Crandon Project tailings storage facility: report on conceptual design. 1982

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EXXON MINERALS COMPANY

CRANDON PROJECT

TAILINGS STORAGE

REPORT ON
CONCEPTUAL DESIGN

FEBRUARY 19, 1982

...nited Kingdom Building
...09 Granville Street
...uver, British Columbia
...nada V6C 1T2

Knight and Piésold Ltd.
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SECTION 1 - INTRODUCTION

1.1 GENERAL

The purpose of this report is to present a conceptual design for the tailings storage facility for the Crandon Project, Wisconsin. The tailings storage facility provides for the storage of the combined tailings material from the process after separation of the coarse fraction for underground backfill requirements. Specific objectives in the conceptual design of the facility are for total confinement of all solid waste materials and the control and removal of all excess liquid wastes associated with the tailings, to ensure that the release of contaminated seepage to the environment is virtually eliminated.

Conceptual studies and design criteria have been carried out taking account of the proposed regulations and guidelines contained in the Order of the State of Wisconsin Natural Resources Board, Chapter NR 132, Metallic Mineral Mining, and Chapter NR 182, Regulation of Metallic Mining Wastes. In particular, this report is structured to meet the requirement of Section NR 182.08, Feasibility Report.

1.2 REFERENCE INFORMATION

A detailed laboratory testing program has already been carried out on the tailings material for the project to determine the physical characteristics of the tailings materials. The following report, which is summarized in Section 2.0, Tailings Characteristics, forms an essential reference document in the reading of this report:

(i) Crandon Project. Report on Laboratory Tests on Tailings Materials. Knight and Piesold Ltd., June, 1981.

Geotechnical and hydrogeological baseline studies have been carried out for the general area of the tailings storage facility by Golder Associates. The studies are reported in the following Golder Associates' reports which form reference documents in the reading of this report:

(ii) Geotechnical Investigation. Crandon Project. Waste Disposal System. Volume 1. Geotechnical Data Review, Golder Associates, September, 1980.

(iii) Geotechnical Investigation. Crandon Project. Waste Disposal System. Volume 2. Test Boring and Test Pit Logs. Golder Associates, September, 1980.

(iv) Geotechnical Investigation. Crandon Project. Waste Disposal System. Volume 3. Laboratory Test Data. Golder Associates, September, 1980.

(v) Crandon Project. Waste Disposal System. Project Report No. 7. Groundwater Basemap. Golder Associates, January, 1981.

Relevant information from the above reports is summarised in Section 3.0, Site Characteristics, of this report.

Preliminary meteorological data has been obtained from the following report:

(vi) Crandon Project. Environmental Baseline Study. Meteorology and Air Quality Study and Study Methods. Dames and Moore, May, 1981.

SECTION 2 - TAILINGS CHARACTERISTICS

2.1 GENERAL

Processing of the Crandon ore body will result in the production of a total of 33.041 million tonnes of tailings material after separation of the coarse fraction from the tailings for mine backfill. This tailings material will originate from the mill in slurry form and will require permanent and secure confinement of the solid material, with control and removal of all excess liquids associated with the material.

Samples of tailings material from the Crandon Project were obtained by Knight and Piesold Ltd. from process research work carried out by Lakefield Research of Canada Limited. This enabled a series of tests to be carried out in order to study the physical characteristics of slurries prepared from the materials. The testwork provides a means of evaluating the performance of the tailings slurries under various deposition techniques and in particular the application of the sub-aerial technique of tailings deposition to these particular materials.

The sub-aerial technique takes advantage of the large increase in density that can result from drainage and air drying of tailings during deposition, and of the reduction in moisture content as the material progresses from a fully saturated to a partially saturated condition. Having achieved a dense, partially saturated condition, the tailings mass is structurally stable, will not yield any seepage and has little propensity for liquefaction.

The technique involves the systematic deposition of the tailings in thin layers and allowing each layer to dry out to a particular desired state prior to blanketing with a subsequent layer. Consolidation of the material is induced by the removal of the hydrostatic pore pressure distribution, and the development of large negative pore pressures that result from drainage and evaporation at the surface. Any pond on the tailings surface is kept to minimal proportions and, if practicable, entirely removed.

Initial testwork carried out included the determination of bleeding rates, settled and air-dried solids densities, viscosity characteristics and the permeability of the drained settled tailings. An independent laboratory provided information on grain size distribution, specific gravity and Atterberg Limits.

The three samples of tailings materials received were representative samples of the combined zinc tailings, and the two products of its separation into a pyrite concentrate and a non-pyrite tailings. At the request of Exxon Minerals, testwork was concentrated on the combined zinc tailings, which represented the tailings product from the currently favoured process flow sheet. Details of the tests carried out on all three materials, and the results achieved, are given in the Knight and Piesold report, reference document No. (i).

Subsequent to the above laboratory testing of the tailings materials, further testing was carried out on the combined zinc tailings to determine the shear strength, permeability and consolidation characteristics of the material. Details of these additional tests are contained in sub-sections which follow.

2.2 MATERIAL DESCRIPTION

The combined zinc tailings material is dark grey, predominantly silt sized material with a distribution of particle sizes from 75 microns to 3 microns. Particle size distribution curves determined by conventional hydrometer analyses are shown on Figure A1.

The Atterberg Limits of the material were as follows:

Liquid Limit	19.8
Plastic Limit	16.2
Plasticity Index	3.6

The material is essentially non-plastic which confirms the absence of any significant clay content.

The specific gravity of the material was determined, using standard laboratory procedure, as 3.46.

2.3 SLURRY CHARACTERISTICS

Sedimentation and drained sedimentation tests were carried out at various initial solids contents to determine the bleeding rates and settled densities of the material. The volume of supernatant water released in the sedimentation tests is representative of the water volume recoverable from a layer of tailings by physical settling of the solids alone. The drained sedimentation tests, while not strictly resembling field conditions, provide an assessment of the additional water recoverable due to gravity drainage.

The sedimentation tests indicated total bleed time for the slurry in the order of five to ten hours for a solids contents of 40%, increasing with increasing solids content to 24 hours for an initial solids content of 68.6%. Settled dry densities of the tailings solids increased with increasing initial solids content from 1.4 t/m^3 for an initial solids content of 40% to a maximum of 1.6 t/m^3 for an initial solids content of 68.6%. The results of the sedimentation tests are plotted on Figures A2 and A6.

The drained sedimentation tests showed a further increase in dry density of the tailings solids due to gravity drainage of approximately 10%. This increase was achieved irrespective of initial solids content. Results of the tests are plotted on Figures A3, A4 and A6.

Viscosity tests were carried out on the various slurries using a U.S. Corps of Engineers standard Flow Cone. The test allows an assessment of viscosity to be made by measuring the time of efflux of a specified volume of slurry from the cone. The apparent viscosity of the material remained low up to a solids content of 65%, at which point a rapid increase was observed. Results of the test are shown on Figure A5.

In practical terms the slurry could be pumped at a solids contents of up to 65% solids. The higher the solids content chosen, the higher will be the pumping head required, although the overall pumping costs remain roughly constant because the reduced through-put at a higher solids content offsets the increased head required.

2.4 EFFECTS OF AIR DRYING

Samples of tailings slurry were allowed to settle and air dry under monitored conditions to investigate the relationship between density, volume and moisture content during air drying of a layer of tailings material. Samples of the slurry at different initial solids contents were air dried in a monitored environment with routine measurements of sample weight and volume. The maximum dry densities of the tailings solids achieved by air drying are plotted on Figure A6.

The densities achieved by air drying represent an increase of approximately 25% over the densities that could be achieved by settling and drainage alone.

In general, air drying of the tailings after initial settling and supernatant runoff produces a significant increase in density. Once the surface is exposed, water is lost to the atmosphere by evaporation, resulting in a reduction in volume of the sample induced by capillary tensions, or negative pore water pressures, which act to maintain the saturation of the pore spaces. After continued air drying a stage is reached where the rate of volume reduction of the pore spaces is reduced by particle interaction, to less than the rate at which water is lost from the surface and air is introduced into the pores. The saturation then falls below 100%. Consolidation is generally found to continue until a certain saturation level is reached, depending on the material under test, and this corresponds to the maximum density than can be achieved by air drying of that material. Tests on other tailings materials have shown that very large negative pore pressures are induced by the air drying and that these negative pressures are maintained, provided the moisture content is not significantly increased from an outside source. For this material the maximum dry density was reached at a moisture content corresponding to a saturation level of 50%

However, drying to a moisture content corresponding to a saturation level of 80% was sufficient to achieve 95% of the maximum dry density.

Significant apparent cohesion was developed on air drying, and the resulting consolidated tailings material exhibited a dense competent structure. The apparent cohesion, however, is entirely due to the development of negative pore pressures and as the material approached zero moisture content, surface dusting became apparent. The apparent cohesion is completely dissipated by resaturation of the material.

2.5 STRENGTH AND CONSOLIDATION PARAMETERS

The shear strength parameters of the material were determined in a multi-stage consolidated undrained triaxial test with pore pressure measurements on a sample prepared by settling and drainage from an initial solids content of 50%. A multi-stage test was used due to the limited quantity of material available.

Shearing of the triaxial sample was carried out at consolidation pressures of 100, 200 and 400 kPa, using a failure criteria of maximum principal stress ratio to avoid excessive strains in each shearing stage. Permeability tests were also carried out at each consolidation stage. The strength parameters of the material were determined as:

$$c' = 0 \quad , \quad \phi = 37^{\circ}$$

A summary of the test results is included in Appendix A as Figure A7, with plots of the test results on Figures A8 to A17.

A single consolidation test was carried out in a $2\frac{1}{2}$ inch diameter oedometer with loading stages up to 1600 kPa. The sample was prepared by air drying of a single layer from a slurry of initial solids content of 50% to a moisture content of 24%. The test indicates a small preconsolidation pressure due to the limited air drying in the order of 125 kPa, which is equivalent to a surcharge loading of approximately 5 metres of saturated tailings. The coefficients of consolidation determined in the test concur with the values obtained in the triaxial tests. On the basis of the consolidation test the profiles of final dry densities within the tailings storage facility have been calculated and are shown on Figure A18. These show the anticipated increase in density with depth for fully drained tailings with varying degrees of air drying.

Detailed results of the consolidation tests are shown on Figures A19 to A23.

2.6 PERMEABILITY TEST RESULTS

Falling head permeability tests were carried out in the initial laboratory testing program on settled and drained samples of the tailings slurry. Further constant head permeability tests were carried out in the triaxial cell at each consolidation stage of the multi-stage shear test. The results of the tests are summarised below:

Consolidation Pressure kPa	Dry Density t/m^3	Coefficient of vertical Permeability m/s	
3	1.58	2.69×10^{-7}	- Settled and drained sample - no air drying
100	2.05	1.80×10^{-8}	
200	2.08	1.60×10^{-8}	
400	2.11	1.28×10^{-8}	

The tests indicate that the coefficient of permeability of the tailings material at the base of the final depth of tailings will be in the order of 1.3×10^{-8} m/s.

2.7 RECOMMENDATIONS

On the basis of the tests carried out it was recommended that the tailings be thickened to the maximum possible extent and delivered to the tailings storage area at a solids content of between 50% and 65%. This will cause a significant reduction in the water return from the tailings slurry and will reduce to the minimum practical limit the volume of water required to be lost by evaporation, in order to achieve the partially saturated condition and the increased final densities that result from air drying. The tests indicated that the density of the tailings solids that can be achieved with the implementation of the sub-aerial technique is greater than can be achieved with sub-aqueous deposition by approximately 25%.

SECTION 3 - SITE CHARACTERISTICS

3.1 REGIONAL TOPOGRAPHY

The Crandon Project is located in north-central Wisconsin at approximate latitude 48°29' N and longitude 88°54' W. The general location of the project site is shown on Figure 1 together with topographical details of the immediate area.

The regional topography is characterised by gently undulating glacial drift deposits with occasional drumlins originating primarily from the Wisconsin stage of Pleistocene glaciation. Upland areas are typically the result of glacial movements trending north-east to south-west. Glacial drift deposits of both till and stratified drift are found in the general area, with a predominance of till near the surface in the immediate vicinity of the proposed tailings storage area.

The proposed site for the tailings storage area is located at an average elevation of 510 metres above mean sea level, and is at present heavily wooded. The site is bordered on the east by Hemlock Creek, at an approximate elevation of 480 metres, on the north by Swamp Creek and on the west by Duck Lake and Deep Hole Lake. Surface drainage in the immediate vicinity of the storage facility is towards the south-west.

Details of the regional surficial geological origins of the area are reported by Golder Associates in reference document No. (ii).

3.2 HYDROMETEOROLOGY

3.2.1 General

Climatic data for the Crandon mine site (88°54'W, 45°29'N, elevation 1700 ft) was estimated from published data for nearby stations. The most relevant of these are listed below.

Station	Elevation ft.	Remarks
Laona 4 SSW	1670	Temp. and precip. before 1969
Laona 6 SW	1525	Temp. and precip. after 1969
Rhinelander	1580	Long term temp. and precip.
Rainbow Reservoir	1600	Evaporation, temp. and precip.

The Laona stations are closest to the Crandon site being within about 10 miles, but the period of available records is only 15 years. Much longer records are available for Rhinelander, which is about 28 miles WNW of the site. The published data are for the Wastewater Treatment Plant, and long term records in Rhinelander from 1980 are also available for Nicholet College. Rainbow Reservoir is about 38 miles NW of the site.

3.2.2 Climate

Crandon has the typical continental climate of interior North America. Temperature extremes range from about -30° to -40°F in winter to about 90°F in summer. Lakes remain frozen from about mid-December to early April, and the soil surface is frozen from early December to late March. Thunderstorms are frequent during July and August.

3.2.3 Precipitation and Temperature Normals

The available records for Laona were compared to those of Rhinelander, and other long term stations. It was noted that all stations showed similar mean annual precipitation. It was concluded that there is very little precipitation gradient across the area, and that the Rhinelander long term data closely approximates conditions at the Crandon site.

The precipitation and temperature normals (1941-70) for Rhinelander are given below:

Month	Precipitation, in.	Mean Temperature, °F
January	1.00	12.3
February	0.74	15.1
March	1.50	25.9
April	2.21	42.1
May	3.53	54.0
June	4.42	63.5
July	3.67	67.7
August	3.89	65.9
September	3.80	56.9
October	2.29	47.5
November	1 84	31.0
December	1.14	17.7
Year	30.03	41.6

About 6 in water equivalent of the annual precipitation above occurs as snow during the period mid-November through March.

3.2.4 Evaporation

Based on the evaporimeter data for Rainbow reservoir, and the Atlas (1) values for pan coefficient and water loss in winter, the following average monthly evaporation values were derived.

Month	Mean pan evaporation in. (1954-1980)	Estimated lake Evaporation, in
May	4.1(e)	3.2
June	5.09	3.97
July	5.44	4.24
August	4.43	3.46
September	2.76	2.15
October	1.6(e)	1.3
November through April*	-	4.9
Year	-	23.2

* including evaporation from snow.

(1) Climatic Atlas of the United States, June 1968.

(e) Estimated

3.2.5 Storm Rainfall

Data on storm rainfall were obtained from the published rainfall frequency atlases (1,2,3), and are summarised below:

Duration	Rainfall, in Return Period			
	5 yr	25 yr	100 yr	PMP
30 min	1.2	1.6	1.9	6.9
1 hr	1.5	2.0	2.4	11.3
6 hr	2.4	3.1	3.8	23.0
24 hr	3.2	4.2	5.0	27.6
7 d	5.2	7.3	9.0	48*

* estimated from world curve

(1) Rainfall Frequency Atlas of the United States, Soil Conservation Service, USDA, Technical Paper No. 40, 1961.

(2) Two to Ten Day Precipitation, Soil Conservation Service, USDA, Technical Paper No. 49, 1964.

(3) Design of Small dams, USBR, 1974.

3.3 GEOLOGY

Bedrock in the general project area is located at an elevation of between 420 and 460 metres, an average depth in the order of 70 to 100 metres below the ground surface. The regional trend of the bedrock surface in north central Wisconsin is a gentle dip of approximately 0.2 percent towards the east and south-east.

The bedrock in the area is an extension of the Canadian shield, comprised of Precambrian igneous and metamorphic rocks. Within the localised project area, the bedrock is primarily a metavolcanic tuff.

Detailed bedrock mapping has been carried out by Golder Assoicates and is presented in reference document No. (ii).

3.4 HYDROGEOLOGY

General groundwater flow patterns within the project area have been assessed on the basis of topographical features, and hydrogeological boreholes installed by Golder Associates and Dames and Moore. A detailed groundwater basemap has been developed by Golder Associates and is presented in reference document No. (v).

In general the topographical high on which the project area is located represents an area of groundwater recharge. The existing groundwater table reaches a high of 486 metres immediately to the north of the proposed tailings storage facility, with regional gradients towards and surface discharge into Hemlock Creek to the north and east, and Pickerel and Rolling Stone Lakes to the south. The closest point of surface discharge is into Hemlock Creek at an elevation of approximately 481 metres immediately to the east of proposed facility location.

A number of small lakes in the immediate vicinity of the site, including Duck Lake and Deep Hole Lake, are isolated above the groundwater table and represent probable areas of groundwater recharge. Potentiometric contours for the localised region of the facility are shown on Figure 1.

3.5 GEOTECHNICAL INVESTIGATION

Detailed geotechnical investigations of the project area have been undertaken by Golder Associates and are reported in reference documents Nos. (ii), (iii) and (iv). A brief summary of the relevant information is contained below.

"The predominant soil types from an engineering classification standpoint found at this site, and which apparently predominate over an even larger area, are granular materials ranging from silt to gravel size particles. The common combination of grain sizes in the samples obtained ranged from poorly graded sands with very little to some silt and combined sands and fine gravels with little to some silt. Small amounts of clay were sometimes noted mixed with the granular deposits. Boulders, cobbles and coarse gravels were also periodically encountered. The predominantly fine grained soils, silty clays, clayey silts, sandy silts and sands mixed with high proportions of silt were usually encountered in the wetland areas."

"From the geologic history and results of the penetration tests taken during the boring program, it is evident that the till and stratified drift materials are compact to dense within the upper 15 to 20 feet and very dense below this level. The individual grains of the granular materials are rounded to sub-angular. The high density of these materials, their grain angularity and their grain size make them excellent materials for embankment foundations and embankment construction. Although these soils may range from sands, gravels and cobbles with little fine material (silt and clay) to sands or sands and gravels with up to 40 percent fines (predominantly silt), their overall engineering strength characteristics will be similar, having high friction angles and little to no cohesion."

"The majority of all overburden materials encountered in the project area are granular soils, sands and gravels, with varying amounts of silt, sometimes traces of clay, and often including cobbles and/or boulders. Although the amount of clay in most samples was small, clay mineralogy tests by Dames and Moore (Ref. 1) indicate all samples tested to have montmorillonite clay (swelling clay) minerals present. In 13 of the 18 samples tested, more than 25 percent of the clay minerals present were montmorillonites. The presence of these swelling clays in the natural soils tends to create permeabilities lower than might be otherwise expected from soils with fairly low fines contents. This condition would be particularly noticeable where the clay content of the soil is more than a few percent, such as the till materials which are predominantly SM soils."

"The granular soils encountered at this site have been grouped into three catagories based on the percentage of fines (material passing the #200 U.S. Standard sieve). This grouping was selected because the fine grained portion of the materials which is the primary determinant of their permeability. The Unified Soil Classification System designations for coarse grained soils are differentiated at 5 percent and 12 percent fines content. Thus, the three groupings used herein are soils with less than 5 percent fines (GW, GP, SW, SP), soils with more than 12 percent fines (SM, GM) and soils having between 5 percent and 12 percent fines (borderline cases requiring dual symbols such as SP-SM or SW-SM)."

"The coarse grained soils with less than 5 percent fines were the least abundant of the granular materials. These soils are believed to be primarily coarse grained stratified drift materials and have estimated permeabilities ranging from 5×10^{-6} to 5×10^{-4} m/sec. The friction angle of these materials is estimated to range between 33 and 42 degrees depending on their specific grain size distribution and density. The permeability values are primarily estimated from grain size curves. No specific samples of this material were obtained from the test pits and density and friction angles have been estimated from the borehole penetration tests and experience. The band of gradations and typical gradation for the samples tested is shown on Figure B1."

"The soils having between 5 percent and 12 percent fines are very abundant throughout the soil profile. They are believed to primarily be coarse grained stratified drift but could be till. At higher elevations these materials are not commonly found at the ground surface. Based on the grain size distribution and borehole permeability tests, these soils are estimated to exhibit permeabilities between 5 x 10^{-7} and 5 x 10^{-5} m/sec. Friction angles are estimated to range between 33 and 40 degrees depending on grain size distributions and density. The typical gradation of these soils is shown on Figure B2 along with the range of grain size distributions for the samples tested.'"

"The predominant material found at the ground surface at the higher elevations has more than 12 percent fines. These soils are believed to be till and are abundant throughout the profile. Based on grain size distribution, borehole permeability tests and recompacted laboratory samples, these soils are estimated to exhibit permeabilities from 1 x 10^{-8} to 1 x 10^{-5} m/sec. Insitu density tests from the test pits ranged from 110 to 138 pcf (1.76 to 2.21 t/m^3) dry density. Triaxial shear tests on recompacted laboratory samples resulted in friction angles from 33 to 40 degrees. The method of preparation of the samples for triaxial testing limited the density of the specimens to the low end of the estimated range. Thus, a slightly higher friction angle range might be expected for the higher densities. The apparent cohesion suggested by the triaxial test results is believed to be an artifact of the test so that cohesion is not included as a strength parameter. The typical gradation of these soils is shown on Figure B3 along with the range of grain size distributions for the samples tested."

SECTION 4 - DESIGN OBJECTIVES

4.1 ENVIRONMENTAL OBJECTIVES

The fundamental objectives in the design of the tailings storage facility are:

i) Permanent, secure, and total confinement of all solid waste materials.

ii) Confinement of all contaminated waste liquids and control and strict monitoring of these liquids to ensure that seepage from the facility is reduced to minimal quantities. In particular such systems should ensure compliance with NR 182 requirements with regard to groundwater quality.

iii) Permanent facilities to monitor all aspects of the performance of the tailings storage facility including facilities to sample seepage water and to intercept, recover and treat this water if necessary.

iv) A decommissioning program which will ensure the long term security of the storage facility and yet require only minimal surveillance and maintenance.

v) Minimal aesthetic and environmental impact on the surrounding area.

4.2 ENGINEERING OBJECTIVES

In order to satisfy the environmental considerations for the design, the following engineering features are desirable:

i) The general location of the site should be such that all surface runoff from outside the boundaries of the site is minimal and can be permanently diverted away from or around the site.

ii) The confined waste materials should be located above, and isolated from, the natural ground water table, and have positive underdrainage and sealing systems which ensure that vertical seepage from the deposited waste materials can be intercepted and collected for recycling or treatment to the maximum practicable extent.

iii) All construction materials used in the embankments, filters and seals should be resistant to chemical attack from the contained materials and have permanent durability characteristics.

iv) All embankments should be designed and constructed to withstand erosion and have adequate factors of safety.

v) The method of deposition of the solid waste materials should be such that they are at least drained sufficiently to reduce the retained mass from a plastic to a solid state. Preferably this drainage should be such that all free draining liquid is removed to the extent that seepage discharge is completely eliminated by the time the project is decommissioned.

vi) A final seal should be constructed over the entire storage facility when the mine is decommissioned which will ensure that infiltration of precipitation and recharge of the pore spaces in the stored solids is eliminated.

4.3 DESIGN PARAMETERS

The tailings storage facility has been designed to the following parameters:

Total tonnage of tailings material :	33.041×10^6 tonnes
Annual production rates and cummulative tonnage of tailings solids as shown on Figure 5.0	
Average dry density of tailings as determined by laboratory tests :	2.0 t/m^3
Solids content of tailings slurry at deposition:	50%
Average number of days production per year :	350
Flood absorption capacity of facilities :	PMP volume*

* Detailed calculation of PMP volume would be part of final design.

SECTION 5 - DETAILS OF DESIGN

5.1 GENERAL DESCRIPTION

The most important objective of the design for the tailings storage facility is to achieve a partially saturated, drained and consolidated deposit of tailings such that seepage discharge to the environment will be reduced to negligible proportions during operation, and will be virtually eliminated by the time the operation is decommissioned.

This can be achieved by developing a system in which the liquid fraction of the tailings slurry is reduced after deposition by an amount sufficient to produce a partially saturated condition in the deposited solids. Due to the fine grading of the material this partially saturated condition develops the inherent capillarity in the pore spaces and induces high negative pore pressures which permanently retain any residual moisture in the material. Such a partially saturated deposit is physically incapable of yielding any seepage provided the negative pore pressures are not dissipated by recharge of the pore spaces with additional moisture from an external source, or re-saturation due to additional loading does not occur.

The design for the Crandon Project storage facility integrates a deposition strategy based on the sub-aerial technique with a comprehensive under-drainage system and underseal. The storage facility has been designed to minimise the aesthestic and physical impact on the area by limiting the maximum heights of the embankments, and to utilise the natural topography as far as possible to provide storage volume and natural confinements.

The proposed location for the tailings storage facility is immediately to the east of Duck Lake in the natural topographical lows forming a valley trending south-west towards Deep Hole Lake. Existing topography in the area and the outline of the facility are shown on Figure 2 In order to make maximum use of existing topography and to minimise the overall impact on the area, the facility will be split into two areas, designated Area 1 and Area 2, with maximum final elevations of 532 metres and 520 metres respectively. This optimum layout has resulted in the facility encroaching on the 1000 feet lake setback restriction for Deep Hole Lake and a variance to this restriction would have to be requested. The final layout and general arrangement of the facility are shown on Figures 3, 4 and 5.

The entire area under the tailings storage facility will be sealed to provide an impervious underseal graded towards the south-west end of the facility adjacent to Deep Hole Lake. The underseal will be covered by an underdrainge system comprised of a sand filter blanket, coarse filter blanket and perforated drainage pipes that will intercept and direct vertical seepage from the stored tailings to collector sumps. At decommissioning a single outlet point for the entire underdrainage system will provide a long term monitoring installation for the overall performance of the storage facility. A diagrammatic section through the tailings storage facility is shown on Plate I.

The depth capacity and depth area relationships for the two storage areas are shown on Figure 6 together with the production rates and cummulative tonnage of tailings material for the project. The two areas provide a total storage volume of 18 x 10^6 cubic metres with one metre of freeboard. For this conceptual design study the storage volume provided is conservative by up to 15%. The graduated build-up to full production over the first five years of operation of the mill will allow for phased construction of the storage facility, with Area 1 being constructed prior to mill start up and Area 2 being phased in at the beginning of 1992. Details of the proposed construction schedule are given in Section 8.0.

