Case Study
Eagle Project, Michigan

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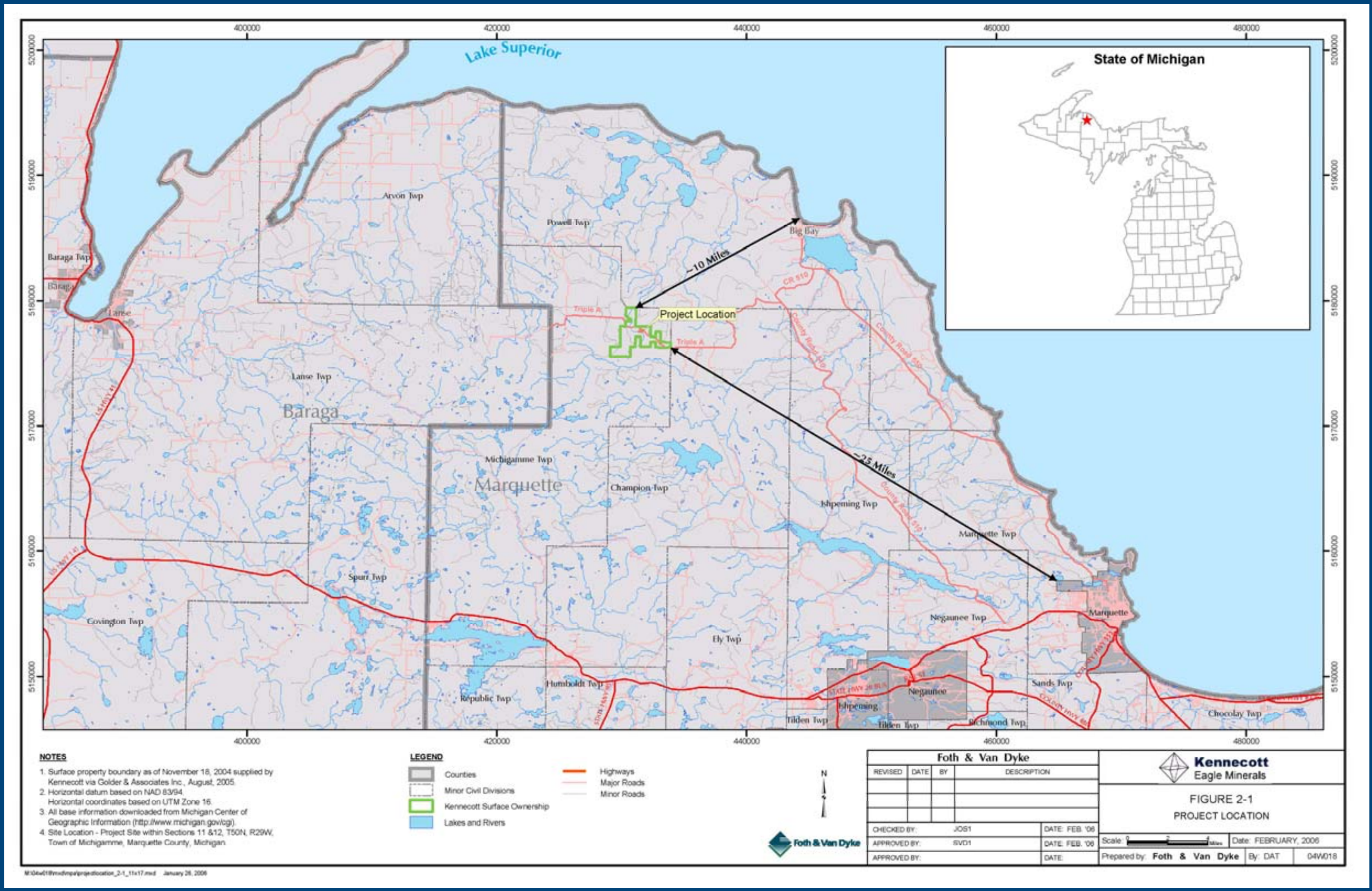
Water Boards
Training Academy

Map of the Eagle Project location and surrounding area



Source: Foth & Van Dyke and Associates, 2006a, Figure 2-1.

