GEOMECHANICAL INVESTIGATION OF POST-RECLAMATION SUBSIDENCE OF PRAIRIE STRIP MINE SPOIL

by:

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INTRODUCTION

The post-reclamation subsidence of cast-back overburden is of interest to mining companies and regulatory agencies. Although subsidence may be of lesser concern than the prevention of soil degradation and the re-establishment of productivity, the amount of subsidence, the time-frame for the subsidence, and the amount of differential settlement have an influence on land use which must be evaluated. The effects of subsidence can be seen on highways constructed over reclaimed spoil, where a very rough surface develops and requires frequent resurfacing. In cultivated reclaimed fields, a corrugated surface develops over some time after reclamation, affecting runoff and causing waterlogged areas. Other behavior may be affected by subsidence; permeability changes associated with destruction of porosity, subsurface soil erosion because of the disturbed condition, and loss of integrity of buildings built on reclaimed spoil because of differential settlement may be important factors worthy of evaluation. Ideally, an ability to predict these factors should be developed. Realistically , the processes are extremely complex, and a complete predictive framework is not a reasonable goal. This paper will outline the major practical concerns in the study of the subsidence processes and show how we are developing an approach incorporating understanding of processes, laboratory and geophysical measures, and instrumented field sites to quantify the settlement process and achieve some capacity to predict behavior. This study has in large part been funded by the Plains Hydrology and Reclamation Project, and we are grateful for their support and encouragement.

MATERIALS

The project we are involved in is related specifically to surface mining of coal in the Alberta prairies. The material encountered as overburden is generally non-cemented sedimentary rock of relatively high porosity containing large volumes of clay minerals. The term "rock" is really a misnomer as these materials are much softer than rock, but much stiffer than soil. The term "transitional materials" has recently been introduced to describe them (Deen, 1981) as their properties are intermediate between those of soil and rock.

The sedimentary strata containing coal in the Alberta Plains are Cretaceous to Early Tertiary beds which were deposited in environments ranging from shallow marine to continental regimes near the coast line of a shallow sea. There are few massive beds of limestone, strongly cemented sands, or other similar resistant strata. The sediments are sands, silts, and clays of detrital origin, although some proportion of the clay minerals had their origin in volcanic processes. The most important characteristics from the mining and reclamation aspects are the high porosities of the materials, their low strengths, their tendency to slake and swell upon exposure to water, and the sodic nature of the clay minerals (in particular, smectite). Table 1 contains a summary of the properties of the major lithologies encountered as overburden material at the Forestburg mine sites 200 km southeast of Edmonton.

Delineation of properties involves the study of geophysical logs, core examination, and simple tests of engineering properties related to perfomance. Figure 1 contains typical geophysical data obtained from a borehole in the study area along with a visual description of the lithology of core samples from the same well. The porosities can be calculated accurately from geophysical data if the density of the mineral component can be accurately determined in the laboratory and if the materials are saturated, which is almost always the case in these clay-rich deposits.

The sand and silt portions of the sediments are usually dominated by quartz grains, but the materials contain large quantities of feldspar, volcanic, and lithic fragments. The proportion of clay is variable; even the sandstone units have relatively large proportions of clays present as decomposed volcanic grains and as interstitial material. The clay mineralogy is dominated by smectite (montmorillonite and beidellite) and illite. Smectite has the greatest impact on the behavior of cast-back overburden because it readily takes up interlayer water and will swell dramatically on exposure to rain or groundwater of low salinity. Even if little smectite is present, the materials have a strong tendency to slake because there is little grain-to-grain cement to resist the destruction of the fabric.

SEQUENCE OF EVENTS IN MINING AND RECLAMATION

The following section is a summary of the mining sequence and reclamation procedure for a typical mine in the Forestburg area. First, the soil horizon is removed and stored in dumps for future reclamation purposes. Assuming there is a shallow coal seam present, the thin overburden is stripped by scrapers and hauled to the most convenient permanent dump location. An alternate technique is to use the dragline as a chop-cutter in a backwards facing mode to expose the coal seam for mining. The upper seam is mined by scrapers and the overburden above the lower seam is removed by the dragline operating from the top of the highwall. The overburden is spoiled by casting it across the mining slot into windrows which have an orientation parallel to the mine and a windrow-to-windrow spacing equal to the width of the slice removed at each pass of the dragline. The mine progresses backwards by repeated removal of slices once the coal in the bottom of the slot is removed by scrapers. After some time, the windrows are levelled with bulldozers (Figure 2). The material which was stored for reclamation is replaced in a manner dictated by the best principles of reclamation, the soil is levelled, rocks are removed, and a suitable vegetative cover is re-established, bringing the terrain back to a productive state. At this stage, the mining company has fulfilled the requirements for returning the land to at least a pre-mine condition.

Other mining methods , such as truck-shovel or scraper mining, result in different placement properties and different post-reclamation subsidence behavior. The data in this paper deal with the results of our field monitoring, our laboratory assessments of water sensitivity, the potential of geophysical logs as predictive tools, and the design of the laboratory study of compaction we will presently be undertaking.

FIELD MONITORING OF SUBSIDENCE

We have installed two field sites to monitor post-reclamation subsidence. These sites were established at the Diplomat Mine north of the Battle River at Forestburg and at the Vesta Mine south of the river at the same location. The former site was established on 11 m of spoil of glacial origin in the summer of 1980, and the latter site was established in the summer of 1981 on 25 m of cast-back smectitic spoil. The sites were established only after the land surface had been contoured, as pre-contouring subsidence is of much lesser interest. Each site consists of an array of surface monuments on a rectangular grid and an array of multi-point and single-point extensometers to monitor vertical movements throughout the height of reclaimed overburden. Figure 3 shows a plan and section view of the instrumentation strategy. It is of interest to mention that our surface monuments do not protrude above the ground, and do not interfere with standard cultivation. Only the extensometers are above the ground surface for ready access. The sites are carefully surveyed at several intervals each year; the surface sites are levelled and a reed switch on a tape is used to measure the location of the multi-point extensometer points. Data are reduced and plotted by computer in areal or cross-sectional form.