5.2 TAILINGS DEPOSITION

The tailings will be deposited from the south-west embankment of each area using the sub-aerial technique and will be managed in a manner such that

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DIAGRAMMATIC SECTION THROUGH TAILINGS STORAGE FACILITY

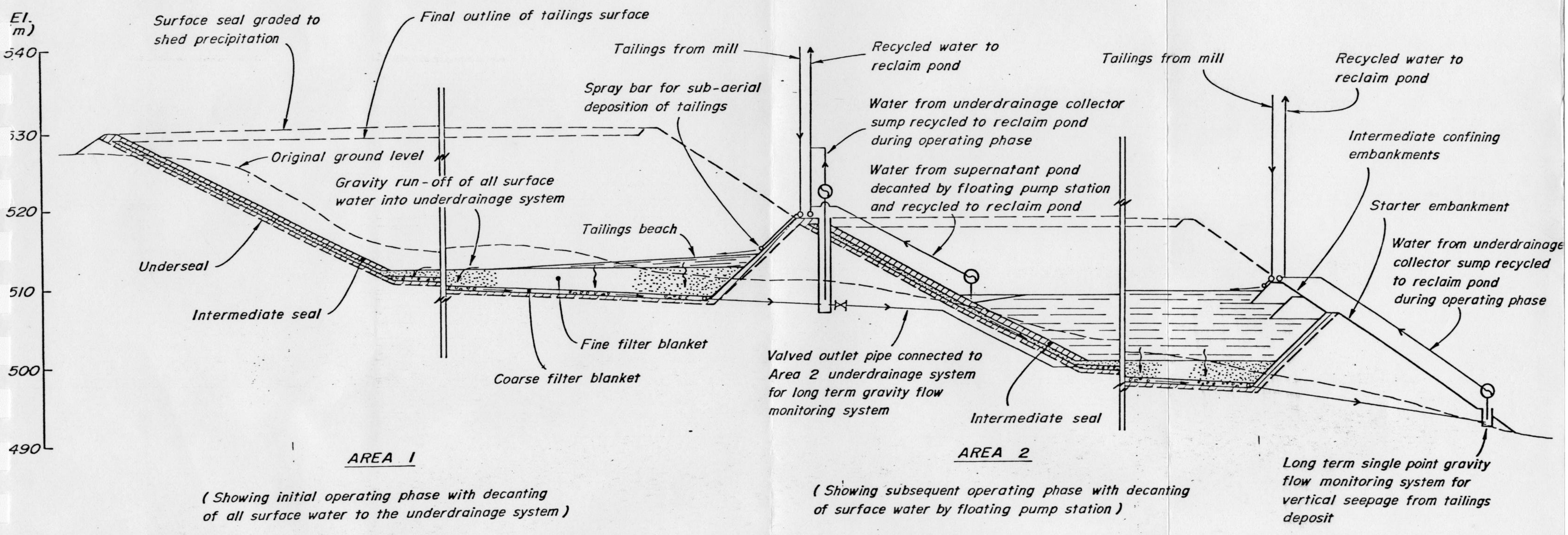

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PLATE I

the surface slopes towards the north-east edge of each area at the natural slope formed by the beaches. The general layout of the tailings distribution pipelines is shown on Figure 7. The natural shear strength characteristics of the tailings material will be utilised in the sections of embankment from which deposition is carried out, and details of embankment construction in these areas is given in Section 5.5.

In the sub-aerial technique the tailings slurry is discharged onto a section of gently sloping beach of previously deposited tailings by means of distribution spray bars located along the upper edge of the beach. After it leaves the spray bars the slurry flows gently over the sloping beach and forms a uniform layer. The slope of the beach and the thickness of the layer formed are functions of the characteristics of the slurry, typically the slope being between 0.2 and 1.0 percent and the thickness of the layer between 100 and 150 mm prior to settling.

Once the section of beach has been covered with the slurry, the discharge is moved to another section of beach and the newly deposited layer is left to settle, drain and bleed. During this process the coarser fractions settle towards the bottom of the layer and the finer fractions concentrate at the surface. The liquid released to the surface by the bleeding flows over the sloping surface to the bottom end of the beach and collects in the supernatant pond or is removed by a decant system. Because of the relatively flat slope of the beach the flowing liquid does not generate enough velocity to disturb the solid particles and the supernatant liquid is generally clear and free of suspended solids. In some cases the scrubbing action of the slow, laminar flow over the relatively rough surface helps to remove suspended solids from the liquids. Drainage of liquid from the newly placed layer also occurs during deposition and continues while settling and bleeding is taking place. The liquid draining from the bottom of the layer is absorbed by the air filled pore spaces in the partially saturated layer beneath, or, during the initial years of operation, collected by the underdrainage system. The amount of liquid from the newly placed layer absorbed by an underlying layer is a function of the void ratio and degree of partial saturation of the tailings solids.

The time required for settlement, drainage and bleeding to be completed is a function of the solids content of the slurry and the physical characteristics of the tailings solids, and in the case of the Crandon tailings will take up to 24 hours.

After the bleeding has ceased the layer is left exposed and additional moisture is removed by evaporation. Significant negative pore pressures are induced immediately after evaporation commences and this causes the solid particles to be drawn together or consolidate. The amount of consolidation that can be attained by drying shrinkage is governed by the characteristics of the solids and in general, finer materials will consolidate to a greater extent than coarser materials. By minimising the area of the supernatant pond the amount of moisture lost from the tailings material, and thereby inducing consolidation, is maximised, in contrast to conventionally placed subaqueous tailings in which evaporative losses generally only offset precipitation input into the pond.

An important characteristic resulting from the sub-aerial technique is the particle segregation which occurs during the settling of each layer. This produces an anisotropic condition in which the vertical coefficient of permeability can be up to two orders of magnitude less than the horizontal coefficient of permeability. This condition reduces the infiltration of precipitation into the deposit and helps maintain the partially saturated conditions in underlying layers. Consequently, the major portion of precipitation on the tailings beaches will be shed immediately and recycled to the reclaim pond.

After the tailings has been allowed to drain by gravity the high capillarity inherent in the fine grained material will retain residual moisture below a specific saturation level provided no additional water is permitted to enter the tailings. If the saturation level of the tailings is further reduced by air drying, then the tailings will absorb and retain additional moisture until this critical saturation level is reached.

The tailings for the Crandon Project will be delivered to the storage facility at a minimum temperature of 50°F. On the basis of climatic records and other factors, it is anticipated that it will be possible to deposit the tailings by means of the sub-aerial technique for at least 8 months of each year.

Deposition of tailings during the winter period, when sub-aerial deposition will not be possible, will be by open ended discharge over half of the available beach area to form a uniform layer, approximately 800 mm thick. The thicker layer deposited during the winter period will be left exposed during the ensuing spring and summer to thaw, settle, drain, and consolidate before any further tailings are placed over it. The area selected for winter deposition will be changed each year in order to distribute the thicker layers throughout the facility. This strategy will eliminate the possibility of any large, long term differential consolidation and will prevent the formation of lenses of frozen material being trapped in the tailings.

Dusting from wind erosion has historically been a problem at abandoned tailings sites in the United States, and experience has shown that most dust is raised during short period of high winds. As a precaution, provision will be made to introduce water into the tailings spray bars by interconnection with a water recirculation pipeline, thus allowing the tailings surface to be temporarily flooded in the event of unusually severe wind conditions and at any time once areas of tailings beach have dried out to the target saturation level. Conceptual details of the water recirculation system are shown on Figure 7. The tailings material, on exposure to air drying, develops an apparent cohesion due to the development of large negative pore pressures. These pore pressures will be destroyed by resaturation of the material, which would not, however, make the tailings susceptible to wind erosion, or by excessive drying, which poses the principal danger to wind dispersion of the tailings solids.

The drained and consolidated condition of the deposited tailings will greatly facilitate decommissioning and reclamation when mining operations cease, and it will be possible to immediately construct a permanent seal over the facility. Unique features of the design are that at full storage capacity and at any time during deposition no excess pore pressures exist within the tailings mass, and the tailings material has been consolidated to densities over and above those that could be achieved by physical loading and dewatering of conventionally placed tailings. Settlements during construction of the final seal will be immediate and will be a function of the compressibility of the consolidated tailings only.

5.3 SEEPAGE CONTROL

There are two primary sources contributing to the potential for seepage from the tailings storage facility. The first of these is from precipitation, and the second is from the excess free liquid in the tailings slurry which is released from the slurry after it has been deposited. The deposition strategy and operational management of the facility will be such that water from precipitation and supernatant liquid will not be permitted to pond on the surface of the deposited material, but will drain rapidly over the sloping, relative impervious surface of the beach to a small surface pond, from which it will be removed by a floating pump station. A significant further proportion of the liquid remaining in the tailings after deposition and settling will be removed by evaporation from the exposed beaches.

These measures in effect eliminate the major portion of the sources for potential seepage from the storage facility. The potential for seepage of any residual moisture to occur after tailings have been managed and deposited in this manner can be completely eliminated if the evaporation losses are sufficient to reduce the moisture content in the stored tailings to a partially saturated condition in which the air space within the pores has the capacity to absorb the vertical seepage from a newly placed layer and rainfall infiltration without becoming re-saturated.

In addition to the deposition management and strategy, the design of the storage facility provides for the interception and collection of vertical seepage from the stored solid waste materials by means of a comprehensive underdrainage system installed immediately beneath the tailings. This will ensure that the drained condition of the entire mass of stored waste materials will be permanently maintained. By maintaining a fully drained condition within the tailings, and by continuously removing any vertical seepage within the underdrainage system as it occurs, thereby preventing any build-up of hydrostatic head on the underseal, seepage losses through the underseal into the environment will be reduced to a practical minimum.

5.4 UNDERDRAINAGE SYSTEM

A key element in the design of the tailings storage facility is the underdrainage system and underseal. In the short term the underdrainage system will collect all surface runoff and vertical seepage from the tailings, and in the long term will remain as a monitoring system on the storage facility to collect any long term percolation that may occur.

The underseal is essential to minimize the amount of seepage from the facility to ensure that the required primary and secondary drinking water standards are met in the groundwater at the compliance boundary. The inclusion of a drainage blanket immediately above the underseal greatly enhances the efficiency of the seal by significantly reducing the hydraulic gradient across it, and the most efficient design of the combined underseal and underdrainage system represents a major component of the overall facility in terms of both performance and capital expenditure.

The predominant material type occuring at the site is a till containing more than 12 percent fines and broadly designated SM and GM, as shown on Figure B3. Excavation for the tailings storage facility will be almost entirely in this material and as such it provides an abundant source of material that could be processed to provide the component materials of the underdrainage system and underseal. Considerable advantages accrue in using this material in terms of long term durability, reduced cost and reduced impact on the surrounding area.

The material contains an average of approximately 24 percent minus 200 mesh silt and clay sized particles and it is proposed that this fraction would be separated, using a screw feed coarse material washer-dewaterer set-up, to provide the principal component of the underseal. In order to minimise the vertical seepage through the seal, a high permeability drainage zone is required immediately above the seal which in turn requires separation from the tailings material by a fine filter layer. The required fine and coarse materials can be produced by screening of the washed sand and gravel fraction of the till and separation on approximately a No. 4 mesh to provide the two material components.

The underdrainage system has been designed with the underseal sloping towards the south-west end of the facility so that long term gravity drainage of the system will be possible. The underseal is also extended up the sloping sides of the facility so that all the tailings material is fully confined. The silt and clay fraction from the washing plant will be pumped as a slurry and deposited in paddocks on the base of the facility in a similar manner to the proposed tailings deposition. In this way the underseal will be built up of a number of thin layers of silt and clay, and the full benefit of the clay fraction, which has a large percentage of montmorillonite clays, will be gained in the laminations and vertical segregation of the material within each layer. Construction of the paddocks and deposition of the underseal would take place progressively across the area in close proximity to the point of excavation by using a mobile washing and screening plant. Subsequent placing of the coarse and fine filter layers would be carried out from stockpiles after deposition and optimum drying of each area of underseal. Paddock walls required between areas of deposition of the underseal would be removed. On the basis of the anticipated split within the till material, the final thickness of underseal constructed in this manner would be in the order of 400 mm.

Construction of the underseal on the sloping sides of the facility will be carried out by blending into the in-situ material additional quantities of the silt and clay fraction, moisture conditioning and compacting. On the upstream edges of both areas an additional seal and filter layer is provided immediately beneath the location of the supernatant pond to prevent an excessive head build-up on the underseal in this area. Drainage of intercepted seepage water within the coarse filter layer will occur along the sloping underseal, and will be augmented by a comprehensive network of perforated polyethylene drainage pipes leading towards the underdrainage collector sumps at the low points within each area. Details of the underdrainage system and underseal are shown on Figures 4 and 5.

On the basis of available information on the proposed construction materials it is anticipated that the following target material parameters could be readily achieved.

Coefficient of permeability:

coarse filter material	- 1×10^{-2} m/s
underseal	- 1×10^{-9} m/s

The proposed design of the underdrainage system with the above assumed material parameters would result in a maximum total seepage quantity through the underseal in the order of 115 m^3 per day (21 US gpm). This estimated maximum quantity applies both to the initial deposition condition in which all surface water is decanted through the underdrainage system, and to the normal operating condition with a supernatant pond and floating pump station, in the early years of operation. This quantity will reduce as the depth of tailings with the facility increases.

The total seepage quantity is directly proportional to the coefficient of permeability of the underseal and specific testing of these materials would be required to confirm the assumed parameters. Target values better than those assumed may be practical to achieve by the proposed methods.

An additional or alternative method to achieve the required permeability of the underseal would be the blending in of bentonite, a naturally occuring clay comprised of swelling-type sodium montmorillonite. The addition of this material in relatively small quantities, with correct handling would allow coefficients of permeability of 1×10^{-9} m/s or less to be readily achieved. The use of bentonite, however, requires the importing of large quantities of additional material, and the competency of the seal in the presence of the specific seepage water characteristics would require positive confirmation. We do not believe that it would be necessary to use this alternative and it is cited merely to indicate that a viable alternative is available.

5.5 EMBANKMENT CONSTRUCTION

The tailings materials will be confined on all sides by embankments constructed or faced with inert naturally occuring till material. In areas where the facility is predominantly in a cut section and the required height of embankment is small, the embankments will be constructed to full height in the initial construction phase using till material from the necessary excavations. The in-situ till material, with correct handling, is readily suitable as such a construction material, with high strength and low compressibility characteristics.

In areas where the required confining embankment height is in excess of 12 metres, the embankments will be constructed utilising the engineering strength characteristics of the tailings materials themselves, thereby achieving a considerable saving in both material handling and physical size of the facility required. As described in Section 5.2, such areas will be the deposition points for the tailings slurry using the sub-aerial technique. All embankments constructed using the tailings material are underlain by the underdrainages system thus ensuring full drainage of the material with no possibility of a build-up of excess pore pressure within the embankment sections.

During deposition and air-drying of the tailings, consolidation is induced by evaporation at the surface and the development of large negative pore pressures. This preconsolidation, and resulting increase in density, will allow the full shear strength characteristics of the material to be developed as deposition and build-up of the embankment proceeds. The slurry will initially be discharged within a confining embankment at elevation 518 for Area 1 and elevation 506 for Area 2 When the surface of the tailings comes within one metre of this embankment crest, an intermediate confining embankment will be constructed from till material, on top of the existing tailings, to provide an additional 2 metres of freeboard. Deposition would then continue, with the addition of further lifts up to the full height of the embankments. Construction of each lift would be at approximately three yearly intervals in each area, and would be scheduled for the latter part of the summer when full drying shrinkage of the tailings adjacent to the embankment would have occured. The rate of confining embankment construction will be designed to meet the undrained strength and consolidation characteristics of the material. Dissipation of any excess pore-pressure that may result from construction of each lift is estimated to be complete within one day.

Laboratory testing of the tailings material has shown the material to have shear strength parameters of $c' = 0$, $\phi = 37^{o}$. On the basis of the design downstream slopes of 1 in 3, this will result in a factor of safety of 2.26 for fully drained conditions. Such conditions are likely to prevail at all times. In the extreme event of the underdainage system becoming non-operational and with the development of a hydrostatic pore-pressure distribution within the embankment, the factor of safety would reduce to the order of 1.0, with critical failure surfaces being located on shallow surface slip circles. However, the likelihood of this situation ever developing is extremely remote and would be clearly indicated well in advance with the installation of normal geotechnical instrumentation. Outline details of such instrumentation is given in Section 6.0.

Progressive construction of a large portion of the overall confining embankments using the tailings material itself will result in considerable savings in materials handling, with an estimated reduction in excavation and placing of fill material of 2.4×10^{6} cubic metres for the conceptual facility layout, together with an equivalent loss of available storage volume.

5.6 WATER BALANCE

The estimated average daily water balance for the tailings storage facility is shown on Plate II. The water balance has been calculated on the basis of estimated hydrometeorological data for an average year, as given in Section 3.2, and the design parameters outlined in Section 4.3. Precipitation and evaporation figures have been averaged over a 365 day period. The following assumptions have been made:

1. Water inflow is based on a maximum tailings production of 3934 tonnes per day at 50% solids. Water input with the slurry will therefore be 3934 cubic metres per day.

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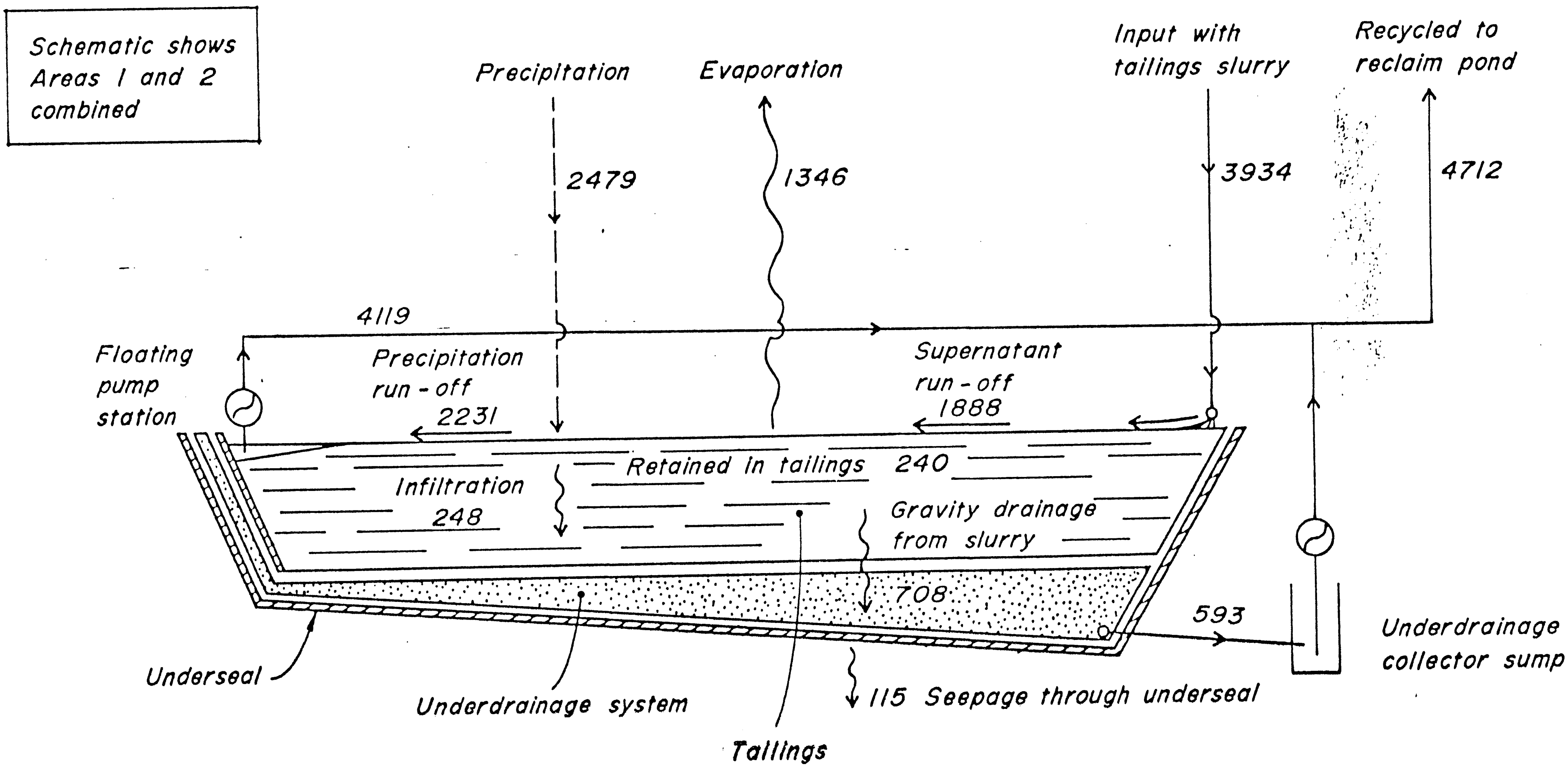
IDEALISED WATER BALANCE FOR FULL TAILINGS PRODUCTION
FLOWS IN M^3/ DAY



NOTES:
1. Total catchment area : 115 ha
2. Average surface area of tailings beach : 106 ha
3. Tailings input : 3934 tonnes per day at 50 % solids
4. Precipitation and evaporation averaged over 365 days
5. All flows are in m^3 water per day
6. Seepage through underseal is for coefficient of permeability of 1×10^{-9} m / s

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PLATE II

2. Mean annual precipitation 787 mm
   Mean annual potential lake evaporation 465 mm

   No allowance has been made for evaporation from snow.

3. Water distribution for a slurry deposited at 50% solids
   Supernatant bleed 48% of water input
   Gravity drainage 18% of water input

4. Target moisture content of of tailings material : 10% of solids weight

5. Total catchment area: 115 ha
   Average surface area of tailings: 106 ha

6. An average runoff coefficient of 0.9 has been used for precipitation. Infiltration on saturated areas of beach will be virtually nil, and on unsaturated areas will be relatively high until saturation of the surface is achieved.

7. The estimated maximum vertical seepage through the underseal is for a coefficient of permeability of 1.0×10^{-9} m/s.

The minimum required area of the tailings facility should ideally be such as to allow for the loss by evaporation of the retained water after bleeding and gravity drainage to a target moisture content corresponding to the maximum drying shrinkage that can be achieved. For an initial solids content of 50%, this required evaporative loss is equal to 23.5% of the water input. The existing design for the facility is conservative in the area provided, partly due to a maximum elevation limitation for the final embankments, and is larger than the minimum requirement by approximately 40%. However, this extra area will have the resulting advantage that any additional drying of the tailings will provide further capacity for absorption of vertical seepage from subsequent layers and infiltration of precipitation. This will result in a further decrease in the infiltration into the underdrainage system and hence seepage through the underseal.

The average volume of water being recycled to the reclaim pond is estimated at 4712 cubic metres per day, reducing to a minimum of 4119 cubic metres per day as the depth of tailings increases and recovery of water from the underdrainage system decreases.

It should be emphasized that retention of water within the tailings facility is disadvantageous to the overall system and the maximum volume of water should be decanted at all times. The reclaim pond should therefore be sized to accommodate the seasonal fluctuations in the water return from the tailings facilities with peak inflow most likely in the spring thaw period. Pump capacity within the underdrainage sumps and the floating pump stations will be sized to handle the maximum potential inflows in a reasonable period of time.

In calculating the estimated water balance for the tailings storage facility, no allowance has been made for evaporation from snow. In order to provide a more accurate water balance further work would be required in this area, together with a detailed assessment of evaporation rates from the actual tailings surface. Such additional work would also include estimates of the monthly variation in return water flows from the tailings facility.

SECTION 6 - MONITORING

6.1 GENERAL

Instrumentation of the tailings storage facility will be included in the design to monitor various aspects of the performance of the facility during operations. Such instrumentation will be permanent and will remain as an essential feature of long term monitoring of the storage facility. The instrumentation will be made up of the following components:

(i) Embankment piezometers. These will monitor flow conditions within the structural and drainage zones of the embankments.

(ii) Foundation piezometers. These will monitor flow conditions beneath the storage facility and will form an essential part of the performance monitoring of the underseal.

(iii) Continuous flow recorders. These will provide continuous recording of flows from the underdrainage and supernatant recovery systems.

6.2 EMBANKMENT PIEZOMETERS

Embankment piezometers will be of two different types. In all zones upstream of the starter embankment centrelines, piezometers will be twin tube pneumatic type piezometers with high air entry ceramic tips. Due to the fluctuating flow conditions within the tailings material and drainage zones, and the probability of unsaturated flow conditions, air will gradually diffuse into the piezometer tips. Provisions will therefore be made for de-airing of the tips using two additional tubes for each tip through which water can be circulated. As a precaution against mechanical failure each tip location will have a duplicate piezometer installation. Downstream of the starter embankment centrelines, pneumatic piezometers will be duplicated with stand-pipe piezometers. Provision will be made for placing de-airable pneumatic tips directly within the structural zone of the tailings mass by placing leads through the starter embankment during construction. All pneumatic piezometers leads will be led in trenches through the embankment to monitoring terminals on the downstream face. Reading of the piezometers will be carried out on a routine basis using portable readout equipment.

6.3 FOUNDATION PIEZOMETERS

Foundation piezometers will be standpipe piezometers with perforated screened sections below the existing groundwater table. Standpipe piezometers lcoated along the embankment centrelines will form the principal monitoring locations for groundwater quality and performance monitoring of the underseal.

Additional piezometers will be located at the compliance boundary for groundwater quality regulations. Preliminary details of the layout of groundwater monitoring foundation piezometers are shown on Figure 3.

The water quality parameter which would first reveal the presence of seepage from the tailings is likely to be SO_4 ions. Since these ions would occur in significant concentrations, their appearance could easily be detected by an increase in specific conductivity of the groundwater. Specific conductivity measurements can be easily carried out in the field by means of down hole logging and would form the basis of a routine monitoring program. Sampling of groundwater and a full analysis would be carried out on a less frequent basis, or if specific conductivity readings justified futher investigation.

6.4 CONTINUOUS FLOW RECORDERS

The underdrainage collector sumps and floating pump stations will be designed for independent recording of the flows. Recording of the flows will be carried out downstream of the pumps using magnetic flow meters, or similar devices. All flows will be continuously recorded on digital flow recorders located within the pumphouses. Continuous recording of the flows will provide monitoring of the performance of the underdrainage and supernatant recovery systems and, combined with hydrometeorological and moisture content data for the tailings material, will allow an annual water balance for the storage facility to be calculated.

The underdrainage system will remain as an important feature of long term monitoring of the facility. Recording of flow rates from the system will continue to be possible after decommissioning, in the unlikely event that any continuing seepage from the tailings will occur.

