Borehole Mining of Manganese at Emily, MN

Or…Mn in MN

by

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This talk will cover:

- Geology of the Manganese Deposit in Emily
- Proposed Mining Methods
- Bulk Sample Collection Project
  - Permitting Requirements
  - Hydrogeologic Evaluation
Overview of the Project

- Collect a “bulk sample” (>12,000 cubic yards) of manganese-rich iron formation from 1 borehole
- Evaluate borehole mining technology
  - Uses high-pressure water jet to mine *in situ*
  - Ore-water slurry is pumped out, filtered and re-injected
- Filtered material (ore) is trucked to U of M minerals research facility in Coleraine for processing
- EAW developed **ONLY** for collecting the bulk sample – EIS will be required if full-scale operation is implemented
Who is proposing to do the project?

- Cooperative Minerals Resources (CMR) – a wholly-owned subsidiary of Crow Wing Power Cooperative
  - Profits will be shared with their 36,000 members – mostly in Crow Wing County
- Environmental permitting & hydrologic evaluations by Barr Engineering Co.
- Bulk sample collection to begin in August 2010
Geology of the Manganese Deposit at Emily, MN

Photo of Borehole Mining Site (by Ellen Considine, Barr Engineering Co.)
The Cuyuna or “Old” Iron Range

- Iron mining from 1904 to 1984
- 106 million tons for iron ore mined

After Southwick et al., 1988
Cuyuna Range is Divided Into 3 Districts

- Emily District
- North Range
- South Range

Croft Mine Historical Park, Crosby, MN
Emily District
Iron-Formation is a thin band on the limb of a north-plunging anticline.
Emily District Iron-Formation Units A, B, & C correlate with the Biwabik Iron-Formation of the Mesabi Range.

After Morey et al. (1991)
Depositional History

- Similar to Biwabik Iron Formation – chemical precipitation of iron and silica in a shallow Precambrian sea
- Abundance of oolitic hematite indicates wave-action reworking

From: Morey et al., 1991
Manganese Enrichment is Present in Two Zones Corresponding to Oolitic Zones

Reflux Model of Enrichment
Manganese and barium were carried to their final depositional site by anaerobic water systems.

Both precipitated when the anaerobic water met and mixed with aerated water in uncemented iron-formation on the seafloor.

After Morey et al., 1991
Manganese Mineralogy of the Deposit

- Manganite - MnO(OH) – primary ore mineral
- Psilomelane – (Ba,Mn)₃(O, OH)₆Mn₈O₁₆
- Cryptomelane - K(Mn)₈O₁₆

- Manganese Concentration (by weight) greater than 50% in 2 zones (i.e. “high-grade” ore)
- Hematite is dominant iron mineral
- Almost zero sulfur
What is Manganese Used For?

- Essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties (there is no substitute)
- Alloying agent in aluminum (especially in beer cans – really!)
- New generation batteries
- Pollutant removal from coal-fired power plant emissions (Pahlman process)
World Sources of Manganese

- **High-grade (> 44% Mn)**
  - 680 million tons ore world-wide
  - Mostly in southern hemisphere – countries using for internal use (limited export)

- **Low-grade (<44% Mn)**
  - Russia’s low-grade ores are depleting
  - China has very low-grade ore for internal use
  - Thin layers of 25% Mn in nodules on ocean floor (not yet mined)

Total world production and consumption of Mn ore in 2003 was 23 million tons
U.S. Manganese Sources

- The US imports **ALL** its manganese from Gabon, South Africa, France, and Brazil (692,000 tons in 2003)
- The US currently has no high-grade (>44%) Mn reserves
- Strategic stockpiles of Mn in the U.S. are essentially depleted
- Manganese from recycled materials is negligible
- Recent price of Mn: @ $1.30/lb
How much Manganese is Available at Emily?