Ore and host rock overview

- High grade nickel-copper sulfide deposit
- Main ore minerals are pentlandite (nickel sulfide mineral) and chalcopyrite (a copper-iron sulfide mineral) in pyrrhotite (iron sulfide)
- Massive sulfide unit (MSU)
  - Ore, known to produce acid drainage
  - 50 to 100% sulfide (~32-38% sulfur)
- Semi-massive sulfide unit (SMSU)
  - Ore, known to produce acid drainage
  - 30 to 50% sulfide (~12-15% sulfur)
- Peridotite/intrusive unit
  - Alternatively considered ore and non-ore; development rock
  - Up to 30% sulfide, mostly acid generating
- Country rock/sedimentary units
  - Non-ore, host rock; development rock
  - 0.2 to 1.4% sulfur, mostly acid generating
- High sulfide content of underground workings – cement backfilling unproven technology

Geochemical characteristics and testing of deposit

Rock type/geochemical unit	%S or sulfide in unit	Acid generation potential summary[a]	Number of kinetic tests run	%S of samples for kinetic tests
Sedimentary units (sandstone/siltstone/ hornfels)	0.2-1.4%S	69% AG; 11% uncertain; 20% non-AG	Siltstone: 5 Sandstone: 1 Hornfels: 1	0.31 to 2.1%S
Peridotite/disseminated sulfide unit/ pyroxenite (along margins of the intrusions, above and below the upper sulfide zone and above the lower sulfide zone)	3-15% sulfide (disseminated sulfide) Disseminated sulfide = < 30% sulfide	61% AG; 16% uncertain; 23% non-AG	Peridotite: 4 Pyroxenite: 1	Peridotite: 0.2 and 2.44%S Pyroxenite: 0.99%S
Massive sulfide unit (MSU)	> 80% sulfide 50-100% sulfide 32-38%S	3/3 Phase I samples AG	1	36.1%S
Semi-massive sulfide unit (SMSU)	30-50% sulfide 12-15%S	3/3 Phase I samples AG	2	12.9 and 8.13%S

a. Using 3:1 NP:AP and Sobek method.

AG = acid-generating; S = sulfur.
%S in most common sulfides (pyrrhotite, pentlandite, chalcopyrite) ranges from 33 to 42%.

Sources: Geochimica, 2004 (for sulfur percentages); Kennecott Exploration, 2005 (for sulfide percentages).

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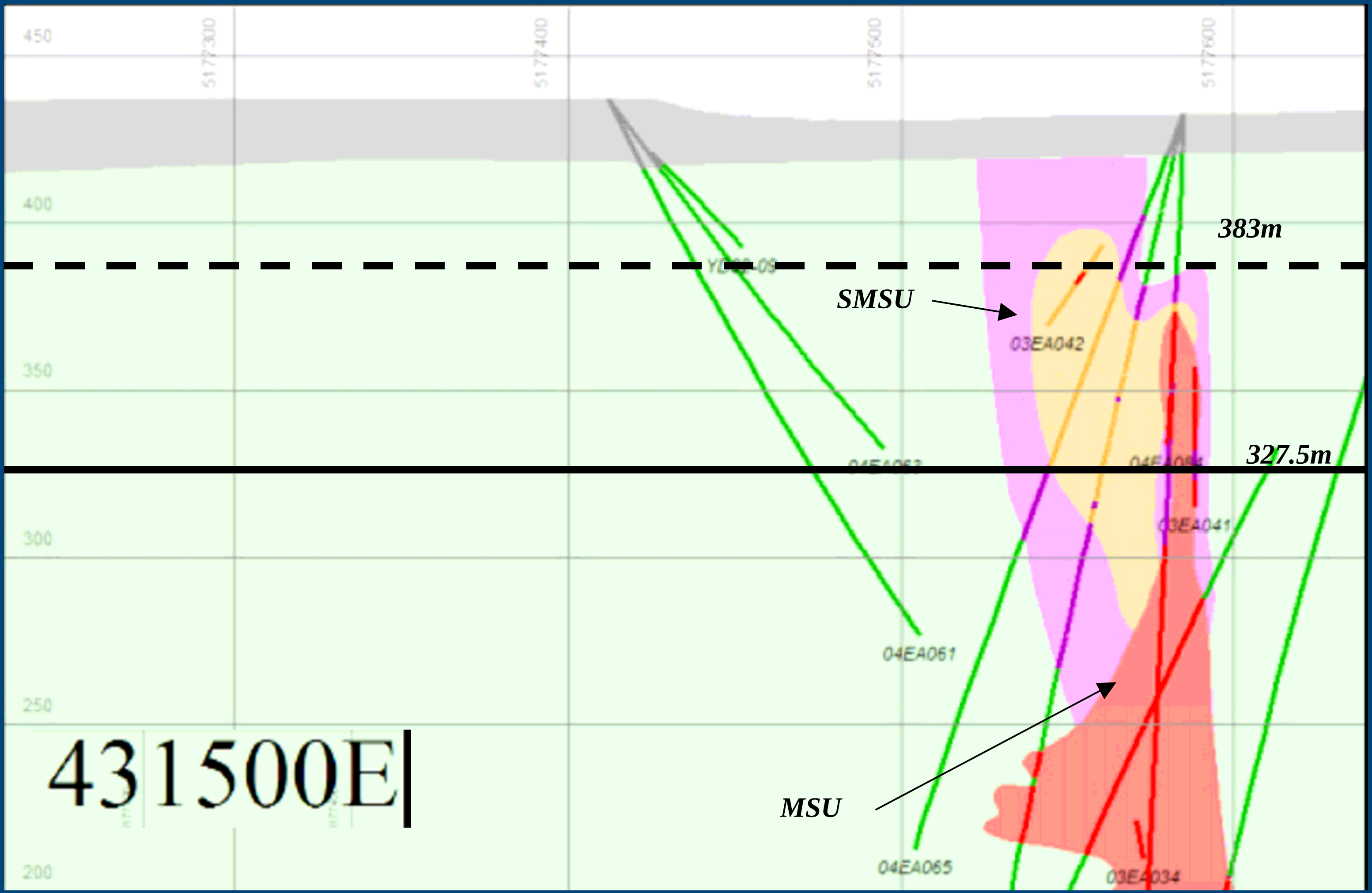
Cross-section through crown pillar and ore body



