EVALUATION OF MAN-MADE SUBAQUEOUS DISPOSAL OPTIONS AS A METHOD OF CONTROLLING OXIDATION OF SULPHIDE MINERALS - BACKGROUND AND GENERAL DESCRIPTION

MEND Project 2.12.1b

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SOMMAIRE EXÉCUTIF

Le présent rapport décrit les aspects reliés à la construction de deux cellules d'essai dans le cadre d'un programme de recherche sur l'utilisation de couverts d'eau comme moyen pour réduire l'oxydation des résidus générateurs d'acide. Les aspects couverts dans ce rapport incluent la construction des cellules d'essai à la Mine Louvicourt.

Les objectifs du programme de chantier étaient de:

1) Créer une installation pilote à l'intérieur du bassin de rétention des résidus qui reproduirait autant que possible les conditions qui pourraient exister à la suite de la fermeture du bassin Louvicourt. De façon à ce que cette installation soit la plus représentative des conditions de fermeture, elle se devait d'être isolée autant que possible des eaux de procédé du concentrateur et être réapprovisionnée avec de l'eau naturelle;
2) Instrumenter l'installation pilote de façon à permettre la collecte des données hydrogéologiques et hydrologiques nécessaires à la présente étude;
3) Échantillonner et analyser régulièrement l'eau du couvert, les résidus solides, l'eau interstitielle contenue dans les pores des résidus et l'eau souterraine de façon à rencontrer les objectifs généraux de l'étude préalablement définis; et
4) Faire un suivi du bassin de rétention des résidus de façon à permettre de faire le lien entre les résultats des programmes d'essais de laboratoire et de chantier et les conditions actuelles dans le bassin.

L'investigation de chantier incluait la conception, la construction et l'instrumentation de deux cellules d'essai, chacune mesurant approximativement 20 m x 20 m, dans un secteur adjacent au bassin de rétention des résidus de Louvicourt. Quelques problèmes de construction survenus lors des travaux ont nécessité certaines modifications au concept initial. Un niveau du roc moins profond que prévu et la proximité du bassin de rétention des résidus ont nécessité la relocalisation des cellules et un rehaussement du fond des cellules. Les dimensions et la forme des cellules étaient également légèrement différentes et le fond des cellules dût être reprofilé. Les cellules furent remplies avec de 2 à 3 m de résidus lors des trois premières semaines du mois d'août 1996 et recouvertes de 0,3 m d'eau.

Lors du remplissage des cellules, de grandes variations des caractéristiques géochimiques des résidus furent rapportées. Cela eut un grand impact sur la reproductibilité d'essai in-situ entre les deux cellules. Les caractéristiques comparables des surfaces des résidus entre les deux cellules sont donc différentes et le sont également dans une même cellule. Les deux cellules d'essai étaient équipées d'instrumentations permanentes composées d'un puits d'échantillonage/piézomètre et d'un lecteur de pH à batterie, d'un lecteur de niveau d'eau et débitmètre avec système d'enregistrement en continu situé à chacun des déversoirs des deux cellules.

Les objectifs du programme furent rencontrés même si la différence entre les caractéristiques de surface des résidus des deux cellules limite la possibilité de comparer directement les résultats obtenus des deux cellules.

EXECUTIVE SUMMARY

The current report describes the aspects related to the construction of two test cells as part of a research program on the use of water cover as a means of reducing oxidation of acid generating tailings. The aspects covered in this report include the construction of the test cells at Mine Louvicourt.

The objectives of the field program were to:

1) Create a test facility within the tailing impoundment which simulates as closely as possible the conditions which might exist following the closure of Louvicourt basin. In order for this facility to be representative of post closure conditions, it had to be isolated from mill process water and replenished with natural water.
2) Instrument the test facility in a manner, which allows the collection of the necessary hydrogeological and hydrological data for the study;
3) Regularly collect and analyse representative samples of cover water, tailings solids, interstitial tailings porewater and groundwater to meet the overall study objectives previously provided; and
4) Monitor the tailings basin in a manner which will allow the results of the laboratory and field test programs to be related to actual conditions in the basin.

The field investigation included the design, construction and instrumentation of two test-cells, each measuring about 20 m x 20 m, in an area adjacent to the Louvicourt tailings pond. Some construction problems were encountered during construction and required deviation from the proposed design. The presence of shallow bedrock and the proximity of the tailings pond resulted in a slight relocation of the cells, a raising of the cell floor levels. Cells were also slightly different in size and shape and ended up with sloped floors. Cells were filled with 2 to 3 m of tailings during the first three weeks of August 1996 and covered using a 0.3 m deep water cover.

During filling of the cells, large variations of the geo-chemical characteristics of the tailings were reported. This had a large impact on the reproducibility of in-situ testing between both cells. The comparative characteristics of the surface of the tailings between the two cells are therefore different and they are even different within each cell. Both test cells were provided with permanent instrumentation consisting of a sampling well/piezometer installation and a battery operated pH meter, water level and flow meter with continuous recorder at each cell overflow.

The goals of the program were met even though the difference in surficial tailings characteristics between both cells restricts the capacity to directly compare results obtained from both cells.

TABLE OF CONTENTS

SECTION PAGE

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background and Project Description

Acidic drainage has long been recognised as the largest environmental liability facing the Canadian mining industry, and to a lesser extent, the public through abandoned mines.

Acid Rock Drainage refers to a bacterially-mediated oxidation process that occurs over time when sulphide minerals, especially pyrite, are exposed to air and water. This process can occur in mine tailings and waste rock, and can result in the release of both acidity and metals in waters draining these materials, in such quantities to cause significant environmental impact. By limiting the exposure of the sulphide minerals to either air or water, or both, it is possible to greatly reduce, or completely prevent, the formation of ARD.

Although Acid Rock Drainage is not new and has an extensive history spanning decades and even centuries in Europe, it is not fully understood. In the past decades, changes in socio-economic expectations and heightened environmental awareness have made the management of waste a relatively new concept in the mining industry. This coupled with the potential impacts to the environment from mining operations have made the mining industry one of the most intensively regulated and scrutinized industry in the world.

In 1989, the Canadian mining industry, provincial governments and the government of Canada established a partnership to develop technology to predict, prevent and control acidic drainage. This $ 18.0 million industry-led program called the Mine Environment Neutral Drainage program or MEND, was the first multi-stakeholder initiative to develop scientifically-based technologies to reduce the effect of acidic drainage. A toolbox of technologies is now available to open, operate and decommission a mine property in an environmentally acceptable manner. Amongst these technologies water covers are considered as very promising.

Because of its low oxygen diffusion coefficient (2×10^{-9} m^2/s) and low oxygen solubility (8.6 g/m^3 at 25°C), water can act as an effective barrier to oxygen transport. Accordingly, in areas where the hydrological balance is favourable, water covers are considered the most economical and effective oxygen limiting cover material for preventing ARD. The calculated oxygen diffusion flux into water-covered mine waste is approximately 3000 times less than for air exposed, unsaturated wastes (MEND 2.12.1e).

While a water cover significantly reduces the oxidation of reactive mine wastes, oxidation is not completely eliminated. Oxidation accompanied by a slow rate release of some metals is still possible under certain conditions, as described by Morin (1993), and measured in a few long-term laboratory experiments (Ritcey, 1989; NTC, 1994). Metal releases can also be induced by variations in the chemistry of the water cover such as that produced by the replacement of process water by acid rainwater, as discussed in St-Arnaud (1994). In addition, re-suspension or disturbance of the deposited waste material by wind-induced waves, ice, vegetation or wildlife may increase the available surface area of the reactive waste to dissolve oxygen.