Observations are limited as we have been monitoring for a short period only. The amount of settlement at the Diplomat site is shown in Figure 4. Very little subsidence has occurred to date, and we feel that this is because the groundwater tables have not yet recovered appreciably, and because runoff in the winter of 1980-81 was low as the result of low precipitation and gradual melt. The one area where any significant settlement was measured was an area of temporary free-standing water in the fall of 1980. We presume that this caused saturation and consequent slaking of the top few feet of the reclaimed profile, which is reflected only in those local instruments.

The settlement at the Vesta Mine site is very small as yet, because the site has been in place for only a few months, and the materials have not been exposed to run-off or groundwater recovery.

LABORATORY EVALUATION OF WATER SENSITIVITY

There is some interest in evaluating the water sensitivity of materials encountered in mining situations to be able to choose superior material for re-establishing the subsoil, to define areas of materials particularly sensitive to water which may affect transportation and mining, and also to categorize materials by simple index tests. Some tests techniques have been proposed or are in use for particular purposes: the dry or saturated crumb test (Holmgren and Flanagan, 1977), the pinhole dispersion or piping test (Lewis and Schmidt, 1977), the intact clay slaking test (Moriwaki and Mitchell, 1977), the slake durability test (Franklin and Chandra, 1972), and the swell/slake test (Eigenbrod, 1972). Although these tests are widely known and well understood, they do suffer several limitations. Some are applicable only to material which is partly or totally desiccated, some are dynamic in nature and do not reflect the conditions in this study, some are tests of deflocculation of recompacted material (such as in earth dams), and most of them require a fairly extensive laboratory set-up and are therefore not conducive to testing of large numbers of specimens for classification purposes. We have developed our own version of a swell/slake test to meet the following requirements: the test should be semi-quantitative, simple, rapid and economic, repeatable and not operator-sensitive, and discriminatory among materials (Dusseault et al., 1982b) The static swell/slake test consists of the immersion of an intact piece of undesiccated core in water of desired cation content, and measurement of the disaggregation of the material at specified time intervals up to 24 hr. Behavior is assessed by a qualitative scale presented in Table 2. The dynamic test, developed in an effort to model the turbulence in a slurry transport environment, involves immersion in water of desired salinity and rotation in a small chamber with a tumbler bar for a 10 min period. The material passing a 65 mesh screen is considered as the measure of dispersion.

To interpret the tests, the meaning of the terms swell and slake should be reviewed. Slaking, in our usage, is the disaggregation of a material without appreciable volume increase and with no auto-dispersion of clays. Slaking may take place in fully saturated conditions, such as those in our test, or may be associated with drying. Fully or largely saturated conditions occur during resaturation of spoil whereas drying slaking takes place in the top metre or so of spoil. The former is strongly related to the processes of subsidence; therefore our tests are in saturated conditions. Swelling is the volume change associated with the taking up of water by swelling clays. It is dependent on the salinities of the pore fluid and the saturating water; saturation water of a salinity higher than the pore liquid inhibits swelling behavior, but has much less effect on slaking. Swelling is almost always accompanied by dispersion of smectitic clays into the water.

Figure 5 shows behavior of Forestburg smectitic overburden cores in solutions of different salinities. Figure 6 shows how salinity of solutions affects the disaggregation of samples in our dynamic swell/slake apparatus. The major findings of these studies may be found in several reports (Dusseault and Cimolini, 1981; Dusseault et al., 1982a). A few major conclusions are listed here:

1. Cretaceous overburden materials are in general highly water sensitive; glacial overburden is much less water sensitive;
2. Carbonaceous shales and smectite-poor clay-shales are much less water sensitive than smectitic sandstones and clay-shales;
3. Swelling is inhibited by high salinity saturation water whereas slaking behavior is not;

4. Materials dispersed in saline water auto-flocculates, leaving a clear supernatant liquid; and,
5. The tests devised appear to discriminate adequately, meet most of the requirements listed, and are therefore probably useful in material studies.

USE OF GEOPHYSICAL LOGS FOR MATERIAL CHARACTERIZATION

A suite of geophysical logs is normally run in coal exploration to facilitate correlation and to identify lithologies. An obvious use of these devices is to predict material behavior. The logs most commonly used are the natural radiation log (Gamma Log), the density log (Gamma Ray Density Log), and the resistivity log ("E" Log). These logs are excellent tools for identifying the different lithologies and have been used, in the right environment, for correlation to geotechnical behavior (Isaac et al., 1982). We have not found them useful as yet for relation to water sensitivity or compaction behavior of cast-back spoil. This may be in part because we have not yet identified how to use them correctly, or it may be that the logs do not provide sufficient discrimination to isolate the parameters of interest. With knowledge of the mineral grain specific gravities, very accurate porosities can be calculated to evaluate expansion factors. The Gamma Log measures natural radioactivity, but as the major radioactive specie is potassium, and this is found in sandstones as potash feldspar and in clays associated with illite, the device does not give as strong a lithologic discrimination in these deposits as it does in other sedimentary environments. The electrical resistivity log measures a resistivity associated both with the salinity of the natural fluids and the clay content, and it is difficult to fully separate the two. Figure 7 shows several log traces juxtaposed with water sensitivity data and engineering index properties, showing that the interrelationships are not simple. Perhaps more experience and data in this area will be of some use, as we are still learning how to deal with this type of information. Caution is advised in using geophysical logs for purposes other than correlation, coal reserve estimates, and lithological subdividing.

EXPERIMENTAL DESIGN FOR COMPACTION/SUBSIDENCE STUDIES

The Plains Hydrology and Reclamation Project has recently commissioned us to design and carry out a series of laboratory tests to quantify subsidence potential and to try and unravel the complex processes which occur after reclamation during the recovery of the groundwater table and during exposure to meteoric seepage water. We are assembling the apparatus and will soon be conducting tests in an effort to obtain data relevant to the assessment of subsidence of spoil material in terms of magnitude, time, and relation to moisture conditions.

