Environmental geology and geochemistry at the Windy Craggy massive sulphide deposit, northwestern British Columbia

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ABSTRACT

The availability of environmental data is a major concern in the development of an exploration project through the permitting and feasibility stages. The collection of these data should ideally start very early in a major exploration program. Although a large proportion of the environmental data can also be used for exploration purposes, (e.g. stream-sediment, soil, and rock analyses), environmental sampling will rarely have been initiated at an early date. For the Windy Craggy project, a major environmental concern is the potential for generation of acid rock drainage from waste-rock piles. The project is reviewed with respect to the environment of the deposit, deposit geology, mineralization and reserves, the sequence of exploration activities to the present, the potential for the development of acid rock drainage, the geochemistry and water quality, and the integration of exploration and environmental databases and their application to environmental planning.

Keywords: Environmental geology, Geochemistry, Windy Craggy, Sulphide deposits, Exploration.

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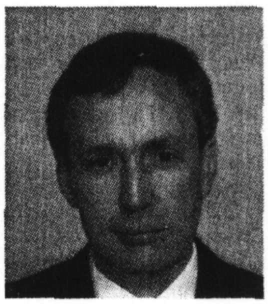

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During 16 years at Inco Ltd.'s Manitoba Division nickel/copper mining complex, he managed many of the milling, smelting, and refining operations, culminating as manager of the 110 million lb/year electronickel refinery. Subsequently, he has been responsible for management of process engineering for several mines in western Canada, most recently the Samatosum deposit in central British Columbia. He joined Geddes Resources Limited in mid-1990, from Barrack Mine Management where he had directed metallurgical testwork for a feasibility study of the Cinola gold deposit on the Queen Charlotte Islands, British Columbia.

Bruce W. Downing is project geologist for the Windy Craggy project. A graduate of Queen's University and the Univerity of Toronto, his 16 years' experience includes exploration for a spectrum of metals across North America, first with Falconbridge Limited and then Newmont Exploration of Canada. His computer experience has been utilized to manage the immense Windy Craggy database commensurate with the magnitude of the deposit.

Introduction

In the classical sense of exploration of a mineral deposit, the efforts throughout exploration are routinely directed at confirming the existence of the deposit and defining its extent, grade and continuity. Environmental issues are usually tackled separately, possibly by different personnel at a later date. When that is the case, an opportunity is lost to build, from an early date, a comprehensive database that (1) will satisfy the needs of conventional exploration and environmental monitoring, and (2) is usable as a predictive tool for environmental impact assessment.

The concept of environmental geochemistry is not complex. The availability of environmental data is a major concern in the development of an exploration project to the feasibility and permitting stages. The collection of data should ideally start very early in any major exploration program. In many cases a significant proportion of the geochemical exploration data gathered early in the life of a project will also be used later for environmental purposes (e.g. stream-sediment, water, soil, and rock analyses). Rarely, however, will the data gathered in a geochemical exploration program provide information as complete as that attainable if environmental objectives had been considered in scoping the work.

A knowledge both of local and regional geochemical processes can lead to a better understanding of environmental impacts. This understanding is the basis upon which good environmental management practices may be built. Geddes Resources Limited has undertaken a major study of the natural environment in the Windy Craggy area which includes geology, surface and underground waters, soils, stream sediments, glaciers and geomorphology (Geddes Resources Limited, 1990). This paper deals with the building and integration of the exploration and environmental databases.

Deposit Environment

The Windy Craggy deposit is in northwestern British Columbia approximately 145 km northwest of Haines, Alaska, and 200 km southwest of Whitehorse, Yukon Territory, (Fig. 1). Access is by aircraft from Whitehorse. The deposit is surrounded by glaciers. Windy Craggy peak, rising to an elevation of 2041 m, is representative of the mountains in this area of relatively low relief compared to the much higher mountains of Kluane National Park to the north and of Glacier Bay National Park to the south in the state of Alaska.

Drainage from the Windy Craggy deposit is into the Tats and Frobisher Glacier systems (Fig. 6). Tats Glacier drains south into Tats Creek, and thence into the Tatshenshini River; the Frobisher Glacier drains west into Frobisher Creek and thence into the Alsek River. The deposit itself occurs approximately 30 km from the Tatshenshini River and 5 km from the Alsek River. The major drainage relief from the peak to the proposed millsite is 1360 m over 11 km, or 1690 m over 30 km to the Tatshenshini River. The drainage away from the deposit is predominantly over limestone, limy sediments, and altered volcanics.

Annual precipitation at the elevation of the deposit is approximately 2.8 m, and in the vicinity of Tats Lake where the camp and processing plant will be built, approximately 2 m. Of these amounts, about 70% falls as snow. At the elevation of Tats Lake, seasonal temperatures range from −30°C during winter to 25°C in summer. More complete weather and visibility data are being gathered by an automated weather-monitoring station installed in 1990 near the peak of Windy Craggy mountain.

Soil coverage over the deposit is minimal, ranging up to 30 cm and averaging 10 cm to 15 cm in depth. The residual soil immediately over mineralized outcrops is reddish-brown, reflecting the gossanous environment, whereas soil over other lithologies is brown to yellow-brown. No organic horizon is noticeable. Soil development in the valley areas is poor, reflecting the moraine source and, more importantly, the presence of a low-temperature regime which inhibits good soil development. Soil types within the area are generally brunisolic to regosolic.

Vegetation in the deposit area consists of scattered patches of scrub grass. The limit of tree growth is below 1000 m elevation in the valley areas and generally consists of short conifers and scrub brush. The Tats Lake area bio-climatic zone is sub-alpine, transitional to alpine.

Adverse weather conditions, principally cold temperatures and heavy snow accumulations, limit surface exploration activities on Windy Craggy to approximately three months per year. During late June and early September, water supply to surface diamond drills can be maintained only with the use of water heaters. For this reason, an underground adit was driven to provide more tangible evidence of the mineralization at Windy Craggy.