Because of the potential controversy associated with using natural lakes for subaqueous disposal of tailings, there is considerable interest in evaluating whether artificial (man-made) basins offer similar advantages to natural lakes. There are numerous sites where tailings have been deposited in a partially or completely submerged state in conventional tailings areas. However, it appears that there have been no detailed geochemical studies, similar to those carried out for natural lakes, undertaken for engineered basins or man-made lakes where tailings have been maintained submerged from the start of operations. The evaluation of engineered basins or man-made lakes for reactive tailings disposal was identified as a priority research area by the (MEND) research program.

In 1989, Aur Resources discovered a polymetallic orebody of copper, zinc, gold and silver. The Louvicourt Mine is a joint venture between the operator Aur Resources Inc., Teck Corporation and Novicourt (a subsidiary of Noranda). The tailings were potentially acid-generating and it was decided from the start to promote underwater disposal of tailings in a man-made tailings impoundment and to conceive a closure plan which would account for permanent submergence of the tailings. The impoundment was to be designed to hold a permanent water cover on the tailings to limit and possibly completely prevent the production of acid drainage. The site selection for the tailings impoundment had to take this fundamental aspect into consideration and enable a regulatory controlled design of the impoundment structure and closure to be developed.

In 1995, a collaborative project using the Louvicourt site to demonstrate the effectiveness of subaqueous tailings disposal in man-made or artificial containment structures under shallow water covers was initiated under the MEND Program. The project was managed by Golder Associés as the lead consultants with Aur Resources, Canada Centre of Mining and Energy Technology (CANMET), INRS-EAU (University of Québec), the University of British Columbia, SENES Consultants and the Noranda Technology Centre as collaborators.

The Louvicourt project encompassed both laboratory and field investigations. The laboratory investigations included humidity cells, oxygen diffusion, sediment erosion, oxidation kinetics and the rate of residual and reaction product migration via surface and groundwater flow regime and modelling downstream water quality and metal loadings. The field investigation included the design, construction and instrumentation of two test-cells, each measuring about 20 m x 20 m, in an area adjacent to the Louvicourt tailings pond. The cells were then filled with 2 to 3 m of tailings and covered using a 0.3 m deep water cover. MEND 2.12.1b (Golder), this report, presents an overview of the project and describes the mine site, the tailings pond, cell design, construction, filling and instrumentation.

1.2 Structure and Objectives of the Project

In 1995, MEND initiated a coordinated and important, multi-participant research project, referred to as the Louvicourt tailings project, to demonstrate the effectiveness of shallow water covers as a permanent means of preventing the oxidation of sulphide minerals and the consequent formation of acidic drainage.

The project has been divided into two phases as follows:

Phase I: Concept design, costing and proposal formulation for Phase II work. This phase was completed in 1995 under a separate contract to Golder (Golder, 1995).

Phase II: Integrated laboratory and field studies (the subject of the present report).

The main objectives of this study are twofold:

- Demonstrate the effectiveness of shallow water covers as a permanent means of preventing the oxidation of sulphide minerals and the consequent formation of acid rock drainage; and
- Establish whether there is any benefit to the additional placement of a thin organic or inorganic cover on the surface of flooded tailings (laboratory).

Some secondary objectives and benefits of the study include:

- Obtaining an in-depth understanding of the physical and chemical interactions within deposited tailings using measurements in both the solid phase and in the tailings interstitial water with emphasis on:
  - Diffusion of oxygen from the water cover into the sediments;
  - Interactions between the aqueous and solid phases (sorption, oxidation and dissolution); and
  - Vertical advection of pore water flow;
- Interpretation of the controls on the chemical behaviour of submerged tailings based upon solid-phase, porewater and water column geochemical data;
- Development of a predictive capacity (i.e. predicting the field behaviour of tailings from laboratory tests) by correlating the results of the laboratory tests with the field tests cells and actual conditions at the Louvicourt site;
- Further assessments using models to improve our capability to predict the long-term behaviour of flooded tailings; and

- Development of additional technology pertaining to mine closure scenarios.

In order to achieve these goals, column testing in the laboratory and pilot-scale testing on site were performed. Laboratory work in humidity test cells and in column test cells were undertaken and two test-cells, each measuring about 20 m x 20 m, were constructed in an area adjacent to the Louvicourt tailings pond. The cells were then filled with 2 to 3 m of tailings and covered using a 0.3 m deep water cover. A total of two cells were built in order to duplicate test results and to allow the versatility of possibly acting on one cell and have the second cell as a base case.

1.3 Study Participants

The participants in the study included:

i) A consultants group consisting of Golder Associés Ltée (lead consultant), INRS-EAU and SENES Consultants;
ii) The CANMET Laboratories in Ottawa and the Noranda Technology Centre in Pointe-Claire, Québec; and
iii) Aur Resources, the mine operator, Teck Corporation and Noranda Inc.

1.3.1 Aur Resources

Aur Resources and Golder have been the major participants to the construction phase.

Aur Resources was responsible for:

1) Test cells construction management;
2) Test cells instrumentation excluding the sampling wells/piezometers;
3) Test cells filling and water level maintenance; and
4) Tailings basin sampling and analyses.

In addition, they were responsible for maintenance and data collection associated with the test cells instrumentation and supply of the laboratory services on site. During years 2 and 3, the Aur Resources participation included the ongoing tailings basin sampling and analyses as well as maintenance and data collection associated with the test cells.

1.3.2 Golder Associés

Golder Associés (Golder) participated as project managers. Golder was responsible for the following tasks:

i) Evaluation of test cells options and preparation of the design and tender documents for test cells construction;

ii) Supervision of test cells construction; and

iii) Installation of the sampling wells and piezometers in the test cells.

1.3.3 Noranda Technology Centre

In the studies, various Louvicourt tailings samples were characterized for grain size, quantitative mineralogy, geochemical whole-rock composition, and extended acid-base accounting. Flow-through cell leach tests were used to assess metal release from the tailings under various conditions in humidity cells. Modelling techniques were applied to examine site-specific factors and chemical and physical processes that influence submerged sulphide oxidation and ultimately the water cover quality . As such, the research directly addressed uncertainties related to the quantification of the effects of four mechanisms for the transport of dissolved oxygen to submerged sulphide tailings: diffusion, convection, circulating current, the resuspension of tailings solids, and wave action.

1.3.4 CANMET

A two-phase column study was carried out by CANMET. In Phase I the effects of circulated and non-aerated water covers was examined, and Phase II also included precipitation, runoff and drawdown at rates comparable to those observed at the Louvicourt site. The column testing involved the following four disposal scenarios:

- A 0.3 m deep water cover over the tailings;
- A 0.3 m water cover over a 0.3 m peat intermediate layer over tailings;
- A 0.3 m water cover over a 0.3 m sand intermediate layer over tailings; and
- A 1 m deep water cover over the tailings.

In other words, the column experiment was designed to evaluate the effectiveness of two water cover depths (0.3 m and 1.0 m) and two intermediate barriers (peat and compost from the mine site) to prevent weathering of submerged tailings.

1.3.5 INRS-EAU

INRS-Eau undertook a geochemical sampling and analysis program from 1996 to 1998 to assess the chemical stability of the submerged tailings in the test cells. The work involved the following three major components:

1) The profiling of pH and dissolved oxygen at the water/tailings interface using a microelectrodes with 1 mm resolution.
2) The sampling of overlying water and the tailings pore water (at 1 cm resolution) using in-situ dialysis arrays (peepers) and subsequent analysis to determine the water chemistry.
3) Sequential extraction analysis of the superficial layer of the tailings to assess metal leachability.

1.3.6 SENES Consultants

SENES Consultants prepared an in-depth review of the methodologies and results of the Louvicourt tailings project studies.