The test equipment consists of three special large diameter consolidation cells 300 mm by 250mm high. The cells are lined with Teflon to reduce side friction, loads are imposed by a static load (dead weight or a stress-controlled test frame) imposed through a loading cap. Spoiled overburden is obtained from the field and not allowed to desiccate, as we wish to model the behavior of buried material. A filter paper is placed on the bottom of the cell, and the spoil is placed in the cell to a depth of 225 mm. The spoil is lightly compacted manually to create an approximately flat surface, another filter paper is placed, and the desired load is imposed in stages. No water is allowed to contact the spoil and no drying occurs at this stage because the procedure is meant to model the static compaction that occurs in windrowing overburden. The vertical movement is measured for each increase of load to assess the unsaturated compressibility of the spoil. When the sample is stable under the desired load, saturation water of a known salinity is introduced at the bottom to simulate the recovery of the groundwater. The vertical load is kept constant throughout this portion of the test. The head of water is level with the top of the sample so that the test stabilizes under low hydraulic pressure. The time-dependent deformations associated with swelling, slaking and the destruction of the suction of the spoil are continually monitored on an electronic data acquisition system. The resaturation segment of the test models the subsidence that takes place after reclamation during water ingress.

At Forestburg and other sites, several tens of meters of spoil are cast back. The stresses at the bottoms of the piles are much higher than at the tops, therefore we will conduct a series of tests at different equilibrium stresses from 50 kPa to about 700 kPa, which represent depths of burial of from 2 to 35 metres. We hope to do two series of tests, one using fresh water, the other using groundwater of known salinity, to evaluate the effect of the cation content of the resaturation water on subsidence behavior. The equipment is sketched in Figure 8 and the proposed test series is outlined in Table 3.

The materials will also be characterized by tests of clay mineral content and speciation, grain size, and engineering index properties. Post-test samples will be tested for bulk density and other properties of interest such as permeability. We hope that this information, coupled with our knowledge of water sensitivity and field subsidence data, will provide a framework to make some useful generalizations on the amount, location (in a vertical sense), and time factors associated with the settlement of strip mine spoil.

CONCLUSIONS

This paper has outlined our approach to the study of the geomechanics of post-reclamation settlement. The components of this approach include field instrumentation, material characterization by laboratory tests of water sensitivity, use of geophysical logs to evaluate lithology and in-situ porosity, and a laboratory program intended to closely simulate field loading conditions encountered in a typical strip mine. The major conclusions are that the materials are water sensitive, short-term post-reclamation subsidence in the absence of groundwater recovery is small, and geophysical logs are not useful in this context, although they have other powerful uses.

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Table 1

Major Lithologies and Properties of Forestburg Strata

Lithology	Geophysical Density (gm/cm^3)	Cramma Ray Density (API units)	Plasticity Index (% water)	Water Susceptibilty
Glacial Till	1.75-2.15	75	15	medium to low
Smectitic Sandstone	2.2-2.45	60-90	13-50	high to medium
Smectitic Sultstone	2.1-2.3	70-100	20-70	high to very high
Clay Shales	1.9-2.3	80-120	20-90	high to very high
Carbonaceous Shales	1.4-2.0	30-90	less than 20	very low
Coal	1.2-1.4	15-40	0	nil

TABLE 2: Swell/Slake Qualitative Scale

CLASSIFICATION AND SLAKING DETERMINATIONS

Category	Description
A	No sample deterioration
B	Slight deterioration (water clean, minor flecks or fragments)
C_1 C_2	Medium deterioration - original shape largely preserved - surface deteriorated 1....water murky 2....water clear
D_1	High amount of deterioration - largely or completely destroyed - many fragments and flecks. 1....water quite murky 2....water slightly murky
E_1 E_2 E_3	Total Disintegration 1....water completely muddy 2....water slightly muddy 3....water clear

SWELLING CATEGORIES

No Swelling	- No increase in volume
Little Swelling	- Slight increase in volume ~(0-20%)
Medium Swelling	- Some increase in volume ~(20-50%)
High Swelling	- Large increase in volume ~(50-100%)
Very High Swelling	- At least a doubling of volume

Table 3

Test Series for Subsidence Simulation

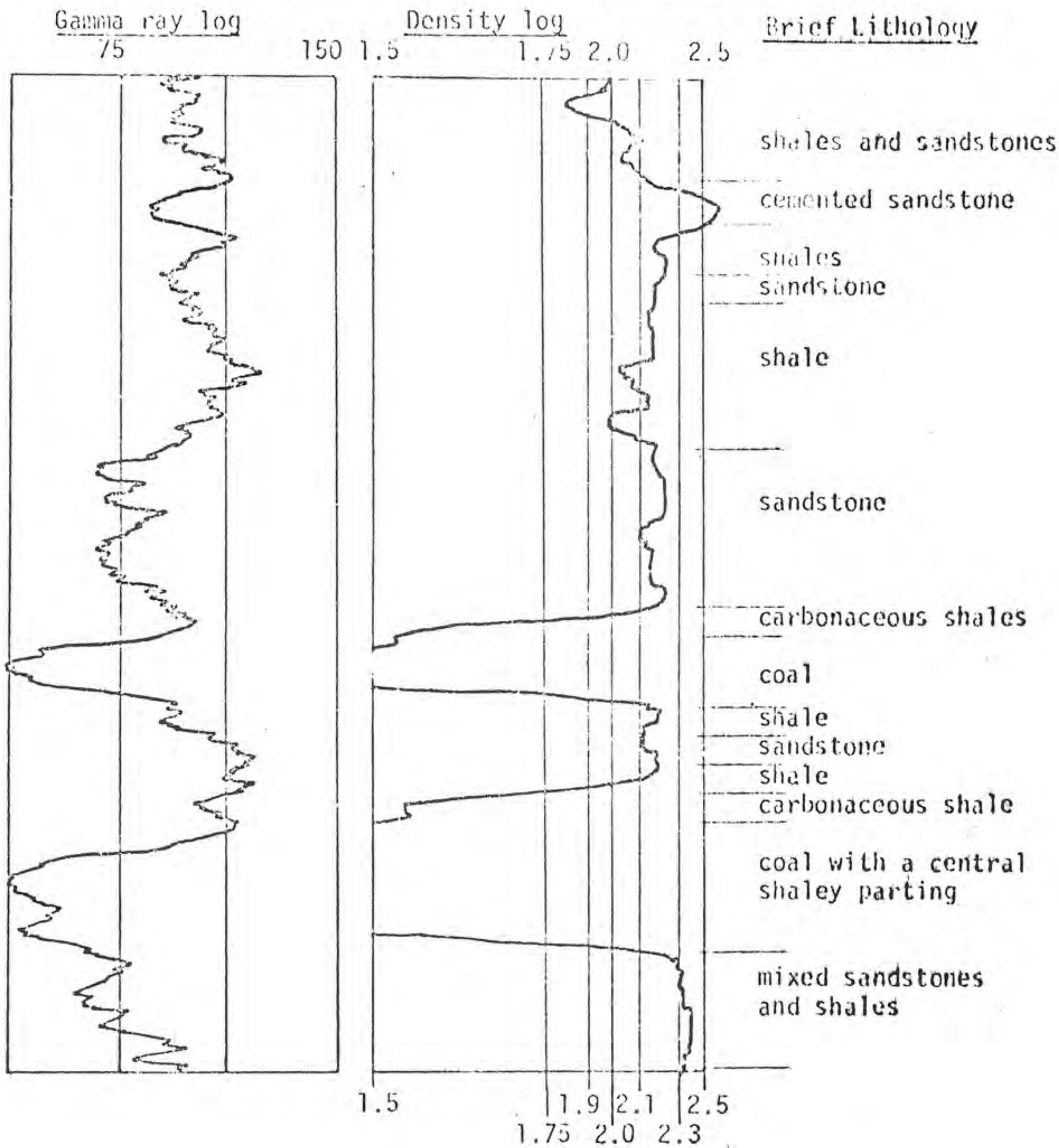
Test Number	Compaction Stress Path kPa	Saturation Water (Constant Final Stress)
PHRC-25A	0-25	fresh water
PHRC-25B	0-25	ground water
PHRC-75A	0-25-75	fresh water
PHRC-75B	0-25-75	ground water
PHRC-150A	0-50-100-150	fresh water
PHRC-150B	0-50-100-150	ground water
PHRC-300A	0-100-200-300	fresh water
PHRC-300B	0-100-200-300	ground water
PHRC-700A	0-200-500-700	fresh water
PHRC-700B	0-200-500-700	ground water

