a soil, range from 4 to 11 (mean 8) for medium-textured materials and 3 to 38 (mean 23) for fine-textured materials.

* Soil textural classes in this report are grouped as follows:

Coarse-textured: sand, loamy sand, sandy loam.
Medium-textured: loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam.
Fine-textured: sandy clay, silty clay, clay, heavy clay.



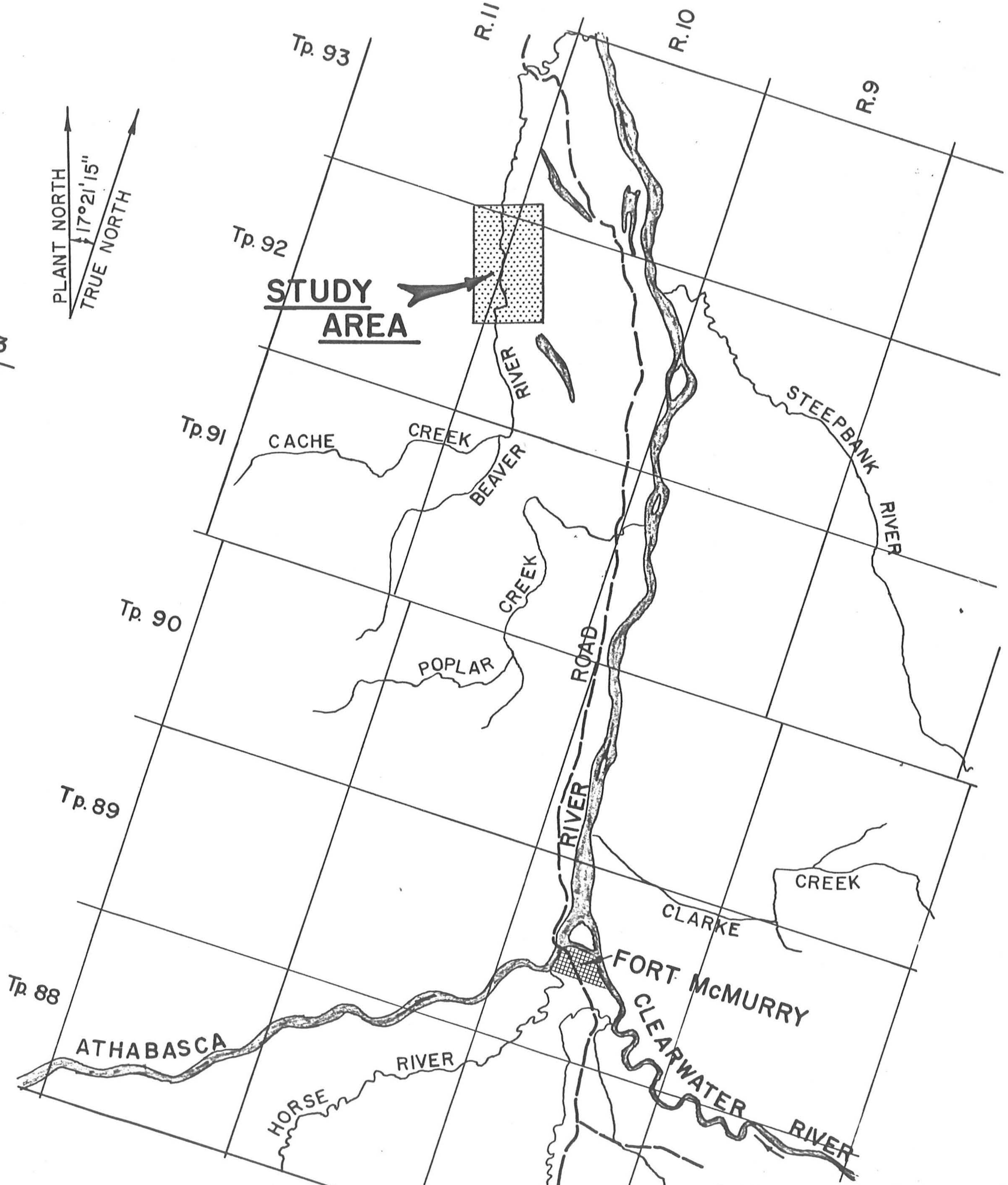


FIGURE 1
LOCATION PLAN

TABLE 1. Oil sand overburden materials

Site 1

15-0 cm:	peat; black (10 YR 2.5/1)
0-45 cm:	glaciofluvial; reddish brown (2.5 YR 4/4), sand and gravel
45-105 cm:	glaciolacustrine; reddish brown (2.5 YR 5/4), clay
105-170 cm:	glacial; dark brown (10 YR 3/3), sandy loam

Site 2

90-0 cm:	peat; black (10 YR 2.5/1)
0-30 cm:	glaciolacustrine; olive gray (5 Y 5/2), sandy clay
30-150 cm:	glaciolacustrine; very dark gray (7.5 YR 3/0), sandy clay to sandy clay loam

Site 3

0-90 cm:	glaciofluvial; dark brown (7.5 YR 4/4), sandy clay loam
@ 90 cm:	glacial (lean oil sand); black (10 YR 2.5/1), sandy loam

Site 4

0-45 cm:	glaciofluvial or glaciolacustrine; yellowish red (5 YR 4/6), sandy loam
45-105 cm:	glaciofluvial or glaciolacustrine; very dark grayish brown (2.5 Y 3/2), sandy clay loam
105-215 cm:	glacial (lean oil sand); black (10 YR 2.5/1), sandy loam

Site 5

15-0 cm:	organic debris (LFH)
0-45 cm:	glaciolacustrine; grayish brown (2.5 Y 5/2), sandy loam
45-170 cm:	glaciolacustrine; yellowish brown (10 YR 5/6), loam to sandy clay loam
170-350 cm:	glacial; very dark gray (7.5 YR 3/0), sandy loam
@ 350 cm:	glacial (lean oil sand); black (10 YR 2.5/1), sandy loam

TABLE 1. Oil sand overburden materials - continued

Site 6

15-0 cm:	peat; very dark brown (7.5 YR 2.5/2)
0-45 cm:	glaciofluvial; yellowish brown (10 YR 5/6), sandy clay loam
45-135 cm:	glaciolacustrine; dark gray (10 YR 4/1), clay
135-170 cm:	glacial; very dark grayish brown (2.5 Y 3/2), clay
170-185 cm:	glacial (sandstone inclusion); dark yellowish brown (10 YR 4/4)
185-230 cm:	glacial (lean oil sand); dark brown (10 YR 4/3), sandy clay loam

Site 7

60-0 cm:	peat; black (10 YR 2.5/1)
0-30 cm:	aeolian and/or glaciofluvial; very dark grayish brown (10 YR 3/2), loam
30-75 cm:	glaciolacustrine or glaciofluvial (ice rafted till); very dark grayish brown (10 YR 3/2), sandy clay loam
75-90 cm:	glaciolacustrine or glaciofluvial (ice rafted till); brown (7.5 YR 5/2), clay
90-135 cm:	glacial; gray (5 Y 5/1), sandy loam
@ 135 cm:	glacial (lean oil sand)

Site 8

30-0 cm:	peat; black (7.5 YR 2.5/0)
0-120 cm:	glaciolacustrine or glaciofluvial (ice rafted till); dark grayish brown (10 YR 4/2), clay
120-245 cm:	glacial (lean oil sand); very dark gray (5 Y 3/2), sandy loam

Site 9

90-0 cm:	peat; very dark brown (7.5 YR 2.5/2)
0-45 cm:	glaciofluvial; very dark grayish brown (2.5 Y 3/2), sandy clay loam
45-290 cm:	glaciolacustrine; very dark gray (10 YR 3/1), clay

Site 10

0-45 cm:	glaciofluvial; dark yellowish brown (10 YR 4/4), sandy loam
45-120 cm:	glaciofluvial; dark yellowish brown (10 YR 4/4), sand and gravel