2.0 LOUVICOURT MINE

2.1 Design Parameters of the Project

The Louvicourt mine is a base metal (Zn, Cu) underground mine developed about 20 km east of Val d'Or, Québec (see Figure 1). At the time of the project start up and design in 1994, it was assessed that the polymetallic orebody would have geological reserves in excess of 14 Mt averaging 3.83 % Cu, 1.75 % Zn, 31.97 g/t Ag and 0.95 g/t Au. A phased start-up program began in July 1994. The mill capacity is now 4,300 t/d. Reserves were reassessed since 1994 and current reserves would make mine exploitation last to 2005.

The tailings are potentially net acid generating with the predominant sulphide mineral, pyrite, representing about 30 to 45 wt % of the tailings mass. The tailings also contain minor trace amounts of pyrrhotite, sphalerite and chalcopyrite. The predominant carbonate minerals are ankerite and siderite, and the main silicate neutralizing mineral is clinochlore. The carbonate mineral content of tailings samples have ranged from near zero to 24 wt %.

2.2 Tailings Impoundment Site Selection

Taking into account current and projected regulatory requirements in Canada, the design philosophy established for Louvicourt is summarized as follows:

- Design for closure and operate for closure;
- Tailings is potentially acid generating and will be managed as such; best available technology economically achievable will be used to prevent acid rock drainage;
- Minimize the quantity of ARD producing waste materials generated by the facility (i.e. maximize the placement of waste materials underground);
- Maximize water recycling; and
- Use Mother Nature to advantage wherever possible.

When taken as a group, the design philosophy had a significant overall effect on all decisions related to site selection and design. In practice, this meant that a tailings site had to be selected so as to provide:

- good topographic relief;
- hydrogeological containment sufficient to maintain a permanent water cover over the tailings;
- a watershed of sufficient size to ensure maintenance of a water cover even during drought conditions; and
- seepage losses and flows through the tailings that were relatively small.

The design philosophy also governed the dam design (geometry, slopes, erosion protection), the requirements for both operational and emergency water control structures (variable flow, mechanically controlled, spillways) and management of the upstream watershed (temporary stream diversion during the mine operations and stream path restoration for closure). The site selection study was based upon a series of criteria developed and prepared with respect to:

- Technical and economic consideration;
- Geology and physical features;
- Hydrology and hydrogeology;
- Ecological and environmental impact; and
- Social considerations and usage of the land.

Low topographic relief, generally poor drainage, frequent swamps and a few scattered small, relatively shallow lakes characterise the area surrounding the mine site

Golder Associates Ltd. was retained by the mine to develop the tailing disposal infrastructures design. Six possible sites for the future tailings basin were identified and compared against a series of criterion. The main objective in the site selection process was to identify sites that could permit flooding of the tailings from day one during and after operation. The selected site was retained on the basis that it satisfies:

- Sound environmental review;
- Permits flooding of tailings during and after operation;
- Facilitates closure; and
- Was not expected to cause delays during the approval process based on the current regulatory environment in Québec.

The selected tailings basin location is about 8.5 km north-west of the mine. Figure 2 presents site and the existing structures (including the test cells). The tailings basin area is relatively flat. The site was selected after a careful study of several potential sites (Golder, 1992 – reports #901-7043G and 901-7043I). The tailings basin was constructed in 1993 and has a total capacity of about 4.2 Mm^3 (7.1Mt). There is also a treatment plant and polishing pond east of the impoundment.

2.3 Post Closure Water Balance

A water balance is a compilation of all the inflows and losses to a given system in order to determine the annual net accumulation or loss of water. Generally, in Northern Québec, there is a net accumulation of water and this volume can be significant. In 1993, Cumming Cockburn Ltd. (report no. 7392-2B) performed a water balance analysis for the study area. The purpose of the analysis was to determine the feasibility of maintaining a water cover over the tailings impoundment.

The water balance was performed for both proposed impoundment cells taking into consideration precipitation, evaporation and seepage losses.

The area has moderate net positive precipitation. The average annual precipitation for the Val d'Or area for the recorded period (1961 to present) is 954 mm. If the average annual evaporation or evapo-transpiration is subtracted, the net annual precipitation is about 413 to 465 mm. With a proper watershed feeding the tailings impoundment, permanent flooding of the tailings can therefore be foreseen as a measure to inhibit tailings oxidation as confirmed by (Robertson, 1991; Morin, 1993 and Pedersen et al., 1993).

3.0 FIELD PROGRAM

3.1 General

The objectives of the field program were to:

1) Create a test facility within the tailing impoundment which simulates as closely as possible the conditions which might exist following basin closure. In order for this facility to be representative of post closure conditions, it had to be isolated from mill process water and replenished with natural water.
2) Instrument the test facility in a manner, which allows the collection of the necessary hydrogeological and hydrological data for the study;
3) Regularly collect and analyse representative samples of cover water, tailings solids, interstitial tailings porewater and groundwater to meet the overall study objectives previously provided; and
4) Monitor the tailings basin in a manner which will allow the results of the laboratory and field test programs to be related to actual conditions in the basin.

3.2 Test Impoundment Cells

3.2.1 Test Impoundment Cells Design

Two experimental impoundment cells were constructed at the Louvicourt site in the summer of 1996. The test cells are located at the south-west side of the tailings basin as indicated on Figures 2 and 3. Topography in this area is suitable for limited excavation and fill requirements. Geological and hydrogeological conditions are relatively representative of the basin and consists of a thin organic layer overlying silt/clay, glacial till and bedrock.

The dimensions of the cells are 15 x 15 m in plan at the floor level and 30 x 30 m in plan at the crest level. Cells are 3 m deep on average. The test cells were constructed by excavating the cells area to elevation 3,317.11 to 3,318.5 m and then constructing the perimeter dykes using a combination of excavated material (where suitable) and compacted glacial till borrow obtained from borrow pits near the site (see Figure 4). The dyke crests were constructed to 3,320.4 m to 3,321.0 m and are around 4 m wide to allow access around the cells. The dyke crests and exterior slopes were protected with a layer of coarse sand and gravel for facilitating vehicles traffic and for erosion protection.

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1 Elevations refer to the Mine datum which is 3000 m above the geodetic datum.

Some differences from the proposed design were introduced during construction due to the existing site topography. The cells were initially supposed to be oriented NE-SW. The limited area left adjacent to the tailings pond forced the cells to be pivoted 90 degrees in order to stay away from the adjacent pond. During the stripping of the vegetative cover in the area of the cells, a rock outcrop with vertical faces was encountered. It was decided that instead of blasting this outcrop, it was preferable to move the test cells further south and to raise the base of the ponds by 4.1 to 5.5 m compared to the proposed elevation of 3,313.0 m. As shown on Figure 3, both cells ended up with sloped bases rather than the planned horizontal base. The two cells were also supposed to be identical. Due to the slope of the rock foundation, it was, however, impossible to accommodate fully identical cells. Consequently, the plan layout of the two cells, instead of being identical and rectangular as previously planed, was modified to accommodate the local bedrock topography as shown on Figure 3.

Between July 31 and August 23, 1996, the two cells were filled with tailings and water to the design elevations using the adjacent main tailings pipeline. The cells hold approximately 2.0 to 3.0 m of tailings depending on the bottom slope (see Figures 3 and 4). Tailings deposition is described in more details in Section 4. Pond water levels were held constant at elevation 3,319.5 m and were kept 0.3 m over the tailings surface. Spillways were provided in both cells for pond water control. Details of installation are provided in Section 3.2.2. A very shallow water cover of 0.3 m is considered to be most appropriate for man-made basins since it would tend to promote vegetation growth (i.e. the wetlands scenario) and because the facility would be more secure in the long-run with reduced risk of dam overtopping and failure.