SECTION 7 - CLOSURE AND LONG TERM CARE

7.1 DECOMMISSIONING

During the final two years of operation the location of the tailings deposition spray bars will be moved progressively towards the supernatant pond in order to counteract the natural slope on the tailings beaches and to fully utilise the available storage volume. This will also allow areas of tailings beach behind the discharge point to be shaped prior to installation of the surface seal.

Decommissioning will be possible immediately after tailings deposition ceases when the entire surface of the tailings facility will be covered with a surface seal. Specific details of the seal will be decided at the time of decommissioning. However, the surface seal would likely accommodate an impervious layer overlying a coarse filter layer that would be drained at all times. This coarse filter layer can provide an effective barrier to vertical migration of seepage by producing a capillary break at the interface. Resaturation of the coarse layer is then required before any downward movement of water will take place. If infiltration into the impervious layer is small compared to evaporation, the unsaturated condition of the coarse layer can be maintained. The requirements of the seal will be to ensure that infiltration of precipitation into the tailings and erosion of the surface are reduced to the maximum practical extent. Construction of the surface seal will likely require further processing of stockpiled till material.

All direct precipitation onto the area will be shed towards the surrounding embankments where it will be discharged down the embankment slopes in structures suitably protected against erosion prior to discharge into the natural environment. The surface of the facility will be recovered with topsoil after completion of the seal, and revegetated in a manner suitable to complement existing features, whilst ensuring a high percentage runoff over the particular area.

7.2 LONG TERM MONITORING

The entire storage facility is located above the natural water table thus eliminating any possibility of resaturation of the tailings from beneath. The underdrainage collector and supernatant recovery systems will remain intact and the sumps will provide permanent monitoring installations for any future seepage from the tailings mass, and will continue to provide the means to collect and treat this water in the unlikely event that this should ever occur.

All piezometers and groundwater sampling points will be regarded as permanent installations to monitor the long term performance of the storage facility.

SECTION 8 - CONSTRUCTION SCHEDULE AND COST ESTIMATES

8.1 CONSTRUCTION SCHEDULE

The tentative construction schedule for the tailings storage facility is shown on Plate III. Construction of Area 1 would be required to commence in 1987 with completion by July, 1989, with construction of Area 2 commencing in 1991 and completion by the spring of 1993.

A summary of the material handling requirements for completion of the two areas is shown diagrammatically on Plate IV. In calculating the cut and fill balance for the required material handling, an increase of 10% in the compacted dry density of the material over the in-situ density has been assumed.

8.2 COST ESTIMATE

Preliminary capital cost estimates for the conceptual design have been calculated on the basis of 1981 U.S. dollars. The estimated capital costs for the facility are presented below in relation to the proposed construction schedule for the facility:

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TAILINGS STORAGE FACILITY CONSTRUCTION SCHEDULE

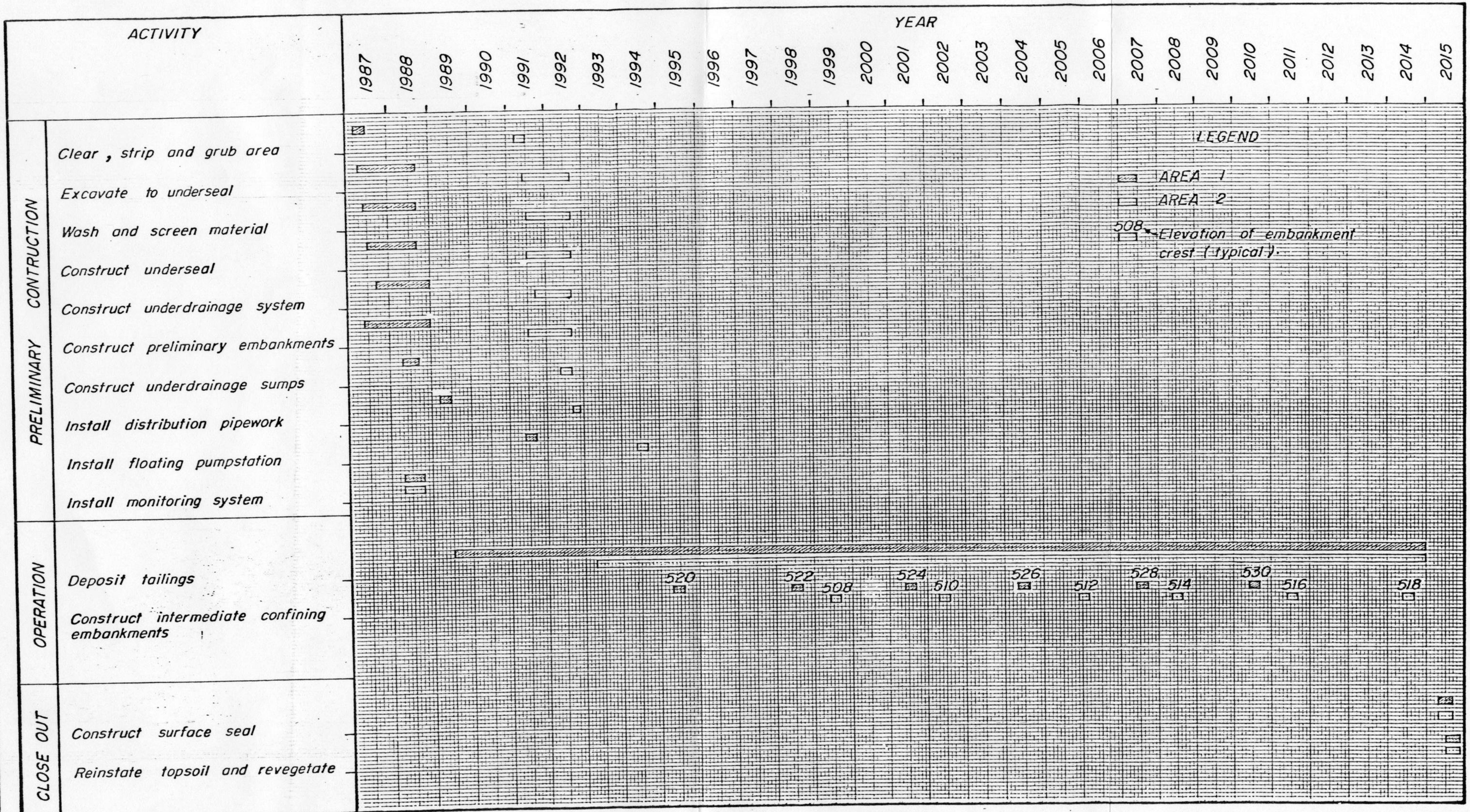

PLATE III

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CONSTRUCTION MATERIAL HANDLING REQUIREMENTS

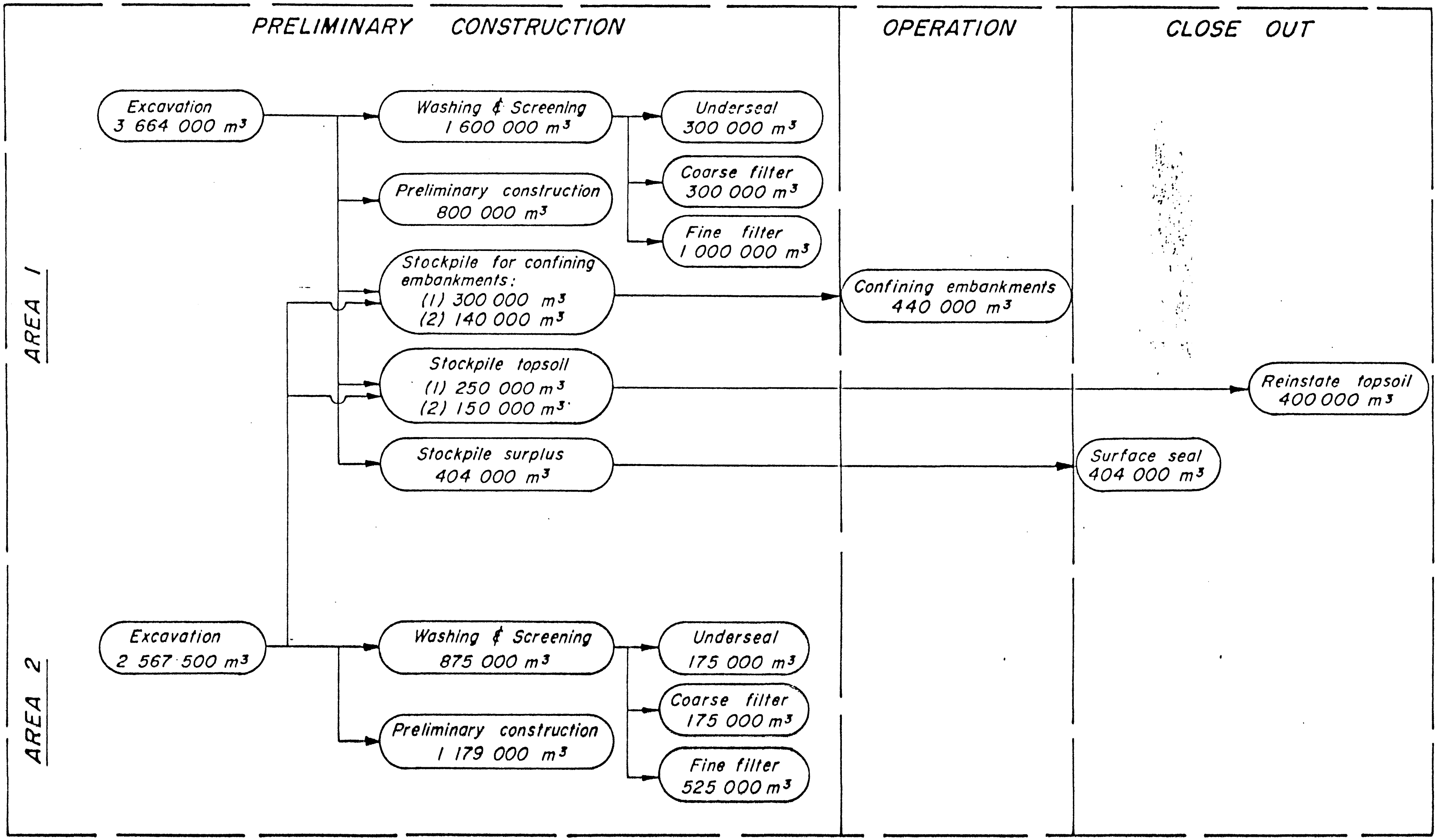
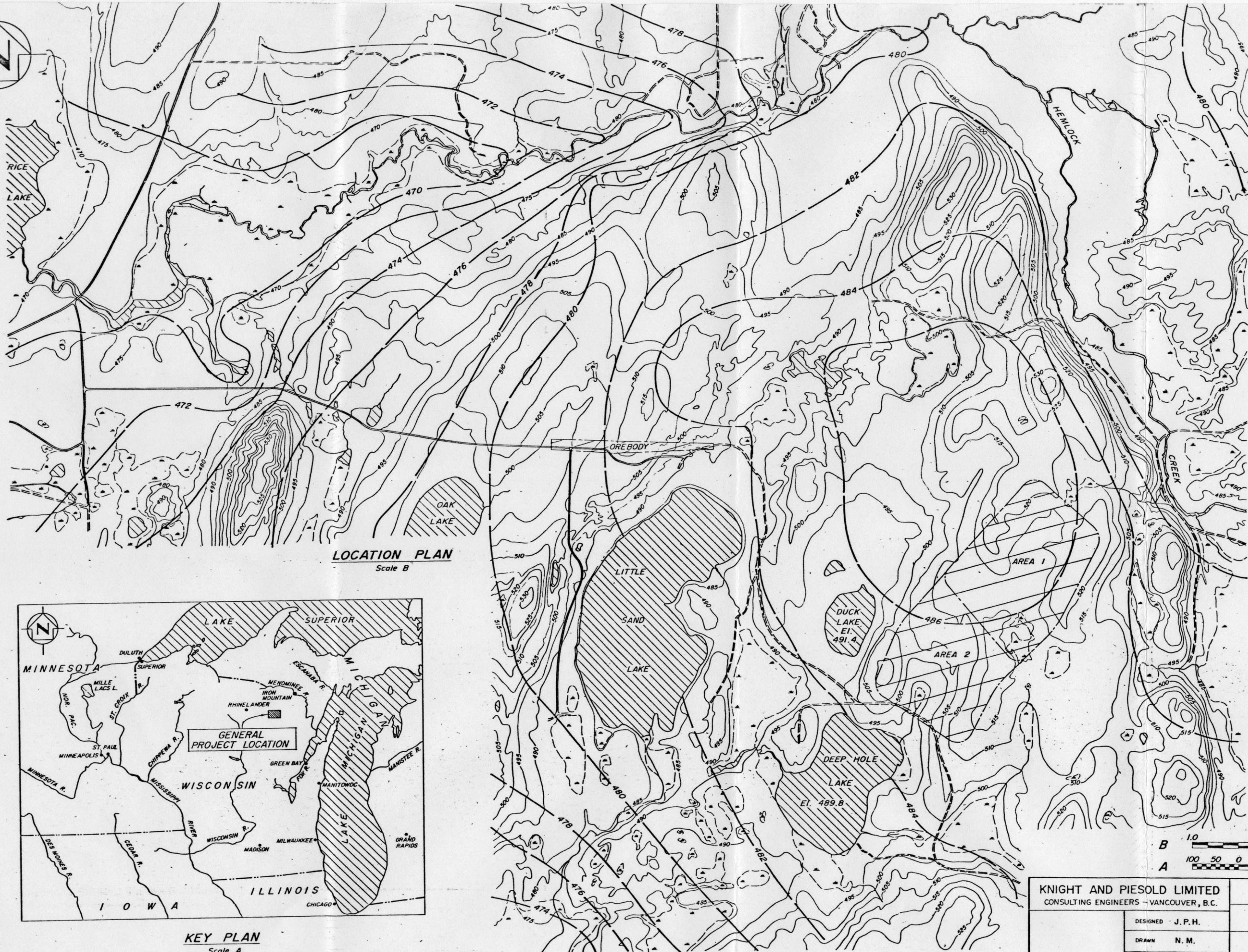


PLATE IV

Activity	Year		Amount (1981 US $)
1 Preliminary construction of Area 1	1987	1989	15,250,000
2. Preliminary construction of Area 2	1991	1992	10,750,000
3. On-going construction of Areas 1 and 2	1995	2014	800,000
4. Close out	2015		5,200,000
Total estimated capital cost			$ 32,000,000

Operating costs will be limited to one full time operator on one shift per day, routine maintenance on all pumps and fittings and the power consumption of the pumps. This has not been estimated at this stage as the location of the reclaim pond is not known. In addition, relocation of the tailings distribution pipelines will be required every three years in each area, for each additional lift of confining embankment.



LOCATION PLAN
Scale B

KEY PLAN
Scale A

NOTES

1. All elevations are in metres.
2. Groundwater potentiometric contours interpolated from Golder Associates Drg. No. 050-1-81106

LEGEND

- Wetlands
- Creek
- Paved road
- Gravel road
- Lake
- Groundwater contours
- Centreline of embankment

B 1.0 .5 0 .5 1.0 km

A 100 50 0 100 200 300 400 500 km

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DESIGNED	J.P.H.
DRAWN	N.M.
CHECKED	[signature]
APPROVED	

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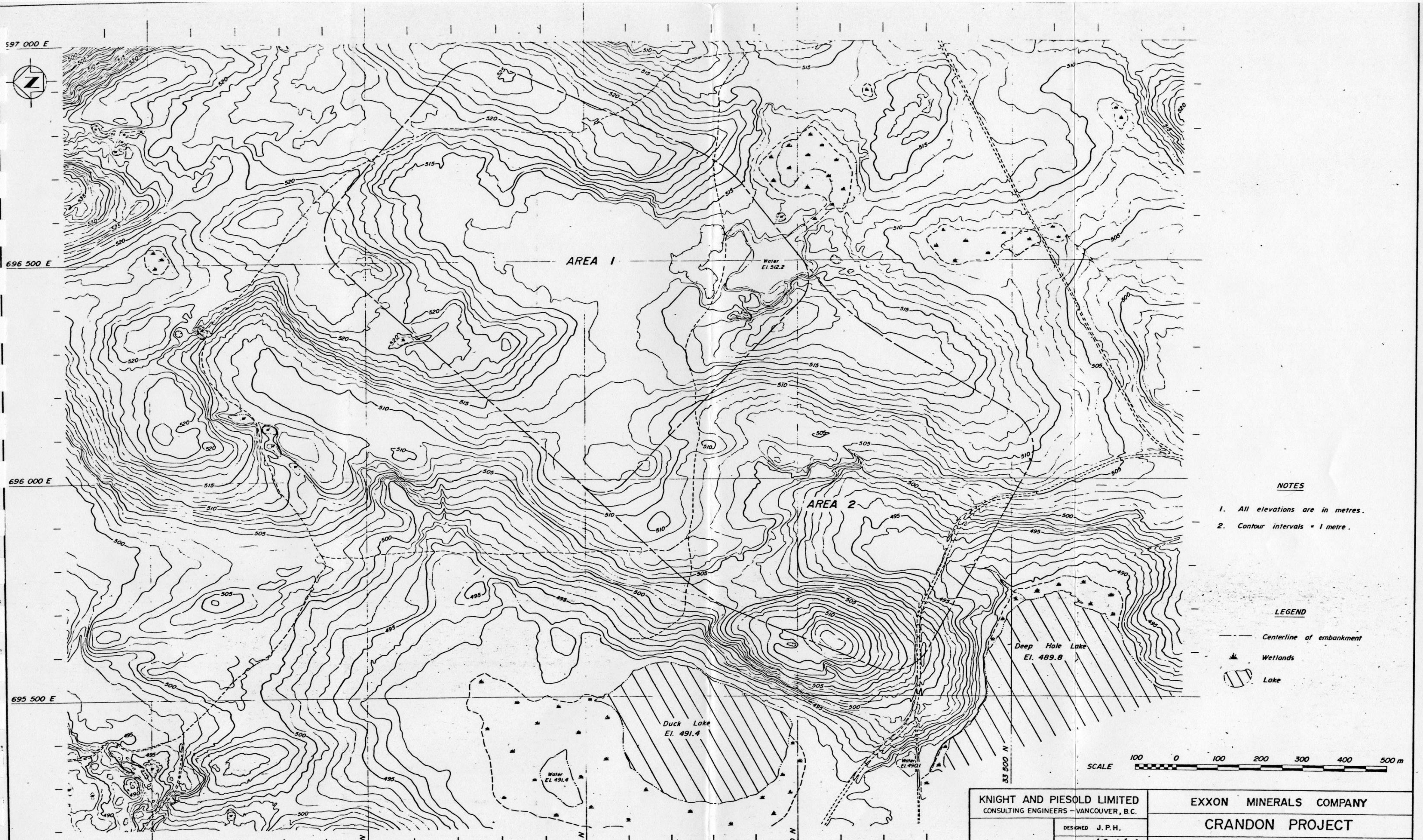
CRANDON PROJECT

TAILINGS STORAGE FACILITY
GENERAL PROJECT LOCATION

DRG NO	DESCRIPTION	REV	DATE	DESCRIPTION	APPROVED	REV	DATE	DESCRIPTION	APPROVED
REFERENCE DRAWINGS		REVISIONS				REVISIONS			

DATE OCT. 30, 1981 | SCALE AS SHOWN | DRG. NO. 3113.101 | REV.

FIGURE 1

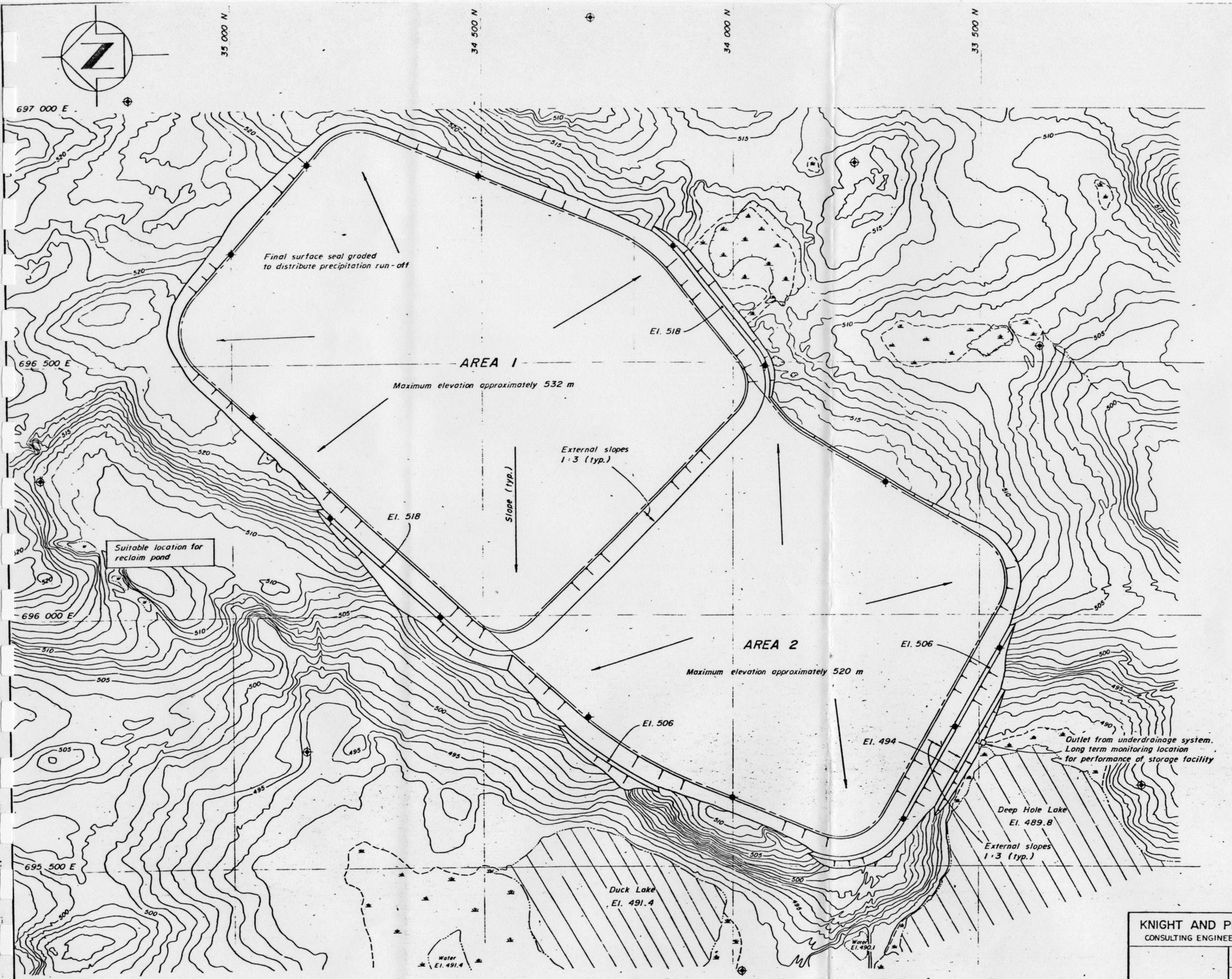


KNIGHT AND PIESOLD LIMITED CONSULTING ENGINEERS – VANCOUVER, B.C.	EXXON MINERALS COMPANY
DESIGNED J.P.H.	CRANDON PROJECT
DRAWN [signature]	TAILINGS STORAGE FACILITY EXISTING TOPOGRAPHY
CHECKED [signature]	
APPROVED	

DRG. NO	DESCRIPTION	REV.	DATE	DESCRIPTION	APPROVED	REV.	DATE	DESCRIPTION	APPROVED
REFERENCE DRAWINGS		REVISIONS				REVISIONS			

DATE OCT. 30, 1981 | SCALE AS SHOWN | DRG. NO. 3113.102 | REV.

FIGURE 2



NOTES

1. All elevations are in metres.
2. Contour intervals = 1 metre.

LEGEND

Top of embankment

Centerline of embankment

Wetlands

Lake

Foundation piezometers - primary groundwater monitoring locations

Compliance boundary monitoring piezometers

SCALE 100 0 100 200 300 400 500 m

DRG. NO.	DESCRIPTION	REV.	DATE	DESCRIPTION	APPROVED	REV.	DATE	DESCRIPTION	APPROVED
REFERENCE DRAWINGS		REVISIONS				REVISIONS			

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DESIGNED J.P.H.
DRAWN N.M.
CHECKED J.P.H.
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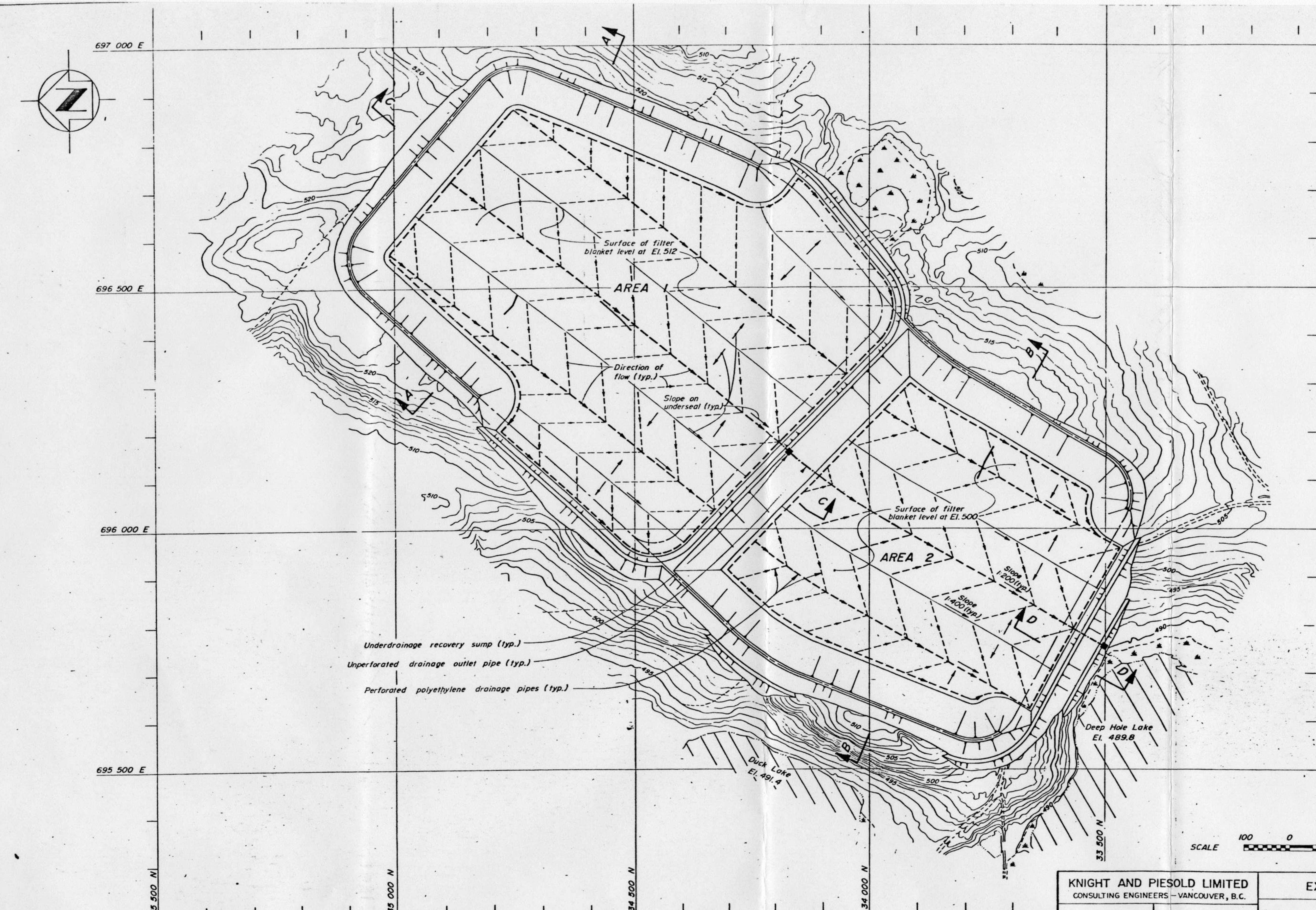
TAILINGS STORAGE FACILITY
FINAL LAYOUT

DATE OCT. 30, 1981 | SCALE AS SHOWN | DRG. NO. 3113.103 | REV.