TABLE 1. Oil sand overburden materials - continued

Site 11

45-0 cm:	peat; black (7.5 YR 2.5/1)
0-30 cm:	glaciofluvial; yellowish brown (10 YR 5/6), sandy loam
30-105 cm:	glaciofluvial; very dark grayish brown (10 YR 3/2), sandy loam

Site 12

0-245 cm:	alluvial; very dark gray (10 YR 3/1), sandy loam to sandy clay loam

Site 13

90-0 cm:	peat, black (7.5 YR 2.5/0)
0-30 cm:	glaciofluvial; dark brown (10 YR 4/3), sandy loam
30-105 cm:	glaciofluvial; dark brown (10 YR 4/3), sand and gravel
@ 105 cm:	glacial (lean oil sand)

Site 14

0-105 cm:	glaciolacustrine; dark brown (7.5 YR 4/4), sandy clay loam
105-230 cm:	glacial; grayish brown (10 YR 4/2), sandy loam

Site 15

0-150 cm:	glaciofluvial; gravel and sand
150-485 cm:	glacial; very dark grayish brown (2.5 Y 3/2), sandy loam

Site 16

45-0 cm:	peat; black (2.5 Y 2.5/1)
0-75 cm:	glacial; dark brown (7.5 YR 3/2), sandy loam
@ 75 cm:	glacial (lean oil sand)

Site 17

0-60 cm:	glaciofluvial and/or aeolian; dark brown (7.5 YR 4/4), sandy loam
60-245 cm:	glacial; black (10 YR 2.5/1), sandy loam
@ 245 cm:	glacial (lean oil sand); black (10 YR 2.5/1), sandy loam

TABLE 1. Oil sand overburden materials - continued

Site 18

60-0 cm:	peat, very dark brown (7.5 YR 2.5/2)
0-120 cm:	glaciofluvial; yellowish brown (10 YR 5/6), gravel and sand
120-335 cm:	glacial (possibly glaciofluvial); very dark grayish brown (10 YR 3/2), sandy loam to silty loam
@ 335 cm:	glacial (lean oil sand)

Site 19

300-0 cm:	peat; black (5 YR 2.5/1)
0-120 cm:	glaciofluvial; gravel and sand
@ 120 cm:	glacial (lean oil sand); dark gray (5 Y 4/1), sandy loam

Site 20

30-0 cm:	peat; black (7.5 YR 2.5/0)
0-120 cm:	aeolian and/or glaciofluvial; strong brown (7.5 YR 5/6), loamy sand to sandy loam
120-185 cm:	aeolian and/or glaciofluvial; light brownish gray (10 YR 6/2), sand
185-215 cm:	aeolian and/or glaciofluvial; dark gray (10 YR 4/1), sandy loam
@ 215 cm:	glaciofluvial; gravel and sand

Site 21

30-0 cm:	peat; black (2.5 Y 2.5/0)
0-90 cm:	aeolian and/or glaciofluvial; dark brown (10 YR 4/3), sand
90-150 cm:	aeolian and/or glaciofluvial; pinkish gray (7.5 YR 6/2), sandy loam
150-215 cm:	glacial; dark grayish brown (2.5 Y 4/2), sandy clay loam
@ 215 cm:	glacial (lean oil sand); black (10 YR 2.5/1), sandy loam

Site 22

0-60 cm:	glaciolacustrine; dark grayish brown (10 YR 4/2), sandy clay loam
60-185 cm:	glacial; very dark grayish brown (2.5 Y 3/2), sandy loam
@ 185 cm:	glacial (lean oil sand); black (10 YR 2/5/1), sandy loam

TABLE 2. Physical characteristics of overburden materials

Site	Depth* (cm)	Sat. %	Particle size distribution (%) sand	clay	texture†	Specific surface (m^2/g) soil	clay(<2u)	Moisture (%) 1/5bar	1/3bar	15bar	avail. ‡	Atterberg limits** p.l.	l.l.	p.index
1	15-0	400	--	peat	--	-	-	150	140	120	-	-	-	-
	45-105	41	44	48	C	73	130	23	22	13	9	18	21	3
	105-170	40	65	20	SL	19	150	20	18	9	9	-	-	-
2	60-30	320	--	peat	--	-	-	230	190	93	-	-	-	-
	0-30	53	46	38	SC	-	-	28	26	15	11	-	-	-
	30-90	47	48	36	SC	92	270	25	24	13	11	16	33	17
	90-150	45	54	33	SCL	-	-	23	21	11	10	-	-	-
3	0-60	60	57	21	SCL	-	-	22	19	10	9	-	-	-
4	0-45	37	56	20	SL	-	-	21	18	10	8	-	-	-
	45-105	38	55	28	SCL	-	-	21	18	9	8	-	-	-
	105-170	33	79	12	SL	-	-	11	8	4	4	-	-	-
5	0-45	31	69	17	SL	-	-	12	12	6	6	-	-	-
	45-105	38	42	24	L	74	210	21	20	9	11	21	25	4
	105-170	40	60	23	SCL	-	-	20	20	8	12	-	-	-
	170-230	32	79	15	SL	-	-	11	9	5	4	-	-	-
	230-290	36	81	14	SL	-	-	12	10	5	5	-	-	-
	290-350	38	78	16	SL	-	-	13	11	5	6	-	-	-
6	0-45	45	56	22	SCL	-	-	19	19	9	10	14	20	6
	45-105	76	14	66	HC	-	-	42	40	22	18	20	52	32
	105-135	87	30	57	C	-	-	35	35	20	15	-	-	-
	135-170	52	42	44	C	-	-	27	27	14	13	15	32	17
	185-230	45	54	33	SCL	-	-	23	23	11	12	-	-	-

TABLE 2. Physical characteristics of overburden materials - continued

Site	Depth (cm)	Sat. %	Particle size distribution (%) sand	clay	texture†	Specific surface (m^2/g) soil	clay(<2u)	Moisture (%) 1/5bar	1/3bar	15bar	avail. ‡	Atterberg limits p.l.	l.l.	p.index
7	30-0	200	--	peat	---	-	-	150	140	72	-	-	-	-
	0-30	40	41	20	L	-	-	23	20	17	3	-	-	-
	30-75	42	55	28	SCL	-	-	21	20	10	10	-	-	-
	75-90	60	32	58	C	48	140	28	28	17	11	19	39	20
	90-135	32	59	20	SL	-	-	14	14	5	9§	-	-	-
8	30-0	250	--	peat	---	-	-	170	150	70	-	-	-	-
	0-60	66	38	52	C	-	-	26	26	15	11	19	38	19
	60-120	74	30	62	HC	-	-	33	32	18	14	-	-	-
	120-185	35	63	16	SL	-	-	19	17	5	12§	-	-	-
	185-245	34	59	17	SL	-	-	18	17	5	12§	-	-	-
9	60-30	240	--	peat	---	-	-	200	190	68	-	-	-	-
	0-45	44	49	30	SCL	-	-	24	24	10	14	16	25	9
	45-105	82	15	64	HC	-	-	39	38	23	15	-	-	-
	105-170	90	15	65	HC	-	-	40	36	24	12	21	59	38
	170-230	94	15	60	C	-	-	41	41	25	16	32	70	38
	230-290	91	15	64	HC	-	-	44	43	23	20	-	-	-
10	0-45	34	70	17	SL	-	-	17	17	7	10	-	-	-
	120-185	39	53	18	SL	-	-	17	16	6	10	-	-	-
	185-245	44	49	21	L	-	-	20	19	7	12	-	-	-
11	30-0	240	--	peat	---	-	-	190	160	92	-	-	-	-
	0-30	33	70	16	SL	-	-	16	15	6	9	-	-	-
	30-90	32	67	14	SL	-	-	13	12	4	8	-	-	-
	90-150	38	65	18	SL	-	-	17	15	6	9	-	-	-