After the tailings sedimented and stabilised, the first round of sampling was initiated October 1996. Because of the sensitive nature of sample handling and preparation, a small laboratory trailer was installed on site, adjacent to the test cells for the duration of the INRS-EAU group sampling campaigns.

3.2.2 Test Facility Instrumentation

The permanent instrumentation installed at the test cells consists of:

1) A sampling well/piezometer installation in each cell; and
2) A battery operated pH meter, water level and flow meter with continuous recorder at each cell overflow.

➢ **Sampling Well/Piezometer Installations**

The sampling well/piezometer was installed at approximately the centre of each of the cells as indicated on Photograph 1. Access to the installations is provided by a sampling platform that extends into the test cells or by a small boat.

The sampling wells/piezometers were installed during the construction of the test cells after the base was graded and before the cells were filled with tailings. The installations consisted of the following elements:

1) A 1.5-m long, 50-mm diameter slotted PVC well screen to allow sampling of groundwater in the overburden beneath the cells. Depending on the overburden thickness, the well screens were between 1 to 3 m beneath the cells bottom and were provided with a sand filter and bentonite seals as indicated on Figure 5 in order to isolate the well screen in the overburden. The well screen section of the piezometers are partially embedded within the till material and partially within the underlying bedrock.
2) Three (3) porous plastic piezometer tips with 13 mm Ø polyethylene riser tubing clamped to the 50 mm Ø PVC well screen riser pipe. The piezometer tips allow sampling of the tailings porewater at 3 different depths; about 0.25 m, 0.5 m, and 1.0 m below the top of the tailings.

- **Spillway, Water Level and Flow Meter**

Spillways were installed in both ponds to control water levels. Installation was performed by Mine personnel under the supervision of Golder on August 26, 1996. A 1 m deep trench was excavated through the cells east confinement dyke. A series of three zones of bentonite powder were spread on the prepared subgrade. A 1 m diameter culvert was then installed at each location and backfilled with bentonite powder and compacted till. Each culvert was installed with a slight downward slope to the east. Once completed, the bentonite powder formed three continuous loops around the culverts to improve impermeability. Small shacks were installed directly above the culverts to provide shelter to the data collection system. Runoff water obtained from the ditches in the nearby borrow pit was pumped into the ponds on August 27, 1996.

During periods of excess precipitation, water levels in the test cells were controlled by the "V" notched weir, installed in each cell at elevation 3,319.5 m. During dry summer months, the cells were periodically filled with fresh water by Mine personnel to maintain the water level. The pond level in the main tailings basin surrounding the test cells was maintained at or below elevation 3,316 m during the operation of the basin.

It is necessary to monitor water levels and flow from each of the cells. While this could be done manually on a periodic basis, previous experience indicates that the data collected is incomplete and of questionable value. Battery powered electronic water level gauges and flow meters with a continuous data recorder were installed at the outlet weir of each of the test cells. This instrumentation is regularly serviced and the associated data is collected by Louvicourt Mine personnel. This information is used as an input to the water balance analyses for the test cells and for the modelling work.

- **Temperature**

Surface temperature of the submerged tailings is a required input parameter for predictive modelling efforts. Thermistors were installed in each test cell, with results collected on the data logger.

- **Climatic Data**

Climatic data (i.e. precipitation, pond evaporation, wind, temperature, etc.) is obtained from the weather station at the Val d'Or airport. However, the water outflow from each cell due to important rain or thaw periods was measured using the flow meter described here above.

4.0 TAILINGS DEPOSITION AND CHARACTERISTICS

The deposition of the tailings was crucial to the study. The tailings were deposited between the first and the twenty third of August 1996. A 150 mm diameter and 500 m long pulp line was installed between the main pulp line and the test cells. A header was installed and eight 50 mm lines were attached to the header through valves. These lines, made of flexible polyethylene were used by groups of four in each cell. They could easily be displaced to insure an even deposition of tailings. Generally, the deposition slope of underwater tailings beaches is in the order of 10H:1V when laminar deposition of tailings takes place. Frequent displacement of the deposition points had to be done especially at the end of the filling in order to insure even water cover thickness.

During the first 3 days of filling, the pulp was composed of about 40% of solids and each pond was filled with this dense mix from bottom up. Starting on the fourth day, deposition was done at a lower rate using the natural solid content of the pulp and by moving frequently the flexible lines to get an even surface. Cells were filled up to capacity on a daily basis at which point filling was stopped. The tailings were allowed to decant overnight and the excess water was pumped out the next morning using floating pumps. Every precaution was taken to minimise disturbance of the water and to permit adequate sedimentation of the tailings particles. As this process was repeated on a daily basis the remaining space up to the pre established elevation of the proposed spillways was getting smaller and smaller. As a result, the amount of tailings slurry dumped on a daily basis and the resulting thickness of the decanted tailings layers were decreasing from one day to the next. Cell # 1 was also larger than Cell #2. Consequently, Cell # 1 had to be filled three days longer than Cell #2. The ore type varied during these three days causing the zinc circuit at the plant site to be shut down during that time period since the zinc concentration was getting too low. As a result, the mineralogy of the surficial layer in both cells is different.

This change in mineralogy was clearly established based on samples that were taken on a regular basis and analysed at the mine for copper, zinc and iron concentration in order to characterise the geo-chemical variability of the tailings during the filling operation. The graphical results of these measurements are presented in Figure 6. It can be seen that large variations existed during the filling of the cells, especially concerning zinc and iron. The graph shows also major variations during the last 3 days of filling in Cell # 1. This corresponds to the deposition of the last superficial layers of tailings under low zinc concentrations. This has a large impact on the reproducibility of in-situ testing between both cells. The comparative characteristics of the surface of the tailings between the two cells are therefore different and they are even different within each cell.

In retrospect, it would have been wiser to stop the deposition of tailings in both cells at the same time, resulting in different tailings levels. Water outlets would have then been set at different elevations. The advantage of this procedure would have been to maintain a similar mineralogy between the surficial layers of tailings in both cells. These surficial layers are most critical for the comparison of test results originating from both cells.

5.0 CONCLUSIONS

The research project, which involved Golder, Aur Resources, Teck, Noranda, INRS-EAU, CANMET and SENES, as part of MEND program, is composed of two phases:

Phase I, consisted of preparing the concept design, costing and proposal formulation for Phase II work.

Phase II consisted of integrating laboratory and field studies for the comprehension of the behaviour of tailings under a shallow water cover. The main objectives of the Louvicourt cells are twofold: demonstrate the effectiveness of shallow water covers as a permanent means of preventing the oxidation of sulphide minerals and the consequent formation of acid rock drainage; second, establish whether there is any benefits to the additional placement of a thin organic or inorganic cover on the surface of flooded tailings.

In order to achieve these goals, column testing in the laboratory and pilot-scale testing on site were performed. Laboratory work in humidity test cells and in column test cells were undertaken and two tailings test cells were built on site for the study of the water cover.

Two experimental impoundment cells were constructed at the Louvicourt site in the summer of 1996. Some construction problems were encountered during construction and required deviation from the proposed design. The presence of shallow bedrock and the proximity of the tailings pond resulted in a slight relocation of the cells, a raising of the cell floor levels. Cells were also slightly different in size and shape and ended up with sloped floors. Cells were filled with tailings during the first three weeks of August 1996. During filling of the cells, large variations of the geo-chemical characteristics of the tailings were reported. This had a large impact on the reproducibility of in-situ testing between both cells. The comparative characteristics of the surface of the tailings between the two cells are therefore different and they are even different within each cell.

The goals of the program were met even though the difference in surficial tailings characteristics between both cells restricts the capacity to directly compare results obtained from both cells.

