Geochemistry Technical Working Group
Pebble Project
Final Minutes for January 3, 2008
Minutes recorded by Charlotte MacCay/Bristol

Present:

Steve McGroarty/ADNR
Scott Maclean/ADNR-OHMP
Mark Fink/ADF&G
Leroy Phillips/USACE
Andrea Meyer/ADNR
Lorraine Edmond/EPA (via telephone)
Stephen Day/SRK Consulting
Charlotte MacCay Bristol

As with all Technical Working Group (TWG) Meetings, the minutes reflect discussion of suggestions and concerns raised by individuals. Discussion does not reflect any decision making or consensus from the group (with the exception of electing a lead).

Administrative Issues

- TWG objectives and policies were reviewed.
- Steve McGroarty was chosen as the Geochemistry TWG lead.
- Geochemistry is a complex topic. Each agency should consider its own level of understanding and goals for participating in this TWG, and consider what additional resources they may need to effectively participate. The TWG Protocol allows for agencies to hire a consultant to provide technical support.
- Jim Vohden of Alaska Department of Natural Resources can participate in the TWG.
- Agencies would prefer to see the Pebble Limited Partnership (PLP) Environmental Baseline Document in time to incorporate an evaluation of the data into a review of the PLP sampling program.
- Data is needed to determine sample variability, and from that determine whether or not there has been sufficient sampling to characterize that level of variability.
- TWGs may need to work in concert for certain presentations and discussions.
- At some point it would be worthwhile to merge with the hydrology TWG for further discussion and perhaps have a presentation of the hydrologic modeling.
- Web conferencing could be helpful for remote participants.
- Members should review the November Agency meeting PowerPoint and the 2007 work plan more carefully for further discussion at the next meeting.
- The public can attend TWG Meetings and can ask questions at the end of the meeting. The TWG Lead has some flexibility and can allow questions during a meeting if it is felt that this would be productive and non-disruptive to the TWG Meeting.

- Note (by Steve McGroarty) – It would be very helpful if speakers could be identified in the minutes of future TWG Meetings. At a minimum, it should be noted whether the speaker was a Pebble Limited Partnership staff person (PLP), a consultant to the PLP (SRK), an agency staff person (Agency), an agency consultant if one is retained for the review of the geochemistry of the Pebble Project (Agency Consultant), or a member of the public (Public).

Data Requests

- A list of changes to the program over time and the rationale for the changes

- A completion report

    - The 'completion report' should be a consolidation of studies undertaken to date on the geochemical characterization of waste rock, ore and tailings for the Pebble Deposit. It is suggested that the report should at a minimum include sections on:

        - Introduction (background, chronology of investigations – including reasons for change to original characterization proposals, and acknowledgements)

        - Detailed Geology (rock units, sulfide and carbonate mineralogy and deposition patterns, alteration patterns, Pebble East vs. Pebble West)

        - Sampling and testing methods (rock sampling methods and sample selection criterion for both static tests, laboratory kinetic tests, and field kinetic tests)

        - Assessment of 'representivity' by rock type and location (plan maps and a sufficient number of cross-sections should be provided that illustrate sample locations vs. lithologic units, any alteration packages, and current thinking on pit or underground developments)

        - Sampling of 'tailings' from metallurgical tests (static and kinetic tests, Pebble East vs. Pebble West vs. combined ore, and the results of any de-sulfidized tailings studies - i.e. pyrite floatation circuit concentrate vs. tailings geochemical characteristics)

    - Detailed discussion of geochemical characterization results.

    - Plans for additional static, laboratory kinetic tests, field kinetic tests and mineralogical examinations for waste rock, ore and tailings.

    - Discussion of how the results of the geochemical characterization test program will be used to develop source term predictions of water quality effects.