FIGURE 3



NOTES

1. All elevations are in metres.
2. Contour intervals = 1 metre.

LEGEND

Top of embankment

Centerline of embankment

Wetlands

Lake

SCALE 100 0 100 200 300 400 500 m

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	DESIGNED J.P.H.	CRANDON PROJECT	
	DRAWN	TAILINGS STORAGE FACILITY DETAILS OF PRELIMINARY CONSTRUCTION AND UNDERDRAINAGE SYSTEM	
	CHECKED		
	APPROVED		
DATE OCT. 30, 1981	SCALE AS SHOWN	DRG. NO. 3113.104	REV.

DRG NO	DESCRIPTION	REV.	DATE	DESCRIPTION	APPROVED	REV.	DATE	DESCRIPTION	APPROVED
REFERENCE DRAWINGS		REVISIONS				REVISIONS			

FIGURE 4

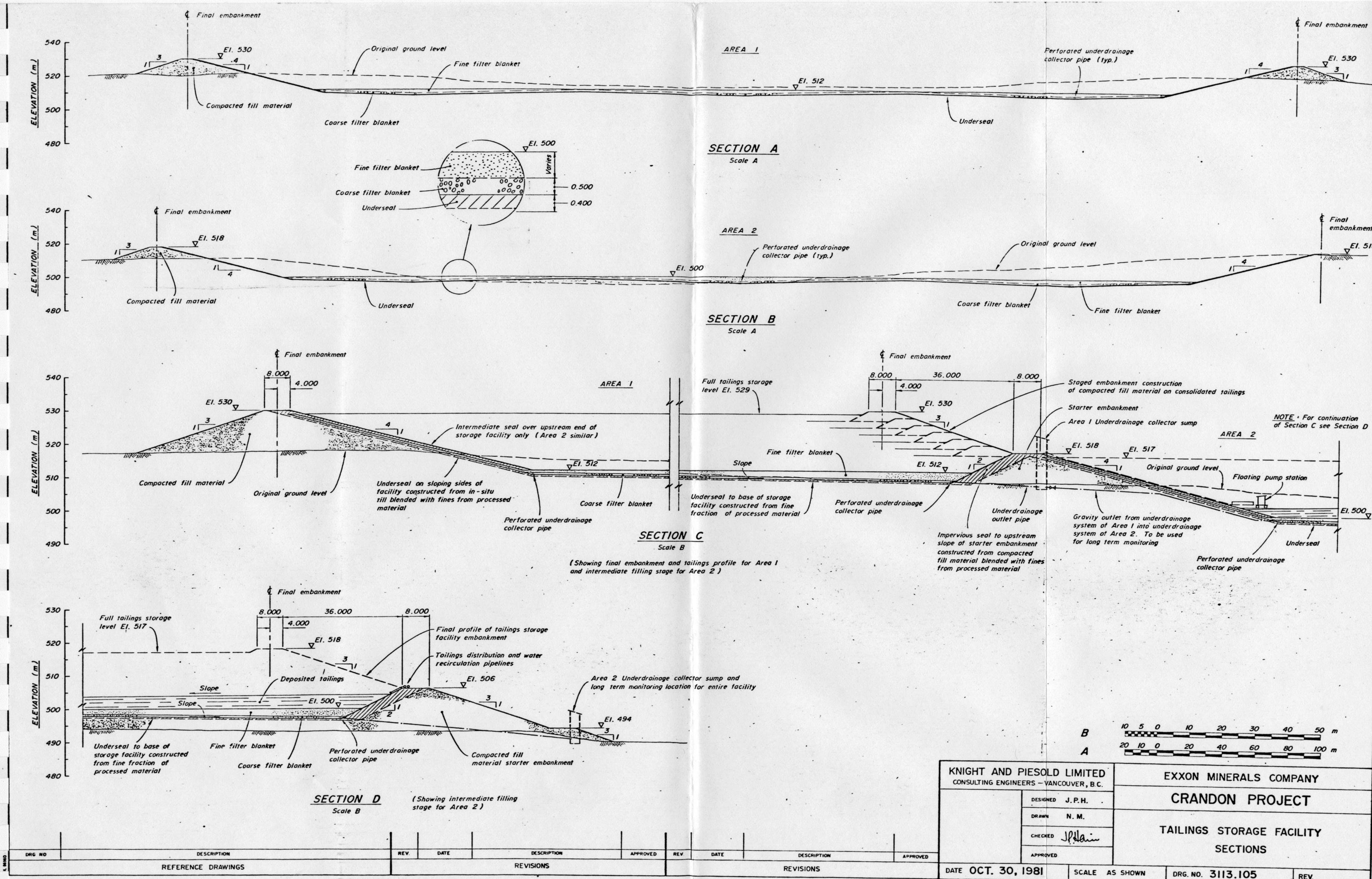
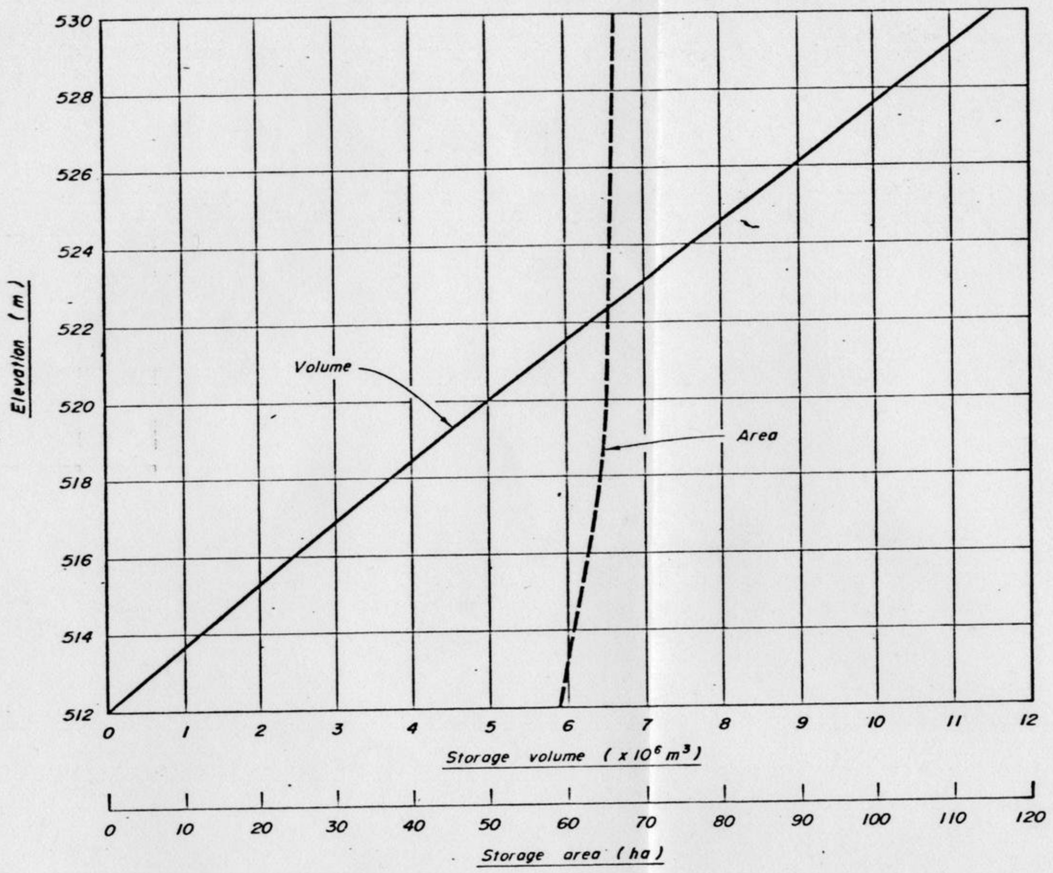
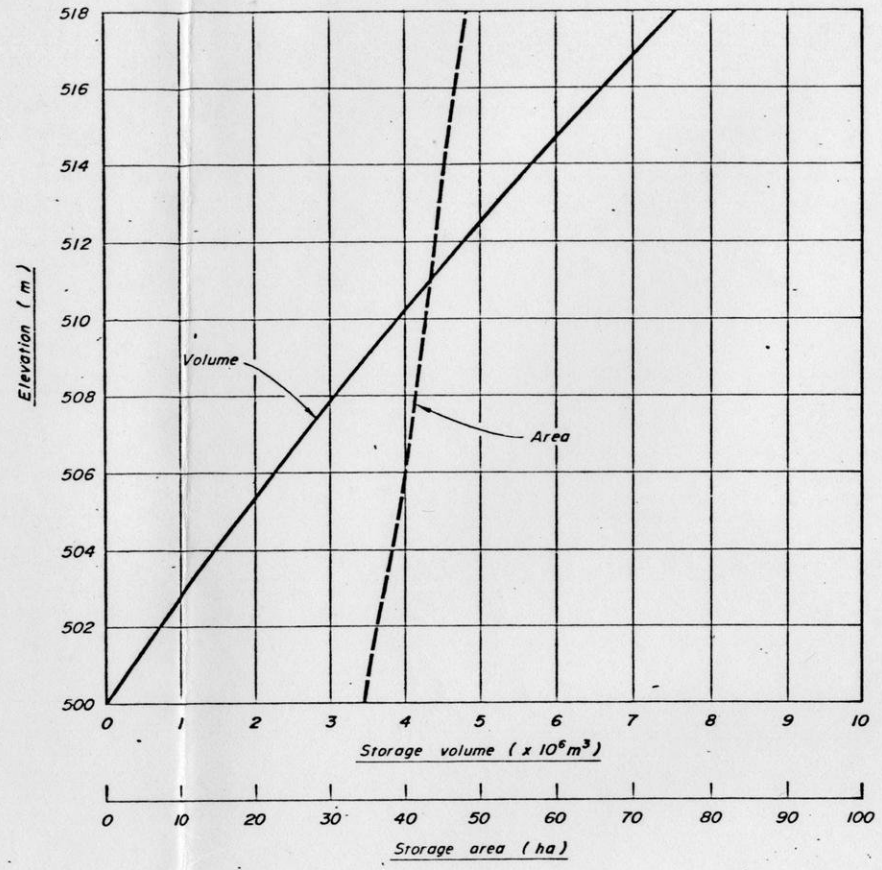

SECTION A
Scale A
AREA 1
℄ Final embankment
El. 530
Original ground level
Fine filter blanket
Compacted fill material
Coarse filter blanket
El. 512
Perforated underdrainage collector pipe (typ.)
Underseal
ELEVATION (m)
540
520
500
480
El. 500
Fine filter blanket
Coarse filter blanket
Underseal
Varies
0.500
0.400
SECTION B
Scale A
AREA 2
℄ Final embankment
El. 518
Compacted fill material
Underseal
El. 500
Perforated underdrainage collector pipe (typ.)
Original ground level
Coarse filter blanket
Fine filter blanket
SECTION C
Scale B
(Showing final embankment and tailings profile for Area 1 and intermediate filling stage for Area 2)
℄ Final embankment
8.000
4.000
36.000
El. 530
AREA 1
Full tailings storage level El. 529
Intermediate seal over upstream end of storage facility only (Area 2 similar)
Compacted fill material
Original ground level
Underseal on sloping sides of facility constructed from in-situ till blended with fines from processed material
El. 512
Perforated underdrainage collector pipe
Coarse filter blanket
Slope
Fine filter blanket
Underseal to base of storage facility constructed from fine fraction of processed material
Perforated underdrainage collector pipe
Staged embankment construction of compacted fill material on consolidated tailings
Starter embankment
Area 1 Underdrainage collector sump
El. 518
El. 517
AREA 2
NOTE: For continuation of Section C see Section D
Original ground level
Floating pump station
Underdrainage outlet pipe
Impervious seal to upstream slope of starter embankment constructed from compacted fill material blended with fines from processed material
Gravity outlet from underdrainage system of Area 1 into underdrainage system of Area 2. To be used for long term monitoring
El. 500
Underseal
Perforated underdrainage collector pipe
540
530
520
510
500
490
SECTION D
Scale B
(Showing intermediate filling stage for Area 2)
℄ Final embankment
8.000
36.000
8.000
4.000
Full tailings storage level El. 517
El. 518
Final profile of tailings storage facility embankment
Tailings distribution and water recirculation pipelines
Deposited tailings
El. 506
Slope
El. 500
Area 2 Underdrainage collector sump and long term monitoring location for entire facility
El. 494
Underseal to base of storage facility constructed from fine fraction of processed material
Fine filter blanket
Coarse filter blanket
Perforated underdrainage collector pipe
Compacted fill material starter embankment
530
520
510
500
490
480
B 10 5 0 10 20 30 40 50 m
A 20 10 0 20 40 60 80 100 m
KNIGHT AND PIESOLD LIMITED
CONSULTING ENGINEERS – VANCOUVER, B.C.
DESIGNED J.P.H.
DRAWN N.M.
CHECKED
APPROVED
EXXON MINERALS COMPANY
CRANDON PROJECT
TAILINGS STORAGE FACILITY SECTIONS
DATE OCT. 30, 1981
SCALE AS SHOWN
DRG. NO. 3113.105
REV.
DRG NO
DESCRIPTION
REFERENCE DRAWINGS
REV.
DATE
DESCRIPTION
APPROVED
REVISIONS
REV
DATE
DESCRIPTION
APPROVED
REVISIONS

FIGURE 5

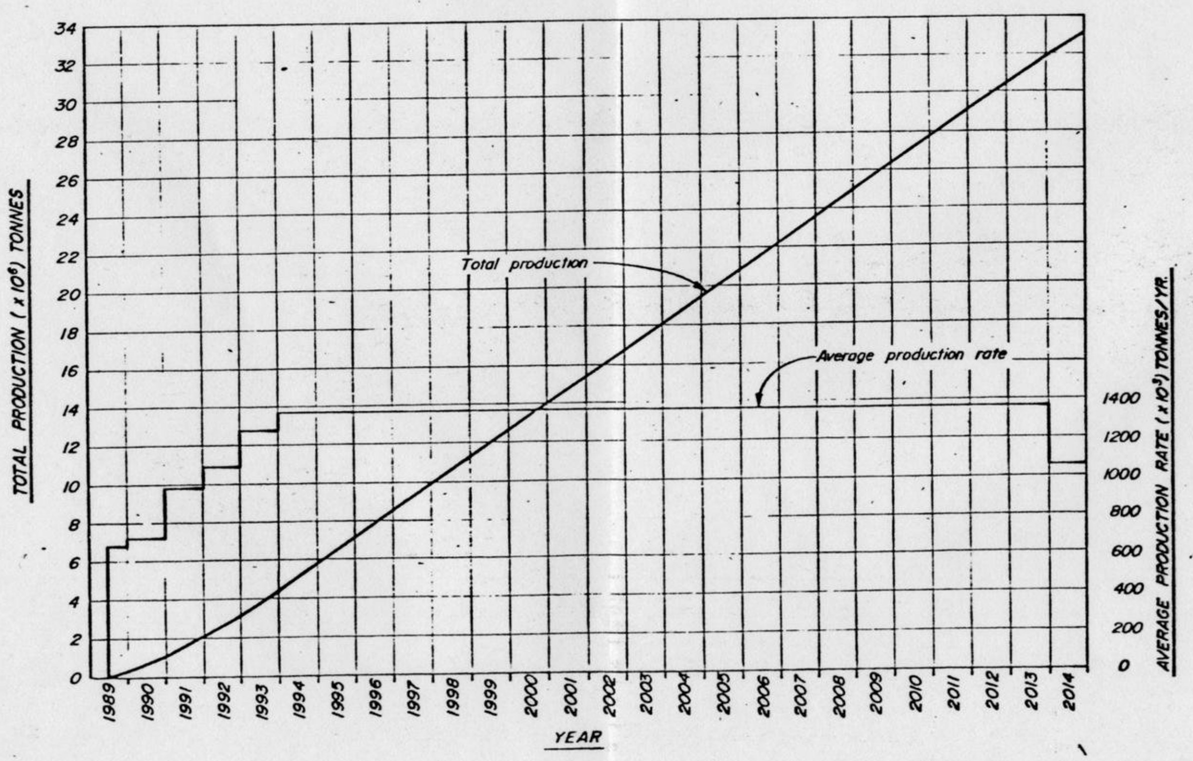
AREA 1



AREA 2



COMBINED TAILINGS PRODUCTION



DRG NO	DESCRIPTION
REFERENCE DRAWINGS	

REV.	DATE	DESCRIPTION	APPROVED	REV.	DATE	DESCRIPTION	APPROVED
		REVISIONS				REVISIONS	

KNIGHT AND PIESOLD LIMITED
CONSULTING ENGINEERS – VANCOUVER, B.C.

DESIGNED J.P.H.
DRAWN N.M.
CHECKED [signature]
APPROVED

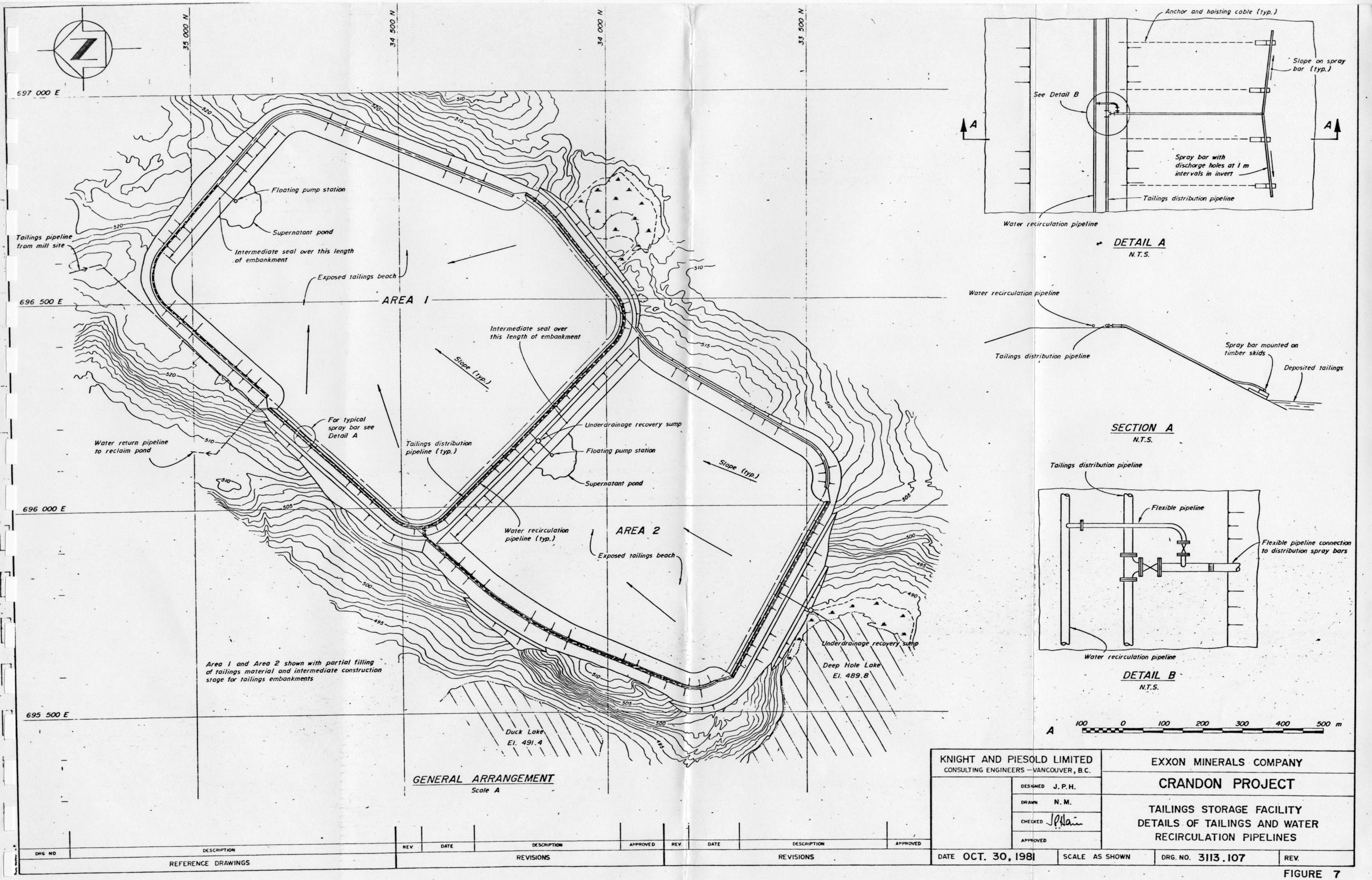
EXXON MINERALS COMPANY

CRANDON PROJECT

TAILINGS STORAGE FACILITY
AREA AND VOLUME CHARACTERISTICS

DATE OCT. 30, 1981 | SCALE AS SHOWN | DRG. NO. 3113.106 | REV.

FIGURE 6



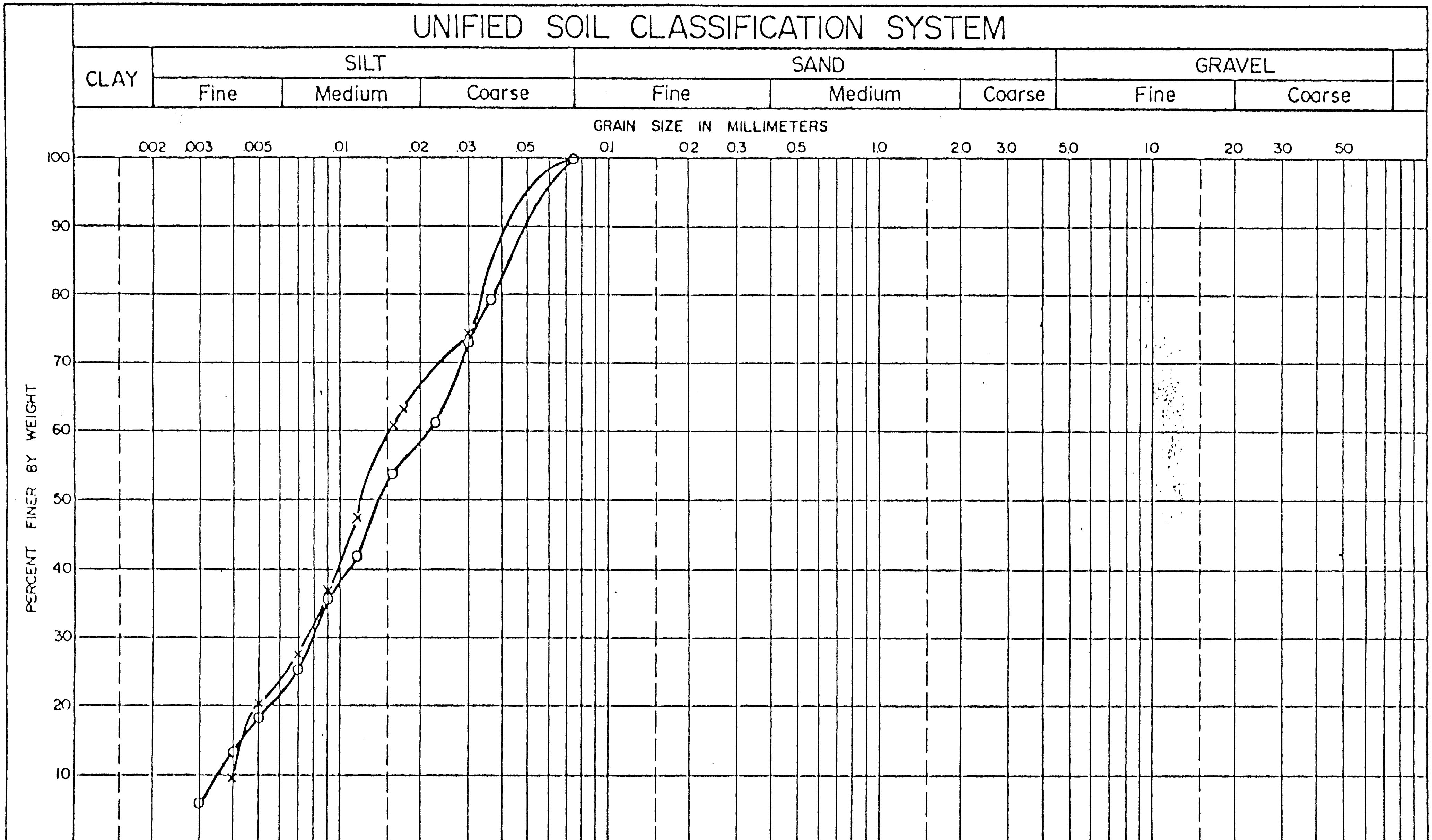
35 000 N
34 500 N
34 000 N
33 500 N
697 000 E
696 500 E
696 000 E
695 500 E
Floating pump station
Supernatant pond
Tailings pipeline from mill site
Intermediate seal over this length of embankment
Exposed tailings beach
AREA I
Intermediate seal over this length of embankment
Slope (typ.)
For typical spray bar see Detail A
Water return pipeline to reclaim pond
Tailings distribution pipeline (typ.)
Underdrainage recovery sump
Floating pump station
Supernatant pond
Slope (typ.)
Water recirculation pipeline (typ.)
AREA 2
Exposed tailings beach
Underdrainage recovery sump
Deep Hole Lake El. 489.8
Area 1 and Area 2 shown with partial filling of tailings material and intermediate construction stage for tailings embankments
Duck Lake El. 491.4
GENERAL ARRANGEMENT
Scale A
Anchor and hoisting cable (typ.)
Slope on spray bar (typ.)
See Detail B
Spray bar with discharge holes at 1 m intervals in invert
Tailings distribution pipeline
Water recirculation pipeline
DETAIL A
N.T.S.
Water recirculation pipeline
Tailings distribution pipeline
Spray bar mounted on timber skids
Deposited tailings
SECTION A
N.T.S.
Tailings distribution pipeline
Flexible pipeline
Flexible pipeline connection to distribution spray bars
Water recirculation pipeline
DETAIL B
N.T.S.
A 100 0 100 200 300 400 500 m
KNIGHT AND PIESOLD LIMITED
CONSULTING ENGINEERS — VANCOUVER, B.C.
DESIGNED J.P.H.
DRAWN N.M.
CHECKED
APPROVED
EXXON MINERALS COMPANY
CRANDON PROJECT
TAILINGS STORAGE FACILITY
DETAILS OF TAILINGS AND WATER RECIRCULATION PIPELINES
DATE OCT. 30, 1981
SCALE AS SHOWN
DRG. NO. 3113.107
REV.
DRG NO
DESCRIPTION
REFERENCE DRAWINGS
REV. DATE DESCRIPTION APPROVED
REVISIONS
REV. DATE DESCRIPTION APPROVED
REVISIONS