Notes: all tests performed with similar castback smectitic overburden.

: saturation performed at constant stress.

: deflection measured continuously for all stages.

FIGURE 1: GEOPHYSICAL LOGS AND LITHOLOGICAL DESCRIPTION



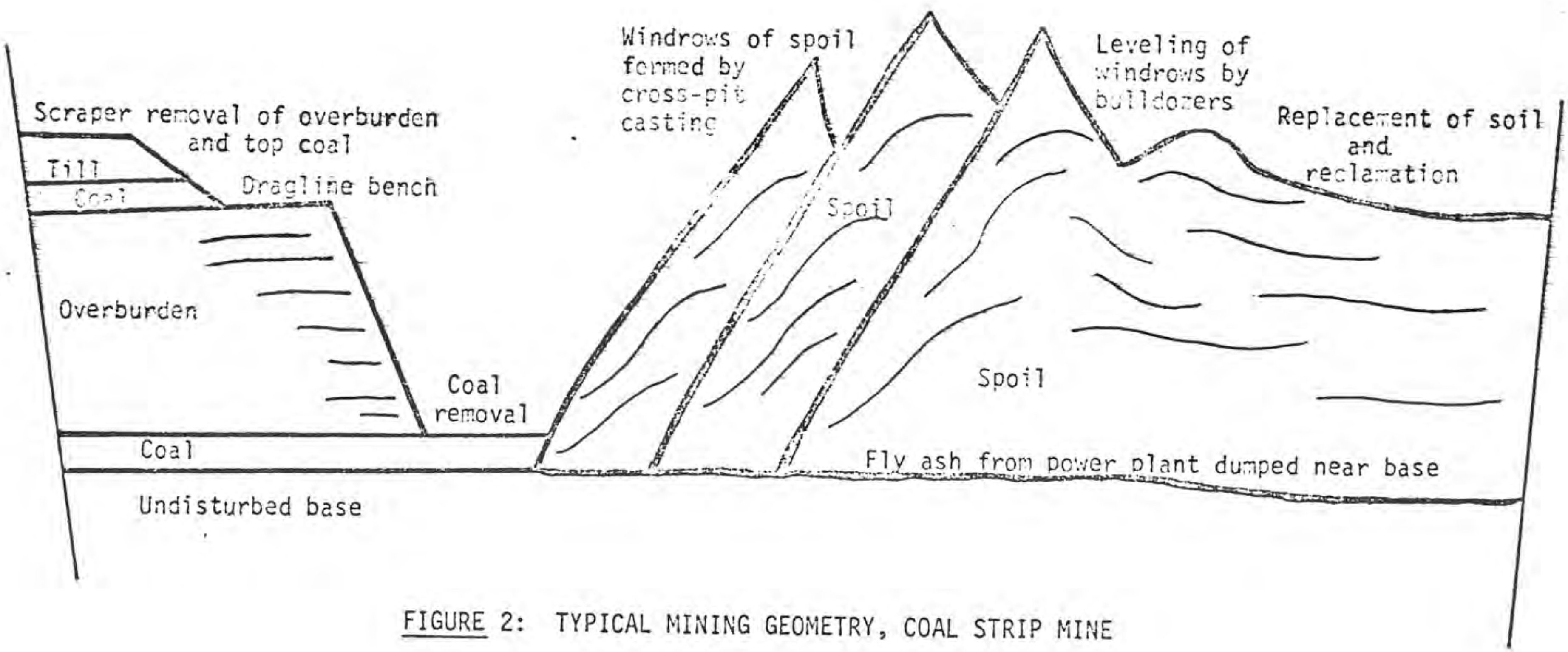


FIGURE 2: TYPICAL MINING GEOMETRY, COAL STRIP MINE

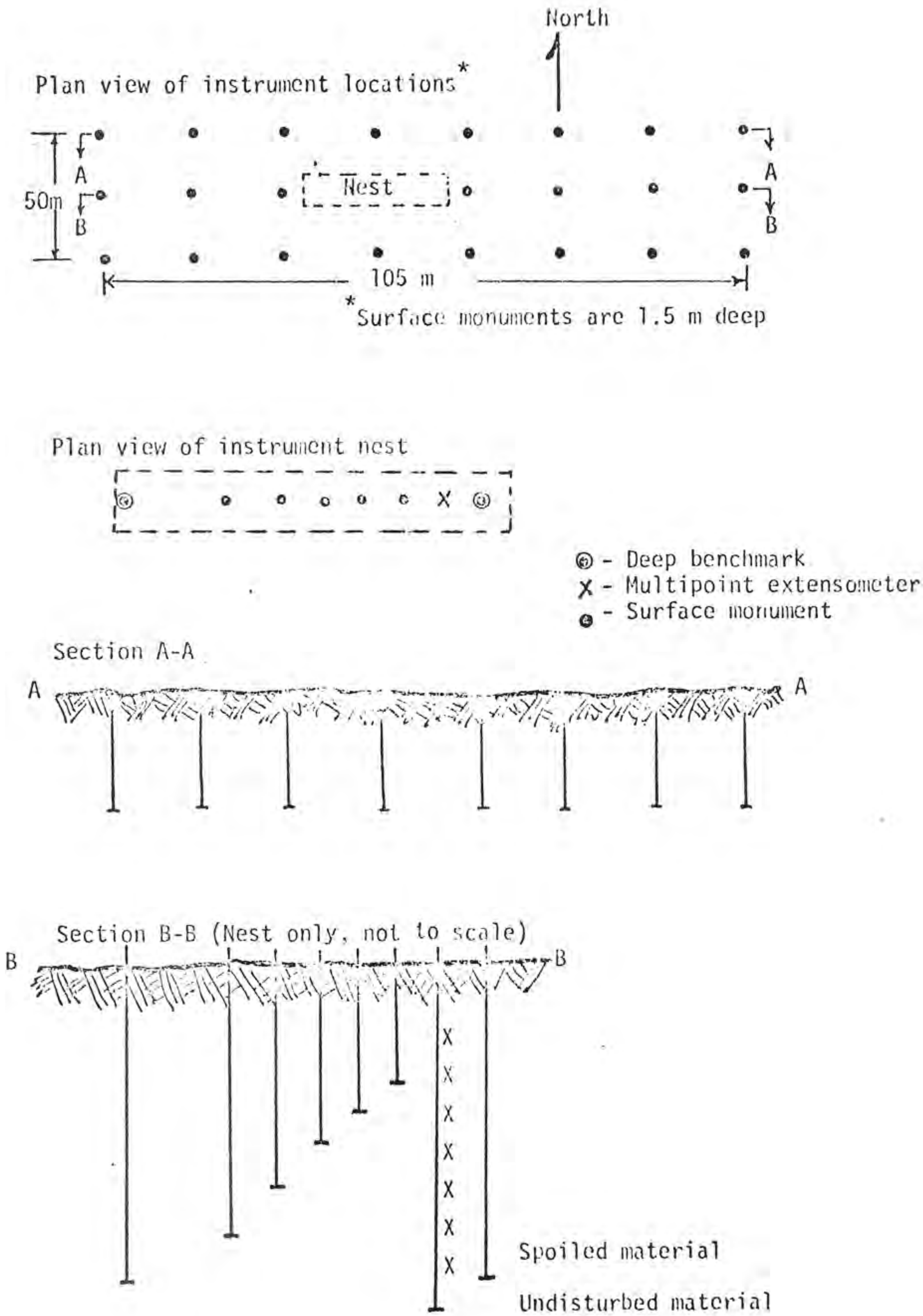


FIGURE 3: PLAN AND SECTION VIEWS OF INSTRUMENTATION STRATEGY

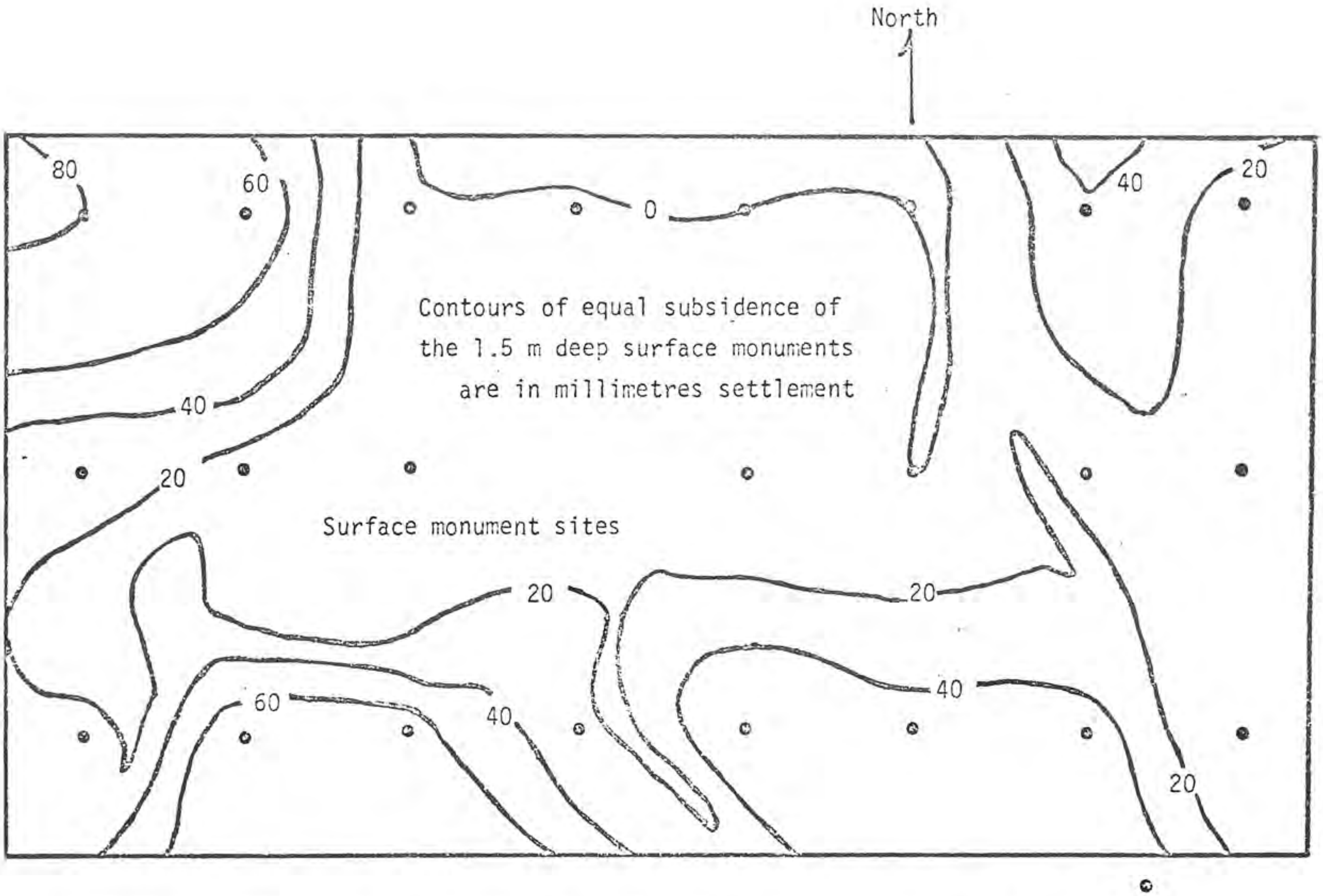