PLP Geochemistry Presentation and Discussion

- The Pebble Project's overall objectives for the program include:
  - Inform waste management and closure planning
    - By "designing for closure," the project can minimize long-term management requirements for the protection of water quality. This is both environmentally beneficial and cost beneficial.
    - A sub-objective is to provide data for estimation of the reclamation bond.
  - Provide source terms for predictions of water quality effects.
    - "Source term prediction" is the prediction of water chemistry which will originate from the facility to surface and/or groundwater.
    - The source term prediction work product ends where the rock drainage enters the local water systems. The interaction of rock drainage with surface and/or groundwater is addressed by the water quality and water hydrology teams. The Geochemistry TWG should not function in isolation of all other TWGs; hydrology and mine plans may affect whether the geochemical characterization program is adequate – changes to mine plans and/or the results of hydrologic investigations may require changes to the geochemical characterization program. At some point it would be critical to have joint meetings of the geochemistry, hydrology, and water quality TWGs, particularly when source term predictions are presented.
- The State of Alaska recommends that PLP consider the recommendations of a number of International Guidelines for ARD/ML Prediction, one of which is the British Columbia, Ministry of Energy Mines and Petroleum and the Draft Guidelines for Acid Rock Drainage (ARD) Prediction (Price, 1998).
  - These guidelines are widely used around the world
  - EPA does not have a parallel set of geochemistry guidelines. The Sourcebook for Alaska is the closest EPA has to geochemistry guidelines.
  - The B.C. Guidelines are more comprehensive than the Sourcebook.
  - The Guidelines are set up as a tool box, not all tools are needed for all jobs, don't need to use every procedure.
  - The Mine Environment Neutral Drainage (MEND) manual is another source of guidance. This is a 7-8 volume set on all aspects of ARD, with one volume dedicated to prediction methods. It parallels the B.C. guidelines, but contains more case studies.
  - There are also many geochemical models for similar porphyry mines, which can provide some guidance for the studies.
  - Geochemistry studies for mines have advanced considerably in the last couple of decades. In the 1980s, there were preliminary studies, but no iterative process.

- Geochemistry is a very iterative process. Typically, geochemistry starts with looking at the geology, then preliminary information on ARD is integrated into project planning, which then triggers more detailed metal leaching (ML)/ARD characterization, water chemistry, and effects prediction.
  - Useful in evaluating waste management alternatives, such as waste rock, tailings, mine drainage.
  - First focus of effects assessment is on the more common parameters, such as copper and molybdenum at Pebble, then you review the geochemistry for other potential parameters of concern.
  - Determine which mineral(s) contain the problem parameters, and how are those parameters being released. This information can also feed back into the mine design.
  - It was noted that this geochemistry iterative process is even more complex at Pebble where the process is advancing down the iterative process for Pebble West, but is relatively preliminary for the newer discovery of Pebble East.
  - Geochemistry and mine design is also integrated with hydrology for further consideration/iteration. Detailed analysis of geochemical and hydrologic affects of block caving will be very complex.
  - This is still the very early stages for Pebble, considering there is no mine design at present. However, due to extensive exploration over the years, and well-preserved drill samples, there is already a lot known and there is a larger more refined preliminary chemical program than usual.
  - Ultimately, the goal is to correlate bulk rock chemistry (not a reference to size, but to general characteristics) with leaching once exposed to air, and note how quickly which minerals are released, and which minerals are present that buffer the leachate. It is important to know how quickly waste rock and pit walls need to be managed after exposure.

- Scale-up methodology and modeling take laboratory and field test results and extrapolate them into source term predictions.
  - Models can be quite elaborate, and are adjusted to fit dissolution of minerals.
  - Usually you start with a simple model (easier to explain), then progress into more complex modeling if additional refinement is needed.
  - Models are sometimes the focal point of lawsuits; need good discussion with the agencies as it is developed.
  - Consider a review of the Kuipers and Maest review of Environmental Impact Statements (EISs) and how well past EISs and model predictions represented reality. However, this report looked at 1980s era models and studies which do not reflect the rigor or interactive nature of studies conducted at this time.