FIGURE 7

APPENDIX A

SUMMARY OF

LABORATORY TEST RESULTS



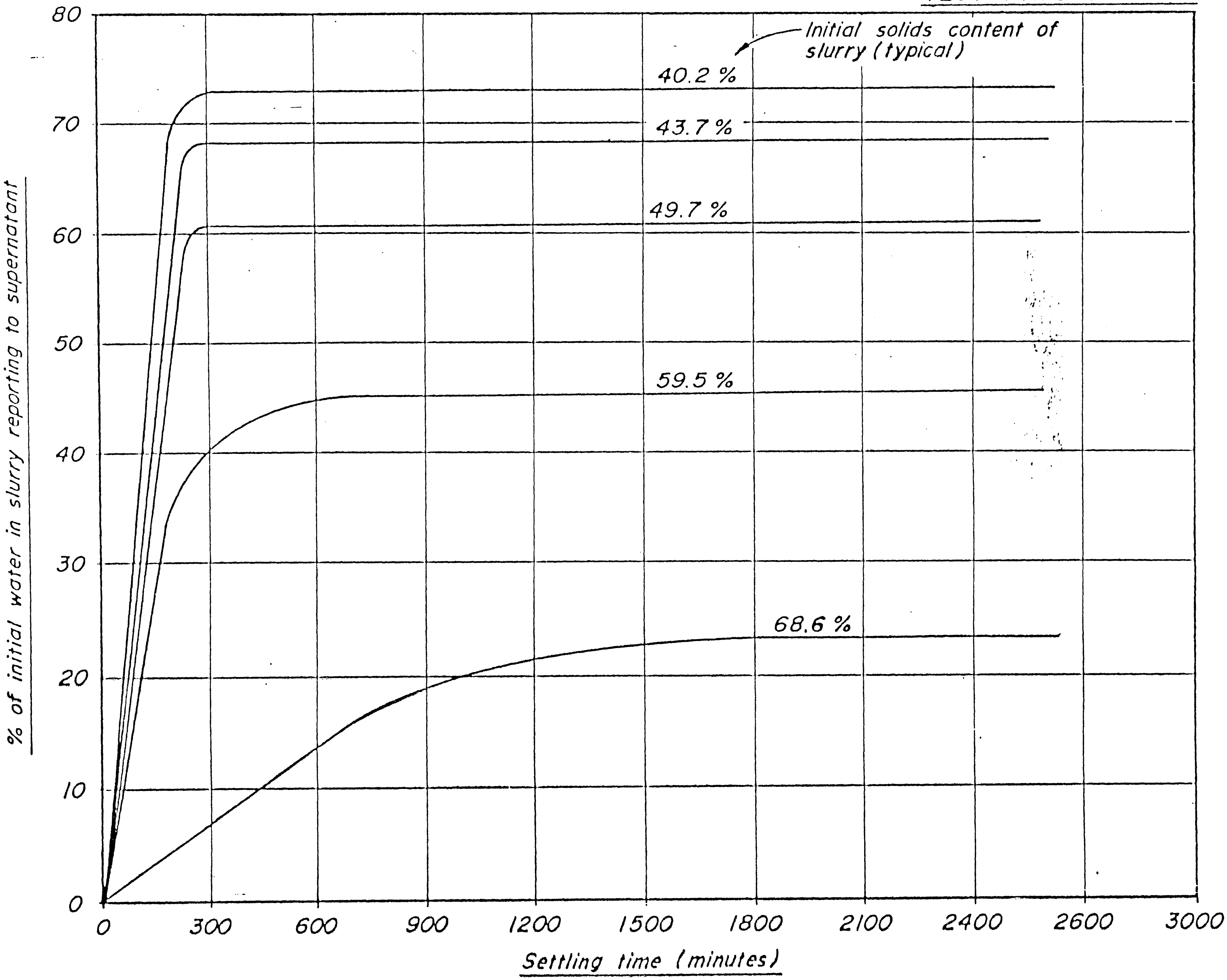
PROJECT *EXXON MINERALS COMPANY*	SAMPLE Nº *FS 6*	KNIGHT AND PIESOLD LIMITED CONSULTING ENGINEERS
CRANDON PROJECT		
MATERIAL *FS 6*		
DUPLICATE PARTICLE SIZE DISTRIBUTION TESTS		
	DATE *MAY 29 '81*	

Figure A1

EXXON MINERALS COMPANY – CRANDON PROJECT

SEDIMENTATION TEST RESULTS

TEST MATERIAL FS-6



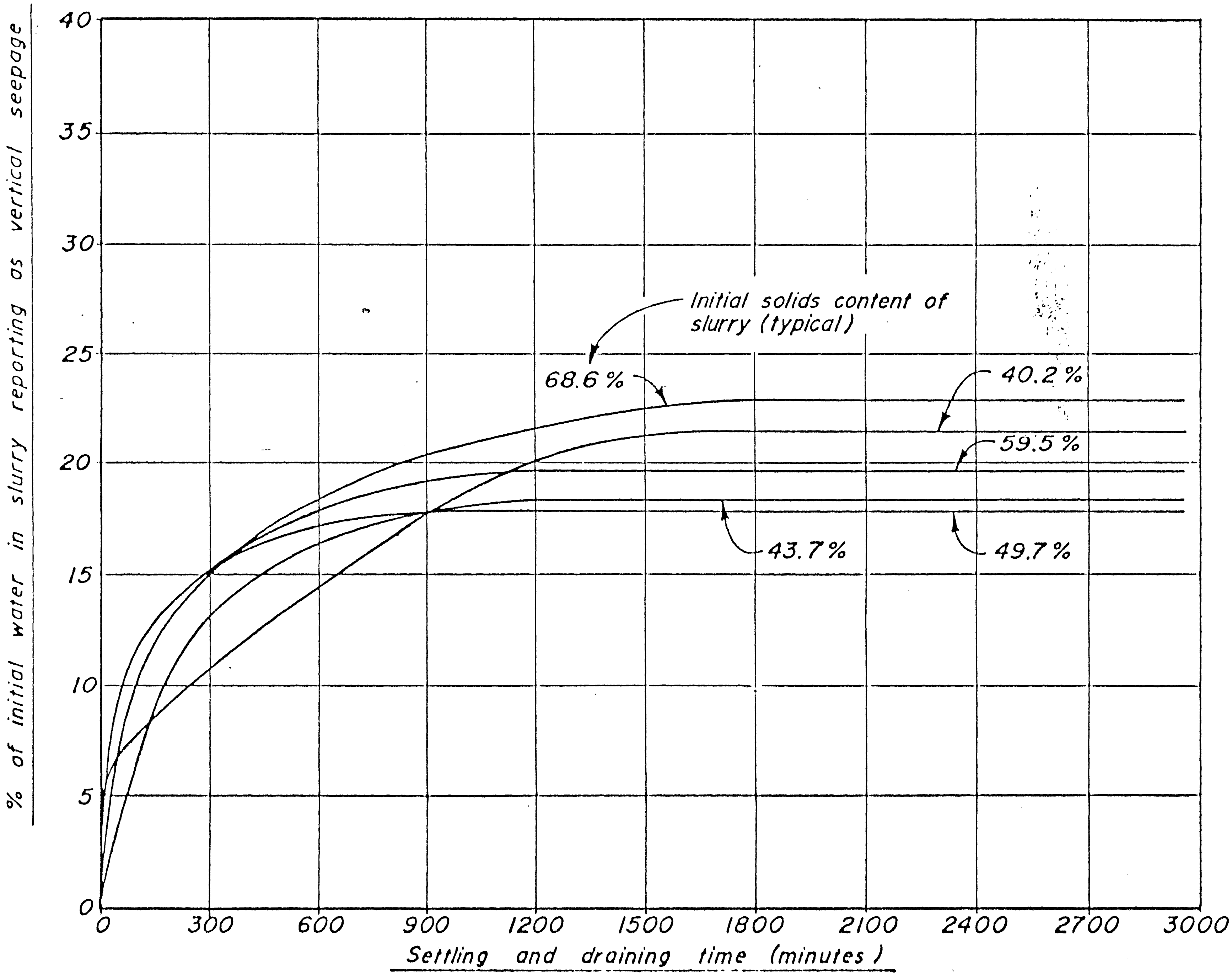
Knight and Piésold Ltd.

Figure A2

EXXON MINERALS COMPANY - CRANDON PROJECT

DRAINED SEDIMENTATION RESULTS

TEST MATERIAL FS 6



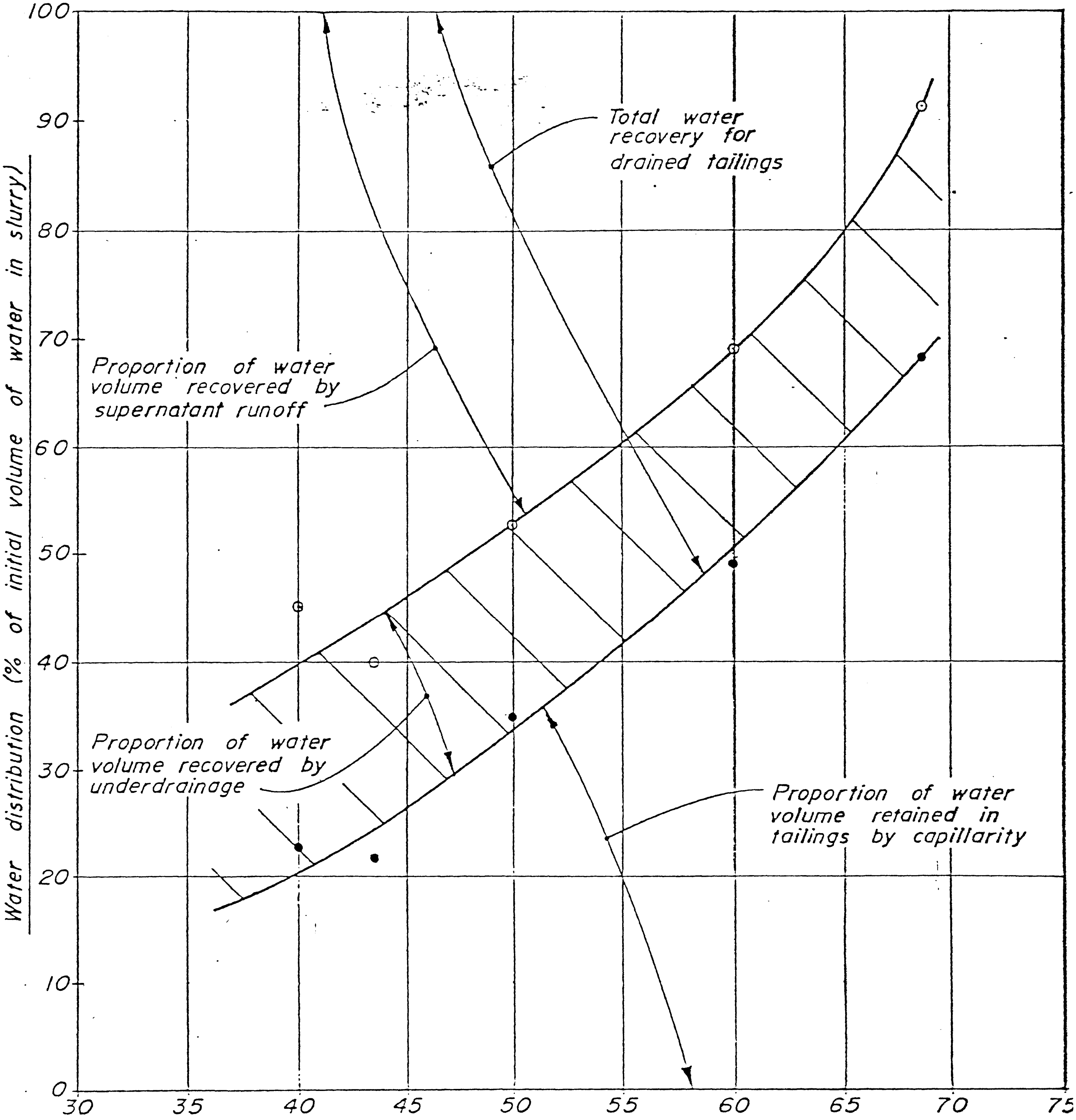
Knight and Piésold Ltd.

Figure A3

EXXON MINERALS COMPANY - CRANDON PROJECT

DRAINED SEDIMENTATION TESTS ON TAILING SLURRIES

TEST MATERIAL FS 6

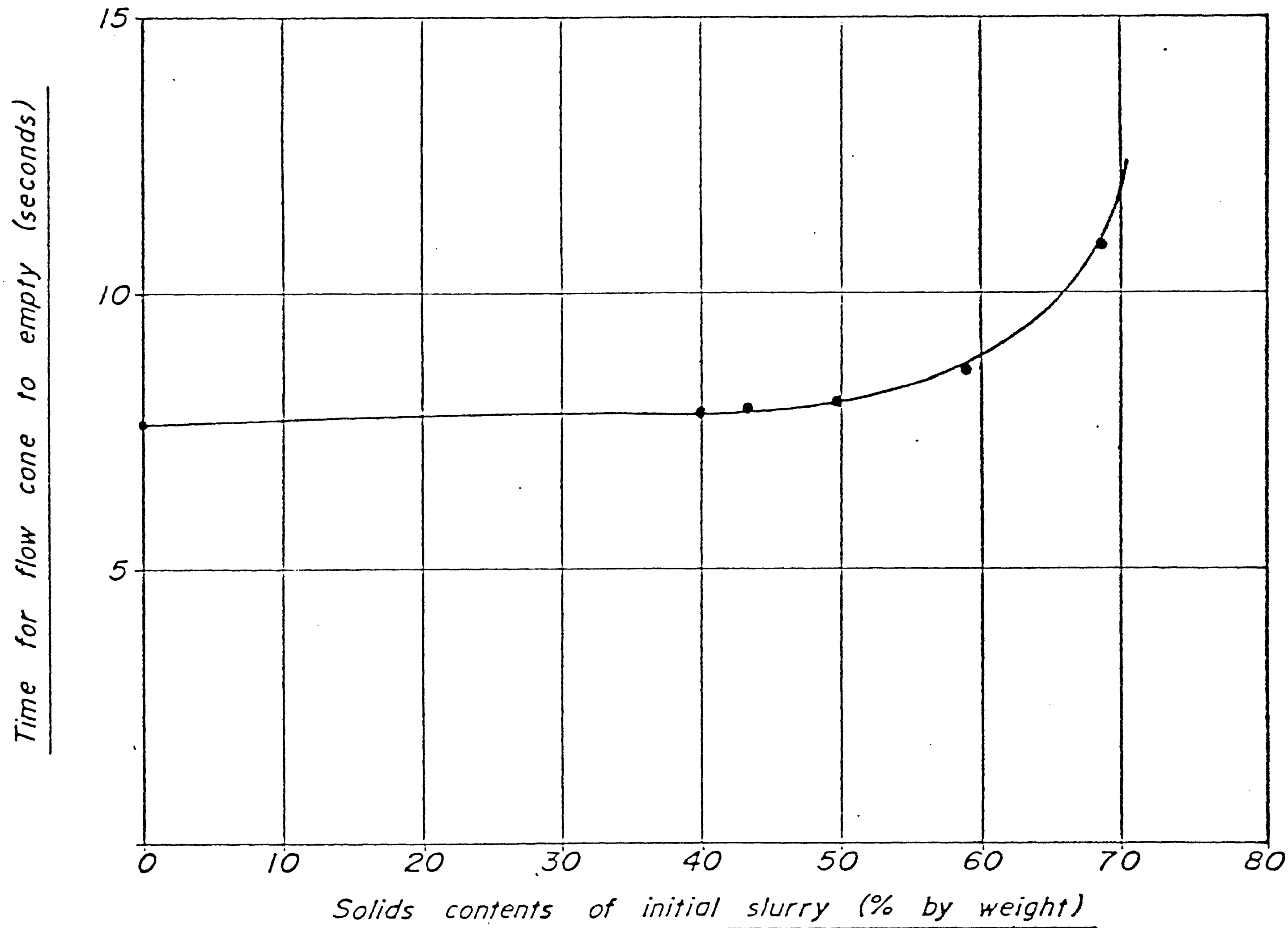


Knight and Piésold Ltd.

Figure A4

VISCOSITY TESTS ON TAILINGS

TEST MATERIAL FS 6



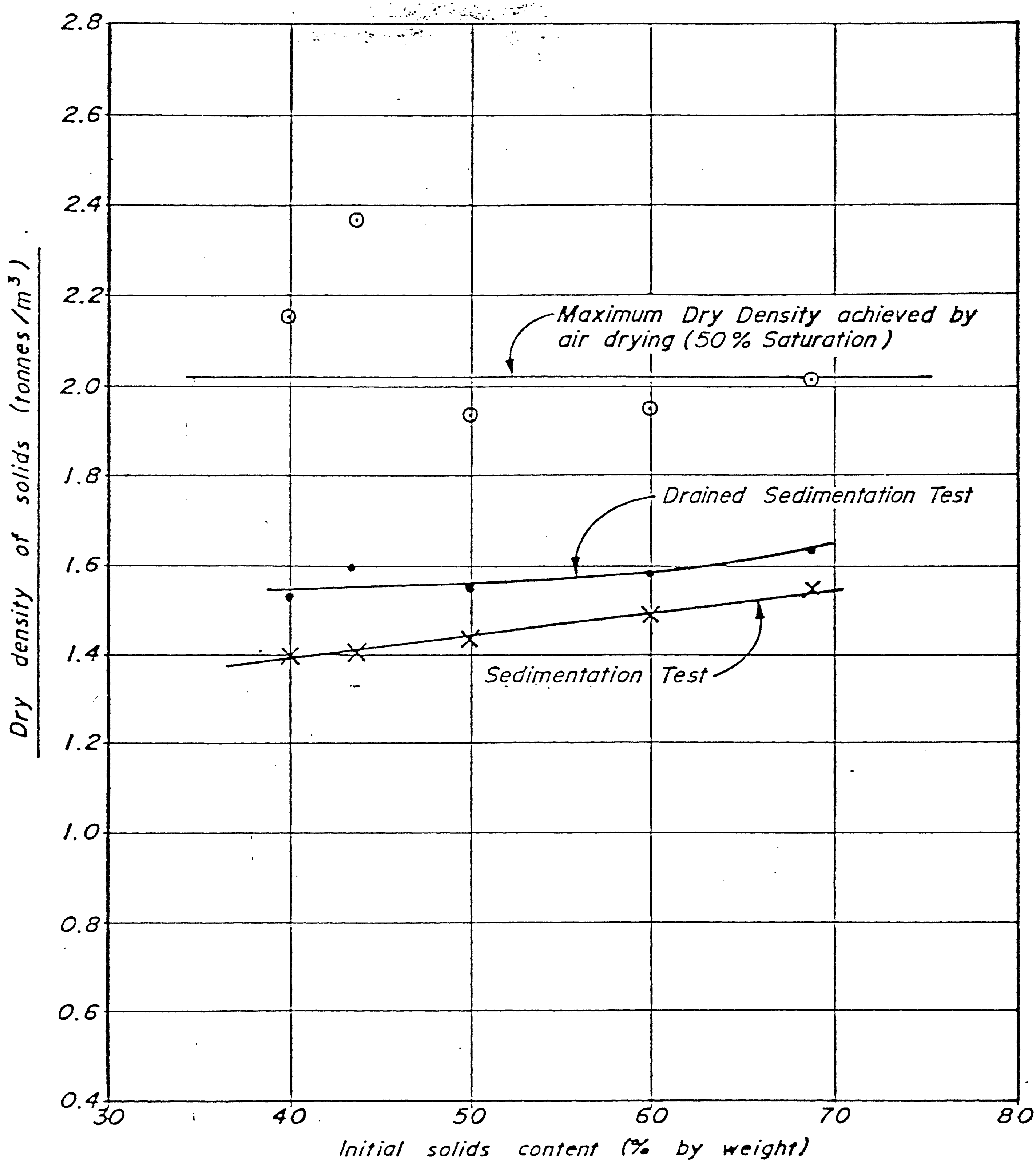
Knight and Piésold Ltd.

Figure A5

EXXON MINERALS COMPANY - CRANDON PROJECT

RELATIONSHIP BETWEEN DENSITIES ACHIEVED AND SOLIDS CONTENT OF INITIAL SLURRY

TEST MATERIAL FS 6



Knight and Piésold Ltd.

Figure A6

TABLE A1

RESULTS OF MULTI-STAGE CONSOLIDATED

UNDRAINED TRIAXIAL TEST

SAMPLE NO. FS6

		STAGE NO. 1	2	3
INITIAL	Diameter (mm)	72.4		
	Length (mm)	144.4		
	Dry density (t/m^3)	2.027		
	Moisture Content (%)	18.9		
	Saturation (%)	92.2		
	Bulk density (t/m^3)	2.409		
SATURATION	Saturated pwp (kPa)	417		
	Final cell pressure (kPa)	448		
	B value	0.95		
CONSOLIDATION	Cell pressure (kPa)	448	552	758
	Back pressure (kPa)	345	345	345
	Initial pwp (kPa)	417	496	662
	Final pwp (kPa)	345	345	345
	Dry density (t/m^3)	2.051	2.079	2.105
	Moisture content (%)	18.3	17.6	17.0
	Bulk density (t/m^3)	2.426	2.451	2.463
COMPRESSION AND FAILURE	Initial σ_3' (kPa)	103	207	414
	Strain rate (% per hr)	.019	.019	.019
	σ'_{1_f} (kPa)	432	845	1515
	σ'_{3_f} (kPa)	109	212	403
	u_f (kPa)	- 6	- 6	10
	$(\sigma'_1 - \sigma'_3)_f$ (kPa)	323	632	1111
	A_f	- .02	- .01	.01
	Strain at failure (%)	8.0	11.1	14.5
CONSOLIDATION PARAMETERS	C_V (m^2/yr)	416	223	592
	k (measured) (m/s)	1.8×10^{-8}	1.6×10^{-8}	1.28×10^{-8}
	m_v (m^2/MN)	.136	.226	.068

Figure A7

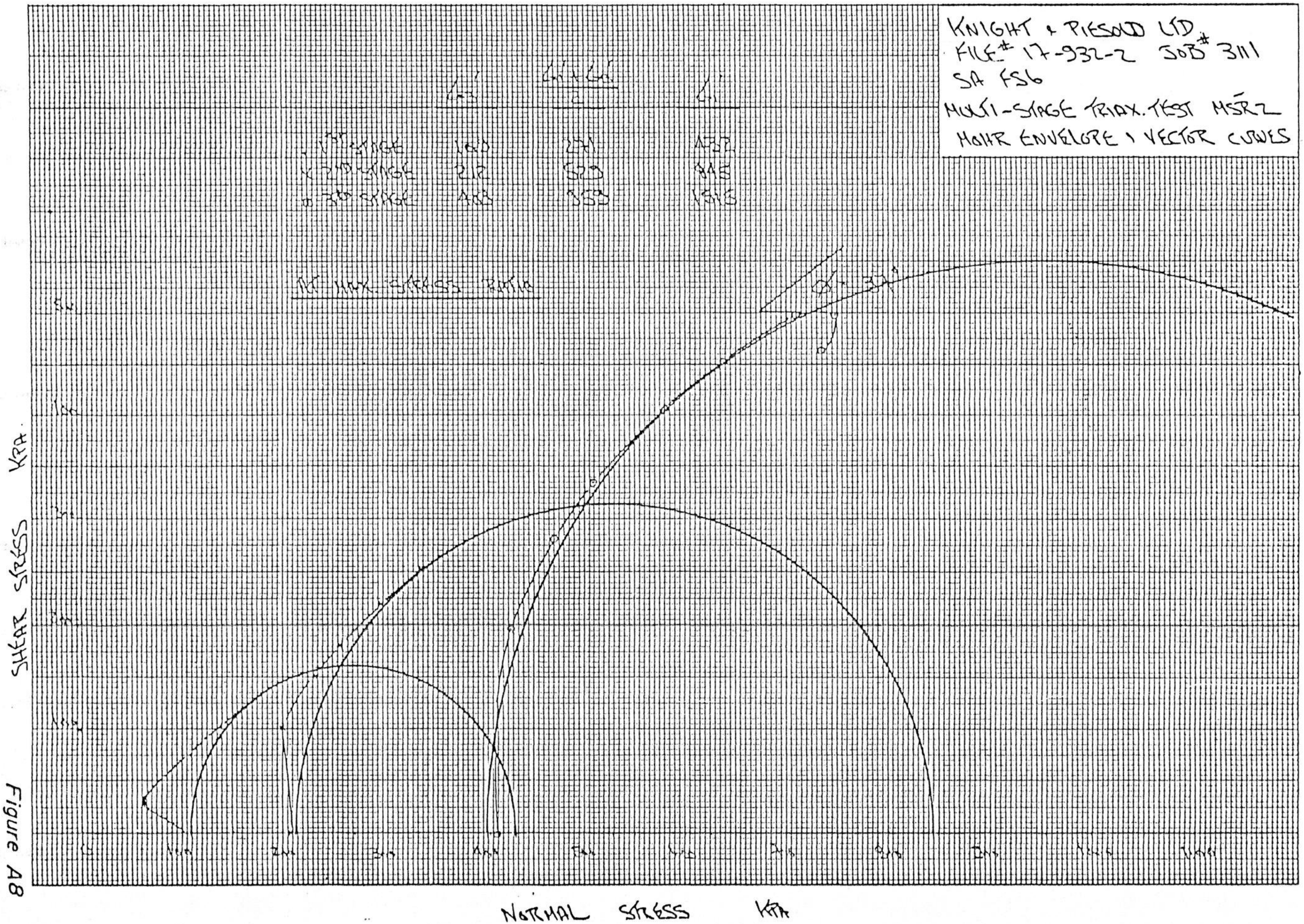

KNIGHT & PIESOLD LTD
FILE# 17-932-2 JOB# 3111
SA FS6
MULTI-STAGE TRIAX. TEST MSR2
MOHR ENVELOPE & VECTOR CURVES
φ' = 37°
SHEAR STRESS KPA
NORMAL STRESS KPA