GOLDER ASSOCIÉS LTÉE

Michel Lemieux, ing. M.Sc.
Associate

ML/lr
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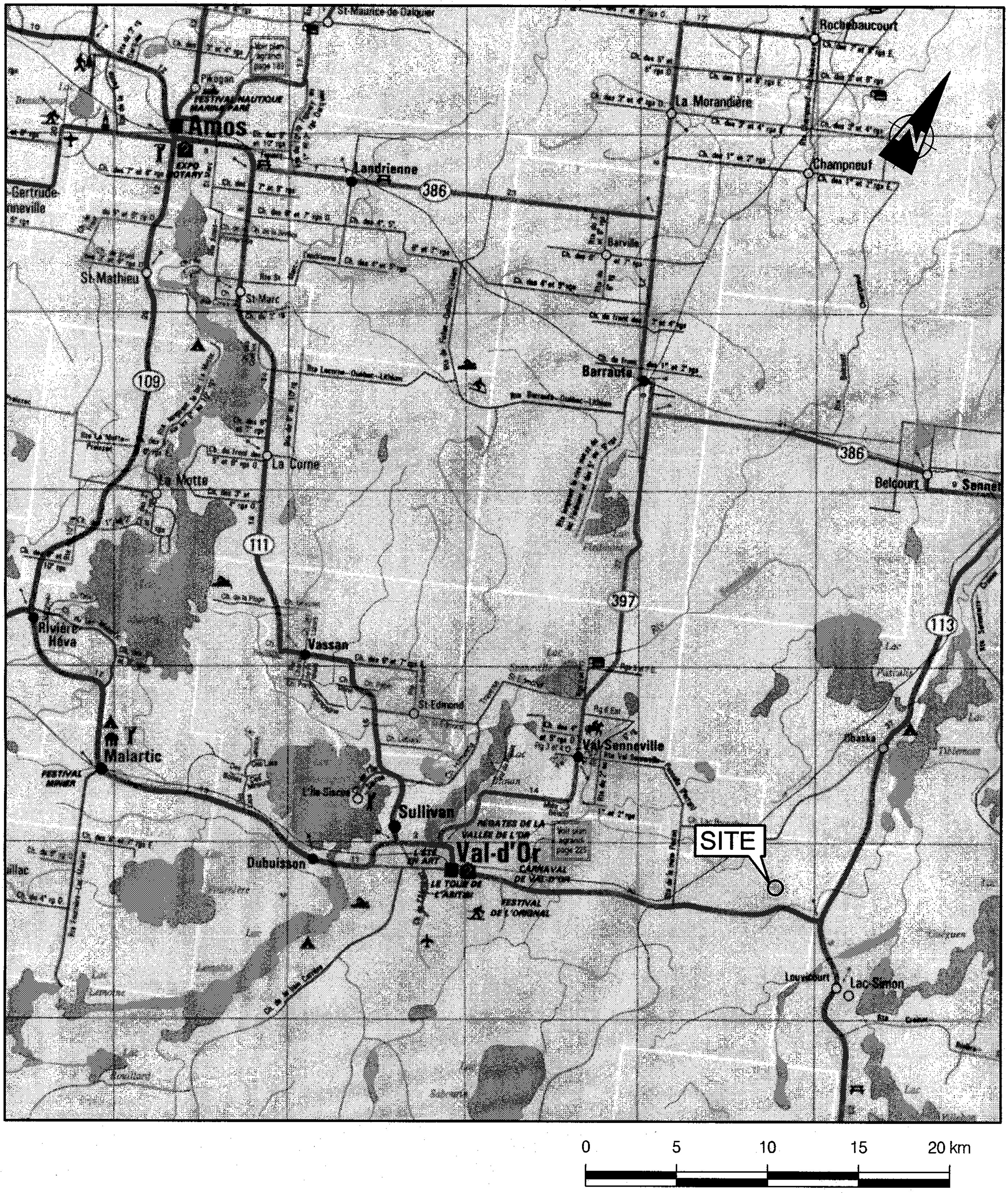
REFERENCES

1. Golder Associés Report 901-7043G, "Screening Study, Tailings Disposal Site Selection and Preliminary Planning, Louvicourt Project, Val d'Or, Québec", February 1992.
2. Golder Associés Project 901-7043I, memorandum to Pierre Lacombe, Ressources AUR Inc., "Evaluation of Alternative Tailings Basin Layouts for Site 2 - Submerged Concept", April 9, 1992.
3. Golder Associés Proposal P17-0154, letter to Pierre Lacombe, AUR Resources Inc., "Preliminary Investigation and Planning, Option 1, Louvicourt Project, Tailings Area", April 20, 1992.
4. Golder Associés Proposal P17-0154, letter to Pierre Lacombe, Ressources AUR Inc., "Additional Investigation and Evaluation, Site 2A, Louvicourt Project, Tailings Area", May 12, 1992.
5. Golder Associés Proposal P17-0154, letter to Pierre Lacombe, Ressources AUR Inc., "Preliminary Investigation of Site B-1, Dam Alignments, Project Louvicourt, Tailings Area", June 30, 1992.
6. Golder Associés Report 921-7025, "Preliminary Water Balances, Louvicourt Tailings Basin", June, 1992.
7. Golder Associés Report 951-7029, “Devis technique, cellules expérimentales, parc à résidus”, July 1995.
8. Noranda Technology Centre, “Assessment of Reactivity of Louvicourt Tailings”, July 12, 1996
9. APHA, 1989, "Standard Methods for the Analysis of Waters and Wastewaters", American Public Health Association.
10. Belzile, N., R.R. De Vitre and A. Tessier, 1989, "In-situ Collection of Diagenetic Iron and Manganese Oxyhydroxides from Natural Sediments". Nature 340: 376-377.
11. Carignan, R., F. Rapin, and A. Tessier, 1985, "Sediment Porewater Sampling for Metal Analysis. A Comparison of Techniques". Geochim. Cosmochim. Acta 49: 2493-2497.
12. Carignan, R., S. St-Pierre and R. Gachter, 1994, "Use of Diffusion Samplers in Oligotrophic Lake Sediments: Effects of Free Oxygen in Sampler Material", Limnol. Oceanogr. 39: 468-474.
13. De Vitre, R.R., N. Belzile and A. Tessier, 1991, 'Speciation and Adsorption of As on Diagenetic Iron Oxyhydroxides". Limnol. Oceanogr. 36: 1480-1485.
14. Filion, M.P., Firlotte, F.W., Julien, M.R. and Lacombe, P.F., 1994. “Regulatory Controlled Design – Louvicourt Project – A case Study”. In: Proceedings of the Third International Conference on the Abatement of Acidic Drainage, Pittsburg, PA, April 1994.
15. Fortin, D., G.G. Leppard and A. Tessier, 1993. "Characteristics of Lacustrine Diagenetic Iron Oxyhydroxides". Geochim. Cosmochim. Acta (in press).
16. Morin, K., Rates of Sulphide Oxidation in Submerged Environments: Implications for Subaqueous Disposal. In: Proceedings of the 17th Annual Mine Reclamation Symposium, Port Hardy, B.C., November 1993.