- Geology at Pebble
  - Pebble has two main features
    - Porphyry sub-volcanic geology – original host rock with igneous intrusions. A rising bowl of molten rock works its way upward through some sort of structural weakness. Intrusions, not mineralization itself, trigger hot water circulating through the rock. The circulating water reacts with the rock dissolving and re-precipitating minerals, creating new types of mineralization. Veins occur where water followed a fracture. When the whole rock heats up, explosions occur and shattered "breccia" material later re-cements.
    - Tertiary overlying rock is younger, laid down tens of millions of years afterwards. The tertiary rock has been largely eroded away in the area overlying the west deposit. It is substantially deeper over the east deposit.
  - Porphyry deposits are a worldwide resource, particularly for copper and molybdenum and are, therefore, well studied. Certain features and their relationships to ML/ARD are well understood and help guide ML/ARD study designs.
  - Porphyries in general do not have mercury issues, because there is so much iron that the mercury adsorbs onto the iron. The mercury levels at Pebble are typical global average levels for mercury at a porphyry deposit.
  - Cominco carefully stored a lot of drill core samples at the site.
  - Porphyry deposits are not continuous and require a lot of drilling to characterize.
  - There are about 400 drill holes to date.
  - Drilling has focused around an economical deposit, not a structural deposit. Changes in metal prices could affect the extent of the economic deposit.
  - Drilling for ML/ARD studies need to address the deposit, as well as the rock which will comprise the pit walls that step back from the deposit.
  - Potentially Acid Generating (PAG) is a term that means there is some potential for the rock to create ARD; however, it may not, and this is dependent on many factors within the mineralogy, including minerals that may be acid buffering and lead to a net Non-PAG drainage.
  - A pyrite "halo" (this is not particularly a symmetrical halo, but occurs in "pulses") often encircles a porphyry deposit and may be PAG. This also occurs at Pebble in areas of waste rock.
  - If a pit design widens, it is important to investigate if the waste rock and pit walls extend into a pyrite halo.
  - Often there is a propylitic alteration just outside the halo of a porphyry deposit, which is often Non-PAG due to more carbonates. A propylitic alteration will also tend to move away from copper and molybdenum as primary metals, and into other base metal veins of different sulphide metals that may leach under non-acid conditions. However, this feature is minimal at Pebble.

- Gypsum veining is a late cooling feature and is often the outermost feature of a porphyry deposit. It is sometimes is associated with sulfate leaching. This feature is basically absent at Pebble.

- General Porphyry characteristics include:

  - The presence of carbonate minerals, which can delay the onset of ARD;
  - Tailings are not often a source of ARD;
  - Aluminum, iron and copper are often main issues for ARD;
  - Zinc and cadmium may be issues for non-acidic drainage if base metal veins are present;
  - Molybdenum and selenium leaching may occur, possible concern for calcareous low sulfide waste rock and tailings; and
  - Don't generally see arsenic, antimony or mercury – relatively simple compared to most gold deposits.

- Many porphyry deposits can be quite complex – Pebble is relatively simple. Based on the PLP Sampling Program:

  - Most of the ore is PAG due to pyrite;
  - Tertiary overburden is typically Non-PAG;
  - The alterations are not well developed within the area of economic interest at Pebble; the most common form of alteration is potassic, with the next most common being phyllic overprinting over the potassic alteration.
  - No base metal veins;
  - No gypsum veins;
  - The dominant carbonate minerals in the mineralized zone are calcite and siderite.
  - The dominant carbonate mineral in the tertiary cover is calcite.
  - SRK is doing additional evaluation of the carbonate mineralogy in the mineralized waste rock, tertiary cover, and tailings.
  - Arsenic is elevated compared to typical porphyry deposits and is probably associated with the pyrite;
  - Ore is everywhere – there are waste rock blocks within the ore; and
  - Low stripping ratio.

- Ore crosses all lithologies in the Pebble West Zone.

  - PLP Sampling Program has, therefore, focused on rock type and not on alterations, as there are no discrete alteration zones. The alteration present crosses all lithologies; therefore the geochemical characterization of the project has focused on lithology and not alteration patterns.
  - To lead predictions, need to characterize release rates for waste-scheduling and need to use units that can be put as a variable in a block model.

    - Predictions and modeling need to relate to mine-scale design features.
    - If there were distinct zones of alterations – even if they were cross cutting numerous lithologies, it could make sense to see if that alteration could be sampled to provide good data. But if it is scrambled, then it is pointless to tailor a characterization program around an alteration feature.
    - If everything in the pit is PAG, then there isn't much to gain from sampling separate lithologies in the pit.
    - It is yet unknown if there are more distinct zones of alteration in the Pebble East Zone – this is still being investigated.
  - Road Corridor Geology
    - For some mines, like Galore Creek, mineralization in the road corridor has been an issue.
    - PLP is aware that significant road cuts and borrow pits will need geochemistry studies conducted for that material, once a road alignment is determined.
    - In choosing road alignment, the study provides pass/fail level of analyses for use of material or placement of a cut. This would be sampling at a lower scale than mine study programs.
    - Roads are not at as great a risk of involving mineralized areas as are mines.
    - Mineralized rock is oftentimes of poor construction quality.
    - Geochemical characterization of the borrow sources and significant road cuts along the road corridor will be a permitting requirement.
    - The geochemical characterization study plans and results for the road corridor should be reviewed by the Geochemistry TWG.
    - Transportation departments have not usually done geochemistry studies associated with their road construction projects; however, this is changing in recent years.
  - Post mineral intrusive dikes
    - Mafic dikes containing unaltered mafic silicates that are typically low-sulfide.
  - Post mineral cover
    - Volcanics and sediments are unaltered but may contain low levels of pyrite and carbonate.
    - There is a wedge of post mineral intrusive in the pit that may be usable for construction rock; however, this wedge of tertiary cover will likely require the development and implementation of an operational waste rock characterization and segregation program, and will be studied further.
  - Surficial Materials
    - Gossan is a minor feature, not as extensive as expected.