Figure A8

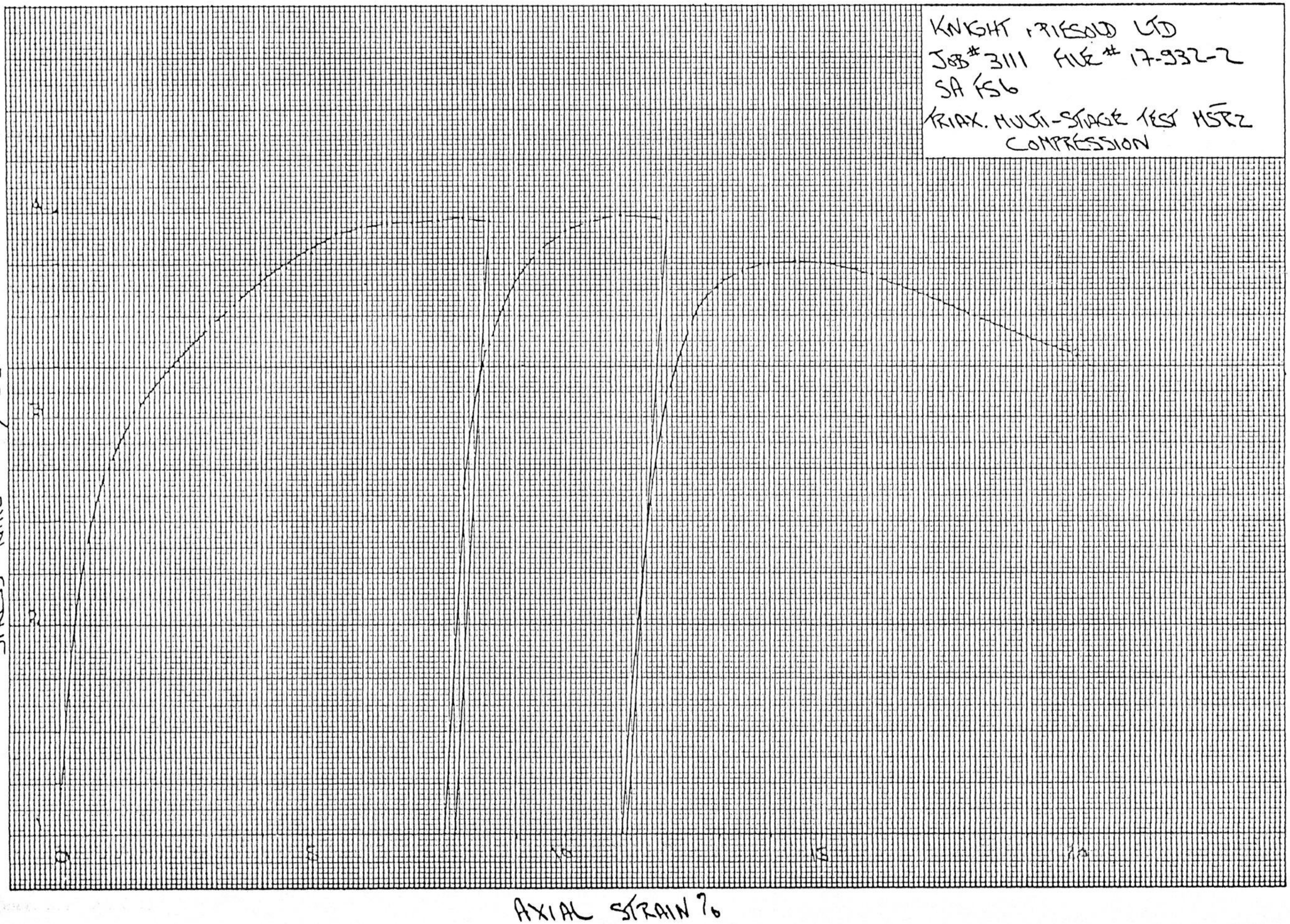

KNIGHT + PIESOLD LTD
JOB # 3111 FILE # 17-932-2
SA FS6
TRIAX. MULTI-STAGE TEST MST2
COMPRESSION
STRESS RATIO σ_1'/σ_3'
AXIAL STRAIN %

Figure A9

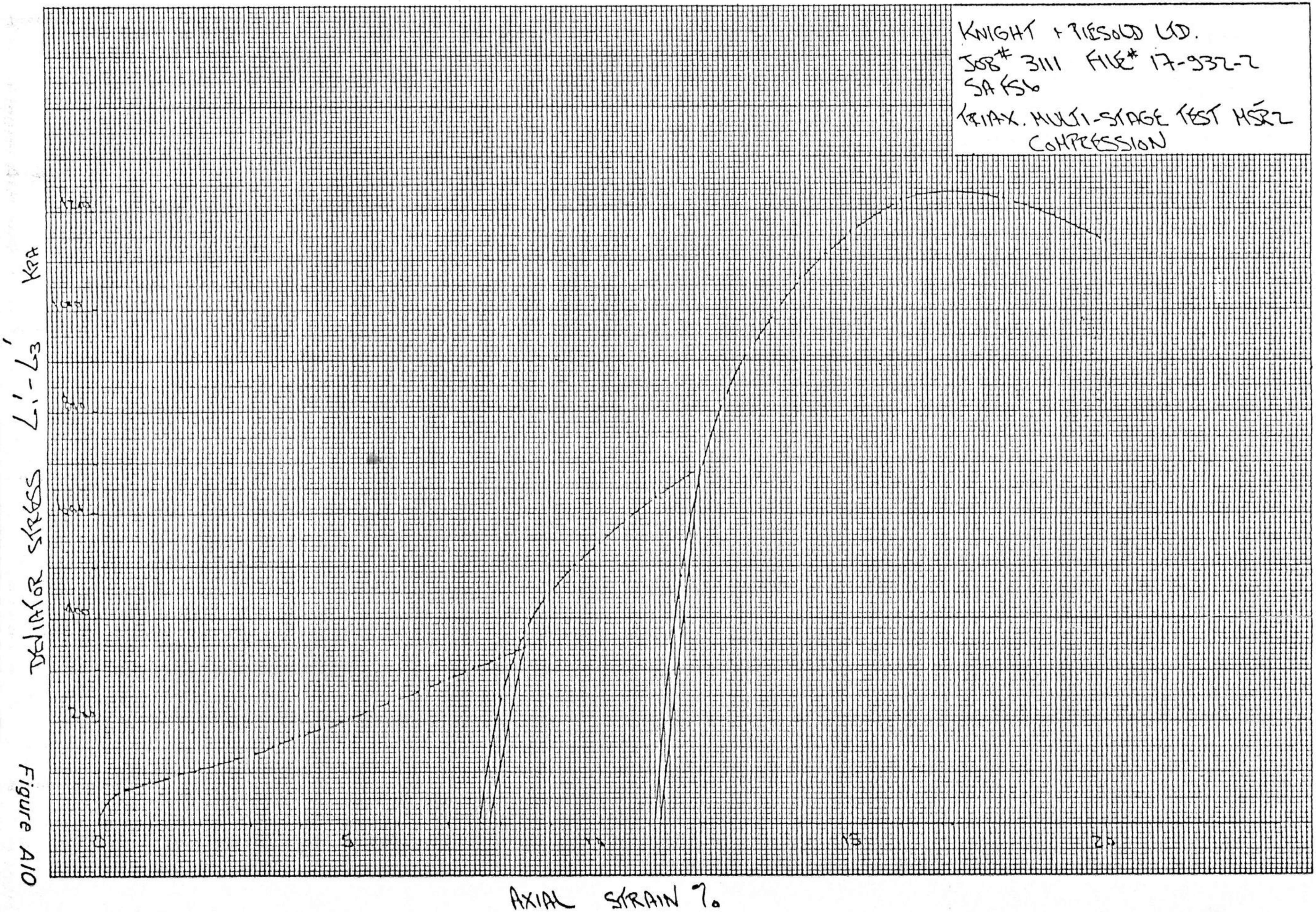

KNIGHT + PIESOLD LTD.
JOB# 3111 FILE# 17-932-2
SA FS6
TRIAX. MULTI-STAGE TEST MSR2
COMPRESSION
DEVIATOR STRESS σ1' - σ3' KPA
AXIAL STRAIN %
0
5
10
15
20

Figure A10

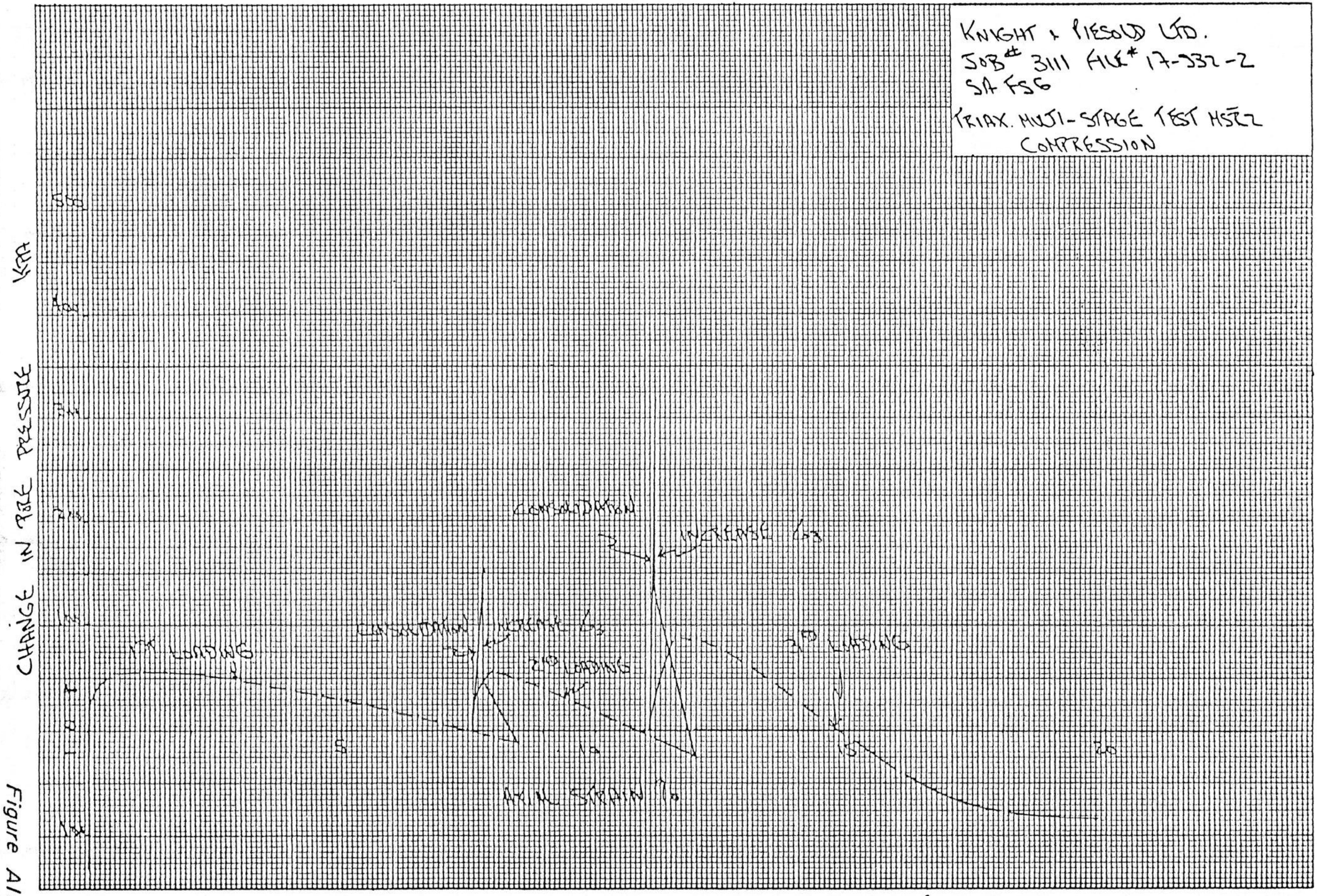

KNIGHT & PIESOLD LTD.
JOB # 3111 FILE # 17-332-2
SA FS6
TRIAX. MULTI-STAGE TEST
COMPRESSION
CHANGE IN PORE PRESSURE kPa
500
400
1ST LOADING
2ND LOADING
3RD LOADING
CONSOLIDATION
INCREASE σ3
5
10
15
20
AXIAL STRAIN %

Figure A11

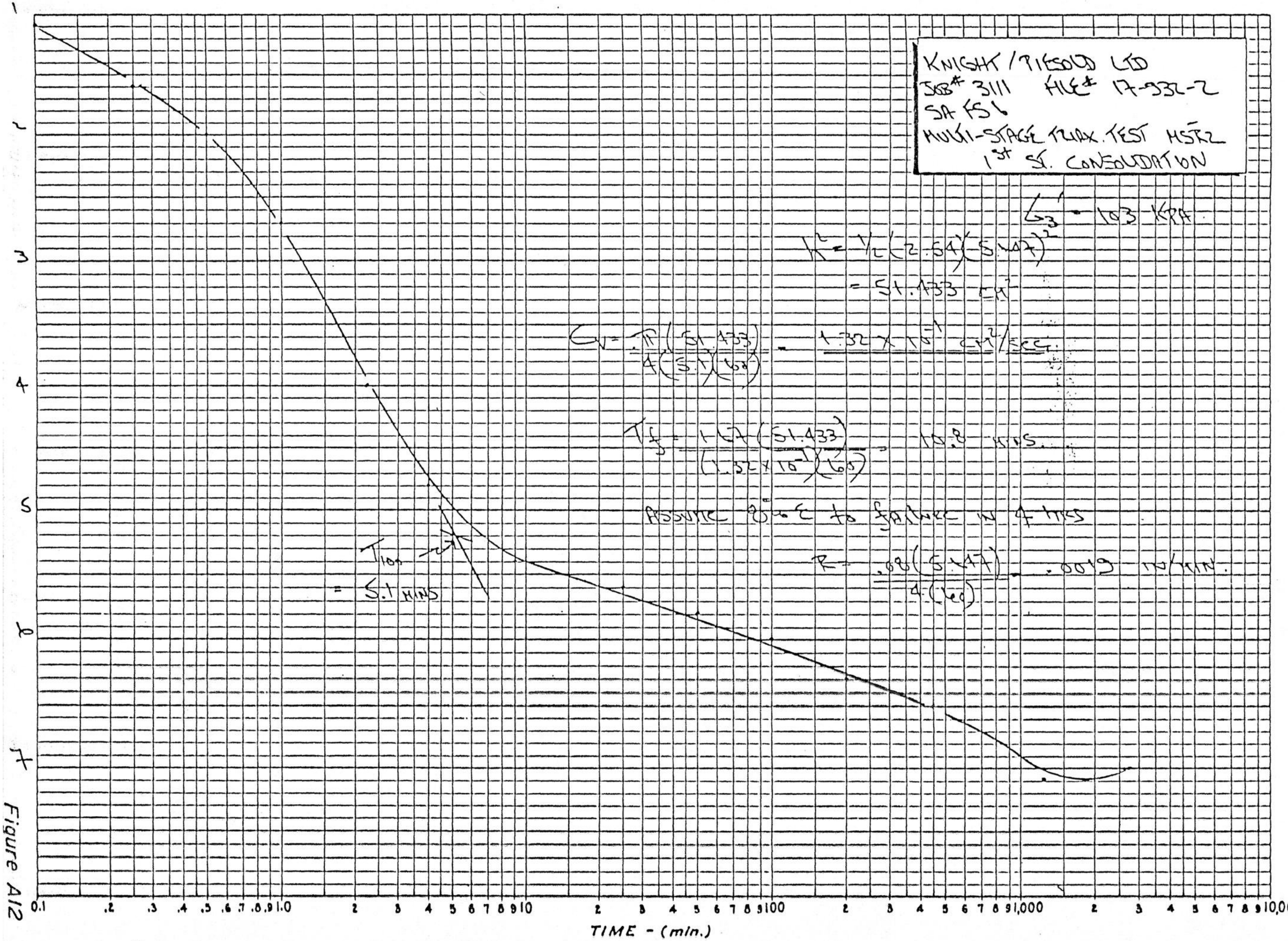
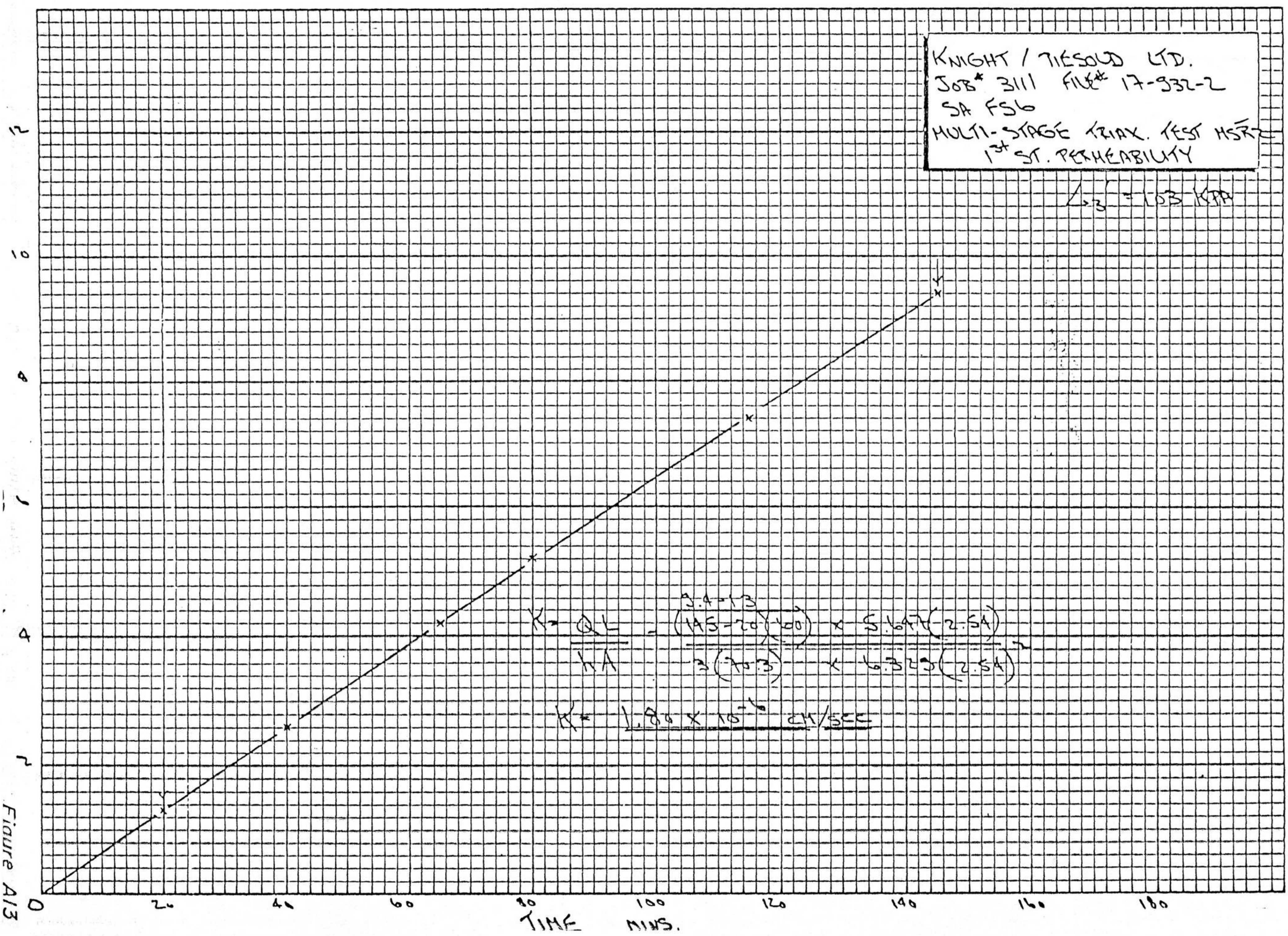

KNIGHT / PIESOLD LTD
JOB# 3111 FILE# 17-932-2
SA FS 6
MULTI-STAGE TRIAX. TEST MST2
1st ST. CONSOLIDATION
σ3' = 103 KPA
H² = 1/2 (2.54)(5.47)²
= 51.433 cm²
Cv = π(51.433) / 4(5.1)(60) = 1.32 x 10⁻¹ cm²/sec.
Tf = 1.47(51.433) / (1.32 x 10⁻¹)(60) = 10.8 mins.
Assume 8% ε to failure in 4 hrs
R = .08(5.47) / 4(60) = .0019 in/min.
T100
= 5.1 mins
1
2
3
4
5
6
7
0.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2
3
4
5
6
7
8
9
10
2
3
4
5
6
7
8
9
100
2
3
4
5
6
7
8
9
1,000
2
3
4
5
6
7
8
9
10,000
TIME - (min.)

Figure A12



KNIGHT / TIESOLD LTD.
JOB# 3111 FILE# 17-932-2
SA FS6
MULTI-STAGE TRIAX. TEST MSR2
1st ST. PERMEABILITY
$\Delta_3' = 103$ KPA
K = QL / hA = (9.4-1.3)/((145-20)(60)) × 5.647(2.54) / (3(70.3) × 6.323(2.54)²)
K = 1.80 × 10⁻⁶ CM/SEC
0
20
40
60
80
100
120
140
160
180
TIME MINS.
2
4
6
8
10
12

Figure A13

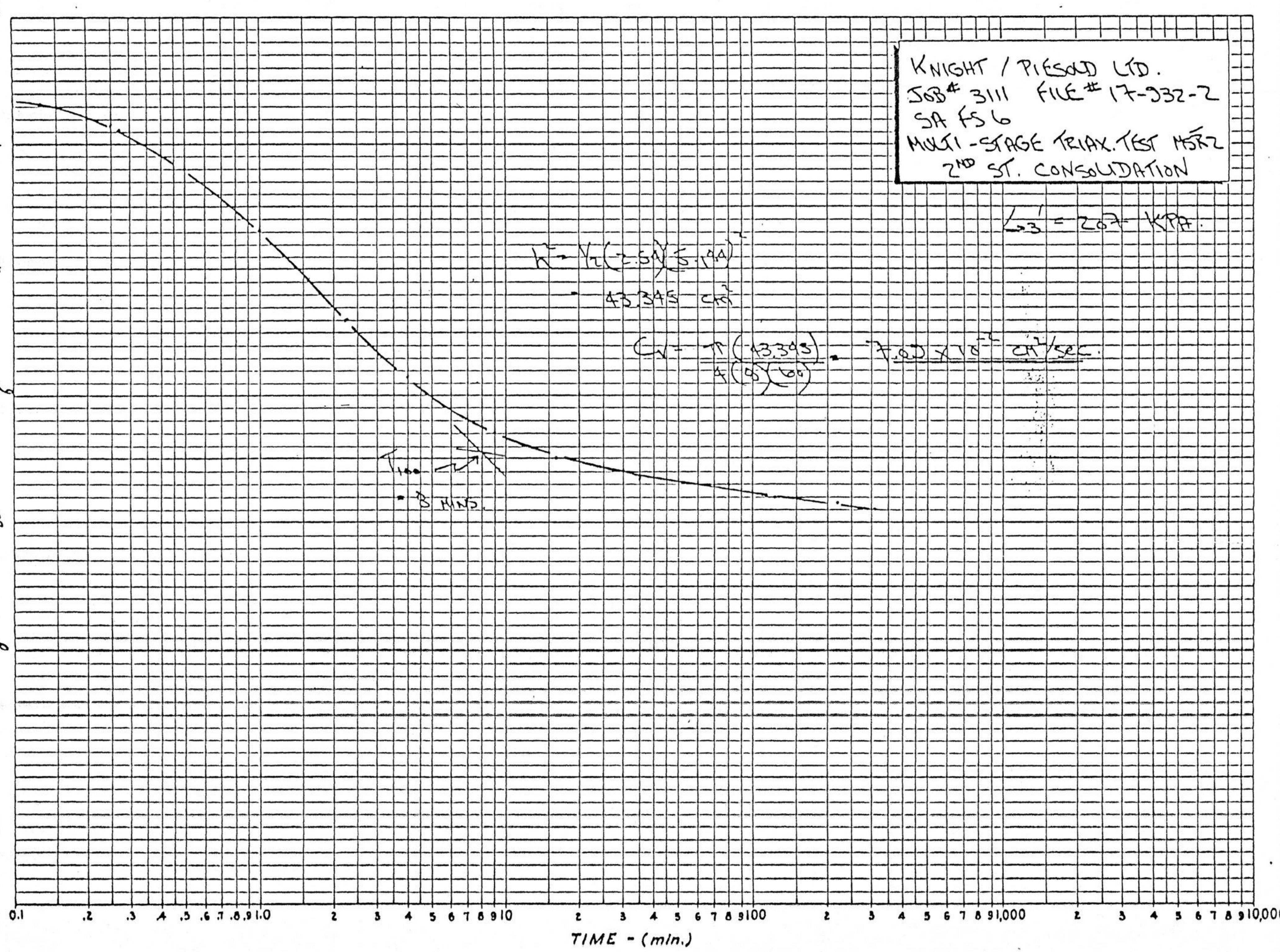

KNIGHT / PIESOLD LTD.
JOB# 3111 FILE # 17-932-2
SA FS 6
MULTI-STAGE TRIAX. TEST MSR2
2ND ST. CONSOLIDATION
σ3' = 207 KPA
T100 = 8 MINS.
43.345 cm²
7.00 x 10⁻² cm²/sec
2
4
6
8
10
0.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2
3
4
5
6
7
8
9
10
100
1,000
10,000
TIME - (min.)