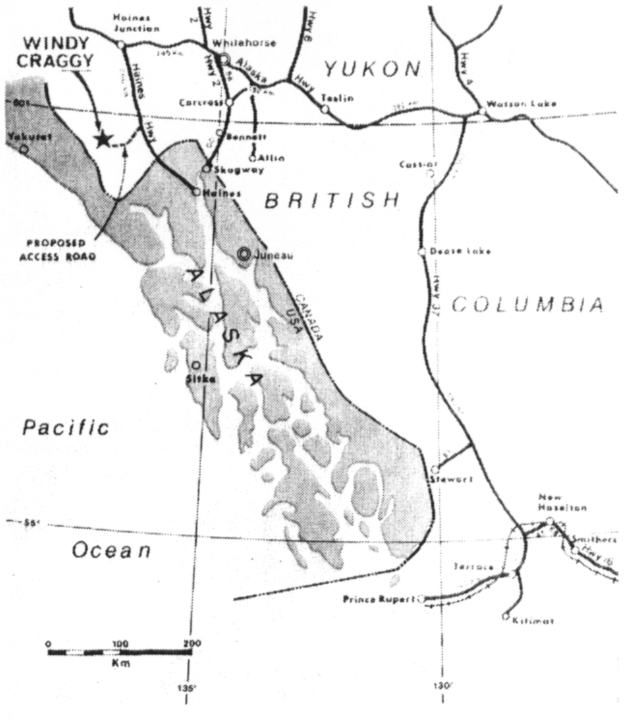

FIGURE 1. Location map.

Deposit Geology and Reserves

Windy Craggy is a volcanogenic massive sulphide deposit containing significant values of copper, zinc, gold, silver and cobalt, hosted by Triassic clastic sediments and mafic flows and sills within a major carbonate basin (Fig. 2). The massive sulphides occur near the transition from a predominantly clastic host to volcanic assemblages. Clastic sediments comprise calcareous, carbonaceous, and sulphidic units. Intermediate to mafic volcanic units have undergone carbonate and chlorite alteration. Structural deformation of the deposit includes steeply dipping faults and isoclinal and open folds, both in massive sulphides and in host rocks.

Major waste-rock types are volcanics and argillites, both of which can either be barren or contain sulphides. Argillites are non-calcareous to strongly calcareous (carbonaceous limestone), and volcanics are non-calcareous to moderately calcareous.

The deposit as currently defined includes the North and South zones, which have a minimum strike length of 1.6 km, a vertical extent of at least 600 m, and a width up to 200 m (Fig. 3). Limited drilling has defined a third zone, designated the Ridge Zone, which is to the northeast and has a possible strike length of 400 m. Sulphide stockwork, including irregular sulphide veins within pervasively chlorite- and silica-altered wallrock, is developed around the North and the South zones. Surface portions of each zone have supergene copper sulphide enrichment overlain by gossan caps enriched in gold and silver.

Principal sulphide minerals are pyrite, pyrrhotite, and chalcopyrite, with lesser sphalerite. Important supergene products are chalcocite, native copper, chalcanthite and limonite. Gangue components include quartz, iron carbonates, magnetite, chlorite and calcite. The geology, mineralization and sulphide geochemistry have been described in previous papers (Downing *et al.*, 1990; Peter *et al.*, 1990).

Exploration to December 1990 included 4139 m of drifting and 64 400 m of diamond drilling in 202 holes. Various bulk sampling, metallurgical testing, geotechnical and engineering studies, and environmental baseline investigations have been completed.

In November 1991, "geological reserves" at a 0.5% copper cut-off were estimated to be 297 million tonnes containing 1.38% Cu, 0.2 g/t Au, 3.83 g/t Ag, and 0.07% Co (Geddes Resources Limited, 1990). Considering these reserves and forecast recoveries, the deposit contains approximately 3.5 billion kg of marketable copper. The total extent of the deposit is not yet determined.

Environmental/Exploration Surveys

The Windy Craggy property was discovered and staked in 1958. Exploration proceeded sporadically until 1980, when Geddes Resources Limited (GRL) was formed specifically to explore this property. By 1983, control of the property was assumed by GRL. In 1988 exploration intensified with the beginning of underground development and an aggressive exploration program which has continued to the present. Collection of environmental baseline data was also initiated in 1988.

Increasingly, the efforts of GRL personnel have been focussed on ensuring that exploration and environmental surveys collect similar data. Exploration and environmental data have now been amalgamated into one database (Fig. 4). Studies have been initiated to increase the understanding of the interaction of lithology and water quality in the project area, focussing on both the deposit itself and the surrounding environment. These studies and surveys include:

1. Geology, mineralogy and structure from drill core and surface and underground mapping, which have been coordinated with:
   - assay and ICP analyses of drill core and chip samples;
   - acid base accounting (ABA) analyses on core samples;
   - geostatistical modelling.
2. Surface water quality over the area, coordinated with:
   - underground water quality from drillholes;
   - underground ditch-water pH monitoring;
   - water quality from test leach pads at the exploration portal;
   - stream-sediment geochemistry in the project area;
   - survey of massive sulphide boulders on Frobisher Glacier.
3. Soil analyses from geotechnical test drilling in the tailings impoundment area.