TABLE 2. Physical characteristics of overburden materials - continued

Site	Depth (cm)	Sat. %	Particle size distribution (%) sand	clay	texture†	Specific surface (m^2/g) soil	clay(<2u)	Moisture (%) 1/5bar	1/3bar	15bar	avail. ‡	Atterberg limits p.l.	l.l.	p.index
12	0-60	60	53	22	SCL	-	-	27	22	11	11	-	-	-
	60-120	41	62	19	SL	-	-	20	16	8	8	-	-	-
	120-185	47	50	25	SCL	60	330	27	22	10	12	19	29	10
	185-245	74	48	34	SCL	-	-	24	20	9	11	-	-	-
13	60-30	280	--	peat	---	-	-	180	150	78	-	-	-	-
	0-30	31	68	17	SL	-	-	15	12	6	6	-	-	-
14	0-45	34	49	25	SCL	-	-	18	17	8	9	-	-	-
	45-105	47	50	33	SCL	-	-	24	22	10	12	16	27	11
	105-170	30	74	17	SL	-	-	13	12	5	7	-	-	-
	170-230	33	78	14	SL	-	-	11	10	5	5	-	-	-
15	150-215	34	66	19	SL	-	-	17	17	5	12	-	-	-
	215-275	30	71	17	SL	-	-	14	12	5	7	-	-	-
	275-335	31	67	13	SL	28	170	14	14	5	9	-	-	-
	335-395	30	68	14	SL	-	-	14	14	4	10	-	-	-
	395-455	36	63	18	SL	-	-	16	15	5	10	-	-	-
	455-485	35	65	15	SL	-	-	16	15	5	10	-	-	-
16	30-0	100	--	peat	---	-	-	180	150	73	-	-	-	-
	0-60	24	78	13	SL	-	-	11	10	5	5	-	-	-
17	0-60	29	71	13	SL	-	-	12	12	4	8	-	-	-
	60-120	38	76	13	SL	-	-	10	10	4	6	-	-	-
	120-185	38	80	12	SL	-	-	10	9	4	5	-	-	-
	185-245	34	62	11	SL	-	-	12	12	3	9	-	-	-

TABLE 2. Physical characteristics of overburden materials - continued

Site	Depth (cm)	Sat. %	Particle size distribution (%) sand	clay	texture †	Specific surface (m^2/g) soil	clay (<2u)	Moisture (%) 1/5bar	1/3bar	15bar	avail. ‡	Atterberg limits p.l.	l.l.	p.index
18	60-0	270	--	peat	--	-	-	170	160	63	-	-	-	-
	120-185	38	64	17	SL	-	-	18	16	6	10	-	-	-
	185-245	32	63	16	SL	18	70	16	16	6	10 §	-	-	-
	245-305	23	33	13	SiL	24	110	11	11	3	8 §	12	15	3
19	185-120	41	--	peat	--	-	-	210	180	110	-	-	-	-
	120-185	26	58	24	SCL	-	-	-	16	3	13	14	17	3
20	30-0	120	--	peat	--	-	-	200	170	82	-	-	-	-
	0-60	24	85	8	LS	-	-	6	5	2	3	-	-	-
	60-120	28	73	14	SL	-	-	10	10	4	6	-	-	-
	120-185	26	89	7	S	-	-	4	4	2	2	-	-	-
	185-215	38	55	15	SL	-	-	13	13	4	9 §	-	-	-
21	30-0	280	--	peat	--	-	-	150	120	89	-	-	-	-
	0-60	27	90	8	S	5	310	7	6	3	3	-	-	-
	90-150	21	75	17	SL	-	-	14	12	6	6	-	-	-
	150-215	41	49	23	SCL	-	-	25	24	8	16 §	16	24	8
22	0-60	30	62	23	SCL	-	-	19	19	6	13	13	18	5
	60-120	35	64	16	SL	-	-	19	18	5	13	-	-	-
	120-185	31	65	15	SL	23	33	14	14	4	10 §	-	-	-
	185-245	34	62	14	SL	-	-	-	16	4	12 §	-	-	-
	245-305	39	57	19	SL	-	-	-	17	5	12 §	-	-	-

* Depth of sample.
† HC, heavy clay; C, clay; SC, sandy clay; SCL, sandy clay loam; SiL, silt loam; L, loam; SL, sandy loam; LS, loamy sand; S, sand (CSSC 1974).
‡ Available moisture: 1/3-15 bar moisture %.
** p.l., plastic limit; l.l., liquid limit; p. index, plasticity index.
§ Incompletely saturated.

TABLE 3. Chemical characteristics of overburden materials

Site	Depth* (cm)	pH	EC (mmhos/cm)	SAR	Water soluble ions+ cations (me/l) Ca	Mg	K	Na	anions (me/l) HCO_3	Cl	NO_3	SO_4	NH_4OAc ext. cations (me/100g) Ca	Mg	K	Na	CEC (me/100g)	TKN (%)	NO_3-N	P (ppm)	Cu	Fe	Mn	Zn	$CaCO_3$ equiv.(%)
1	15-0	7.4	1.16	0.3	8.4	2.8	0.8	0.6	9.8	0.2	ND	0.8	--	--	-	--	-	1.87	48	24	2.3	250	86	9.1	-
	45-105	7.4	0.37	0.5	2.6	0.8	0.1	0.7	-	-	--	-	30.2	2.1	0.2	0.0	15.2	0.02	4.3	0.7	1.0	20	1.8	0.4	5.9
	105-170	7.9	0.43	1.0	2.5	0.7	0.1	1.2	-	-	--	-	21.5	1.7	0.1	0.2	12.8	0.07	3.6	1.7	2.8	115	5.8	0.6	3.3
2	60-30	5.8	0.31	0.7	2.2	0.8	0.0	0.9	-	-	--	-	--	--	-	--	-	1.17	3.5	0.6	<0.6	1100	4.6	<0.6	-
	0-30	7.4	0.51	0.2	3.9	1.2	0.2	0.6	-	-	--	-	36.2	3.7	0.4	0.2	15.0	0.05	3.2	0.1	6.4	160	9.2	2.2	0.2
	30-90	7.3	1.36	0.7	12.4	3.4	0.4	1.9	3.1	0.6	ND*	14.5	35.5	3.7	0.4	0.4	16.2	0.05	5.2	0.1	7.0	120	6.2	2.6	9.2
	90-150	7.3	0.68	0.4	4.5	1.4	0.3	1.2	-	-	--	-	29.0	2.5	0.3	0.2	14.4	0.04	3.3	0.5	6.4	225	2.2	5.4	4.3
3	0-60	7.6	0.39	0.1	3.1	1.0	0.1	0.2	-	-	--	-	28.0	2.4	0.1	0.0	13.0	0.05	5.3	>0.1	0.2	70	60	0.4	-
4	0-45	5.7	0.10	0.5	0.5	0.2	0.1	0.3	-	-	--	-	4.2	1.2	0.2	0.0	14.6	0.06	4.7	2.9	0.4	105	95	0.2	-
	45-105	6.2	0.26	0.4	1.5	0.7	0.1	0.4	-	-	--	-	8.0	2.9	0.2	0.0	14.6	0.04	5.0	24	1.6	95	2.2	0.4	1.3
	105-170	7.1	0.24	0.4	1.5	0.4	0.1	0.4	-	-	--	-	3.5	0.8	0.1	0.0	4.8	0.03	4.9	8.8	0.4	10	0.8	0.6	0.0
5	0-45	7.5	0.25	0.3	2.3	0.4	0.1	0.3	-	-	--	-	20.0	1.2	0.1	0.0	8.6	0.05	4.1	0.6	0.4	20	4.0	0.2	2.3
	45-105	7.7	0.26	0.3	2.0	0.3	0.1	0.3	-	-	--	-	27.7	1.7	0.1	0.0	10.8	0.03	2.3	0.0	0.2	10	15	0.2	8.7
	105-170	7.6	0.30	0.3	2.4	0.4	0.1	0.3	-	-	--	-	27.2	1.7	0.2	0.0	10.4	0.03	3.9	0.0	0.2	15	10	0.2	8.9
	170-230	7.5	0.31	0.4	2.1	0.5	0.2	0.5	-	-	--	-	5.5	0.8	0.1	0.0	5.0	0.02	2.2	13	1.0	10	1.8	0.6	0.4
	230-290	7.3	1.01	0.3	9.1	2.3	0.3	0.6	3.8	0.2	ND	8.8	4.7	0.8	0.1	0.0	4.6	0.03	3.6	13	1.6	30	1.8	1.0	0.2
	290-350	7.5	2.16	0.2	22.8	6.6	0.6	0.8	1.2	0.2	ND	30.0	3.0	0.8	0.1	0.0	4.4	0.03	3.5	17	1.0	45	5.0	3.4	0.0
6	0-45	7.7	0.26	0.3	2.0	0.5	0.4	0.3	-	-	--	-	30.7	2.1	0.1	0.0	12.0	0.04	3.8	0.1	0.4	50	13	0.2	5.2
	45-105	7.4	0.29	0.4	1.6	0.6	0.2	0.4	-	-	--	-	39.2	7.9	0.6	0.0	39.8	0.04	5.0	7.1	4.0	45	0.4	1.0	2.1
	105-135	7.3	0.26	0.4	1.6	0.6	0.2	0.4	-	-	--	-	23.5	7.5	0.6	0.0	36.6	0.04	4.6	3.7	3.4	35	1.0	0.6	0.4
	135-170	7.2	0.30	0.8	1.4	0.6	0.2	0.8	-	-	--	-	13.2	4.6	0.4	0.0	22.6	0.04	5.2	1.0	1.0	25	1.4	0.4	0.3
	185-230	7.2	0.32	0.5	1.8	0.9	0.2	0.6	-	-	--	-	9.5	3.3	0.3	0.0	16.0	<0.01	4.1	3.7	1.8	25	1.0	0.4	0.0