- Bureau of Mines estimated @ 2 billion pounds (1 million tons) in a 9 acre area within 2 zones (50 feet and 70 feet thick) (Pahlman, 1995)
- The deepest of these zones is @ 400 feet below ground surface
- Likely the largest high-grade Manganese deposit in the Northern Hemisphere.
Mn-Rich Sections of Iron-Formation are Very Friable

This is very important in determining whether or not this formation can be mined in an environmentally friendly manner.
Bedrock is Overlain by @ 180 – 200 Feet of Sand-and-Gravel Outwash
Depth to Groundwater is @ 35 Feet at the Project Site

The soils are VERY sandy.

Lakes are in direct hydraulic connection with the sand-and-gravel aquifer.

All wells in the area completed in sand-and-gravel aquifer

Dots show CWI well locations
The Borehole Mining Process
Possible Mining Approaches

- **Open-Pit mining:** Have to deal with 200 feet of saturated overburden and dewatering.
- **Underground mining:** Likely extensive dewatering and expensive.
- **In situ leach mining:** Studied by Bureau of Mines and deemed practical – but probably environmentally unacceptable.
Borehole Mining is performed hydraulically

1. Water is jetted into the formation at @ 1,200 – 1,800 psi. The tool head rotates.
2. Sloughed deposit settles to the bottom of the borehole.
3. The slurry is pumped out, screened, and filtered at the surface.
4. Clear water is re-injected as water jet
Water Cycling in Borehole

12-in. Temporary Casing

Clear water

Tool rotation

Clear water

Slurry

Slurry
Borehole Mining Progression
General Filtration Process at
Ground Surface

Screening/Filtration Process Takes < 1 minute

Re-injection (jetting) 750 gpm

790 gpm water + 118 gpm solids

SLURRY

SCREENS THICKENER FILTRATION

Clear filtrant

To off-site processing
Expected Operation and Water Pumping

- Net instaneous withdrawal rate = 40 gpm
- 8 hours operation, 5 days a week
- Total estimated withdrawal during collection of the bulk sample = 1.15 MG
- Estimated operation days = @ 45
Environmental Evaluations for Permitting the Collection of the Bulk Sample
Required Permits & Environmental Reviews

- Environmental Assessment Worksheet (DNR is RGU)
- Water Appropriations Permit – DNR
- Operation & Reclamation Plan – DNR
- State Disposal System Permit (for stormwater rapid infiltration basin) – MPCA
- Conditional Use Permit – City of Emily
- Underground Injection Control Permit – EPA
Aquifer Testing and Modeling

Photo by Tonia O’Brien, Barr Engineering Co.
Drilling 18-inch Borehole

14-inch Steel Casing

Photo by Ellen Considine, Barr Engineering Company
8-inch Temporary Casing Installed in Borehole

[Diagram showing a section of a borehole with different layers and casing installations, indicating:
- F.S. TO O.G.
- SAND W/ GRAVEL
- 0'-178' B.G.S.
- 19' BOREHOLE O.S. TO 180' B.G.S.
- NEAT CEMENT GROUT IN ANNULAR SPACE O.S. TO 180' B.G.S.
- 14' STEEL CASING O.S. TO 180' B.G.S.
- 12' BOREHOLE 180' TO 270' B.G.S.
- 8' TEMPORARY PVC CASING 0' TO 250' B.G.S. (REMOVED 8/2009)
- 8' TEMPORARY PVC SCREEN 17'-60' 250' TO 270' B.G.S. (REMOVED 8/2009)
- GROUNDWATER EVALUATION
- DEMO WELL
- CROW WING CO. ELECTRIC COOP EMTLY, MN]

Photo by Ellen Considine, Barr Engineering Company
Location of Monitoring Wells

- MW-3s
- MW-3d
- MW-2s
- MW-2d
- PW (demowell)
Non-Pumping Condition

160-190 ft

MONITORING WELL NEST

PUMPED BOREHOLE

MONITORING WELL NEST

SAND-AND-GRAVEL AQUIFER

IRON-FORMATION

SCHEMATIC CROSS SECTION THROUGH AQUIFER TEST AREA
Lake Stage and Pan Evaporation were also monitored before, during, and after test.
Water chemistry in both units are very similar

- Dissolved Iron – 0.02 to 23 mg/L – typically higher in sand-and-gravel aquifer
- Dissolved Mn – 0.086 to 1.4 mg/L - typically higher in sand-and-gravel aquifer
- Major ions @ similar concentrations in both units
- Trace metals non-detect to a few ppb
- pH @ 6.5 to 7
- Eh @ -140 mv in both units
Example of Lake Stage Trends