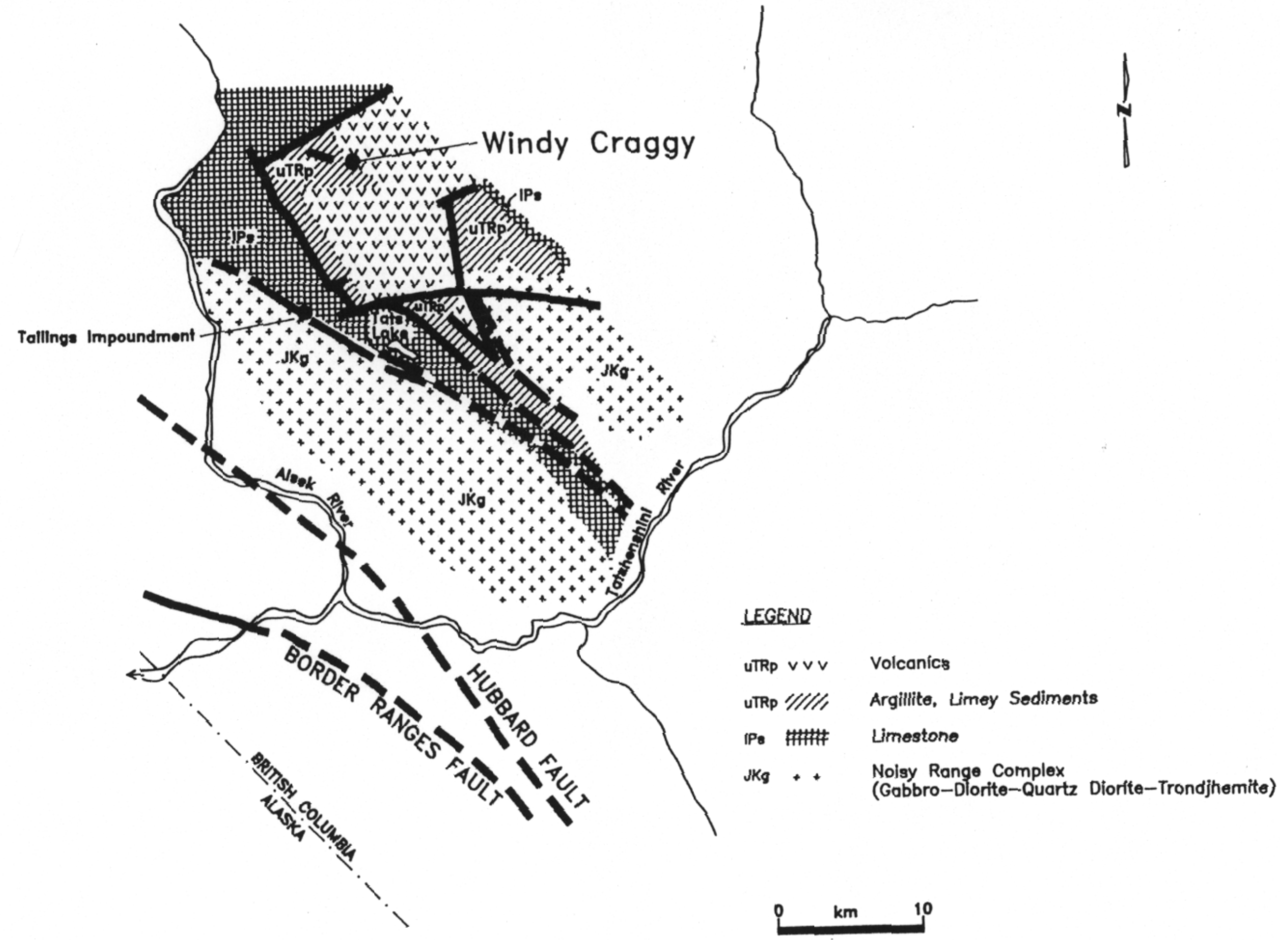

FIGURE 2. Regional geology of the Windy Craggy area.

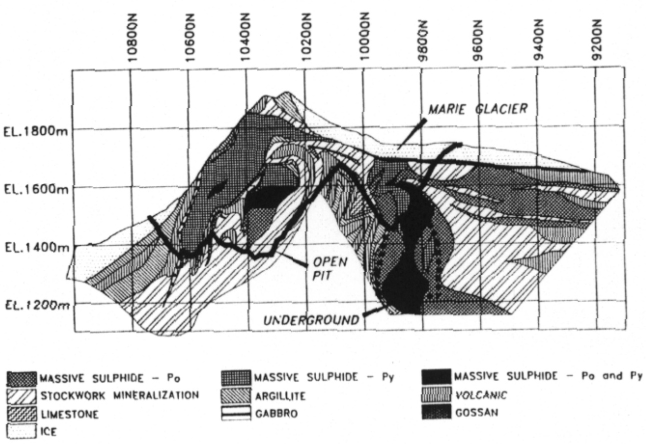

FIGURE 3. Longitudinal cross section of the Windy Craggy deposit.

4. Major acid rock drainage (ARD) test program in progress on underground bulk samples of various waste-rock types.

Database

It is imperative that a good geological database be established so that geochemical data can be directly or indirectly related to geology and mineralogy. The utilization of computers (MS.DOS-based 286 and 386 systems) in the exploration program began in 1989 when compilation of the present database was initiated. The database at present contains analytical information from more than 24 000 samples and, including deposit geological data, contains in excess of 12 Mb.

The construction of a sound exploration/environmental database begins with good sample collection. Appropriate sample collection, preparation, and analytical procedures and standards must be maintained throughout the project life. Careful observations of sample sites, seasonal sampling to monitor possible fluctuations, and sampling a significant number of sites for valid statistical analysis are all part of a geochemical survey. The cost of incorporating statistically correct methods into the sampling program may be high, but poor sampling leads to incorrect results and interpretations. During data collection or analysis, a statistician should be consulted to verify the significance of data and to avoid redundant sampling.

To ensure adherence to acceptable procedures and standards at Windy Craggy, data collection and test procedures have been reviewed on an ongoing basis with various consultants, particularly in sensitive areas such as water quality and wildlife. Provincial and federal government ministry personnel will not formally approve ongoing testing and data-gathering methodologies, but frequent discussion of the procedures being employed or considered with appropriate government personnel can provide valuable feedback on future acceptability of data or test results.