TABLE 3. Chemical characteristics of overburden materials - continued

Site	Depth (cm)	pH	EC (mmhos/cm)	SAR	Water soluble ions cations (me/l) Ca	Mg	K	Na	anions (me/l) HCO_3	Cl	NO_3	SO_4	NH_4OAc ext. cations (me/100g) Ca	Mg	K	Na	CEC (me/100g)	TKN (%)	NO_3-N	P (ppm)	Cu	Fe	Mn	Zn	$CaCO_3$ equiv.(%)
7	30-0	7.4	0.53	0.2	4.4	1.4	0.2	0.3	-	-	--	-	-	-	-	-	-	1.20	15	0.4	<0.2	260	13	1.2	-
	0-30	7.6	2.37	11.3	4.0	2.0	0.1	19.5	5.4	18	ND	2.0	11.0	3.3	0.1	2.4	15.4	0.03	3.6	0.7	1.0	185	1.8	1.2	0.3
	30-75	7.2	0.70	2.8	2.5	0.9	0.1	3.7	-	-	--	-	20.5	2.1	0.2	0.4	11.2	0.05	3.9	1.9	1.6	65	3.0	0.4	2.2
	75-90	7.5	0.37	0.2	2.5	0.8	0.1	0.3	-	-	--	-	26.2	2.1	0.3	0.0	18.4	0.03	3.6	1.5	2.2	20	8.6	0.4	1.6
	90-135	7.5	1.02	0.2	9.1	3.1	0.3	0.4	5.0	0.2	ND	10.2	17.7	1.2	0.1	0.0	4.4	0.03	3.2	1.0	0.4	33	5.4	0.4	4.4
8	30-0	7.3	0.57	0.2	5.1	1.4	0.1	0.3	-	-	--	-	-	-	-	-	-	0.95	14	0.7	0.6	175	13	1.8	-
	0-60	7.5	0.39	0.2	2.9	0.8	0.1	0.3	-	-	--	-	19.2	2.5	0.3	0.0	18.2	0.05	4.8	1.4	2.0	68	2.4	0.4	2.8
	60-120	7.4	0.74	0.2	6.5	1.7	0.2	0.4	-	-	--	-	24.5	2.5	0.4	0.0	16.0	0.04	5.4	0.6	3.2	95	4.8	1.2	2.5
	120-185	7.3	1.87	0.1	19.9	6.0	0.4	0.4	2.8	0.3	ND	22.9	20.2	1.2	0.1	0.0	4.6	0.03	2.9	0.7	0.6	55	3.6	0.4	2.4
	185-245	7.4	1.13	0.2	10.3	3.0	0.3	0.4	2.8	0.2	ND	11.2	21.2	0.8	0.1	0.0	4.2	0.02	3.5	1.3	0.6	45	4.0	0.6	2.7
9	60-30	5.9	0.29	0.3	2.3	0.6	0.0	0.4	-	-	--	-	-	-	-	-	-	1.28	5.3	0.3	<0.6	1300	4.0	1.7	-
	0-45	7.3	1.12	0.2	9.6	3.2	0.4	0.6	2.8	0.3	ND	12.3	11.5	2.5	0.3	0.0	16.8	0.05	4.8	0.1	6.6	225	13	4.4	8.9
	45-105	7.2	1.80	0.5	15.3	6.6	0.9	1.7	1.4	0.1	ND	22.3	25.0	10.0	1.0	0.4	44.8	0.05	6.0	0.2	9.2	85	7.0	8.0	-
	105-170	7.2	1.95	0.8	15.1	7.1	1.2	2.7	1.6	0.1	ND	24.1	23.7	10.8	1.2	0.6	38.6	0.05	6.7	0.2	4.6	80	6.2	5.4	-
	170-230	7.2	3.09	1.0	24.8	15.0	1.6	4.4	1.6	0.2	0.5	43.1	27.0	13.3	1.2	1.0	41.0	0.05	13.7	0.3	5.2	65	5.0	8.0	-
	230-290	7.2	3.48	4.2	18.7	11.5	1.4	16.7	2.2	0.2	ND	45.1	22.5	13.7	1.2	3.2	38.2	0.05	6.3	1.0	4.8	40	4.4	7.2	2.7
10	0-45	7.4	0.35	0.3	2.8	1.0	0.0	0.4	-	-	--	-	13.7	2.3	0.1	0.0	17.0	0.08	8.5	0.3	0.2	100	15	0.2	0.0
	120-185	7.3	0.29	0.4	1.6	0.7	0.1	0.4	-	-	--	-	4.5	0.9	0.1	0.0	5.0	0.03	5.2	1.2	0.8	10	4.6	0.6	0.0
	185-245	7.4	0.31	0.3	1.9	0.9	0.1	0.3	-	-	--	-	4.7	1.0	0.1	0.0	5.6	0.04	5.1	1.5	1.0	10	30	0.8	0.0
11	30-0	7.1	0.41	0.1	4.3	1.7	0.2	0.2	-	-	--	-	-	-	-	-	-	1.27	20	8.5	0.6	86	43	1.1	-
	0-30	7.5	0.31	0.4	2.1	0.8	0.1	0.5	-	-	--	-	9.0	2.5	0.1	0.0	12.4	0.03	5.3	0.2	0.2	45	4.2	0.2	2.2
	30-90	7.5	0.24	0.3	1.8	0.6	0.1	0.3	-	-	--	-	4.0	1.2	0.1	0.0	5.2	0.02	3.3	1.1	0.6	10	5.2	0.2	1.4
	90-150	7.6	0.30	0.3	2.3	0.6	0.1	0.3	-	-	--	-	8.2	1.7	0.2	0.4	6.2	0.03	2.9	0.9	1.0	10	15	0.4	3.1