FIGURE 4: SETTLEMENT CONTOURS AFTER ONE YEAR, DIPLOMAT INSTRUMENTED SETTLEMENT SITE

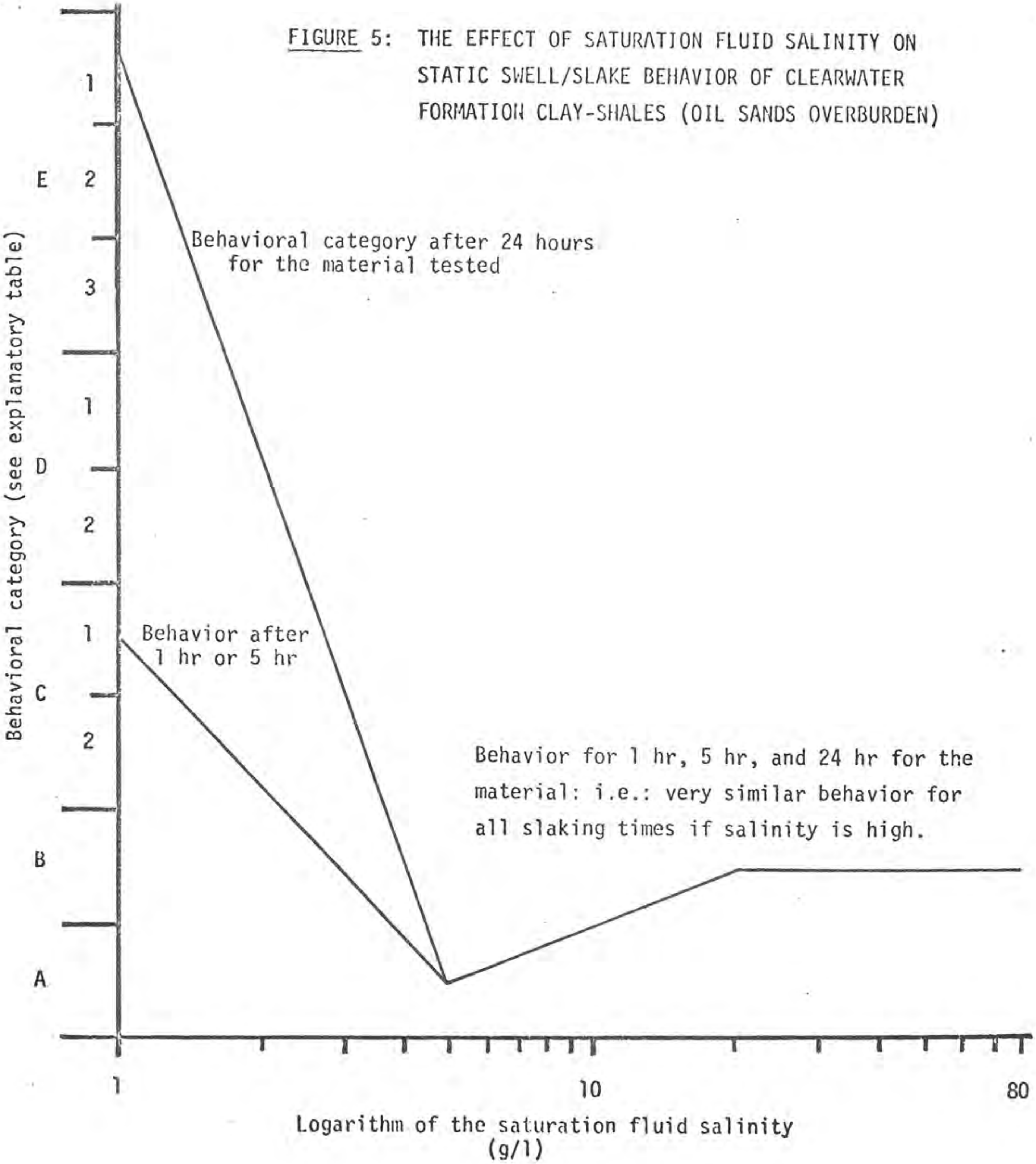


FIGURE 5: THE EFFECT OF SATURATION FLUID SALINITY ON STATIC SWELL/SLAKE BEHAVIOR OF CLEARWATER FORMATION CLAY-SHALES (OIL SANDS OVERBURDEN)