The database comprises lithologic (drill core, chip sample), stream-sediment, and soil- and water-sample data. When detailed drilling commenced in 1988, a decision was made to assay all drill core for Cu, Co, Zn, Au, and Ag, as well as to analyze 30 elements by the inductively coupled plasma emission spectroscopy

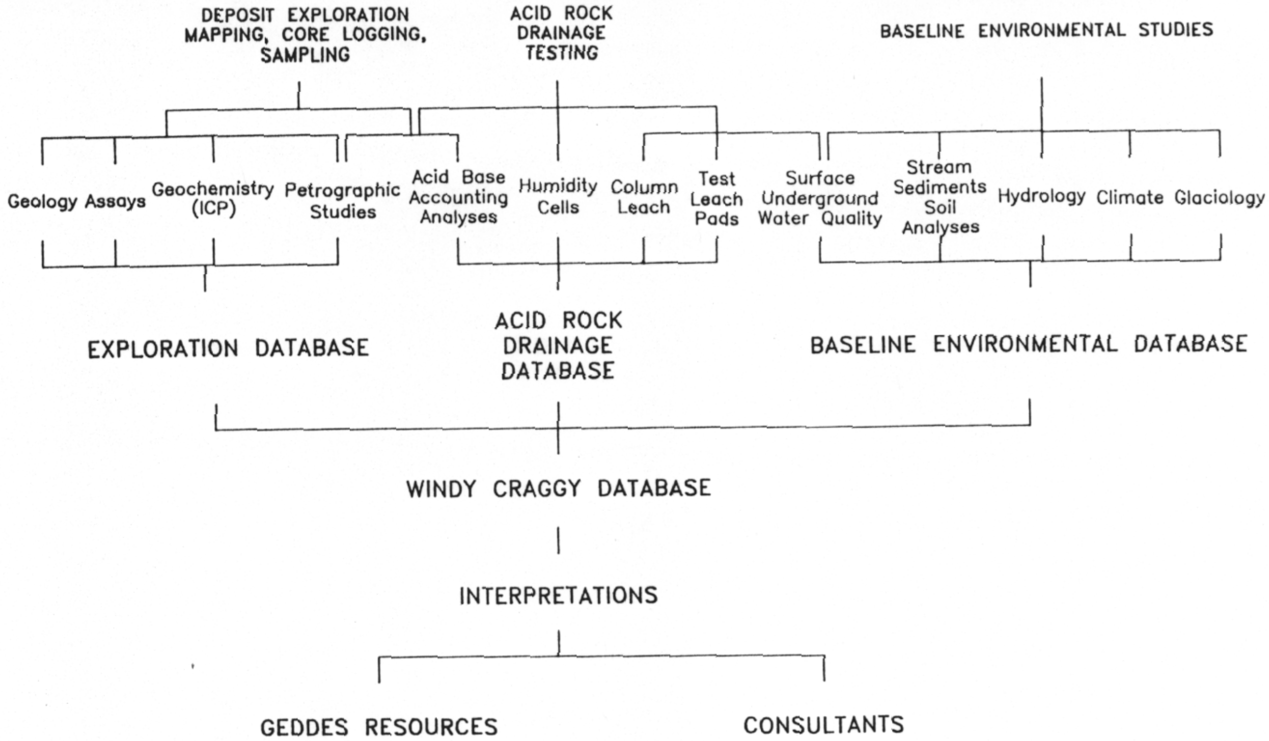

FIGURE 4. Windy Craggy data flowchart.

method (ICP), over 2 m sections. In addition, 1762 of the samples were also assayed for total iron and sulphur. Geological drill logs were redesigned in 1988 to incorporate greater detail in conjunction with the revised sampling. Petrographic studies have been completed on various rock types to determine grain sizes, alteration, and mineralogy.

Chip samples and split drill core are of 2 m widths or intervals and were prepared on site using procedures as specified by the assay laboratory. The pulps were sent to separate analytical laboratories for multi-element assays, for the 30-element ICP analyses using an *aqua regia* extraction, and for acid base accounting (ABA) analyses. Stream-sediment and soil samples (−80 mesh fractions) were analyzed by the ICP method.

Water-quality samples were analyzed at BC Research in Vancouver, British Columbia. Sample collection and preparation procedures were specified by environmental consultants to GRL. Samples were placed in coolers immediately after field sampling. Dissolved-metals samples, including start and end-test blanks, were filtered using a membrane filter on site within 12 hours of sampling. Purified nitric acid was added both to dissolved- and total-metals samples at a proportion of 5 mL/L as a metal preservative. All samples were sent within 24 hours after collection to B.C. Research, where samples were analyzed according to USEPA-recommended sample-handling procedures and analytical methods (McQuaker, 1989).

Check-sampling and validation of the Windy Craggy database have been done in a variety of ways, including manual inspection of analytical data, and computer-generated plots. Comparison of data from chip sampling of walls, bulk sampling, and drill-core samples from the North and South crosscuts indicate consistency of sampling and grades. Replicate and frequent sampling for water quality and ABA have been conducted to test for sample variability, statistical validity, and laboratory precision. Examination of the surface-water quality data by a statistical consultant to GRL resulted in a water-quality control study. Check sampling and analytical validation are important for the over-all reliability and integrity of the database and must be conducted on a routine basis. The importance of these surveys lies in the question "How defensible are your sampling and monitoring data?".

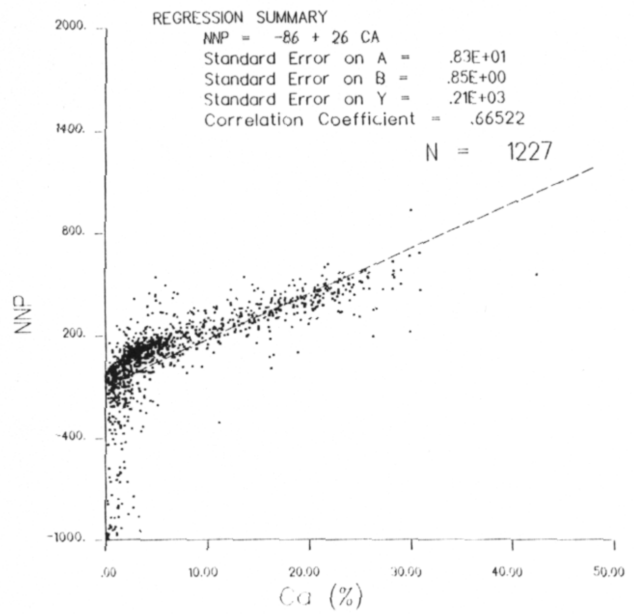

FIGURE 5. Plot of Ca vs S for various NNP values.