TABLE 3. Chemical characteristics of overburden materials - continued

Site	Depth (cm)	pH	EC (mmhos/cm)	SAR	Water soluble ions: cations (me/l) Ca	Mg	K	Na	Water soluble ions: anions (me/l) HCO_3	Cl	NO_3	SO_4	NH_4OAc ext. cations (me/100g) Ca	Mg	K	Na	CEC (me/100g)	TKN (%)	NO_3-N	P (ppm)	Cu (ppm)	Fe	Mn	Zn	$CaCO_3$ equiv.(%)
12	0-60	7.4	0.82	1.4	3.8	2.1	0.1	2.4	1.2	6.1	ND	0.8	12.0	3.2	0.1	0.4	10.8	0.18	7.7	23.	1.2	480	4.8	2.8	0.0
	60-120	7.3	1.97	13.0	2.7	1.2	0.1	17.9	3.5	15.5	0.2	-	7.7	2.3	0.1	2.6	14.0	0.08	5.3	5.5	1.2	280	4.4	1.4	0.0
	120-185	7.3	1.84	8.8	3.2	1.7	0.1	13.7	2.0	15:9	ND	1.6	9.7	3.1	0.1	2.0	17.8	0.09	4.3	11.4	2.2	310	4.0	2.4	0.0
	185-245	7.5	0.28	0.2	2.5	0.6	0.1	0.3	2.8	0.2	ND	0.6	20.5	2.0	0.2	0.0	13.4	0.08	4.5	3.8	1.4	20	2.4	0.2	3.1
13	60-30	7.4	0.35	0.5	2.4	0.8	0.0	0.6	-	-	--	-	-	-	-	-	-	1.10	13	2.0	3.4	630	630	8.0	-
	0-30	6.5	0.56	0.5	4.1	1.4	0.2	0.8	-	-	--	-	9.2	2.1	0.1	0.0	12.6	0.06	9.4	2.7	0.4	45	80	0.2	0.0
14	0-45	5.9	0.17	0.5	0.9	0.3	0.1	0.4	-	-	--	-	4.0	1.7	0.2	0.0	11.8	0.04	3.7	2.1	0.4	95	15	0.4	0.0
	45-105	7.4	0.41	0.3	3.1	0.9	0.1	0.4	-	-	--	-	29.4	2.5	0.2	0.0	13.6	0.04	6.0	0.1	1.4	15	2.4	0.4	4.2
	105-170	7.3	0.65	0.3	4.8	1.6	0.2	0.6	-	-	--	-	5.0	0.8	0.1	0.0	5.2	0.02	6.9	8.3	1.0	15	2.2	1.4	0.0
	170-230	7.3	0.37	0.5	2.5	0.8	0.2	0.7	-	-	--	-	3.5	0.4	0.1	0.0	4.4	0.02	5.7	12	1.2	45	6.0	0.6	0.0
15	150-215	7.4	0.46	0.5	2.9	1.5	0.1	0.7	-	-	--	-	6.5	2.1	0.1	0.0	7.8	0.03	4.6	1.8	0.8	35	10	0.4	0.3
	215-275	7.5	0.36	0.7	2.0	1.0	0.1	0.9	-	-	--	-	14.5	1.5	0.1	0.0	6.4	0.02	4.2	0.5	0.6	30	10	0.2	2.2
	275-335	7.4	0.34	0.5	2.1	0.8	0.1	0.6	-	-	--	-	15.0	1.1	0.1	0.0	5.6	0.02	4.5	0.6	0.6	20	7.6	0.2	3.0
	335-395	7.5	0.32	0.5	2.1	0.7	0.2	0.6	-	-	--	-	21.7	1.1	0.1	0.0	5.2	0.02	4.6	0.5	0.4	15	6.8	0.2	3.4
	395-455	7.7	0.34	0.4	2.1	0.9	0.1	0.5	-	-	--	-	16.2	1.2	0.1	0.0	5.6	0.02	4.7	0.6	0.8	10	6.2	0.4	3.7
	455-485	7.7	0.32	0.3	2.1	0.8	0.1	0.4	-	-	--	-	19.0	1.1	0.1	0.0	4.4	0.02	4.7	0.7	0.6	10	9.0	0.4	4.5
16	30-0	6.7	0.39	0.3	3.4	1.0	0.0	0.5	-	-	--	-	-	-	-	-	-	0.96	7.5	1.5	1.1	485	300	0.6	-
	0-60	6.3	0.31	0.5	1.9	0.6	0.0	0.6	-	-	--	-	7.5	1.7	0.1	0.0	12.0	0.05	5.5	2.9	0.6	105	4.2	0.4	0.0
17	0-60	5.5	0.57	0.9	2.5	1.6	0.1	1.3	-	-	--	-	3.2	0.9	0.1	0.0	7.0	0.03	5.4	0.3	0.2	140	7.2	0.2	0.0
	60-120	6.2	0.54	0.3	3.4	1.7	0.1	0.5	-	-	--	-	4.0	0.8	0.1	0.0	5.0	0.05	5.6	5.0	1.0	70	0.4	0.4	0.2
	120-195	6.6	0.23	0.3	1.4	0.6	0.1	0.3	-	-	--	-	4.0	0.8	0.0	0.0	5.4	0.04	5.2	4.7	0.4	70	0.4	0.2	0.1
	185-245	6.5	0.57	0.3	3.5	1.8	0.1	0.5	-	-	--	-	3.0	0.8	0.0	0.0	4.0	0.04	4.7	4.6	0.8	35	0.4	1.8	0.0