17. NTC (Noranda Technology Centre) “Development and Testing of a Biologically-Supported Water Cover Decommissioning Option for the Louvicourt Tailings”, Proposal submitted to Noranda Minerals, Teck Corporation, AUR Resources and MEND, September, 1994.
18. NTC (Noranda Technology Centre) “Assessment of reactivity of Louvicourt Tailings”, submitted to Noranda Mining and Exploration Inc., Teck Corporation, Aur Ressources and MEND, July 12, 1996.
19. Ritcey, G., Tailings Management, Problems and Solutions in the Mining Industry. Process Metallurgy 6, Elsevier, Amsterdam, Chapter 13: Decommissionaing, Reclamation and Covers. 1989.
20. Rescan Environmental Services Ltd., June 1989, "Subaqueous Disposal of Reactive Mine Wastes: An Overview" MEND 2.11.1a.
21. Rescan Environmental Services Ltd., March 1990a, "Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia". MEND 2.11.1b.
22. Rescan Environmental Services Ltd., March 1990b, "A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba". MEND 2.11.1a And.
23. Rescan Environmental Services Ltd., March 1990c, "A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia MEND 2.11.1a Ben.
24. Rescan Environmental Services Ltd., March 1990d, "A Preliminary Assessment of Subaqueous Tailings Disposal in Mandy Lake, Manitoba". MEND 2.11.1a Man.
25. Rescan Environmental Services Ltd., September 1990a, "Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Snow Lake Area, Manitoba". For: British Columbia Ministry of Energy, Mines and Petroleum Resources, CANMET, Environment Canada, Placer Dome Inc., Hudson Bay Mining and Smelting Co., Ltd., The Canada/British Columbia Mineral Development Agreement.
26. Rescan Environmental Services Ltd., September 1990b, "Geochemical Assessment of Subaqueous Tailings Disposal in Mandy Lake, Flin Flon Area, Manitoba". For: British Columbia Ministry of Energy, Mines and Petroleum Resources, CANMET, Environment Canada, Placer Dome Inc., Hudson Bay Mining and Smelting Co., Ltd., The Canada/British Columbia Mineral Development Agreement.
27. Rescan Environmental Services Ltd., June 1992, "Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver Island, British Columbia". For: Placer Dome Inc., Vancouver, Canada.
28. Rescan Environmental Services Ltd., February 1993, "Subaqueous Tailings Disposal Study - Scope of Work for Anderson Lake Winter Survey (1993)". For: MEND.
29. Rescan Environmental Services Ltd., National Water Research Institute, Environment Canada, July 1993, "Subaqueous Tailings Disposal Study - Scope of Work for Anderson Lake Summer Survey (1993)". For: MEND, Project 2.11.
30. Rescan Environmental Services Ltd., October 1993, "Subaqueous Tailings Disposal Study - Scope of Work for Buttle Lake Summer Survey (1993)". For: MEND.



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CANMET

EVALUATION OF MAN-MADE SUBAQUEOUS DISPOSAL OPTION AS A METHOD OF CONTROLLING OXIDATION OF SULPHIDE MINERALS (PHASE 1)

Golder Associés
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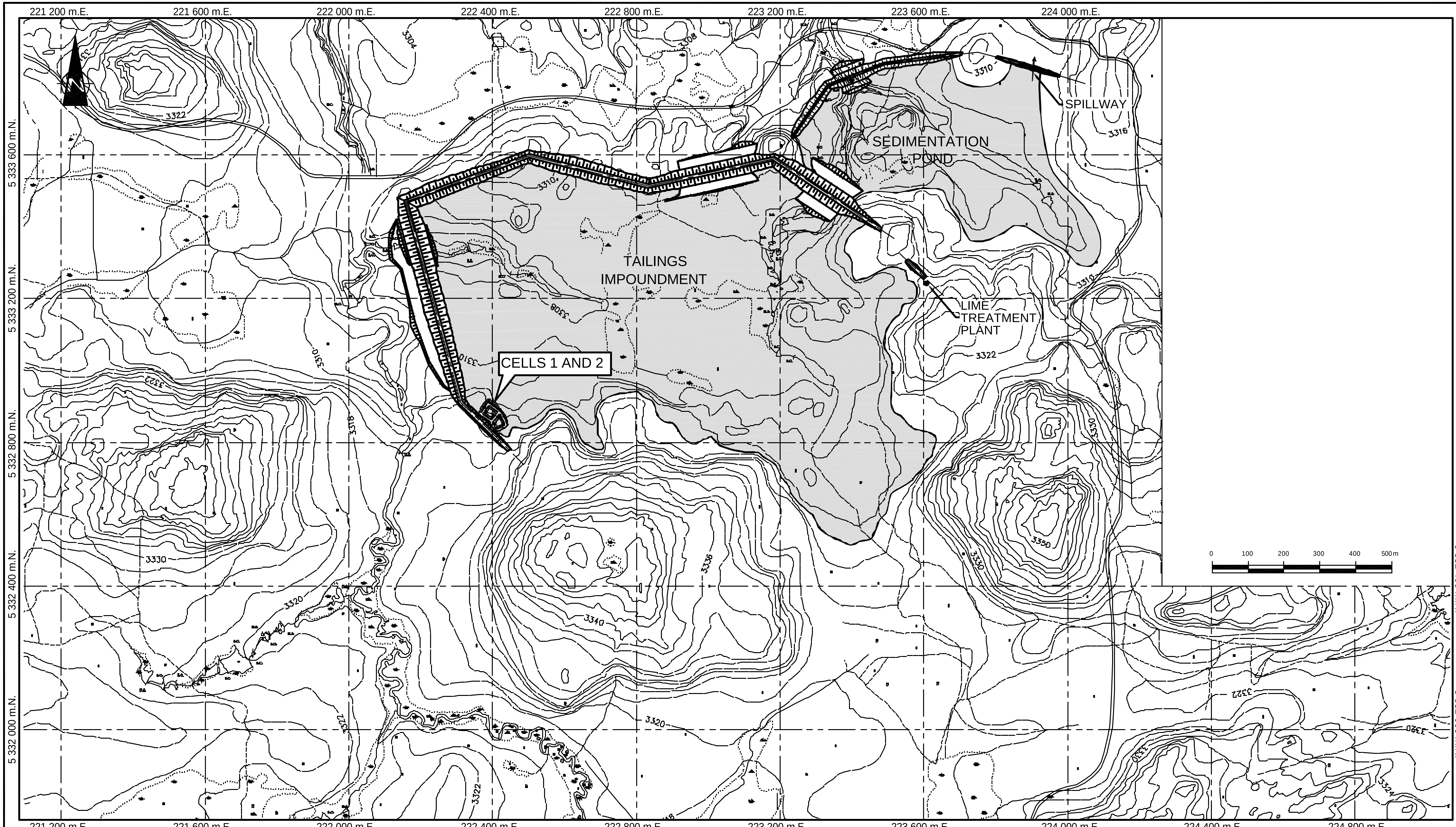
Montréal (Québec) H4N 2T2
Tél.: (514) 383-0990 Fax: (514) 383-5332