Acid Rock Drainage

As acid rock drainage (ARD) is a complex process that is dealt with in detail in other publications (B.C. Acid Mine Drainage Task Force, 1989), only a brief explanation is included here. ARD is a naturally occurring process that results from exposure of sulphide minerals to atmospheric oxygen and moisture, causing oxidation of sulphides to sulphates and thence to production of sulphuric acid.

TABLE 1. Waste-rock classifications

1. Volcanic — Sulphidic
   — stringer zone mineralization; moderately developed stockwork mineralization with 5% to 15% sulphides; very weakly calcareous
2. Volcanic — Calcareous
   — weak to moderately calcareous; <5% sulphides
3. Volcanic — Non-sulphidic and non-calcareous
   — includes gabbro and mafic to intermediate dykes; trace sulphides and very weakly calcareous
4. Argillite — Calcareous
   — argillite, moderately to strongly calcareous; <5% sulphides
5. Argillite — Sulphidic
   — stringer to semi-massive sulphides; generally very weakly calcareous; 5% to 20% sulphides
6. Argillite — Non-sulphidic and non-calcareous
   — trace sulphides and very weakly calcareous

TABLE 2. Water quality — comparison of selected sites

Site	Sulphate (mg/L)	Dissolved Al (mg/L)	Dissolved Cu (mg/L)	Dissolved Zn (mg/L)
Red Creek (W12)	2180	26.0	46.0	0.570
Frobisher Creek (W2)	188	8.1	0.05	0.05
Tats Glacier (W18)	103	1.4	0.0063	0.021
Tatshenshini River (W8)	56	1.4	0.0028	0.0092
Alsek River (W1)	32	2.3	0.0030	0.0092

Metals solubilized by exposure to acidic flows are characteristic of ARD conditions. Buffering or neutralization of acidic flows to neutral pH is not sufficient to precipitate all of the dissolved metals, hence anomalous concentrations of metals such as zinc in neutral-pH waters are generally indicative of ARD conditions upstream.

The propensity of a given rock type to generate ARD is a function of three variables:

(a) sulphide sulphur content, multiplied by a constant, yields the maximum potential acidity (MPA);

(b) content of acid-consuming minerals (e.g. carbonates), determined by acid-neutralization testing, yields neutralization potential (NP);

(c) kinetic response to the presence of air and moisture is determined by empirical testing.

Points (a) and (b) are determined by Acid Base Accounting (ABA) laboratory tests, and for Windy Craggy, (c) will be determined by the ARD Test Program conducted at BC Research, Vancouver.

Major waste-rock types at Windy Craggy have been recognized and classified (Table 1). An extensive and systematic site-specific ABA sampling program was conducted in 1990. A total of 1247 split core samples was analyzed for ABA parameters of total sulphur using a gravimetric method, paste pH, and neutralization potential. A 30-element ICP analysis was also performed on all ABA samples, and each sample was classified according to lithology. Petrographic studies have been carried out on the waste-rock types. The database of more than 24 000 core samples on the Windy Craggy project is now being used in studies of waste-rock management, involving correlations of ABA and ICP data. The database was used to classify each rock type by its geochemical and ABA signature. Detailed knowledge of rock types, mineralogy, hydrology and climatic data is essential to the understanding of the occurrence of ARD.

The ARD test program in progress at BC Research includes four types of tests:

(a) conventional humidity cells for characterization of the sequence and relative rate of oxidation and acid generation from finely crushed samples;

(b) large-scale (modified) humidity cells to determine drainage quality from zones of waste rocks (single-type source);

(c) large-scale column tests to determine a predicted range of drainage water quality from waste-rock dumps, and

(d) column leach tests to evaluate the rate of metal leaching from submerged rock and tailings, and to provide estimates of the quality of supernatant water in the tailings impoundment.

Bulk samples comprising approximately 15 400 kg of representative waste-rock types were collected from seven underground sites for the above tests. These tests were started in December 1990, and are expected to continue for up to two years. The tests are designed to determine the kinetics of acid generation from waste rock, as well as to predict the quality of drainage water from waste piles. While it is too early for the above test program to provide definitive results, qualitative changes indicating sulphide oxidation are apparent in some of the samples which are expected to be net acid producers.

Test leach pads containing bulk samples of massive sulphides and potentially acid-generating and acid-consuming waste rock from underground were built in 1989 and were monitored throughout 1990. These test pads are located at Windy Craggy, near the exploration portal. Water-quality samples were taken weekly for pH determination and monthly for analyses of trace metals. To date, only the massive sulphide sample has generated acidic drainage. Thus, in tests at BC Research as well as those under weather conditions at the site, initial results show acid generation only from samples which are expected to be strongly net acid-producing. Much more complete test results are required to allow application to planning waste-rock disposal.

Naturally occurring ARD has had a significant effect on the immediate environment of the Windy Craggy deposit, and to an unknown degree on the downstream environment. The natural oxidation process which has produced ARD has also resulted in the development of large amounts of gossan and limonite — supergene mineralization. Fine-grained gossanous material, when slurried with water, produces an acidic solution with pH as low as 3.5, which suggests that water directly draining gossan and supergene mineralization will be highly acidic as a result of natural acid-generation processes. Surface drainage from the site exhibits low pH and high dissolved-metals concentrations (e.g. Red Creek, Table 2).

The geological reserve of supergene material has been estimated to be in excess of 1.6 Mt, and the limonite reserve is greater than 3.4 Mt. The rate of generation of natural ARD is unknown, but examination of weathered boulders along the Frobisher Glacier suggests a very slow rate of sulphide oxidation. Strongly acidic flows originating at Windy Craggy are only weakly detectable in water-quality samples taken some distance from the deposit (Table 2). This is a result of dilution and buffering by limestone and limy sediments that surround the deposit (Fig. 2). Prospecting and mapping within the drainage areas of the surrounding water-quality sample sites have located several additional mineralized showings, the extents of which are unknown because of talus and ice cover. These showings will also have some impact on the baseline water quality.