FIGURE 6: EFFECT OF SATURATION FLUID SALINITY ON THE DYNAMIC DISPERSION OF CLEARWATER CLAY-SHALE

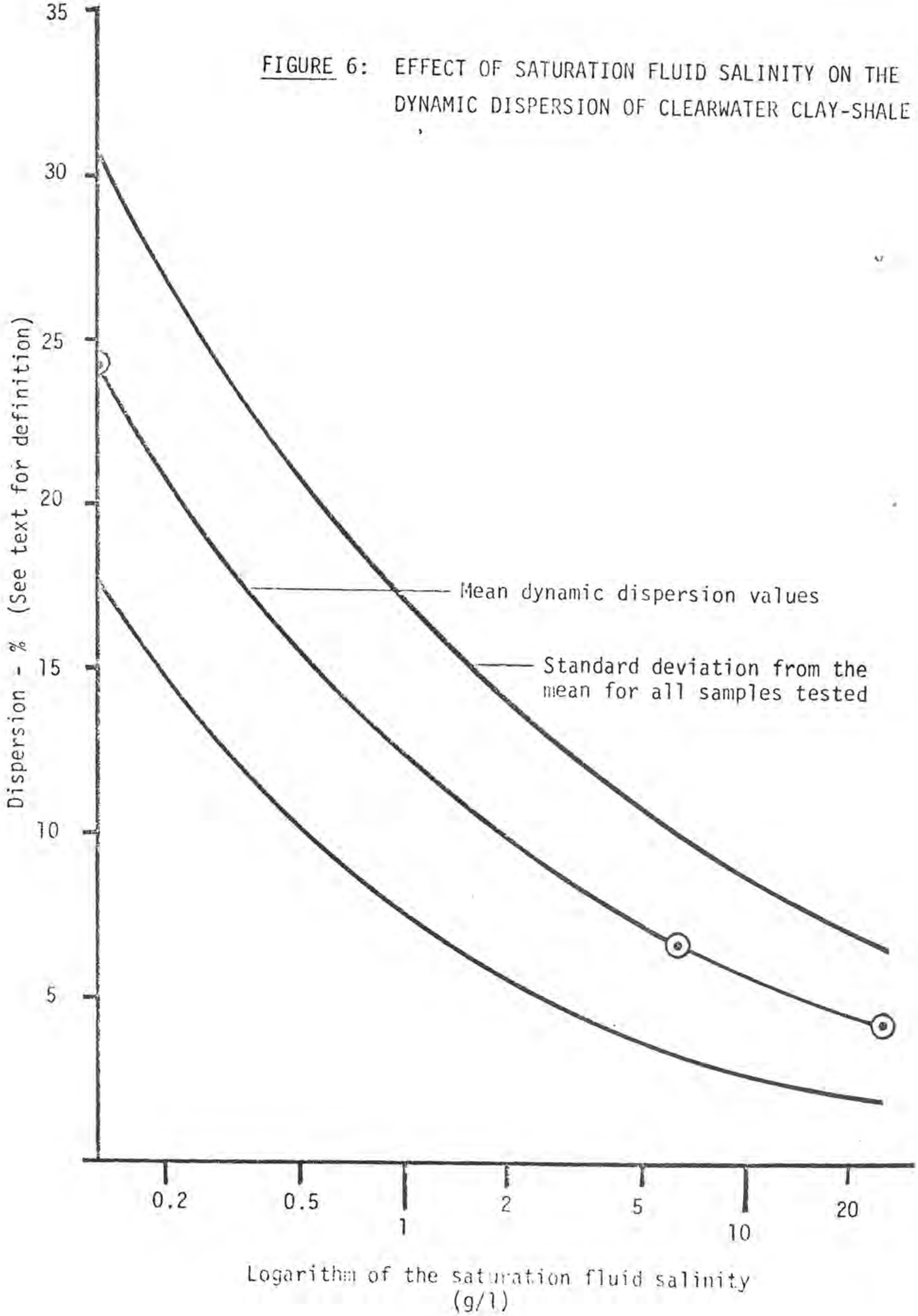
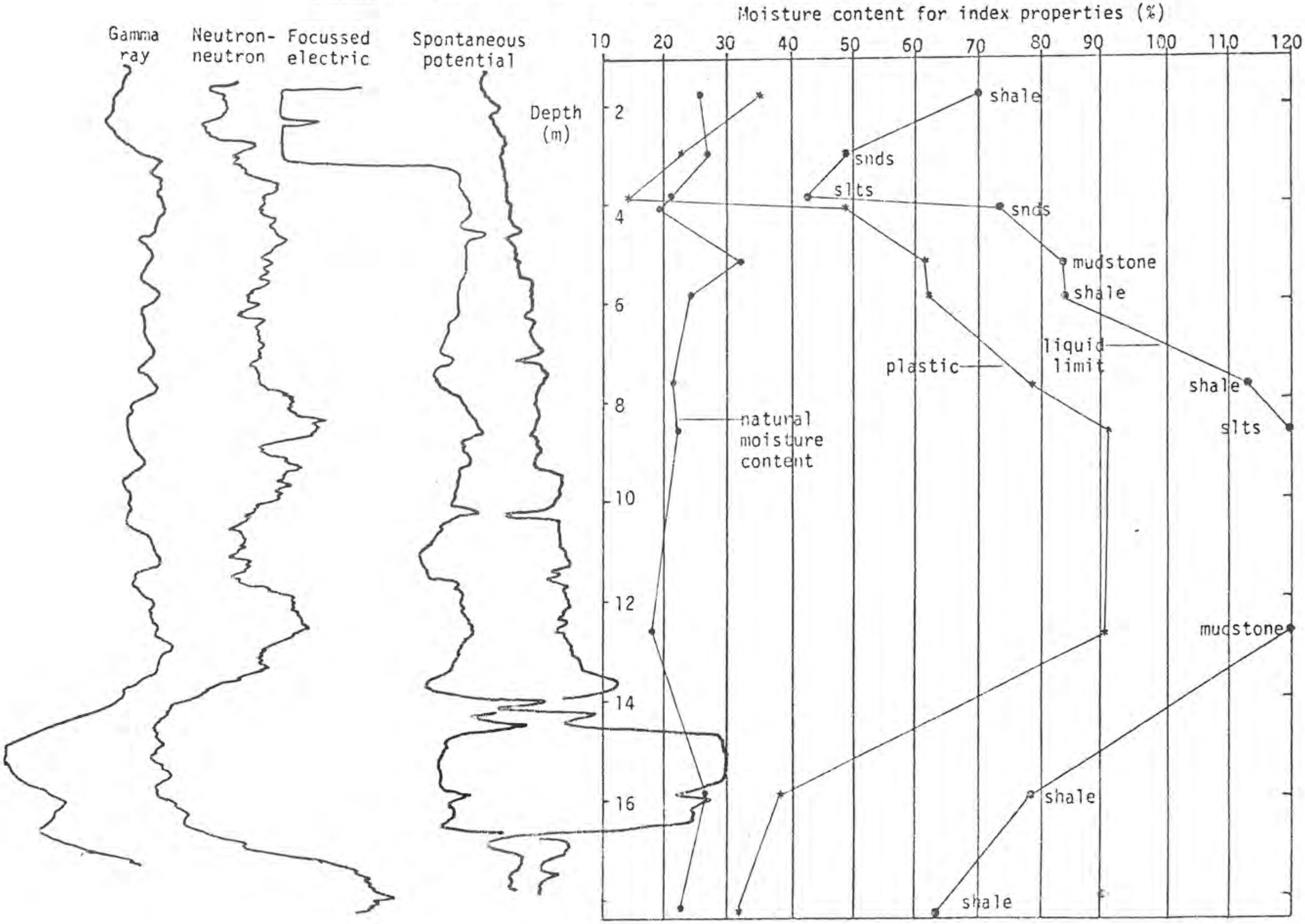