- The East Zone
  - Subsidence may occur with mining of the East Zone. This could selectively expose material along this feature, including potential pyritic exposure.
  - It is too deep to drill out ore-body definition from the surface, and could require underground exploration efforts. This could result in less overburden data than at a surface mine.
  - There could be a data gap for pyrite in the tertiary cover, and construction material. If pyrite is present, it could be handled by segregating waste rock and ongoing characterization.
  - Deposit geology, lithology, mineralogy and alteration play critical roles in determining the adequate density of drill core samples for the geochemical characterization of a site.
  - There is some stratigraphic information from the tertiary core that could be used for acid-base accounting (ABA). There is full inductively coupled plasma (ICP) data all the way down the holes.
  - There is a 3-D model, as well as cross sections of the deposit. This information should be included in a Consolidated Geochemical Characterization Report.
- Management Concepts
  - General approach is to get PAG material underwater where it is not exposed to air, (the oxidation rate for sulfides is orders of magnitude slower when the sulfides are underwater).
    - Oxidation rates affect how quickly materials will become reactive. For subaqueous disposal testing, simulation of pore water chemistry is needed. PAG reacts under water, but much more slowly. Sulfate (which is regulated) and other parameters (i.e., arsenic) will be predicted. Considerations include reducing conditions that occur after saturation, which may change the behavior of the materials.
    - Prior to submersion, waste rock will be exposed for a few years, but pit walls will have a longer exposure period. These considerations are incorporated into the study design.
    - Predictions will also address the chemically reduced groundwater that seeps out under the tailings, which may be iron rich from iron carbonates. This has not usually been done at other sites.
  - Bulk tailings separation can occur during the metallurgical process to separate the bulk (rougher) tailings from the sulphidic tailings. By optimizing sulphide removal, it helps to keep the majority of the tailings as non-PAG. This allows for more protective management of the PAG tailings.
  - Although PLP refers to all ore as PAG, it does also have some neutralization potential (NP), it's just that the NP/acid-generating potential (AP) ratio is <1. Flotation circuits selectively pull out the sulfide minerals as the product to be sent off site, leaving minerals in the material that are of no economic interest; i.e. "tailings". As part of recovery of the minerals of economic interest, the ore is run

through two flotation circuits. The first step separates all sulfide minerals (both economic and waste) to produce a majority of non-PAG tailings. The second step separates the waste sulfide minerals (namely pyrite) from the economic sulfides producing a much smaller quantity of PAG tailings. Thus two streams of tails are produced: a majority of non-PAG tails and a smaller portion of PAG tails.

- Geochemistry testing will look at sand and slimes (finer tails) separately. Tailings may segregate as they are deposited down a long tailings dam beach. Sulfide-dense tailings tend to settle out nearer the discharge point. This information would be useful to address geochemistry of cycloned materials if they were to be used during construction of the dam.
- If the tailings disposal site is flat and above surrounding groundwater table, then seepage will enter the groundwater without much chance for attenuation.
- Managing pit walls
  - Pit walls are economically controlled features, so it is unknown at present where the ultimate walls will lay.
  - Characterization of pit walls can be done through sampling within the walls and extrapolating the data to the lithologies in the wall for its entirety.