Application of Test Results

Application of the exploration database to the understanding of environmental concerns is illustrated by the correlation of ICP analyses with the ABA data. Data processing on site by the geological staff led to the recognition of several parameters in the database that could identify potential acid-generating and acid-consuming lithologies. Carbonate is the major contributor toward acid neutralization. Examination of the geochemical database indicated that calcium was present in all analyses, with values up to 35% Ca obtained by ICP. Petrographic studies established that the Ca content is directly attributable to calcite (Leitch, 1990).

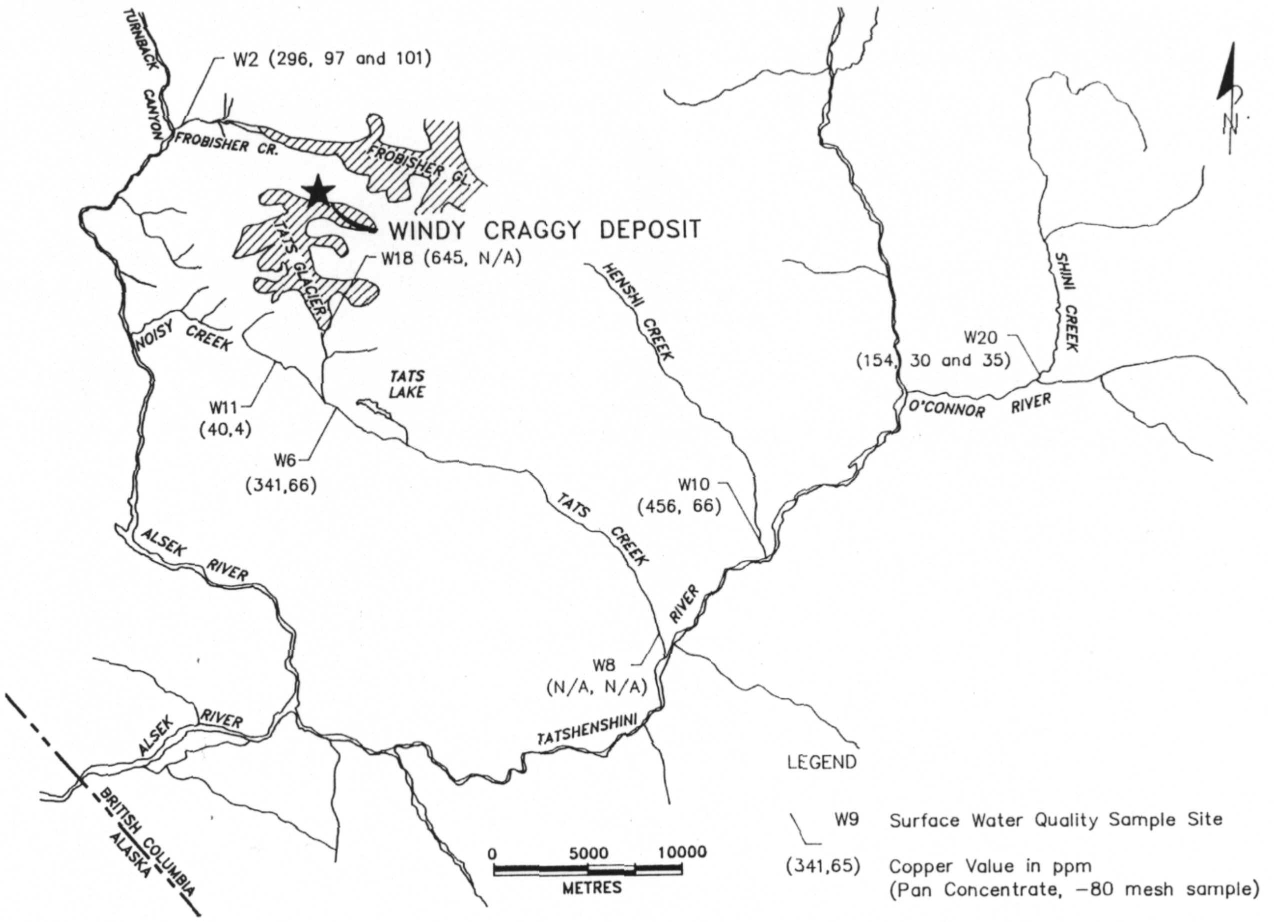

FIGURE 6. Copper values of stream substrates.

The subtraction of MPA from NP yields the Net Neutralization Potential (NNP). A negative value of NNP indicates the potential for net acid generation; a positive value indicates the potential for acid consumption. Examination of the relationship between NNP and Ca content has shown a strong positive correlation for positive values of NNP (Fig. 5). A regression equation based on this relationship can be used to estimate the NNP for each 2 m drill-core section in the database. Modelling of waste rock in this way can be used to assist in the estimation of the fraction of waste rock which is potentially acid generating; it must be noted, however, that this particular relationship ignores the kinetics of ARD development.

A quantitative estimate of waste rock within the projected pit design will be conducted using geostatistical methods. Parameters used in the block model will include Cu, Au, Ag and Zn assays, and Fe and Ca ICP values. Parameters to be kriged for each block include Cu, Zn, Fe, and Ca grades, and neutralization potential (NP). Waste-rock blocks will be classified as four types: argillite, volcanic, gabbro, and a mixture of argillite and volcanic rock. These estimating procedures have incorporated geological parameters and controls. Each waste-rock block will be classified by ABA criteria as either potentially acid generating or acid consuming, which will be one method used to determine the disposal method for the block. For the Windy Craggy operation, proper handling and control of waste rock will be of paramount importance in the prevention of ARD.

Geochemistry and Water Quality

Despite the extent of massive sulphide mineralization, surface expression of the two main zones is very limited; the South Zone lies almost wholly beneath the Marie Glacier, and the North Zone outcrops only in several places on the inaccessible north face of the mountain. Oxidized sulphide mineralization is evident on Windy Craggy mountain from occurrences of limonitic and supergene material on surface, as well as by the extensive drill-indicated occurrences under glaciers. Red Creek, which emerges from under Marie Glacier and drains part of the area of the subcropping South Zone, has an average pH of 3.2. It can only be assumed that the area's remaining drainage, which flows under Frobisher Glacier to its terminus, is initially at the same low pH but is buffered by calcareous subglacial sediments. Water-quality data from creeks draining the Tats and Frobisher glaciers indicate a pH of 7.3 to 8.7. Water sampled throughout the adit has a similarly buffered pH range but is significantly lower in the content of dissolved metals.