TABLE 3. Chemical characteristics of overburden materials - continued

Site	Depth (cm)	pH	EC (mmhos/cm)	SAR	Water soluble ions: cations (me/l) Ca	Mg	K	Na	anions (me/l) HCO_3	Cl	NO_3	SO_4	NH_4OAc ext. cations (me/100g) Ca	Mg	K	Na	CEC (me/100g)	TKN (%)	NO_3-N	P (ppm)	Cu	Fe	Mn	Zn	$CaCO_3$ equiv.(%)
18	60-0	5.7	0.42	0.8	2.6	0.9	0.0	0.1	-	-	--	-	-	-	-	-	-	0.96	9.1	0.2	0.2	480	2.4	2.6	-
	120-185	7.6	0.49	0.3	3.9	0.7	0.2	0.5	-	-	--	-	14.2	0.8	0.1	0.0	5.2	0.02	3.5	0.2	1.4	85	2.2	0.6	2.4
	185-245	7.4	1.45	0.2	15.3	2.6	0.3	0.7	3.6	1.1	ND	14.7	21.7	0.8	0.1	0.0	4.8	0.02	3.3	0.1	1.0	85	2.8	0.6	4.1
	245-305	7.3	2.50	0.2	30.3	8.5	0.4	0.8	2.0	1.0	ND	38.0	17.7	0.8	0.1	0.0	3.2	0.02	2.9	0.7	0.6	50	5.0	1.0	2.0
19	185-120	6.3	1.99	9.3	3.3	1.8	0.1	14.9	-	-	--	-	-	-	-	-	-	1.54	8.0	12	<0.6	1100	6.3	0.6	-
	120-185	7.5	0.85	0.4	7.0	1.5	0.2	0.9	3.3	0.4	ND	8.4	21.0	0.7	0.1	0.0	4.6	0.03	4.8	1.2	0.8	100	7.6	0.6	-
20	30-0	7.0	0.40	0.2	3.5	0.6	0.1	0.3	-	-	--	-	-	-	-	-	-	1.15	5.5	3.9	1.7	1400	110	15	-
	0-60	7.5	0.37	0.4	2.4	0.9	0.1	0.5	-	-	--	-	4.7	0.8	0.1	0.0	4.4	0.01	5.9	0.8	0.2	50	8.0	0.2	0.4
	60-120	7.5	0.41	0.4	2.5	1.0	0.1	0.5	-	-	--	-	7.2	1.5	0.1	0.0	8.4	0.03	6.8	1.7	0.4	45	7.2	0.2	0.0
	120-185	7.6	0.38	0.6	2.1	0.9	0.2	0.7	-	-	--	-	2.7	0.6	0.1	0.0	2.8	0.01	5.2	17	0.2	15	0.8	0.2	0.2
	185-215	7.2	2.86	0.2	29.8	12.8	0.5	0.8	1.5	0.2	ND	40.6	6.2	1.8	0.1	0.0	6.6	0.03	2.6	2.6	8.2	120	1.0	3.4	1.0
21	30-0	7.4	1.47	11.8	4.0	0.8	0.1	18.3	12.3	14.3	ND	-	-	-	-	-	-	1.11	6.8	5.3	1.1	640	590	1.1	-
	0-60	7.5	0.81	5.4	2.6	3.5	1.3	9.5	3.5	3.0	ND	-	1.2	0.8	0.1	1.4	4.2	0.01	4.9	2.0	3.8	35	8.4	0.2	0.0
	90-150	7.3	1.42	12.1	1.5	0.5	0.1	12.1	-	9.6	ND	5.3	2.2	1.2	0.2	1.2	6.2	0.01	8.3	5.6	3.4	35	0.8	0.6	0.0
	150-215	7.2	3.21	4.6	12.5	10.6	0.2	15.6	2.1	12.0	ND	26.7	3.5	2.5	0.2	1.2	9.8	0.04	6.0	3.0	<0.2	350	6.4	1.6	0.0
22	0-60	7.9	0.42	0.5	3.4	0.7	0.0	0.7	-	-	--	-	29.7	1.1	0.1	0.0	6.6	0.04	5.1	>0.1	0.4	35	10	0.2	13
	60-120	7.7	0.35	0.7	2.1	0.7	0.1	0.8	-	-	--	-	27.5	1.1	0.1	0.0	6.0	0.02	5.0	>0.1	0.8	20	20	0.2	5.4
	120-185	7.5	0.74	0.5	5.0	0.8	0.2	1.0	-	-	--	-	20.2	1.0	0.1	0.0	4.2	0.02	5.1	0.2	1.4	15	6.6	0.8	3.5
	185-245	7.3	2.41	0.2	27.9	7.6	0.5	0.9	2.4	0.2	ND	33.9	22.5	1.0	0.1	0.0	4.2	0.03	4.6	>0.1	1.0	55	7.0	1.0	3.9
	245-305	7.3	1.76	0.8	13.6	5.9	0.6	2.6	3.2	0.2	ND	20.8	22.0	1.6	0.1	0.0	5.6	0.03	4.9	0.6	1.2	55	15	1.0	3.9

\+ Concentrations of water soluble ions recorded as 0.0 me/l mean < 0.05 me/l.
* Depth of sample.
** ND, not detectable.

From an engineering point-of-view, the materials may be classed as low to medium plastic soils. Soil activity (determined by dividing the plasticity index by % clay) is a measure of a soil tendency to undergo a volume change with changing moisture content (Pawluk and Bayrock 1969). Materials with activity levels less than 0.75 are relatively inactive. Most of the materials have activities within the range 0.2 to 0.4.

Chemical characteristics

Chemical characteristics of oil sand overburden materials are outlined in Table 3.

Generally the pH values of the overburden materials lie within the neutral to mildly alkaline range (CSSC 1974). Some of the peats and some of the uppermost mineral materials have pH values within the medium acid to slightly acid range. Overburden materials at sites 16 and 17 were uniformly acidic.

Overburden materials with EC values greater than 2 mmhos/cm and/or SAR values greater than 6 are, in this report, considered not suitable for reclamation purposes. An EC value of 2 mmhos/cm is considered to define the soluble salt tolerance level of salt sensitive plants (Salinity Laboratory Staff 1954). Physical soil properties, particularily, are relatively nondetrimental to plant growth if soil SAR values do not exceed 6 (Alberta Dept. of Agric. 1968).

Most of the overburden materials do not have EC values greater than 2 mmhos/cm nor SAR values greater than 6. The one sample of stream alluvium taken from within the Beaver River stream valley suggests that the stream alluvium within the study area contains sufficient soluble salt to be detrimental to plant growth. The bulk of the remaining samples with EC and SAR values in excess of 2 mmhos/cm and 6, respectively, were sampled within the northern portion of the study area. The higher soluble salt contents within this area suggest groundwater discharge.

With the exception of the sampled stream alluvium and some of the materials generally within the northern portion of the study area, water soluble cations are variable and generally increase with depth. Calcium is the predominant soluble cation in samples with SAR values less than approximately 6; with SAR values greater than approximately 6, Na becomes the predominant water soluble cation. Water soluble Mg is less predominant than soluble Ca. The proportion of soluble Ca to soluble Mg ranges from approximately 2:1 to 4:1. Water soluble K is low, generally ranging from 0 to 0.2 meq/l.

Only a portion of the overburden materials, those with EC values greater than 0.8 mmhos/cm, were analyzed for major water soluble anions. Within these samples, SO_4 is the predominant soluble anion. Water soluble HCO_3 concentrations are generally low and secondary in anion predominance. In some instances, however, HCO_3 is the major anion and may, under some conditions of overburden placement, increase the detrimental effect of Na through Ca and Mg precipitation. Chloride concentrations are low except at sites 7, 12 and 21. As with soluble salts, high Cl concentrations suggest groundwater discharge. Except for two samples, each with a relatively high NO_3 content, NO_3 concentrations were not detectable within the saturation extract.

Although exchangeable H and Al were not determined, the oil sand overburden materials seem base saturated. The adsorption complex is generally less than 2 and 1% saturated by K and Na, respectively. Materials at sites 7, 12 and 21, are, however, sodic. Because many of the samples contained free carbonates one can only assume that the remaining portion of the adsorption complex is predominantly saturated by Ca and to a lesser extent by Mg. Samples which showed no free carbonates (those in which extractable Ca, Mg, K and Na approximately equal CEC) as determined by effervescence with 10% HCl, indicate Ca and Mg saturation to be approximately 60 and 20%, respectively. The assumption that exchangeable H and Al are not present in large quantities is somewhat verified in that the major extracted cation concentration approximately equals the CEC in these samples. Additionally, the samples are not acidic.

Total N of peat ranges from 0.95 to 1.87% (mean 1.22%); mineral surface soils (0 to 45 cm depth) contain from 0.03 to 0.18% (mean 0.06%). Total N of subsoils ranges from less than 0.01 to 0.09% with most subsoils falling within the 0.02 to 0.05% total N range. At depths greater than approximately 0.5 m, total N content remains relatively constant although variable from site to site.

Nitrate N within peat ranges from 3.5 to 48 ppm (mean 13 ppm). Although some peat samples contain adequate NO_3-N to support plant growth, the data are misleadingly high if one considers the effect of the low bulk density of peat. Nitrate N within inorganic materials is generally less than 10 ppm - a level considered deficient for plant growth.

Although peat contains somewhat more available P than is within the inorganic materials, available P is generally less than 1 or 2 ppm, and is considered deficient.

DTPA-extractable micronutrient levels are variable within most soil profiles and from site to site. Copper is generally lower in peat than in inorganic materials. Both materials usually contain less than 5 ppm Cu. Iron decreases with depth and is at least 2-fold higher in peat than in the uppermost underlying mineral soil. Surficial mineral soils (0 to 45 cm depth) generally contain up to 2-fold more Fe than the underlying soil. Iron contents are extremely variable and range from 10 to 1400 ppm; lower Fe levels generally occur at depths greater than 1 m. Manganese levels are generally less than 5 ppm, although concentrations as high as 590 ppm were detected in peat. Zinc levels are generally less than 1 or 2 ppm and seem somewhat concentrated in peat, although not in excess of 15 ppm.