LOCATION MAP

FIGURE 1



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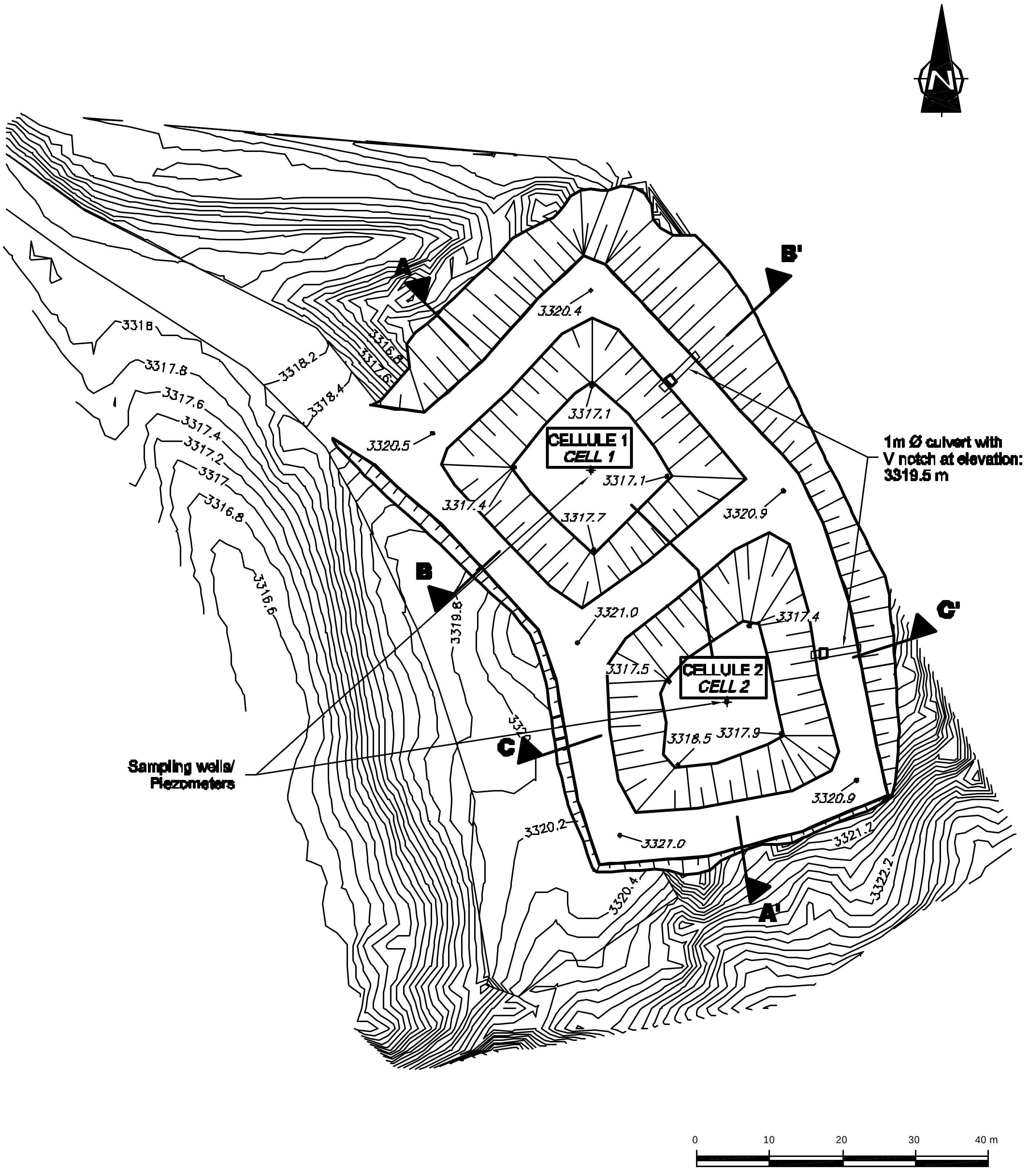
EXPERIMENT CELLS AND SITE PLAN

FIGURE 2

Welcome Screen | Search | Report List



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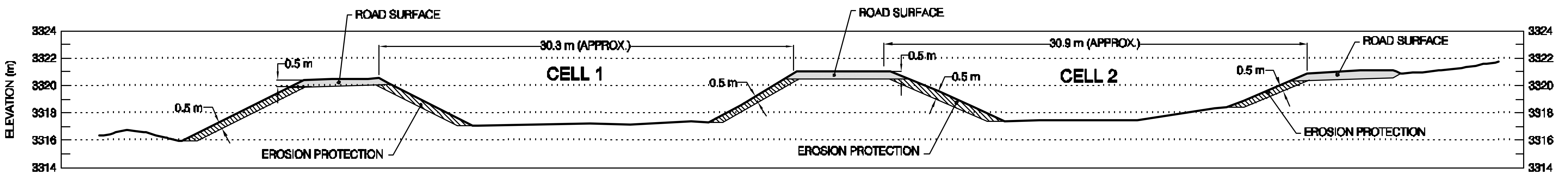
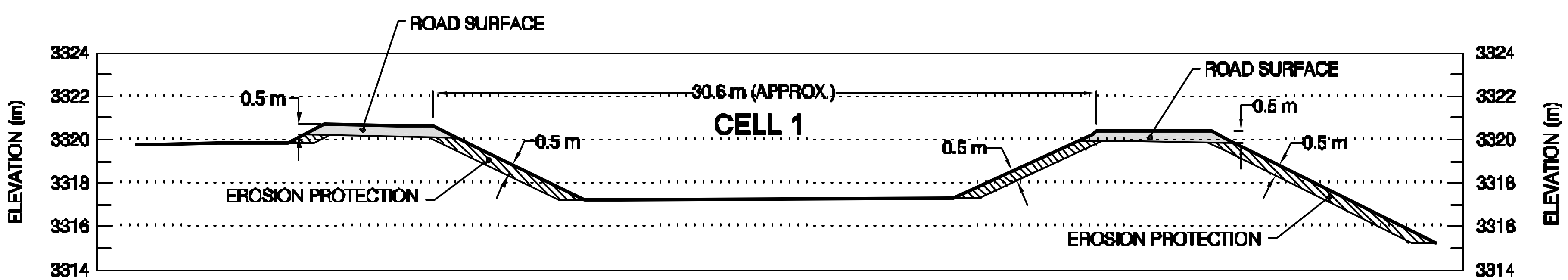
PLAN VIEW (AS BUILT) OF THE LOUVICOURT EXPERIMENTAL CELLS

FIGURE 3



CROSS-SECTION A-A'



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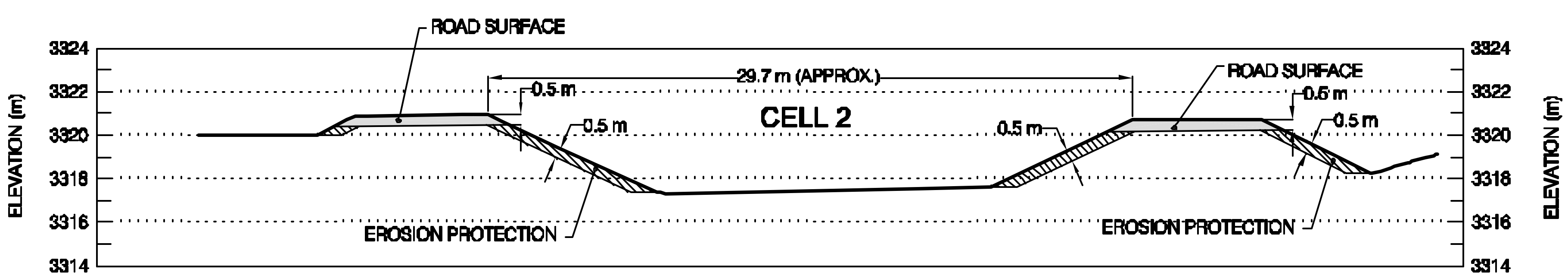

CROSS-SECTION C-C'