A preliminary statistical analysis of data for the quality of surface water over the period from 1987 to 1990 for the 20 sampling sites illustrated in Figure 6 was initiated using BMDP software (Dixon and Brown, 1979). In this analysis, 13 variables appeared to be the most 'robust' (pH, alkalinity, SO_4, and total P, Al, Cu, Fe, Mn and Zn, and dissolved Al, Fe, Mn and Zn). From examination of the means, coefficients of variation, cluster analysis and plots, the data were reduced to two significant principal components, PC1 and PC2. When the PC1 scores were plotted against PC2 scores for each sample, the 20 sites were clearly divisible into three groups:

1. PC2 rises with rising PC1: the elevated total metals occur together for sites 1,2,5,6,8,9,10,15,16,17 and 18. These are all multisource creeks subject to high suspended solids during freshet conditions.
2. PC2 declines with rising PC1: the elevated dissolved metals occur together at sites 12,13 and 14. These sites presumably are showing

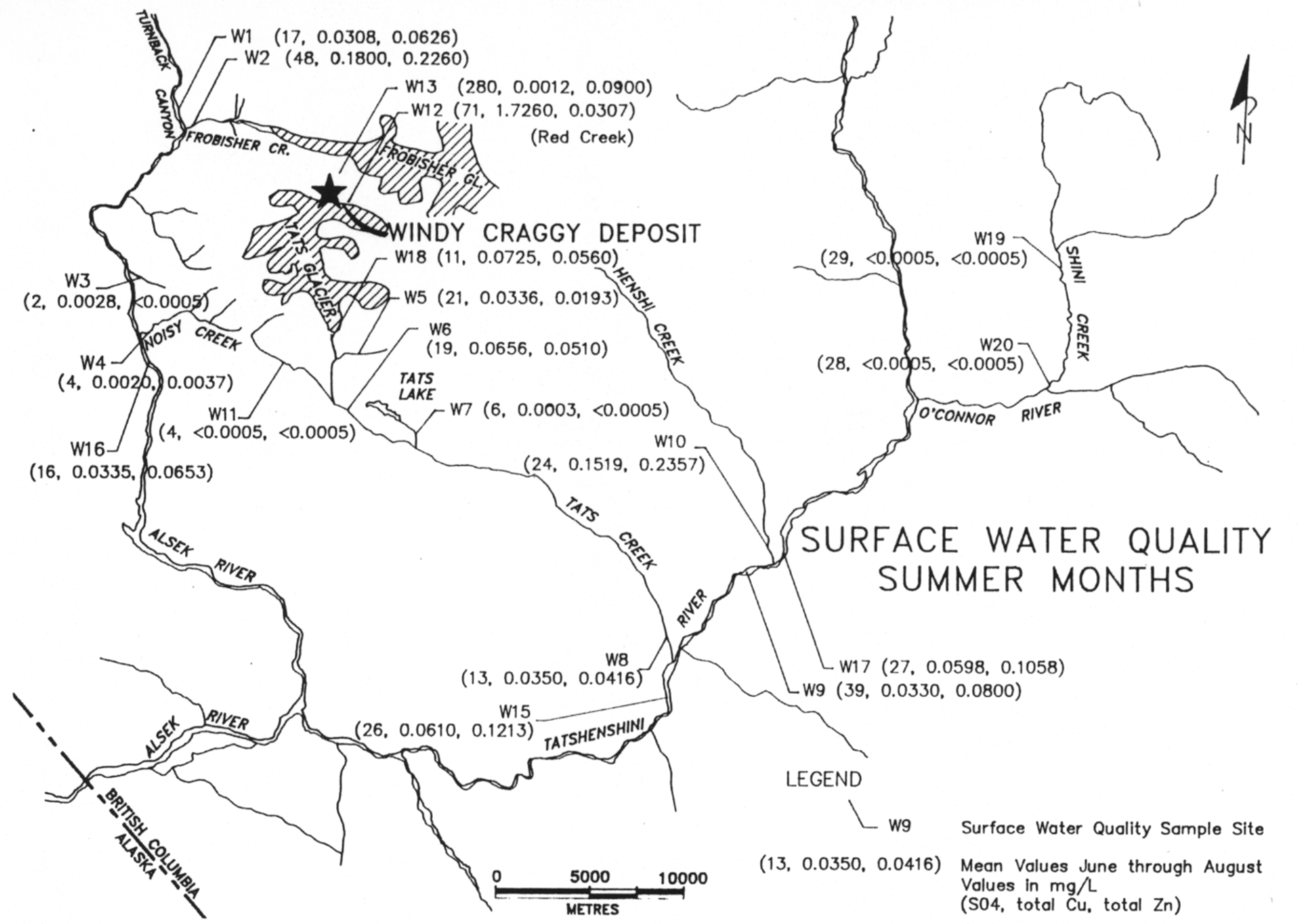

FIGURE 7. SO_4, Cu and Zn for surface-water sites.

the effects of natural rock drainage.

3. PC2 and PC1 are invariant or show very little change at sites 3,4,7,11,19 and 20. These probably represent a constant water source, such as groundwater, or they may be an artifact of sampling (e.g. only days with low concentrations were sampled).

This statistical analysis is important because it offers possible criteria for: (1) selecting a control or compliance site; (2) selecting impact monitoring sites; (3) establishing a seasonal sampling frequency and replication program; and (4) reducing some of the variables for routine analysis.

In the tailings-impoundment area, soil morphology and geochemistry were examined. The −80 mesh fractions of soil samples from the geotechnical drilling and test-pit programs were analyzed by ICP emission spectroscopy. Results indicated no anomalous values except for calcium content, which ranged up to 19%. Anomalous value(s) refer, in this paper, to unlogged values occurring in the upper 10% of the sample population.