Blue Lake Elevation

Pumping period

Lake Elevation (feet)

Aquifer Test

- 162.7 hours of continuous pumping @ +/- 200 gpm
- 1.95 million gallons of water
- That’s about 0.8 million gallons more than will likely be pumped by the entire Bulk Sample Collection Project
Borehole Cave-In Resulted in Huge Improvement in Well Efficiency
Maximum Drawdown in the Sand-and-Gravel Aquifer Monitoring Wells was less than 0.5 feet.
Water-Level Recovery was Rapid
Well pairs were analyzed for aquifer parameters using conventional analytic methods.
A 2-Layer MODFLOW model was developed and calibrated to the aquifer test data.
# Model Calibration Designed to “Honor” Analytic Solution Results

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Parameter Type</th>
<th>Model Calibration Value</th>
<th>Neuman-Witherspoon Value</th>
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<tbody>
<tr>
<td>kz6</td>
<td>vertical K of iron-formation @ MW-3D</td>
<td>0.0058 ft/day</td>
<td>0.00590 ft/day (based on 1/B)</td>
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<tr>
<td>kz7</td>
<td>vertical K of iron-formation @ MW-2D</td>
<td>12.4 ft/day</td>
<td>16.7 ft/day (based on 1/B)</td>
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<tr>
<td>kz8</td>
<td>vertical K of iron-formation @ MW-1S</td>
<td>2.1 ft/day</td>
<td>1.60 ft/day (based on 1/B)</td>
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<td>sy1</td>
<td>specific yield of sand-and-gravel aquifer</td>
<td>0.08 ft/day</td>
<td>0.01 – 0.04</td>
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<tr>
<td>s2</td>
<td>storativity of bedrock units</td>
<td>0.0049</td>
<td>0.0001 - 0.0079</td>
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<tr>
<td>kx6</td>
<td>horizontal K of iron-formation @ MW-3D</td>
<td>24.4 ft/day</td>
<td>24 ft/day</td>
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<tr>
<td>kx7</td>
<td>horizontal K of iron-formation @ MW-2D</td>
<td>18.3 ft/day</td>
<td>16 ft/day</td>
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<td>horizontal K of iron-formation @ MW-1S</td>
<td>24.8 ft/day</td>
<td>25 ft/day</td>
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<td>kx5</td>
<td>horizontal K of sand-and-gravel aquifer in vicinity of Bulk Sample Collection Project</td>
<td>293.6 ft/day</td>
<td>267 to 333 ft/day</td>
</tr>
</tbody>
</table>

Predicted Maximum Drawdown During the Bulk Sample Collection

Sand-and-Gravel Aquifer

Iron-Formation

Contour Interval = 0.01 feet

Contour Interval = 0.1 feet
Model’s Prediction of Changes in Lake Stage Elevation due to Pumping

![Graph showing prediction of changes in lake stage elevation over time due to pumping. The graph plots prediction change in lake elevation (inches) against time (days). The data points and lines represent different names: Davis, Ruth, Andrews, Bushite, Ruth, Anna, and Roosevelt. The graph shows a downward trend indicating a decrease in lake elevation over time.]
Subsidence

- Modeled using program FLAC
- Model used geotechnical parameters from core tests
Subsidence will be monitored during bulk sample collection

- Maximum subsidence predicted to be <10 feet
- Subsidence radius estimated to be <150 ft
- Extensometers will be installed to monitor subsidence
What’s Next

- Bulk sampling is planned to begin in August.
- Continuous monitoring will occur during the sample collection for hydrologic and geotechnical conditions – useful for an EIS.
- Full-scale mining will depend on what is learned during the bulk sample collection project – an EIS will be required for this.
- Full-scale mining will likely be 1 to 4 simultaneous boreholes in operation at any one time.
Acknowledgments

- Ray Wuolo – BARR Engineering
- James Agre – Crow Wing Power
QUESTIONS
please visit our web site:

mndnr.gov/waters