0 2.5 5 7.5 10 m

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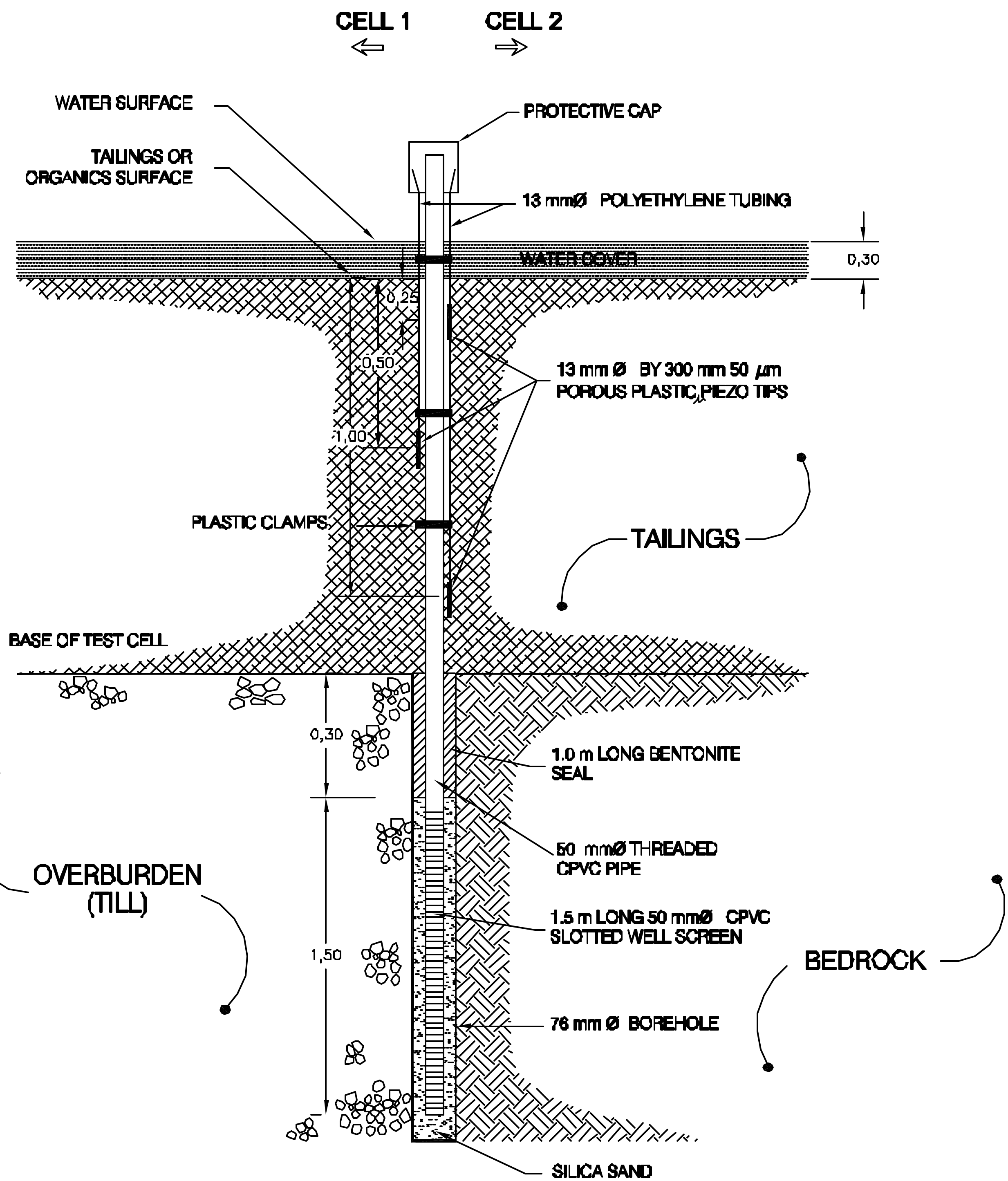
EVALUATION OF MAN-MADE SUBAQUEOUS DISPOSAL OPTION AS A METHOD OF CONTROLLING OXIDATION OF SULPHIDE MINERALS

CROSS-SECTIONS
LOUVICOURT EXPERIMENTAL CELLS

FIGURE 4



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EVALUATION OF MAN-MADE SUBAQUEOUS DISPOSAL OPTION AS A METHOD OF CONTROLLING OXIDATION OF SULPHIDE MINERALS (PHASE 1)

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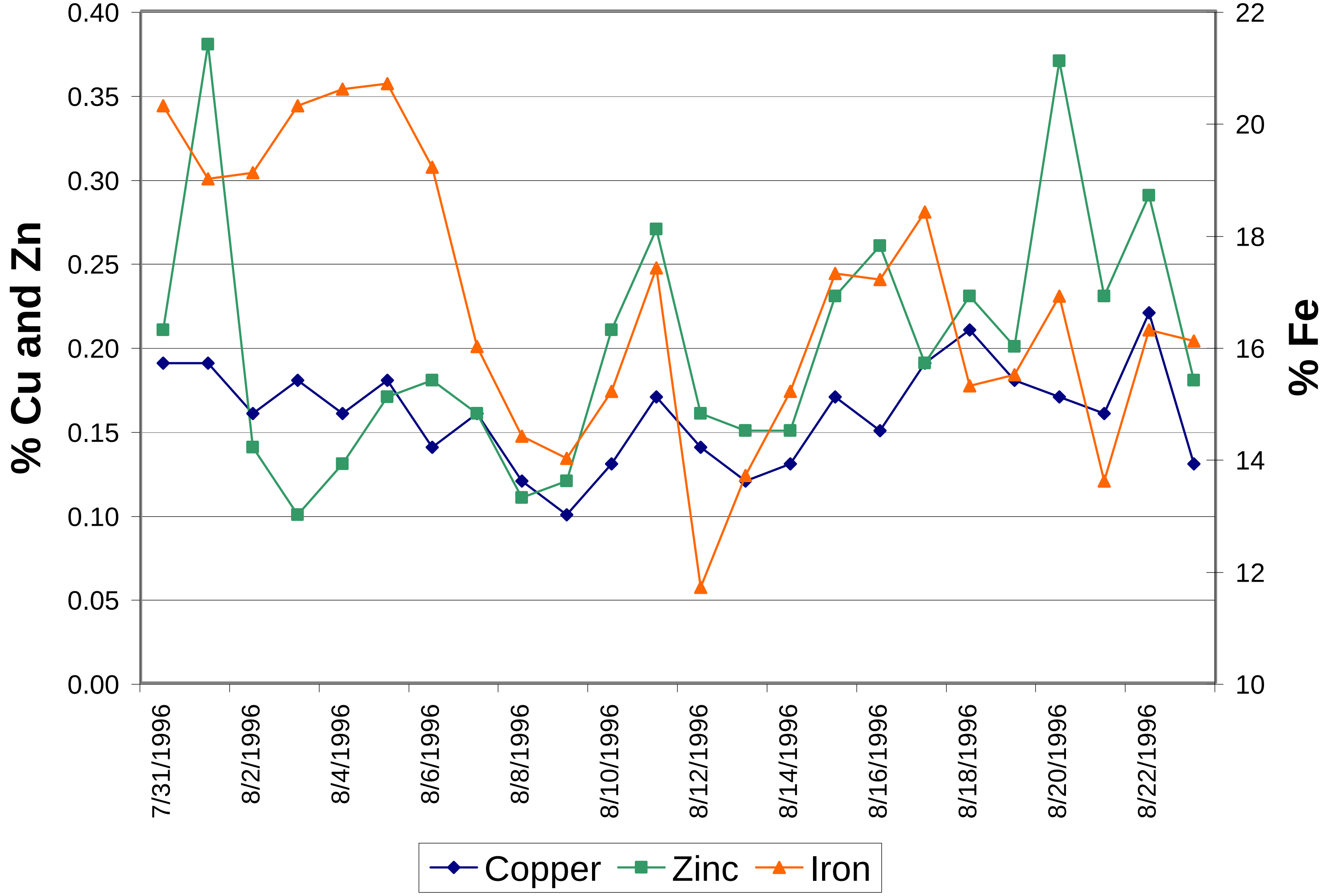
SAMPLING WELL/PIEZOMETER INSTALLATION

FIGURE 5

Figure 6 : Tailings Characteristics during Filling of Test Cells



Picture #1: Cells with the tailings impoundment in the background.

Picture 2: Cell #1 before filling.

Picture 3: Cell # 2 before filling.

Picture 4: General view of cells 1 and 2. (1999)

Picture 5: Monitoring cabin over the instrumented spillway.

Picture 6: pH meter within the spillway pipe.

Picture 7: Intake of the spillway pipe.

Picture 8: Outflow of the spillway and flowmeter.