Stream sediments were collected within and surrounding the deposit area. ICP analysis was carried out on the −80 mesh fraction of sediments and on panned concentrates. There are no anomalous values for the −80 mesh fraction, but there are elevated copper values for panned samples (Fig. 6). Water-quality analyses show anomalies in metals content which outline the deposit well (Fig.7). These results suggest that this deposit would not have been indicated through a conventional regional geochemical survey (assuming that the −80 mesh fraction was analyzed) but would have been indicated using water-quality analyses. It should be noted that water analysis at environmental levels of detection in an exploration-type survey may not be feasible because of prohibitive costs.

The general relationship between geology and the geochemistry of stream sediments and waters is reflected in the following ways:

1. Examination of the multi-element database indicates low to negligible concentrations of deleterious elements such as As, Pb, Mo, and Cd in the various lithologies. This is also reflected by trace levels of these elements in the water-quality data.
2. There is a high content of carbonate in the Tats Glacier moraine and in the stream sediments on Tats Creek, coincident with similar lithologic units. The total calcium in surface and underground waters is also quite high. Ditch water on the 1400 level was tested for pH at 24 sites throughout the 1400 level from June 17 to October 30, 1990: the pH ranged from 4.2 to 8.2, and averaged 7.0 during this time period. The importance of calcium carbonate is its capacity to buffer waters with respect to potential acid rock drainage. Underground water-quality data are generally indicative of the various lithologies they drain.

Conclusions

The original Windy Craggy exploration database is a valuable part of the present environmental database for this area. Environmental data such as climate and water quality are now integrated with exploration data. The exploration and environmental surveys conducted at Windy Craggy have been compiled into a comprehensive database from which various studies can abstract data for exploration and environmental modelling and reporting.

The exploration and environmental database together with the acid rock drainage test program will determine criteria for the disposal of mine waste. Potentially acid-generating waste will be placed in the tailings pond, preventing acid generation by means of submergence. Waste types shown to be acid-consuming are proposed for placement in waste heaps, on rock slopes, and on glaciers surrounding the open-pit mine.

In the interpretation of geochemical/environmental data, each aspect of the total landscape must be examined as water passes through different regimes of geology and climate. There may be a variety of different environmental interactions or impacts along the drainage path. An understanding of the various factors in each drainage basin that would affect water quality is necessary to properly interpret the data.

Natural acid generation occurs in most sulphide-mineralized deposits. It should be recognized and tested for in the baseline studies. It is important to document the amount of natural acid generation, and the degree to which natural buffering occurs.

Environmentally related data collection should be initiated very early in an exploration project. Such collection will provide the background for predevelopment, mining, and reclamation studies. At some period during the studies, a statistical analysis of the data should be performed to determine sampling frequency and replication needs based on existing data and as part of the data quality control.

The concept of environmental geochemistry is many-faceted, involving the efforts of several disciplines (geology, geochemistry, geophysics, biology, statistics and engineering). These multidisciplinary studies involve various personnel, and all should be included in the ongoing data analysis. Creative thinking and provision of the appropriate computer tools enable the various disciplines to examine the data in different ways.

Predevelopment work at Windy Craggy is continuing, and baseline studies involving various types of environmental monitoring are in progress. The ability to identify and minimize any potential environmental problem is dependent upon possession and understanding of appropriate baseline data. With the high level of attention being paid to environmental concerns on this project, environmental geochemistry will continue to be a major part of the environmental management system.

Acknowledgments

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WORLDTech I

Plans for WORLDTech I International Congress on Mining Development, **September 15 to 17, 1993**, Philadelphia Hilton, Philadephia, Pennsylvania, are under way.

WORLDTech I is the first in a triennial series of professionally programmed international mining development meetings. Held in Philadelphia, it is near large eastern mining activities and in the heart of the North American financial and legislative centres.

Technical programming includes: Latin American — Environmental Management, Control Technology, Political/Financial Developments, and Education/Training Issues. Environmental Management — Coal, Resource Recovery, Regulatory Framework/Industrial Minerals. Control Technology — Mining Systems, Coal Mineral Processing. Eastern Europe: Political/Financial Developments. Education/Training — Educating the Next Generation — K — 12th Grade, Operating and Training Issues.

An exhibition featuring some of the most innovative and prominent manufacturers, producers, and specifiers from around the world will be held in conjunction with the meeting.

For more information, contact: the Meetings Department, SME, P.O. Box 625002, Littleton, CO 80162, U.S.A.; Tel.: (303) 973-9550; Fax: (303) 979-3461.

International Symposium on Environmental Degradation of Materials in Nuclear Power Systems — Water Reactors

New insights into materials, methods, and techniques will be shared at the Sixth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems — Water Reactors to be held **August 1-5, 1993**, in San Diego, California.

Materials related problems cause a significant portion of nuclear power plant outage time. The purpose of this conference is to foster the exchange of ideas about such problems and their remedies in nuclear power plants using water coolant.

The conference is of particular interest to utility engineers, reactor vendor engineers, plant architect engineers, and consultants involved in design, constructions, and operation of water reactors, as well as researchers concerned with the fundamental nature of materials degradation.

Symposium topics include:

- Primary and Secondary Side Degradation of LWRs;
- Balance of Plant Problems;
- Irradiation Effects on Mechanical Properties;
- Water Chemistry Control and Irradiation Effects;
- Stress, Intergranular, Wastage, Pitting, Galvanic and Under Deposit Corrosion; Corrosion Fatigue; and
- Remedial Measures to Prevent/Ameliorate Problems.

To submit an abstract, please contact: Bob Gold, Westinghouse Electric Nuclear Services Division, Haymaker Road and Northern Pike, Monroeville, PA 15146, U.S.A.; Tel.: (412) 374-4145; Fax: (412) 374-4338.

For housing and registration information, contact: TMS Meeting Services Department, 420 Commonwealth Drive, Warrendale, PA 15086, U.S.A.; Tel.: (412) 776-9050; Fax: (412) 776-3770.