Most of the mineral overburden materials contain less than 5% free carbonate as $CaCO_3$. Samples which contain no free carbonates are generally either coarse-textured materials or lean oil sand.

General overburden characteristics

Table 4 summarizes the physical and chemical characteristics of spent sand, peat and textural classes of mineral overburden materials. Overburden materials with EC values greater than 2 mmhos/cm and/or SAR values greater than 6 are excluded from the characterization. Additionally, approximately 20% of the data (values which were most divergent from mode-type ranges) from Tables 2 and 3 are excluded if the sample population exceeded 3.

The pH of overburden materials falls within a range suitable for most plants. Materials with restrictive EC and SAR values should not be retrieved for reclamation purposes.

Heavy clay has higher water soluble cation levels than the other materials, however, a trend related to texture is not apparent. Similarily, water soluble anion levels seems not to be related to texture.

Crop requirements for Cl are the highest of the micronutrients. Soils considered low in Cl contain less than 2 ppm (0.06 me/l) water soluble Cl (Reisenauer et al. 1973). None of the overburden materials analyzed (those with EC values greater than 0.8) are deficient in Cl. Nitrates are generally not detectable in saturation extracts from any of the materials. Soils with 5 ppm extractable SO_4-S are considered to contain adequate S (Carson et al. 1972). Although extractable SO_4-S was not determined, SO_4 within the saturation extract of selected mineral samples exceeded 5 ppm (0.3 me/l) SO_4-S. Peat contains lower but adequate S.

Extractable cations do seem to relate to texture. Adequate levels of exchangeable (extractable less soluble, me/100g) Ca, Mg and K are approximately 200 ppm (1.0 me/100g), 50 ppm (0.4 me/100g) and 150 ppm (0.4 me/100g) respectively (Doll and Lucas 1973). All of the mineral overburden materials contain sufficient Ca and Mg, however, only the fine-textured materials contain adequate exchangeable K to support plant growth. Sodium is generally not considered an essential plant nutrient and may restrict plant growth through adverse physical soil effects and nutritional imbalances. Exchangeable sodium percentage (ESP) levels as low as 2 to 10 may induce Na toxicity symptoms in extremely sensitive crops. Sensitive crops will tolerate ESP levels within the range, 10 to 20 (USDA 1960). Overburden materials selected for reclamation use through the limitations imposed by SAR (that is, materials with SAR values greater than 6 are not used) will generally have ESP values less than 15.

Spent oil sand contains no free carbonates whereas mineral overburden materials are generally weakly calcareous (CSSC 1974). Although a definite relationship is not apparent, the finer-textured materials are slightly more calcareous than sand and loamy sand.

The CEC of spent sand is very low (Table 4). It seems that maintenance of a sufficiently high CEC will be a significant factor in the permanent self-sustained establishment of plants within spent sand. Additions of N-forms (Thiourea, urea, $(NH_4)_2SO_4$, $NaNO_3$ and NH_4NO_3) and P (as KH_2PO_4), for example, were found to be readily and almost completely leached from a 75 cm column of spent sand*.

* Personal communication; D. McCoy, Alberta Environment, Lethbridge,

A CEC greater than 10 me/100g seems desirable (Cope and Rouse 1973). Although the CEC of peat is approximately 100 me/100g (Townsend and MacKay 1963), the low bulk density of peat limits the "effective" CEC contribution of peat. Assume, for example, that either 1 cm of peat or 1 cm of heavy clay overburden is added to 4 cm of spent sand. Assume peat to have a bulk density of 0.2 and a CEC of 100 me/100g. Spent oil sand has a bulk density of 1.4 and CEC of 0.2 me/100g (Table 4; McCoy et al. 1976). Assume heavy clay overburden material to have a disturbed bulk density of 1.4 and a CEC of 40 me/100g (Table 4; McCoy et al. 1976). The addition of 1 cm of peat to 4 cm of spent sand will create a calculated CEC of 3.6 me/100g; the addition of 1 cm of heavy clay overburden will create a calculated CEC of 10.8 me/100g. (This kind of argument also often applies to the nutritive contribution of peat. From a physical soil aspect, however, peat likely contributes to the vegetative establishment in spent sand and should not be excluded from a reclamation scheme). Hence, mineral material with the highest CEC values, specifically heavy clay, should be retained for reclamation purposes.

The turnover rate of N compounds within mineral overburden materials is not known. The increasing amount of total N with increasing clay content, however, suggests increased levels of hydrolyzable and nonhydrolyzable organic materials. Increasing clay content would thereby contribute to fertility, including N fertility. Although peat contains a relatively high amount of total N, the effect of low bulk density and the likelihood of relatively stable N substances associated with high amounts of carbon will likely limit the amount of N available from peat for plant growth.

Approximately 30 ppm NO_3-N and 35 ppm P are adequate levels for the establishment of crops*. None of the materials contain adequate levels of NO_3-N nor available P.

Adequate levels of soil DTPA-extractable Cu, Fe, Mn and Zn are 0.2, 4.5, 1.0 and 1.0 ppm, respectively (Viets and Lindsay 1973). Copper is of adequate levels within fine-textured materials, but may be only marginally adequate in peat and some of the coarse-textured materials. None of the materials, including spent sand, lack adequate Fe and Mn. Contents of Zn are deficient in particularily the coarse-textured materials and may be deficient in spent sand mixtures containing fine-textured materials and particularily peat if these materials are sparingly used.

In texturally nonfractioned soil, specific surface seems related to texture. In soils generally, specific surface highly correlates with CEC and water retention (Mortland and Kemper 1965). It follows, then, that soil with higher surface areas are desirable for reclamation purposes.

A soil moisture deficit within the root zone of plants grown on ameliorated spent sand is probable. The magnitude of soil moisture deficiencies will depend largely on precipitation frequency, intensity

* Personal communication; D. H. Laverty, Alberta Soil and Feed Testing Laboratory, Edmonton, Alberta.

TABLE 4. Chemical and physical characteristics of spent sand and overburden according to a peat and textural grouping †

	Spent sand	Peat‡	Heavy clay‡	Clay‡	Sandy clay	Sandy clay loam‡	Loam	Sandy loam‡	Loamy sand	Sand
Number of observations †	3	9	4	5	2	14	2	35	1	2
pH	7.7±0.1§	6.7±0.7	7.3±0.1	7.4±0.1	7.4	7.4±0.2	7.6	7.5±0.2	7.5	7.6
EC (mmhos/cm)	0.41±0.01	0.41±0.10	1.50±0.67	0.33±0.05	0.94	0.38±0.17	0.28	0.37±0.12	0.37	0.60
SAR	2.6±0.4	0.3±0.1	0.6±0.2	0.3±0.2	0.4	0.4±0.1	0.3	0.4±0.1	0.4	3.0
H_2O Soluble cations (me/l)										
Ca	2.1±0.7	3.0±0.8	12.3±5.0	2.4±0.6	8.2	2.8±0.9	2.0	2.6±0.9	2.4	2.4
Mg	0.5±0.1	1.0±0.3	5.1±3.0	0.8±0.1	2.3	0.9±0.3	0.6	0.9±0.4	0.9	2.2
K	0.2±0.0	0.0	0.8±0.5	0.1±0.1	0.3	0.1±0.1	0.1	0.1±0.05	0.1	0.8
Na	2.6±0.1	0.4±0.1	0.8±0.8	0.4±0.2	1.2	0.6±0.3	0.3	0.5±0.1	0.5	5.1
H_2O soluble anions (me/l)*										
HCO_3	2.6±0.2	9.8	1.5	-	3.1	3.3	-	3.5	-	3.5
Cl	0.2±0.0	0.2	0.1	-	0.6	0.4	-	0.4	-	3.0
NO_3	ND**	ND	ND	-	ND	ND	-	ND	-	ND
SO_4	0.4±0.0	0.8	23.2	-	14.5	8.4	-	13.6	-	-
NH_4OAc ext. cations (me/100g)										
Ca	0.2±0.0	-	24.4±0.7	24.8±4.6	35.8	23.6±7.0	16.2	10.4±6.2	4.7	2.0
Mg	0.1±0.1	-	9.6±1.5	2.8±1.2	3.7	2.4±0.5	1.4	1.0±0.3	0.8	0.7
K	0.0	-	0.9±0.3	0.3±0.1	0.4	0.2±0.1	0.1	0.0±0.0	0.0	0.1
Na	0.0	-	0.3±0.3	0.0	0.3	0.0±0.1	0.0	0.0	0.0	0.7
$CaCO_3$ equivalent (%)	0.0	-	2.3	1.3±1.2	4.7	2.9±2.8	4.4	1.2±1.4	0.4	0.1