Figure A14

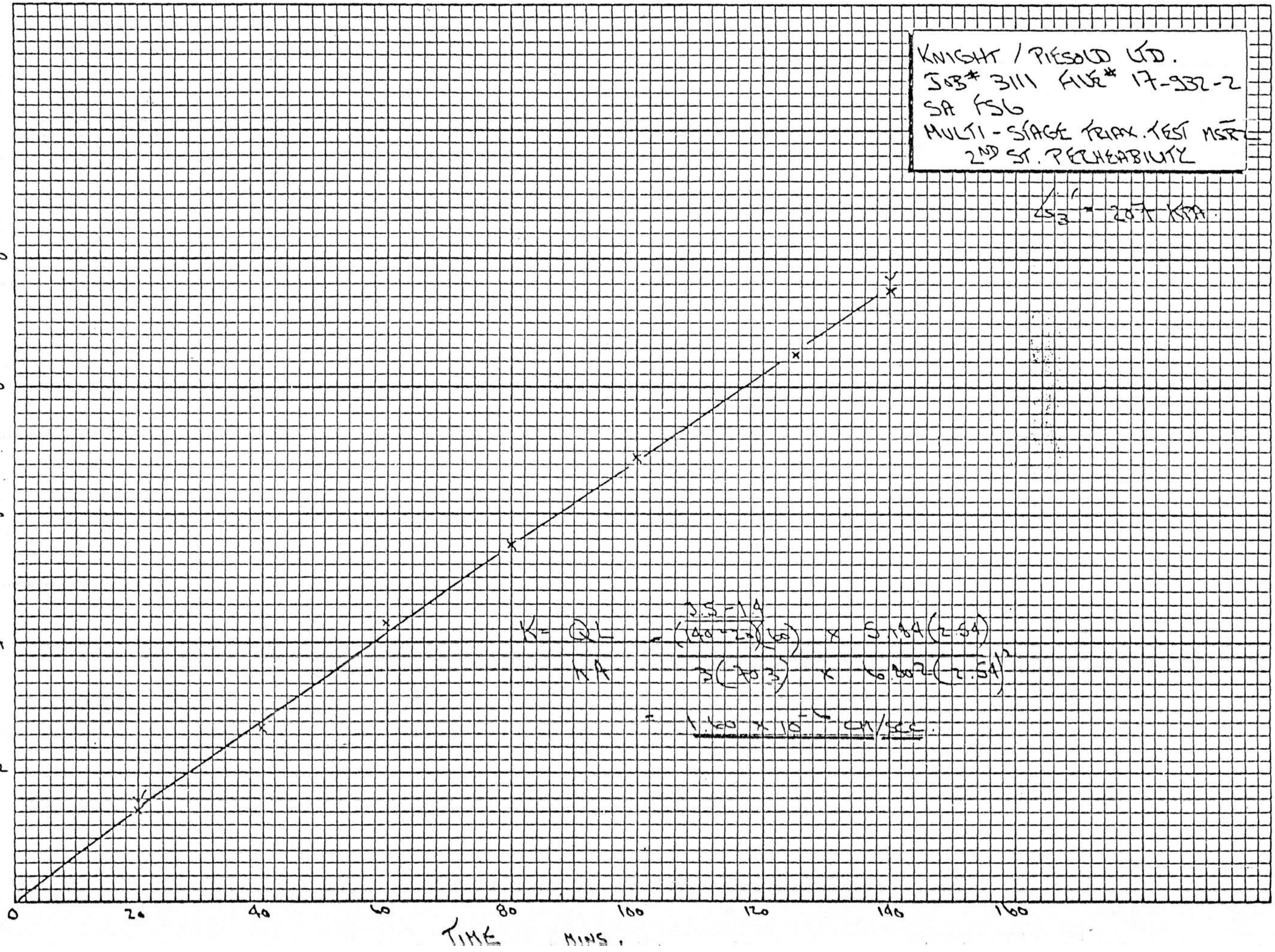

KNIGHT / PIESOLD LTD.
JOB# 3111 FILE# 17-932-2
SA FS6
MULTI-STAGE TRIAX. TEST MSR
2ND ST. PERMEABILITY
σ3' = 207 KPA
K = QL / hA
= 1.60 x 10⁻⁵ CM/SEC
0
20
40
60
80
100
120
140
160
2
4
6
8
10
TIME MINS.

Figure A15

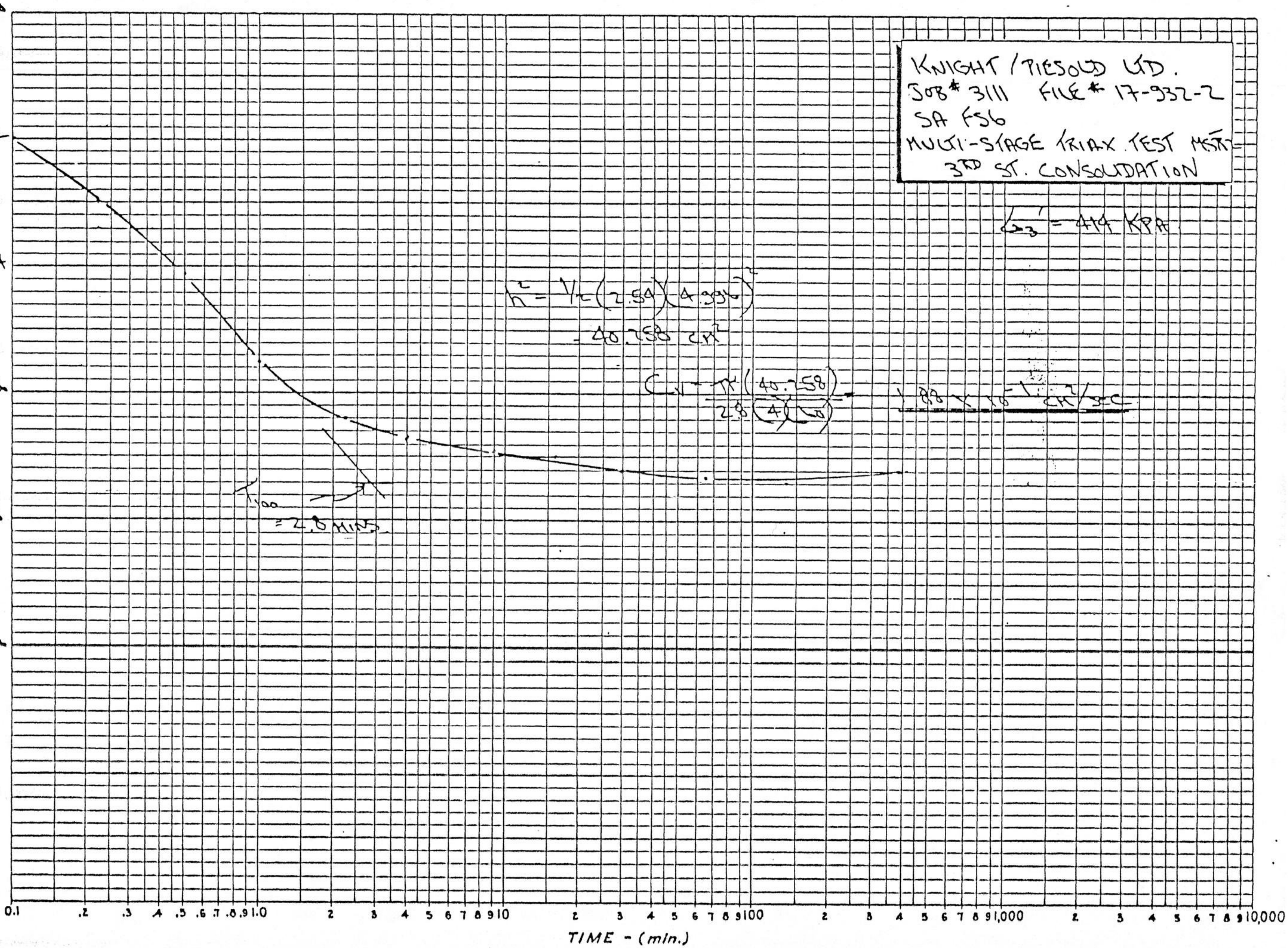

KNIGHT / PIESOLD LTD.
JOB # 3111 FILE # 17-932-2
SA FS6
MULTI-STAGE TRIAX TEST
3RD ST. CONSOLIDATION
= 414 KPA
= 40.258 cm²
T100
= 2.8 MINS
0.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 2 3 4 5 6 7 8 9 10 2 3 4 5 6 7 8 9 100 2 3 4 5 6 7 8 9 1,000 2 3 4 5 6 7 8 9 10,000
TIME - (min.)

Figure A16

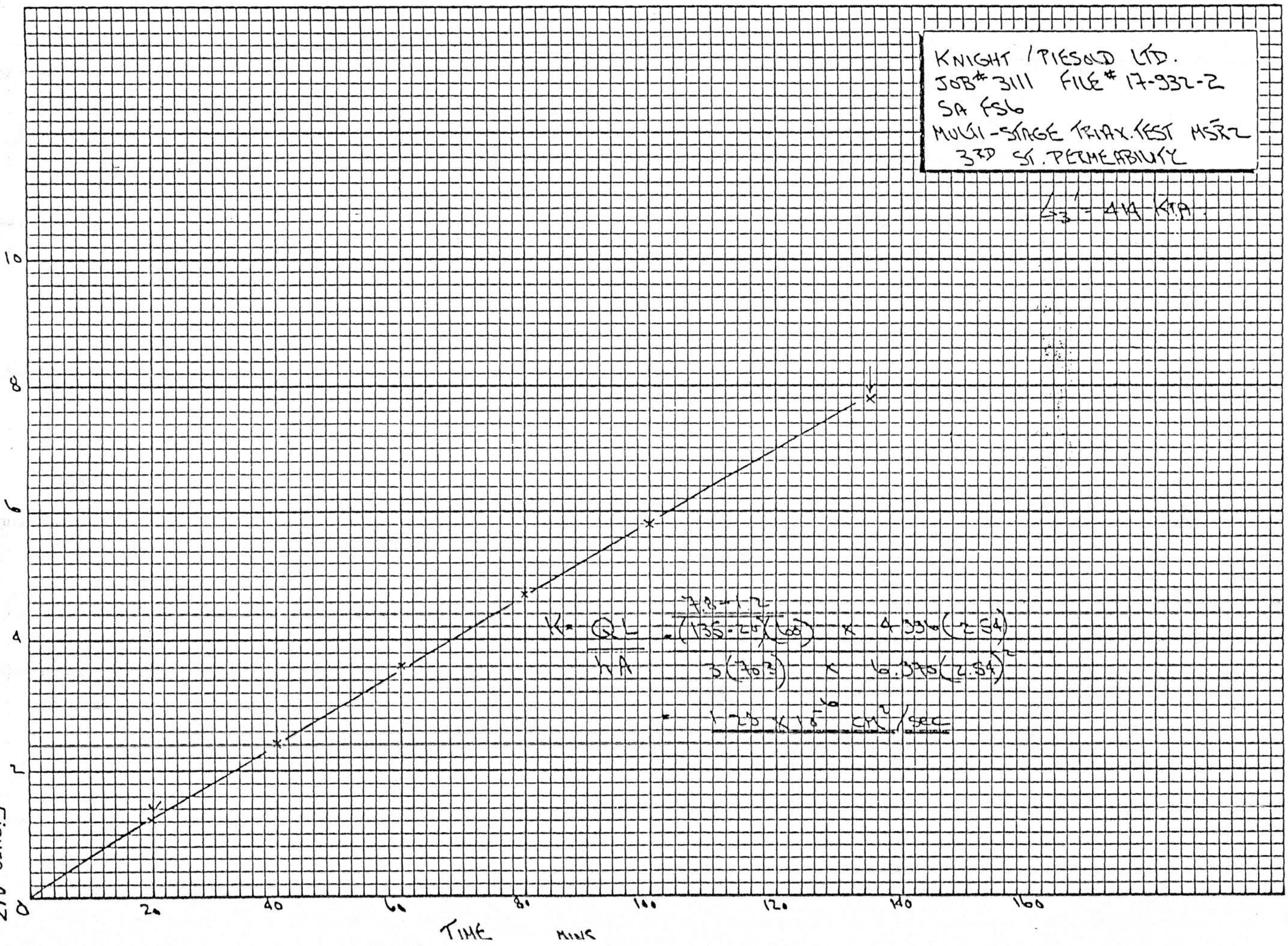

KNIGHT / PIESOLD LTD.
JOB# 3111 FILE# 17-932-2
SA FS6
MULTI-STAGE TRIAX. TEST MSR2
3RD ST. PERMEABILITY
σ3' = 414 KPA
K = QL / hA = (7.8 - 1.2) / (135 - 20)(60) x 4.336 (2.54) / 3(70.3) x 6.370 (2.54)²
= 1.23 x 10⁻⁶ CM/SEC
FLOW cc
10
8
6
4
2
0
20
40
60
80
100
120
140
160
TIME MINS

Figure A17

EXXON MINERALS COMPANY - CRANDON PROJECT

TAILINGS STORAGE FACILITY
PROFILE OF DRY DENSITY WITH DEPTH

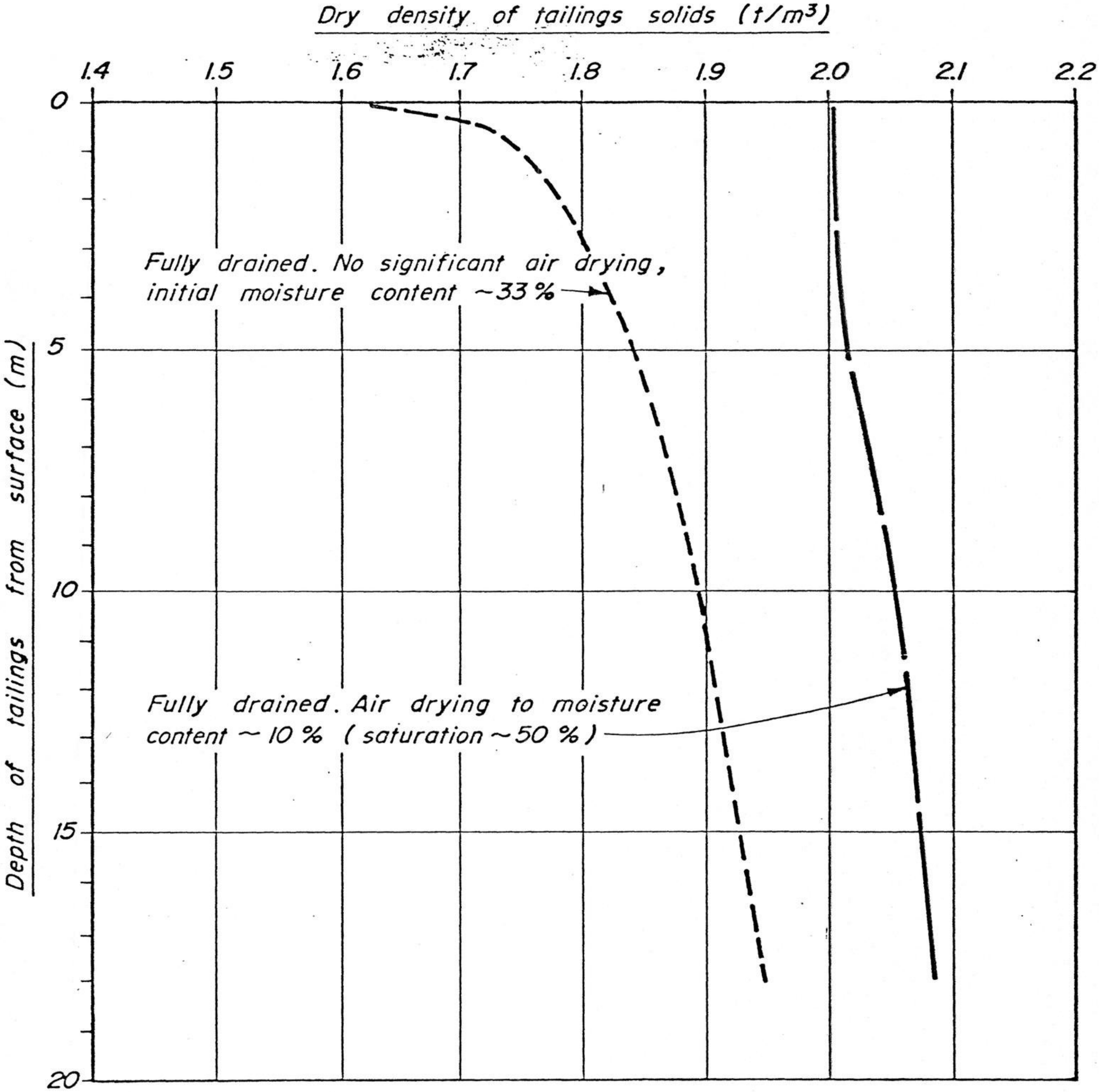
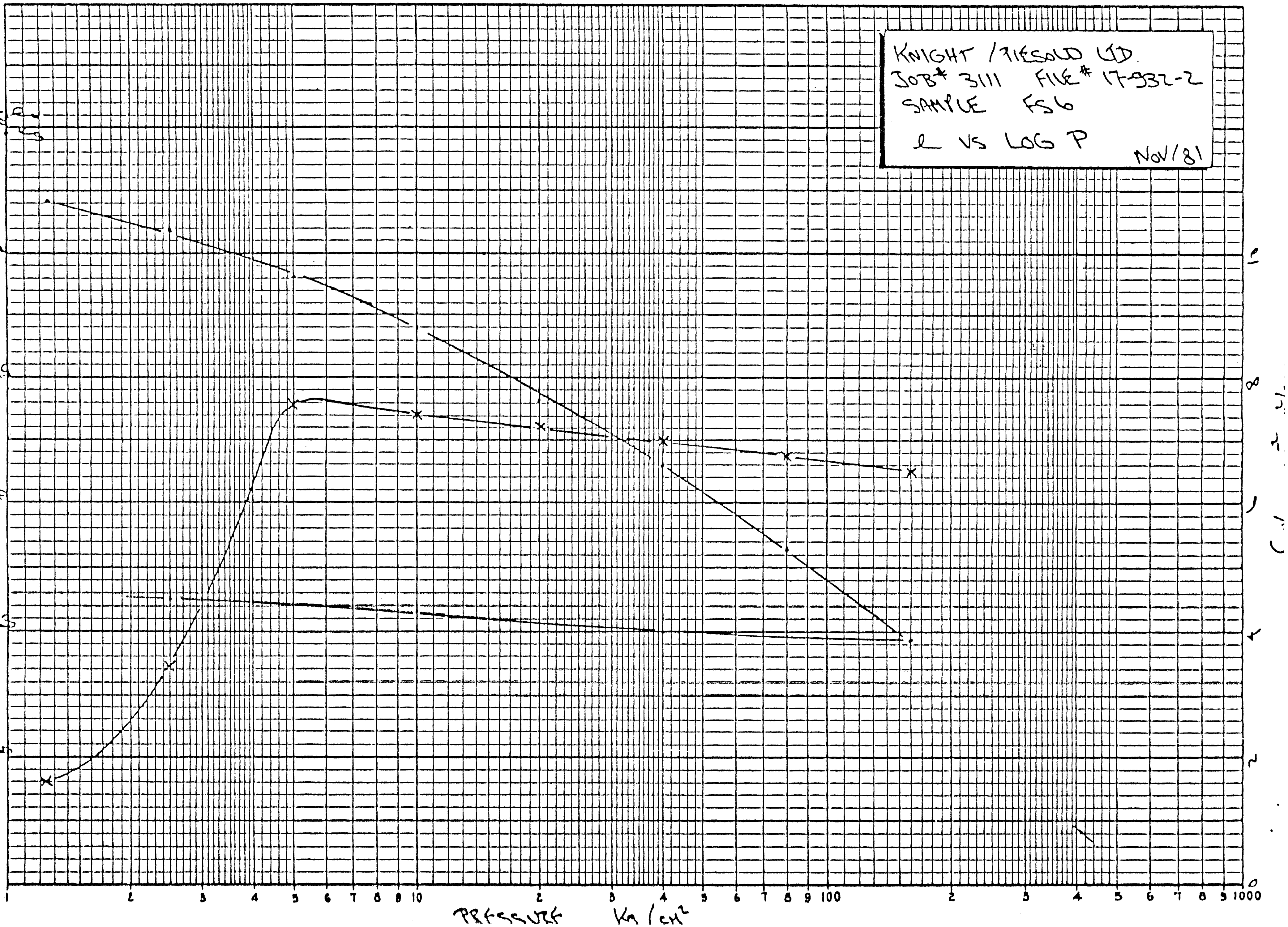
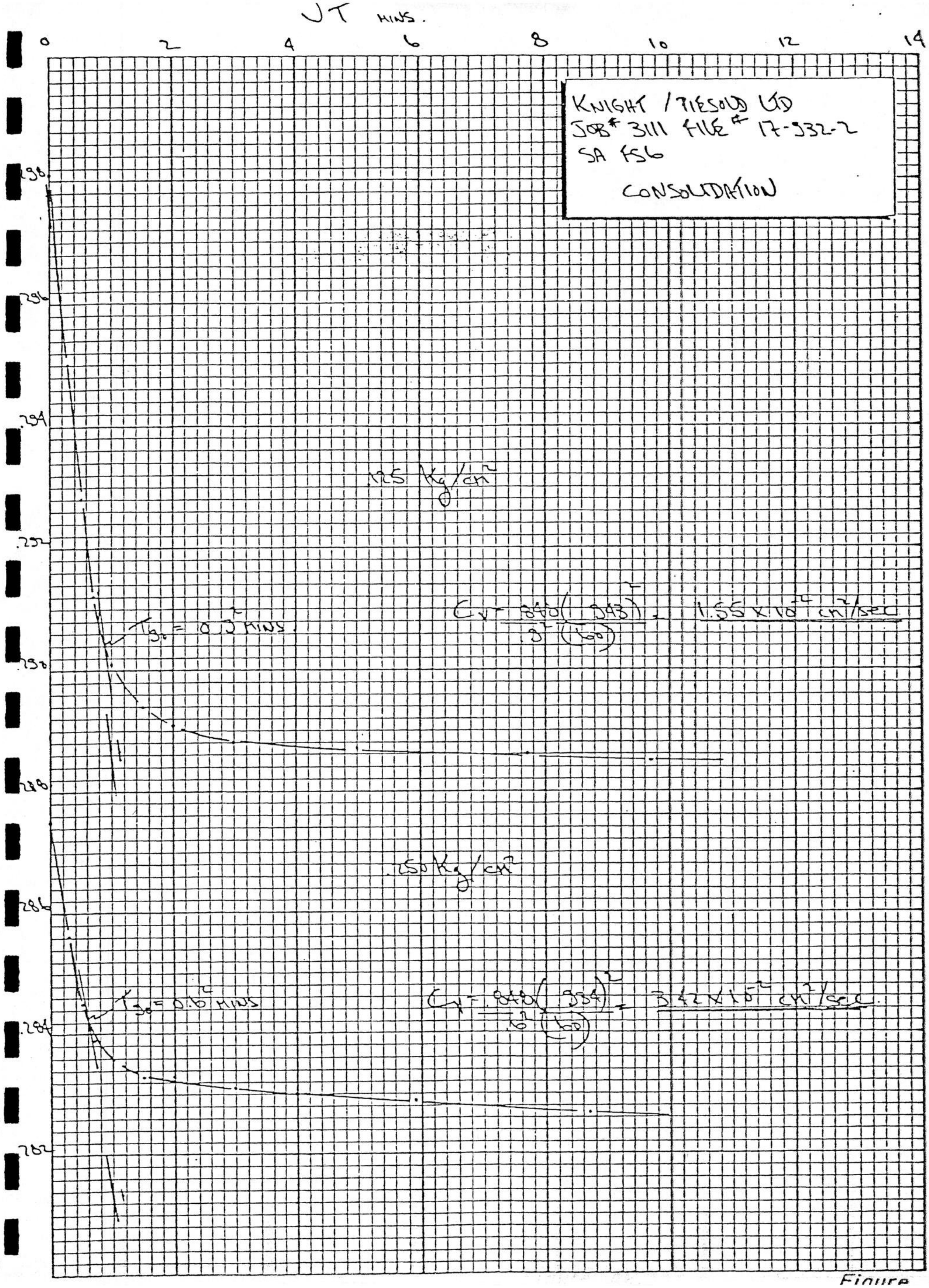


Figure A18



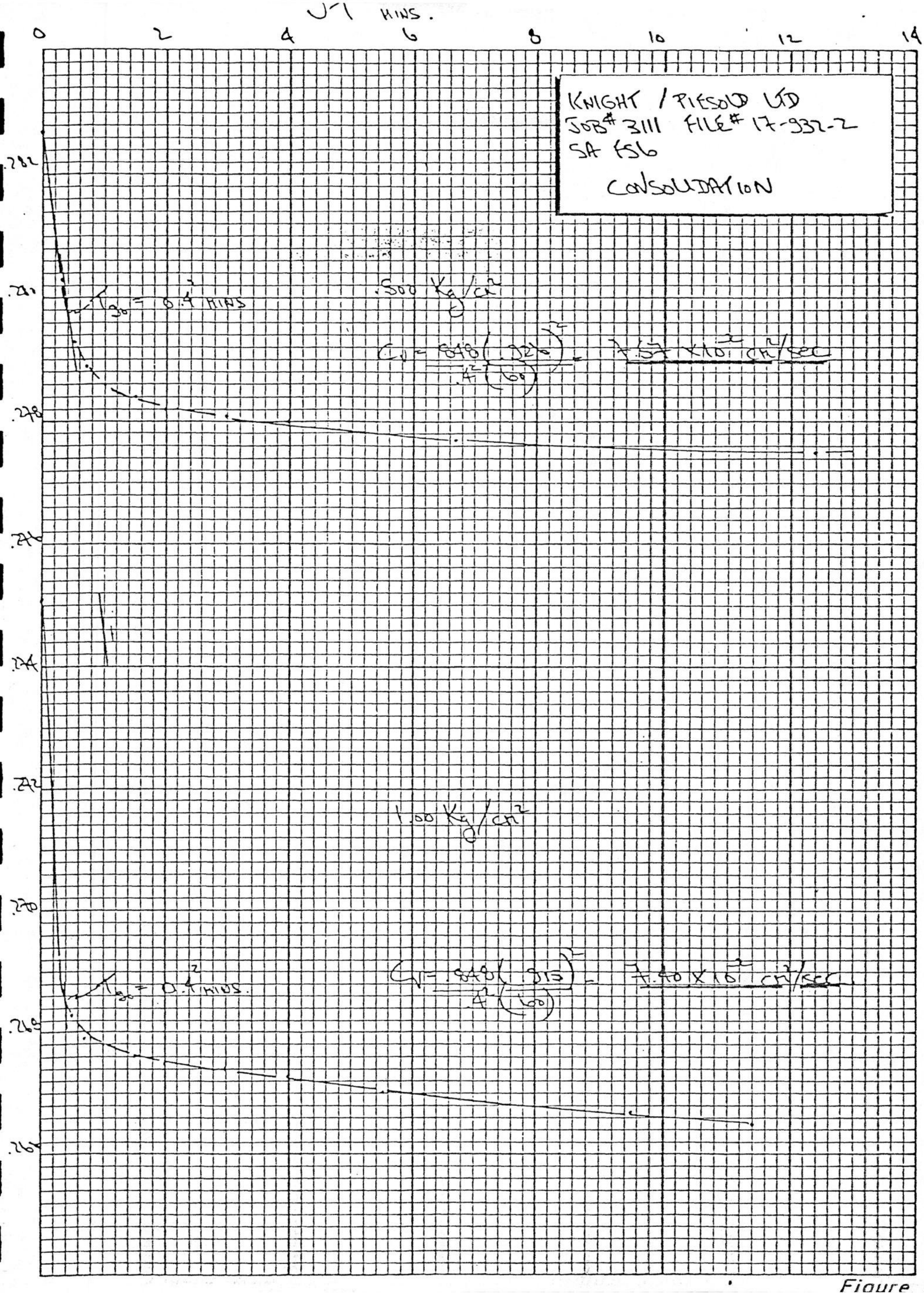
KNIGHT / PIESOLD LTD.
JOB # 3111 FILE # 17-932-2
SAMPLE FS6
e VS LOG P
NOV/81
PRESSURE Kg/cm²