FIGURE 7: GEOPYHSICAL LOGS AND ENGINEERING INDEX PROPERTIES



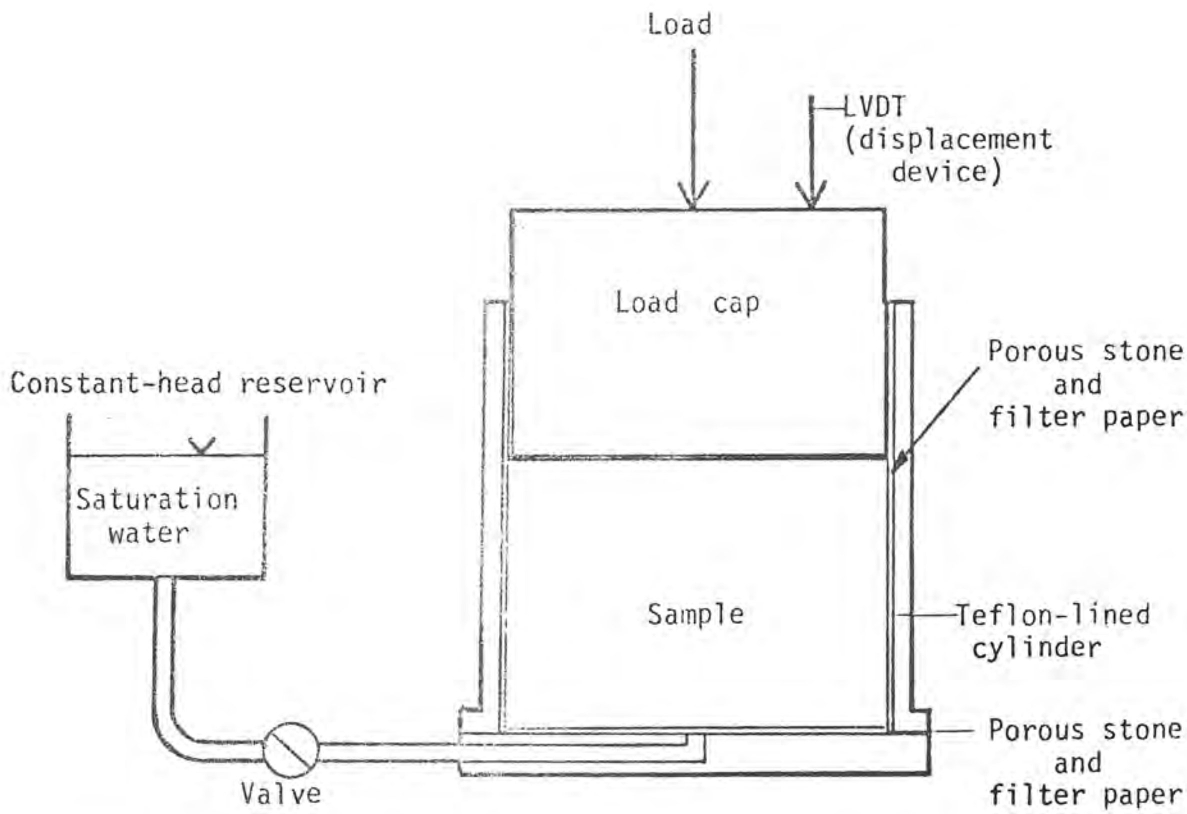


FIGURE 8: SETTLEMENT CELL FOR SIMULATION OF CONSTANT STRESS RESATURATION SUBSIDENCE BEHAVIOR

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INTRODUCTION

Last Spring the Provincial Government's Reclamation Research Technical Advisory Committee presented a two day Reclamation Research Seminar at the Chateau Lacombe. We were surprised by the large turnout and an overwhelming majority of those in attendance indicated the desirability of an Annual Reclamation Conference for Alberta which would focus on Policy and Practice as well as Research and which would include industry, academic and government participation.

These were very sensible suggestions though their implementation would exceed the mandate and manpower of the Reclamation Research Technical Advisory Committee. So various groups were contacted to sponsor and help organize the Conference. Positive responses where received from the Canada Land Reclamation Association (CLRA) The Alberta Government's Land Conservation and Reclamation Council, The Coal Association of Canada and The Oil Sands Environmental Study Group (OSESG).

The CLRA authorized formation of an Alberta Chapter to serve as the umbrella organization with a Program Committee consisting of representatives of the Government and the two Industry groups. Through this Conference and perhaps other functions the Alberta Chapter of the CLRA can fulfill two important roles:

1. To provide an opportunity for members of the Reclamation community to meet, exchange experiences or argue and otherwise improve communications among its industry, government and academic factions.

2. To provide a public forum for reclamation activities, capabilities, issues and challenges.

This was the first function of its kind in Alberta. Special thanks are due the Sponsors, Speakers and the other Members of the organizing Committee: Jennifer Hansen, Malcolm Ross and Al Fedkenheuer. Their talents and efforts made the Conference a success.

One final word on the Speakers: they were given very short notice of the Conference and not only responded enthusiastically but prepared presentations which were of remarkable quality and consistency. We are fortunate to have individuals of this caliber working in the Field of Reclamation in Alberta.

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Ziemkiewicz, P.F. 1982 Proceedings: 1982 Alberta Reclamation Conference, April 1982, Edmonton, Alberta Canadian Land Reclamation Association/Alberta Ch. Pub. 82-1