Source: Enlarged from Kennecott Exploration, 2005.

MSU=red; SMSU=tan; peridotite=magenta; sedimentary=green

Comparison of recommended input leachate values (mg/L) for water quality prediction after mining

	Stratus Consulting, 2007				Geochimica, 2006			
Source rock/type mine ralization	**CR**	**Intrusives**	**SMSU**	**MSU**	**Low-S peridotite**	**High-S peridotite**	**SMSU**	**MSU**
SO_4	161	135	585	474	3.09	57	426	368
Al	5.51	0.0069	0.01	0.005	0.005	0.0078	0.019	0.005
Cd	0.0126	0.000025	0.006	0.00085	0.000025	0.000025	0.003	0.00085
Co	0.245	0.0029	1.4	0.363	0.00005	0.00016	0.721	0.363
Cu	12.7	0.0112	0.0208	0.0048	0.0016	0.005	0.017	0.0048
Fe	26.4	0.015	2.16	89.3	0.015	0.015	0.36	89.3
Pb	0.15	0.00012	0.0005	0.002	0.00005	0.00005	0.00005	0.00005
Ni	2.66	0.754	120	39.9	0.0023	0.0066	68.2	39.9
Zn	1.22	0.0029	0.074	0.0127	0.0014	0.001	0.06	0.0127

CR = country rock; SMSU = semi -massive sulfide unit; MSU = massive sulfide unit; S = sulfur.

Source: Humidity cell testing results, Geochimica, 2004.

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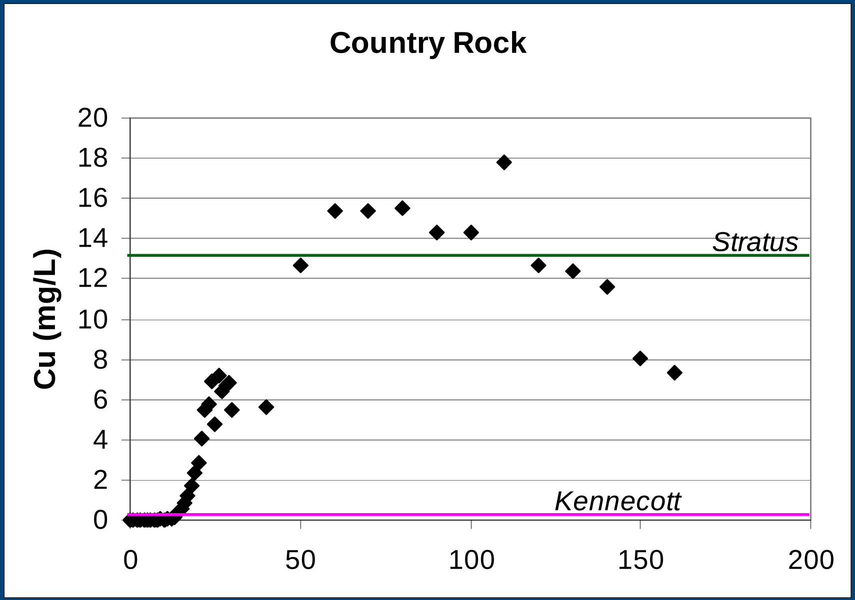
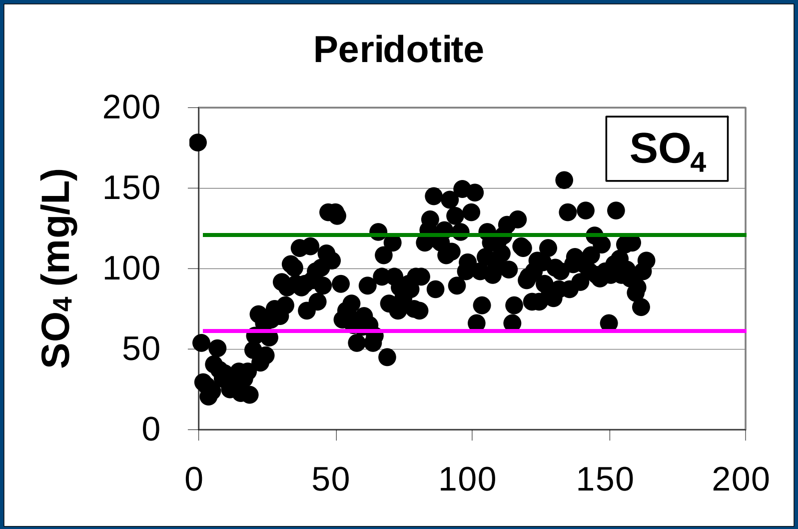
Comparison of HCT Values