Figure A19



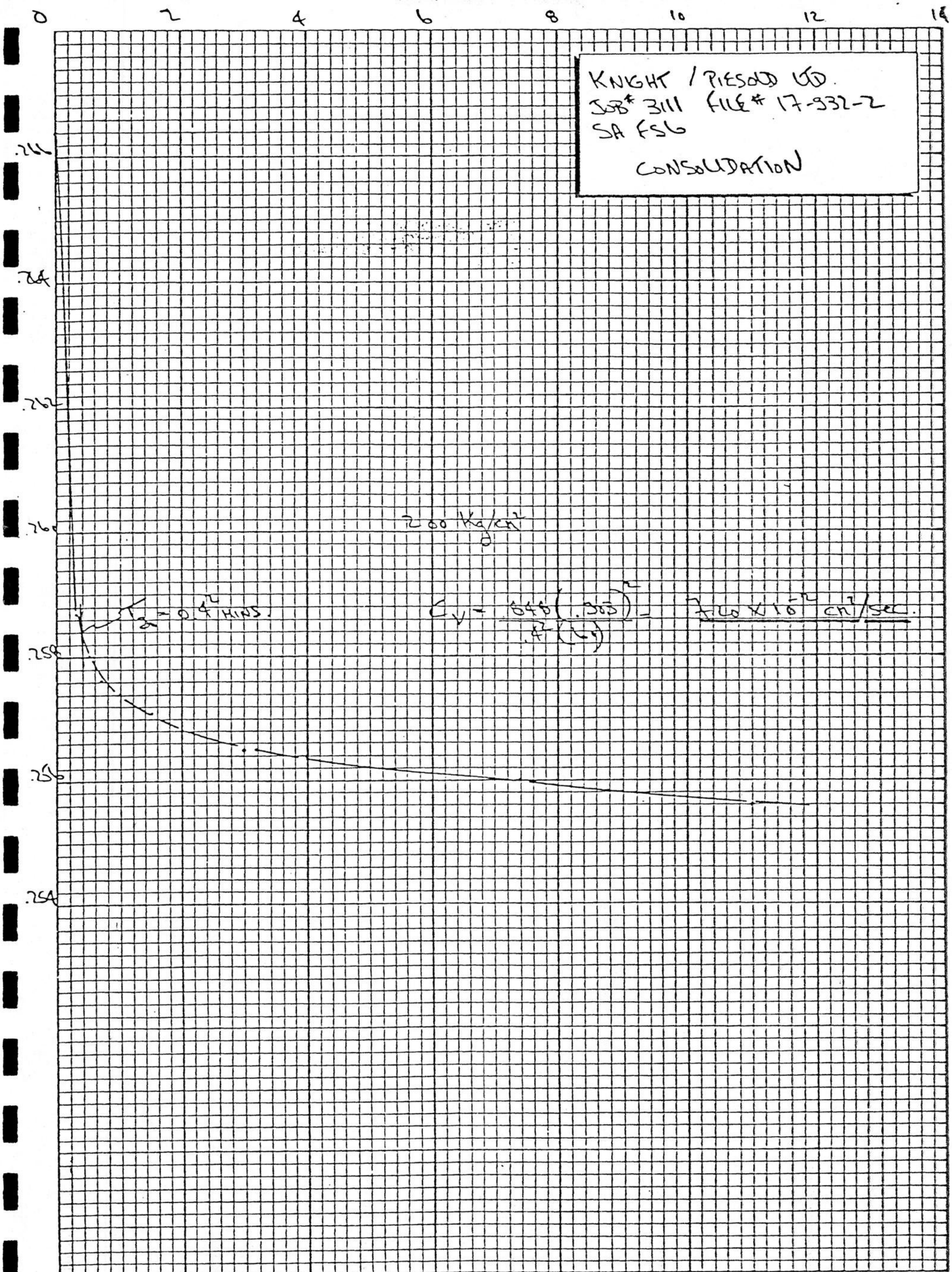
√T MINS.
0
2
4
6
8
10
12
14
KNIGHT / PIESOLD LTD
JOB# 3111 FILE# 17-932-2
CONSOLIDATION
.125 Kg/cm²
.250 Kg/cm²

Figure A20



√t MINS.
0
2
4
6
8
10
12
14
KNIGHT / PIESOLD LTD
JOB# 3111 FILE# 17-932-2
SA 156
CONSOLIDATION
.282
.280
.278
.276
.274
.272
.270
.268
.266
.500 Kg/cm²
√t90 = 0.4 MINS
1.00 Kg/cm²
√t90 = 0.4 MINS

Figure A2



KNIGHT / PIESOLD LTD.
JOB# 3111 FILE# 17-932-2
SA FS6
CONSOLIDATION
200 Kg/cm²
HINS.
0
2
4
6
8
10
12
.266
.264
.262
.260
.258
.256
.254

Figure A2

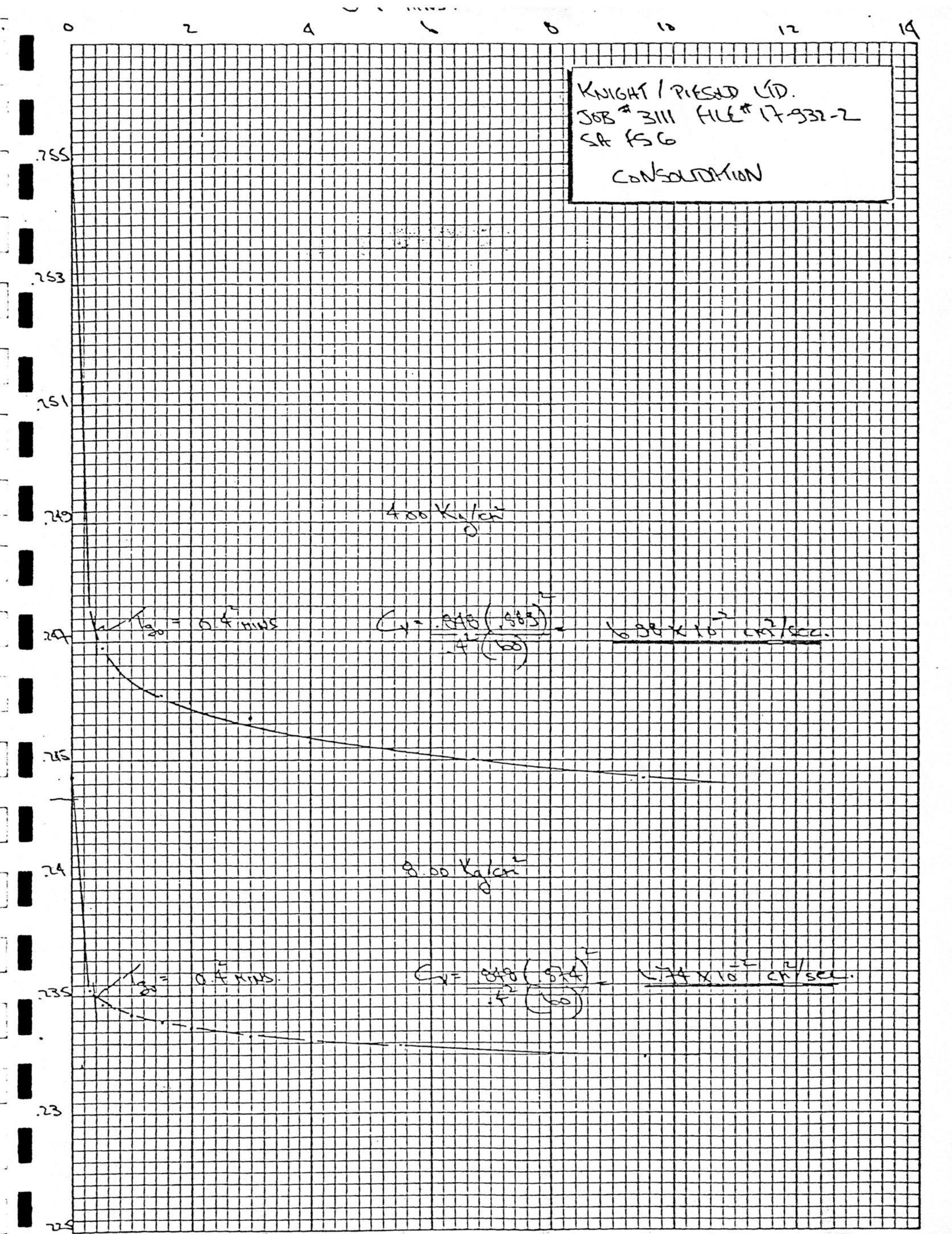

0
2
4
8
10
12
.255
.253
.251
KNIGHT / PIESOLD LTD.
JOB # 3111 FILE # 17-932-2
SA FS6
CONSOLIDATION
4.00 Kg/cm²
= 0.4 MINS
8.00 Kg/cm²
= 0.4 MINS
.23

Figure A23

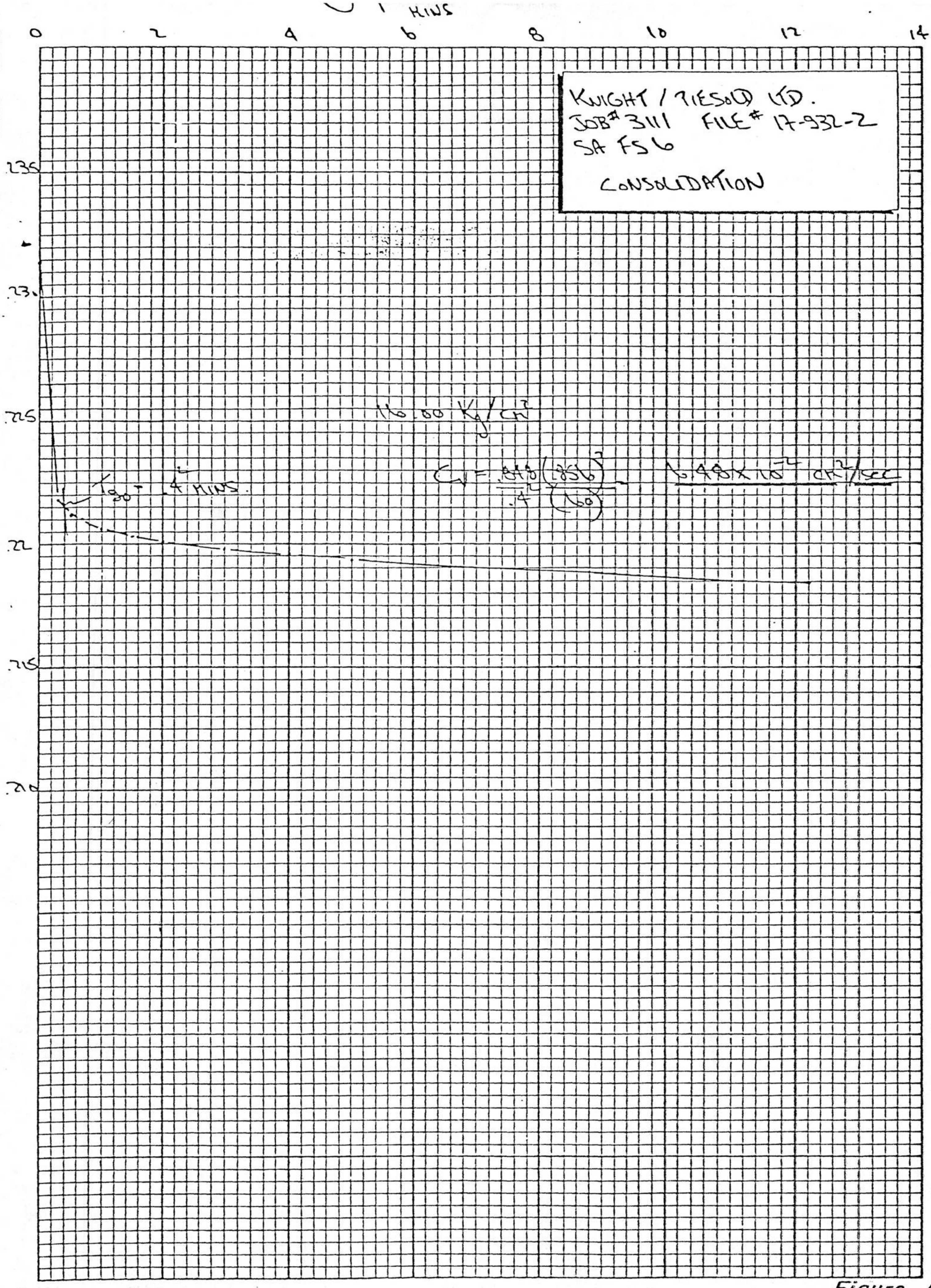
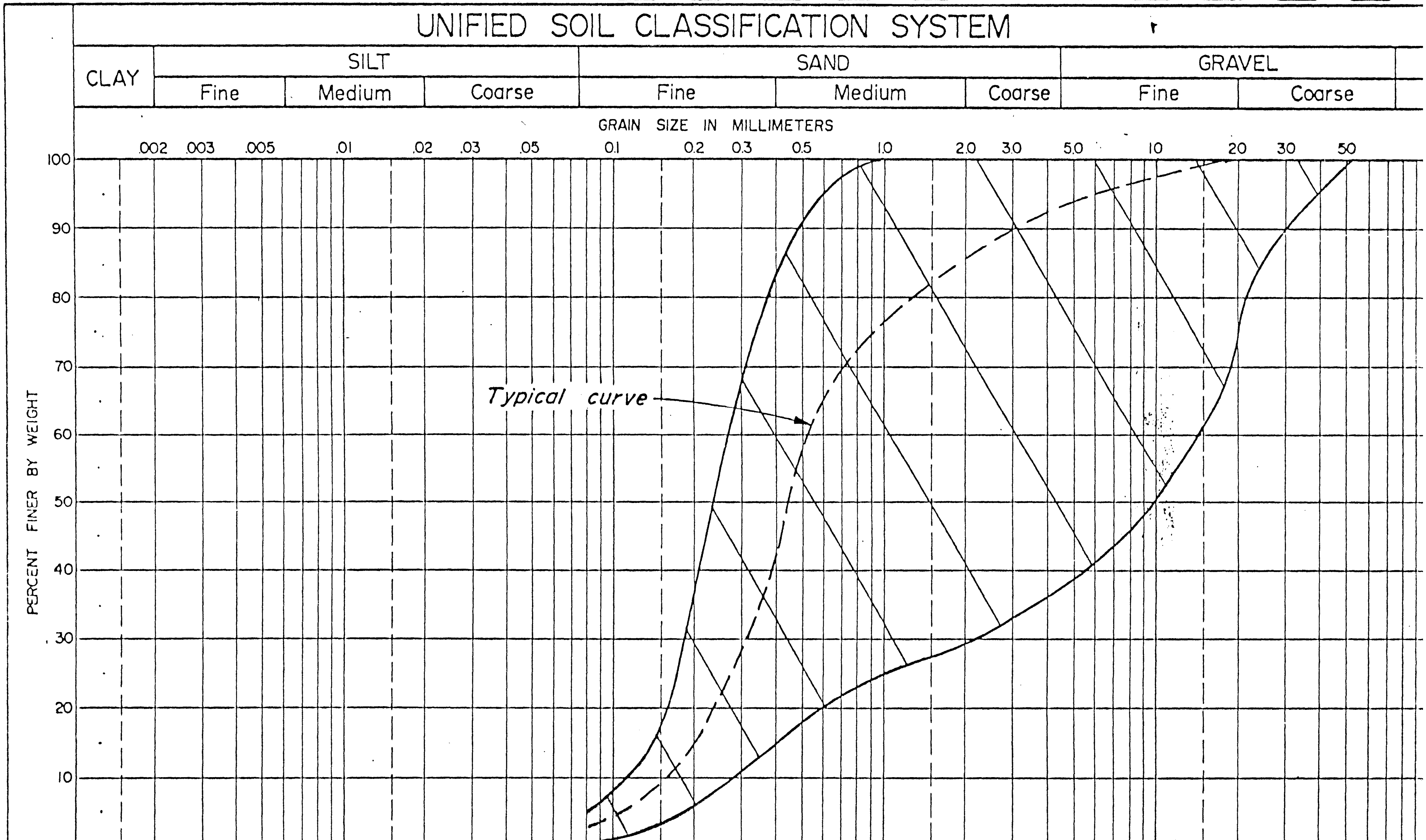

MINS
0
2
4
6
8
10
12
14
.235
.23
.225
.22
.215
.210
KNIGHT / PIESOLD LTD.
JOB# 3111 FILE # 17-932-2
SA FS6
CONSOLIDATION
16.00 Kg/cm²
t90 = .4 MINS
Cv = .848(.856)² / .4(60) = 6.48x10⁻² cm²/sec

Figure A2·

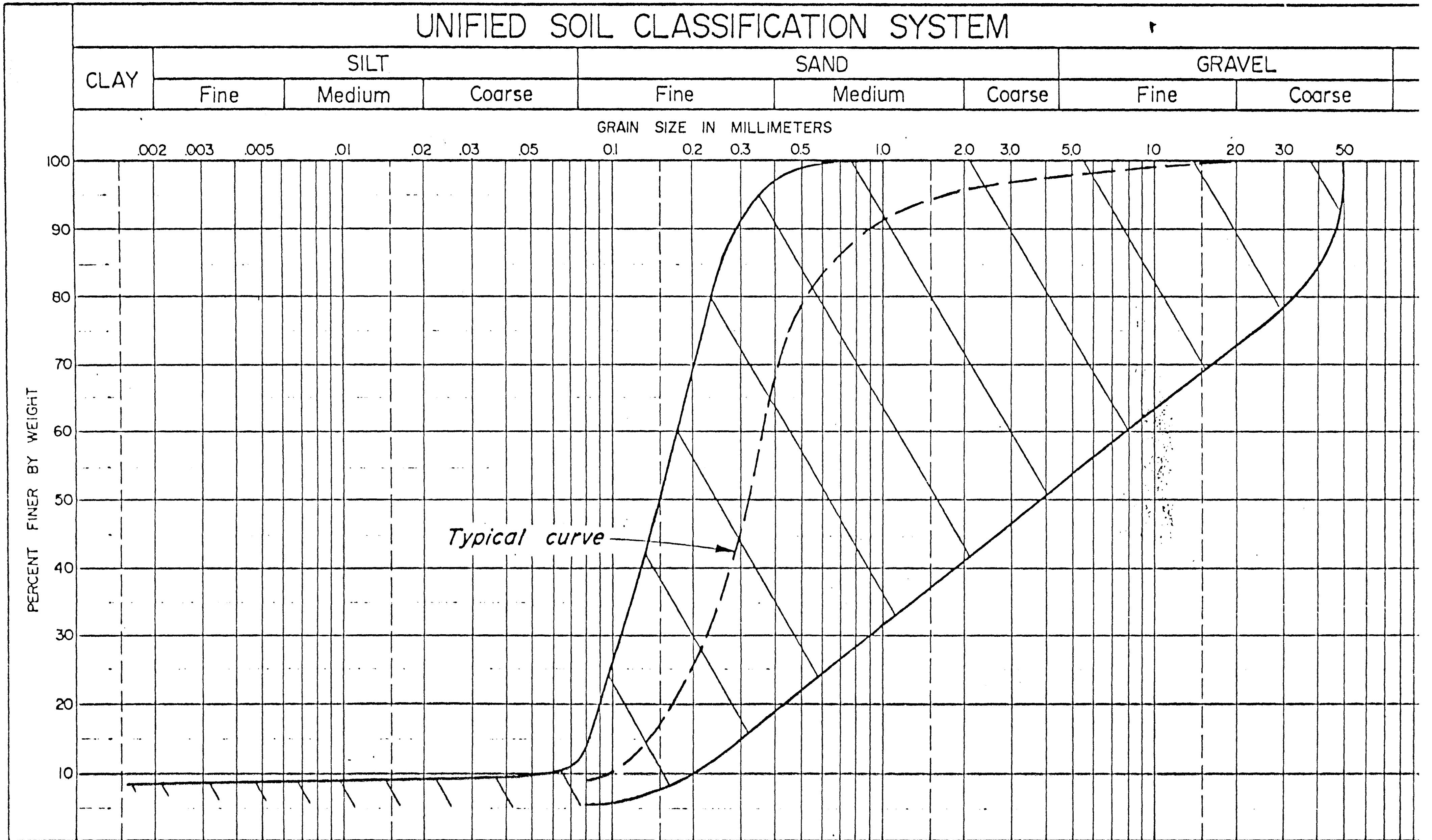
APPENDIX B

GEOTECHNICAL INVESTIGATION

PARTICLE SIZE DISTRIBUTION CURVES



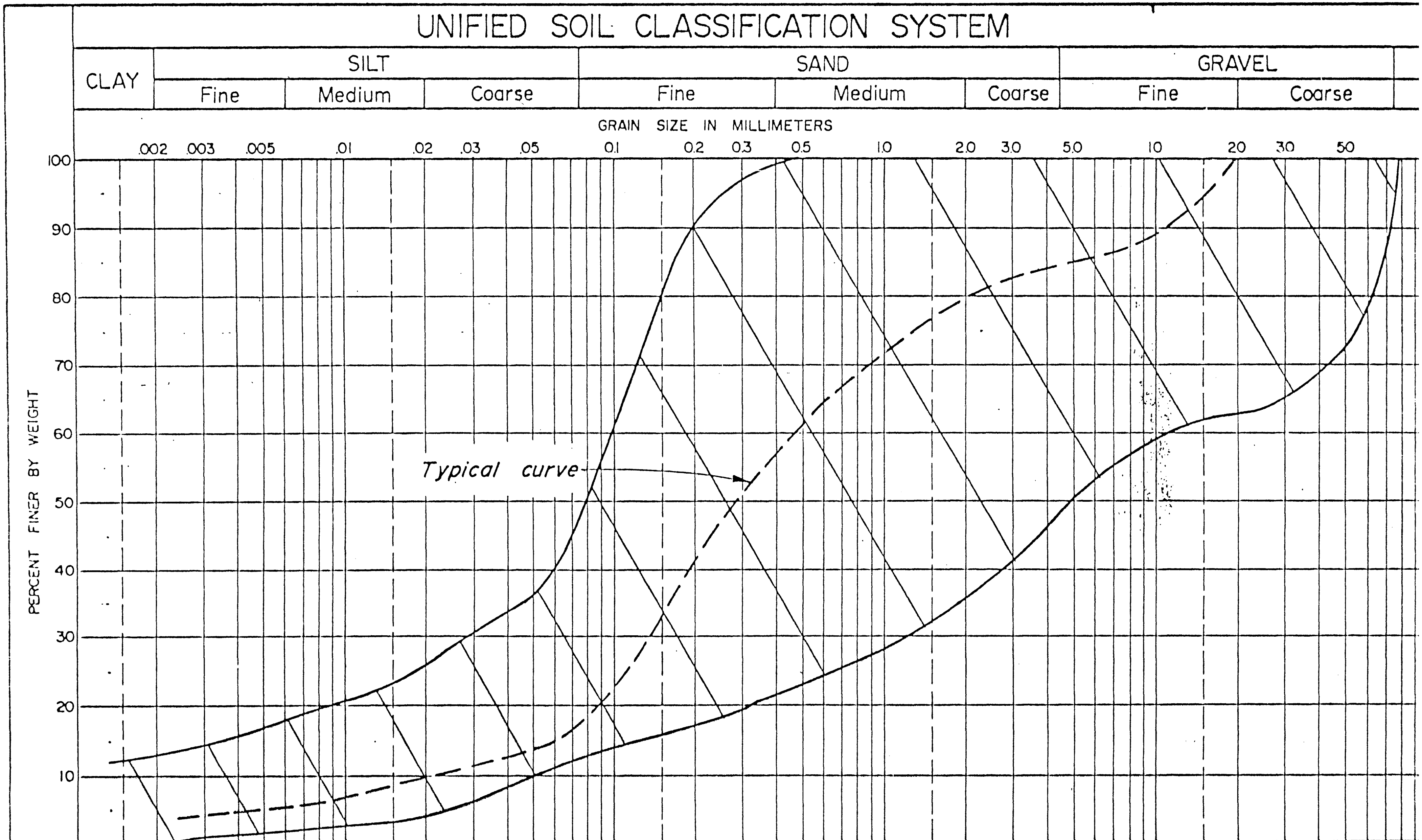
PROJECT	*CRANDON PROJECT*	SAMPLE No.	
	TAILINGS STORAGE FACILITY		
	GRADATION BAND for GW, GP, SW, and SP		KNIGHT AND PIESOLD LIMITED
	DESIGNATION SOILS		CONSULTING ENGINEERS
		DATE	



PROJECT	*CRANDON PROJECT*	SAMPLE Nº
	TAILINGS STORAGE FACILITY	
	GRADATION BAND for SW-SM and SP-SM	
	DESIGNATION SOILS	
		DATE

KNIGHT AND PIESOLD LIMITED

CONSULTING ENGINEERS



PROJECT CRANDON PROJECT

SAMPLE Nº

TAILINGS STORAGE FACILITY

GRADATION BAND for SM to GM DESIGNATION SOILS

DATE

KNIGHT AND PIESOLD LIMITED

CONSULTING ENGINEERS