TABLE 4. Chemical and physical characteristics of spent sand and overburden according to a peat and textural grouping † - continued

	Spent sand	Peat	Heavy clay	Clay	Sandy clay	Sandy clay loam	Loam	Sandy loam	Loamy sand	Sand
CEC (me/100g)	0.2	-	41.1±3.3	18.6±3.0	15.7	12.8±1.8	8.2	5.4±1.2	4.4	3.5
N (Kjeldahl, %)	0.01	1.12±0.12	0.04±0.01	0.04±0.01	0.05	0.04±0.01	0.04	0.03±0.01	0.01	0.01
NO_3-N (ppm)	-	8.3±4.0	6.0±0.7	4.7±0.4	4.2	4.4±0.6	3.7	4.6±0.8	5.9	5.1
P (ppm)	1.9±0.2	0.8±0.7	0.3±0.2	1.2±0.4	0.1	1.4±1.4	0.8	1.2±1.1	0.8	9.5
Cu (ppm)	0.2	0.7±0.5	3.9±0.7	1.6±0.6	6.7	1.0±0.6	0.6	0.6±0.2	0.2	2.0
Fe (ppm)	5.5	480±315	87±8	25±7	140	55±35	10	40±30	50	25
Mn (ppm)	1.0	33±45	6.0±1.1	1.7±0.6	7.7	5.3±4.1	23	4.4±2.6	8.0	4.7
Zn (ppm)	0.4	2.4±2.6	2.5±2.5	0.4±0.0	2.4	0.3±0.1	0.5	0.4±0.2	0.2	0.2
Specific surface (m^2/g)										
soil	6±1	-	-	60	92	-	74	22	-	5
clay (<2u)	80±10	-	-	135	270	-	210	105	-	310
Available moisture (%)	1.2±0.4	-	14±2	11±2	11	11±1	12	8±2	3	3
Saturation %	43±6	240±55	77±4	55±11	50	44±6	41	34±3	24	26

† Excludes samples with EC values greater than 2 mmhos/cm and/or SAR values greater than 6.

‡ Based on approximately 80 % of the number of observations.

§ Standard deviation of the mean.

* Excepting spent sand, determined only for those samples with EC values greater than 0.8 mmhos/cm.

** ND, not detectable.

TABLE 5. Simple correlation coefficients and simple linear regression equations of percent clay, available moisture and cation exchange capacity as a function of saturation percent (x)[+]

Soil characteristic	r ‡	Simple linear regression equation
Clay (%, <2u)	0.89**	$\hat{Y} = -9.74 + 0.82\,x$
1/5 - 15 bar moisture (%)	0.73**	$\hat{Y} = 4.14 + 0.16\,x$
1/3 - 15 bar moisture (%)	0.66**	$\hat{Y} = 3.73 + 0.14\,x$
CEC (me/100g)	0.87**	$\hat{Y} = -9.29 + 0.50\,x$

\+ Calculated from 75 mineral samples.

‡ r, simple correlation coefficient.

** Significant at 0.01 probability level.

and duration, and available water storage capacity. The average precipitation at Fort McMurray during the growing season is: May, 3.3 cm; June, 5.4 cm; July, 6.2 cm; and August 5.4 cm (estimated data, Govt. Alberta and U. of A. 1969). Based on the mean available moisture values in Table 4 and assuming a bulk density of 1.4 for mineral materials, the available moisture storage capacity within a 122 cm depth of a number of materials is as follows: spent sand, 2 cm; sand and loamy sand, 5 cm; and heavy clay, 24 cm. Clearly, fine-textured materials and peat will be required to increase the available soil moisture storage capacity of spent oil sand.

According to the criteria applied in the preceding discussion, spent oil sand lacks adequate levels of Ca, K, NO_3-N, available P, Zn, CEC and available moisture holding capacity. Additionally, spent sand contains marginally adequate levels of Cu, Mn and likely SO_4-S.

Table 5 outlines the simple correlation coefficients and linear regression equations of percent clay, available moisture and CEC as a function of saturation percent. Saturation percent, the weight of water in a saturated soil expressed on the basis of the dried weight of that soil, is easily measured and is the basis of the saturated-soil-extract procedure. Particularily percent clay and CEC correlate well with saturation percent, although available moisture percent is also highly significantly correlated to saturation percent. At least within the study area, saturation percent can be applied in the selection of oil sand overburden materials which are suitable for reclamation purposes.

SUMMARY AND CONCLUSIONS

According to the criteria applied in the foregoing discussion, spent oil sand lacks adequate levels of Ca, K, NO_3-N, available P, Zn, CEC and available moisture holding capacity. Additionally, spent sand contains marginally adequate levels of Cu, Mn and possibly SO_4-S for the establishment and growth of plants. Ameliorative materials are required for the reclamation of spent sand.

Mineral soil materials overlying lean tar sand within the mine area of Syncrude Lease No. 17 vary considerably in both their horizontal and vertical distribution. The materials are generally comprised of coarse-textured glaciofluvial and glacial deposits which are often less than 2 m deep. Fine-textured glaciolacustrien materials have a relatively limited distribution. Peat overlies much of the mineral soil to a depth of approximately 1 m.

The fine-textured overburden materials are relatively inactive, medium-plastic soils.

Mineral overburden materials generally have a pH within the neutral to mildly alkaline range. Peats are slightly more acidic, generally within the neutral to slightly acid range.

EC and SAR values are generally less than 2 mmhos/cm and 6, respectively. Some materials do have higher EC and SAR values and should not be used for reclamation purposes.

Much of the exchange complex of the overburden materials seems saturated with Ca and Mg in the approximate ratio, 3:1. All of the materials contain adequate Ca and Mg for plant growth.

The mineral overburden materials are weakly calcareous.

All of the overburden materials contain adequate levels of Fe, Mn and SO_4-S. None of the overburden materials contain adequate levels of NO_3-N and available P for plant establishment.

Only fine-textured materials contain adequate K to support plant growth.

Copper is of adequate levels in heavy clay, marginally adequate in peat, and deficient in some of the coarse-textured materials. Similarily, Zn is of adequate levels in some of the fine-textured materials, marginally adequate in peat, and deficient in coarse-textured materials.

Compared to peat, a much smaller volume of heavy clay is required to sufficiently increase the CEC of spent oil sand.

Both peat and fine-textured materials can contribute substantially to the available soil moisture storage capacity of spent sand.

Available moisture percent, percent clay and CEC are highly correlated with saturation percent. At least within the study area, saturation percent can be applied in the selection of mineral soil overburden materials suitable for reclamation purposes.

In view of the preceding summary, fine-textured materials overlying lean oil sand can contribute substantially in the reclamtion of spent oil sand. Heavy clay materials, particularily, should be delineated within the mine area of Syncrude Lease No. 17 and retrieved for reclamation purposes.

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