Testing Programs

- There is some data on the onset of ARD from old exploration cores that were left at the site. The average rocks start generating acid in about 20 years; some samples were instantaneous, others are estimated to take up to 60 years to generate acid. Kinetic tests done in the laboratory show a close correlation for these results when corrected for temperature (the laboratory is warmer).
- ABA sampling
  - Multi-element data
  - Extraction of old core – water leach tests
  - Optical and X-ray microscopy are used to observe the mineralogy. These methods cannot differentiate the carbonates, so micro-probe will be added to help differentiate the carbonates.
- Kinetic tests
  - Humidity cell tests are typically 1 kg of rock that are subjected to alternating cycles of wetting and drying. Water quality is sampled. Rock is sampled at the end of the test period, to help to understand the delay to onset of ARD and oxidation rates.
  - Field kinetic tests utilize material selected by pretests. The core was smashed with sledge hammers prior to testing. They were constructed August/September 2007. One sample was collected before freeze-up; by spring the water might show some stable chemistry.
    - How will tailings react if subaqueous conditions don’t occur?
    - Field tests are slower low temperature – low reaction rates.

        - Tests designed to minimize damage from wind and/or bears.
        - Secondary containment is incorporated into the design.
        - Mesh cloth minimizes sediment entering the water sample, which is drawn off the bottom of the barrel. Water is tested for dissolved metals – not total metals.
        - Consider keeping the field tests running for a long time, including after operations has been initiated.
        - It was recommended that the PLP investigate the feasibility/possibility of conducting field kinetic testing of tailings on site.
        - There are meteorological stations within the project footprint area, not too far from the test site, but not directly at the test site.
        - Cautionary interpretation must be considered when looking at scale-up from the field tests due to uncertainty whether the scale-up is direct or not. Past experience comparing field test to laboratory tests show some sites scale-up well and others do not show good parallels.
        - Field tests are more useful for solubility than extraction tests.
        - It was suggested if the project develops underground workings for additional exploration drilling of the East Zone, that consideration be given to the construction of larger field kinetic tests.
    - Originally, there were 3-4 lithologies being tested in humidity cells. But some hits of sulfide and selenium in the tertiary cover rocks were received, so more tests were added.
    - When designing testing for the East Zone, also take into consideration subaqueous testing to cover the potential for underground flooding of tertiary material that has subsided.
    - Some East Zone tests could maybe be considered for extrapolation to the high walls of the West Zone.
- Neutralization Potential
    - PLP is more interested in determining what percentage of the inorganic carbon is calcium or magnesium carbonates, than they are in working with the NP, so that you don't have a concern about how the NP is being affected by picking up NP from silicates.
        - $NP_{(total)} = NP_{(carbonate)} + NP_{(Silicates)}$
        - Inorganic carbon total =NP (calcium carbonate and magnesium carbonate) + IC (ferrous carbonate)
    - Possible test modification to better understand the composition of carbonates.
    - To date, NP has been conducted. Pebble Project has plans for 2008 to include calibrating carbonate to NP.

    - Not all carbonates provide neutralization potential; iron carbonates typically are non-neutralizing.
    - Carbonate and NP interaction don't matter as much with the mineralized pit rock as with the tertiary rock; all the pit rock is considered PAG, but the data can clarify how quickly it will become PAG.
    - The 2008 tailings and ore composite samples are being generated for mine design, and there is hope of finding lots of variability of test material in these samples for use in determining a ratio of sulfur/NP.
  - Other Observations/Discussion
    - Some rock types are more competent than others. There are some well-cemented conglomerates; mudstones breakdown and the andesites are variable.
    - If PLP proceeds with underground drilling and exploration prior to permitting a mine, they will produce waste rock in a quantity larger than a barrel to do field tests on tertiary rock.
    - Samples are always a mixture of alterations and do not demonstrate ARD zoning based on alteration trends.
    - ICP analysis for sulfur may show a good correlation with ARD when displayed in a block model.

- Agency Preliminary Thoughts on the Geochemistry Program
  - The State's preliminary opinion of PLP studies is that the Study Plan appears to be good, but it is hard to judge until a completion report is generated. The State has requested that the PLP produce a Consolidated Geochemical Characterization Report; please see section on Data Requests.
  - Before jumping ahead to review of the data, there are basic questions of how much data is needed and locations which should be sampled. Reviewing the data is important, but also need to decide if this is the right data.
  - The TWG is an integral part of the iterative nature of the geochemistry process.
  - Changes to the program and why they were made need to be reviewed.
  - Kinetic tests sometimes need to run for years; it's important to make sure they are set up correctly and use the correct premises in order to prevent significant delays that could incur if it became necessary to rerun any of the tests.
  - Additional test design is waiting in part on development of a mine plan and knowing such details as how long the block caving would remain open, what material would be left behind, etc.