Modified from Stratus Consulting, 2007

Geochimica's general approach to modeling

- HCT concentrations converted to leach rates per unit surface area per unit time
- Total surface area of exposed rock in the mine (of each rock type) and the development rock used as backfill were used to compute the mass leached
- Mass of leached contaminants was divided by the total water inflow volume
- End = concentrations in backfilled underground mine after mining

Kennecott's modeling assumptions that minimize predicted mine water concentrations

- Mining cannot surgically remove ore
  - Kennecott: Essentially no ore will remain in mine or development rock
  - We used 5% SMSU, 45% intrusives, 45% country rock for development rock; 12% SMSU (vs. 8%), 3% MSU (vs. 2%), 65% intrusives, 20% country rock for mine wall rock
- Development rock contains small particles, and these control leaching
  - Kennecott: 100% are 10 cm in diameter
  - We used 90% at 10 cm, 10% at 1 cm diameter
- Water infiltrating through the crown pillar will contain contaminants
  - Kennecott: No contaminated infiltration will move through the crown pillar to the mine during or after mining
  - We estimated leachate concentrations using HCT results

Kennecott's modeling assumptions that minimize predicted mine water concentrations (cont.)

- End of mining (year 7+) leachate concentrations should be represented by later HCT results
  - Kennecott: HCT results from weeks 20 to 50 are representative of concentrations after mining
  - We used HCT results from weeks 50 and 70
- Groundwater infiltration to the mine is estimated at 75 gpm
  - Kennecott: The amount of water entering the mine will be 180 gpm
  - We used 75 gpm (expected groundwater inflow rate used in water balances for MPA)

Comparison of predicted development rock stockpile water quality using different inputs and assumptions

	Geochimica (2005b)	Stratus Consulting (2007)
Sulfate	575	5,940
Nickel	8.33	102
TDS	956	8,340
Aluminum	3.46	79.8
Beryllium	0.0019	0.051
Cadmium	0.0002	0.185
Cobalt	0.0008	4.14
Copper	5.58	184
Iron	26.8	383
Lead	0.0004	2.17
Zinc	1.90	17.7

TDS = total dissolved solids; Stratus, 2007 = 90% 10cm, 10% 1cm, 5% SMSU
Note: Does not include limestone

Stratus Consulting, 2007

Comparison of predicted mine water quality at the end of mining to relevant standards

	Units	Stratus Consulting (75 gpm inflow)	Geochimica[a] (180 gpm inflow)	Part 201	Part 22 standards	MCL	SMCL	MCLG
TDS	mg/L	**561**	–				500	
Aluminum	µg/L	**4,950**	4.0	300	150		50 to 200	
Beryllium	µg/L	**3.22**	–	4	2	4		4
Cadmium	µg/L	**11.9**	0.08	5	2.5	5		5
Cobalt	µg/L	**362**	18	40	20			
Copper	µg/L	**11,400**	2.1	1,400	500	1,300 (TT)	1,000	
Lead	mg/L	**135**	0.03	4	2	15 (TT)		0
Nickel	µg/L	**15,500**	**1,770**	100	50			
Sulfate	mg/L	**394**	28	250	250		250	

MCL = maximum contaminant level; SMCL = Secondary MCL; MCLG: MCL Goal. TT = Treatment technique. See U.S. EPA, 2007.

a. Geochimica, 2006, Table 2; - = not estimated.

Stratus Consulting, 2007

Overall conclusions

- The ore and host rock will produce acidic, metal-rich drainage quickly (during mining) that will last for long periods of time
- Leaching of contaminants in the crown pillar was ignored, and water contaminant levels during and after mining were underestimated in Kennecott's modeling
- We predict that concentrations of aluminum, boron, cadmium, cobalt, copper, iron, lead, nickel, nitrate, sulfate, and TDS will exceed Michigan water quality standards after mining; Kennecott predicts only nickel and iron will exceed
- More realistic higher concentrations require redesign of water treatment facility and consideration of impacts to groundwater and surface water downgradient of mine and TWIS