

5501 Hobart St.  
Pittsburgh, PA 15217  
July 9, 2009

Bandon Woodlands Community Association  
PO Box 592  
Bandon, OR 97411

Dear Bandon Woodlands Community Association,

Please find attached a response to technical memos from the Oregon Resource Corporation (ORC) and the Oregon Department of Environmental Quality entitled "Continued Chromium Geochemistry Concerns with Proposed Mining Activity on Oregon's Bandon Coast". This response details concerns that, in my professional opinion, remain with the mining of chromite sand deposits in the Bandon Coast region. The ORC has apparently detected concentrations of hexavalent chromium, a toxic material, in groundwaters collected from the sand deposits. Moreover, these hexavalent chromium concentrations (~7 ppb) are approaching surface water quality criteria (chronic: 11 ppb; acute: 16 ppb). However, the sampling methods employed by ORC are not clearly documented and therefore may not reflect actual conditions in the groundwaters. With this uncertainty, it is impossible to accurately assess risk to the residents of the Bandon Coast area and to the riverine systems draining the area. Further, with the detection of hexavalent chromium on the site, it follows that additional characterization is essential to ensure that mining activity will not change the chemical dynamics of the groundwater system, increase the oxidation of chromium to the hexavalent form, and potentially impact downstream residents and biota.

This response grows from a report entitled "Geochemical Risk and Chromite Mining Activity on the Bandon Coast" I submitted to you June 2, 2008. I am attaching this report as well for your reference as you consider my response.

Please feel free to contact me with questions about the report as they may arise.

Respectfully submitted,

Daniel J. Bain, PhD

Attachment 1: Continued Chromium Geochemistry Concerns with Proposed Mining Activity on Oregon's Bandon Coast

Attachment 2: Geochemical Risk and Chromite Mining Activity on the Bandon Coast

## Continued Chromium Geochemistry Concerns with Proposed Mining Activity on Oregon's Bandon Coast

This report serves as a response to the technical memo prepared for the National Marine Fisheries Service by the Oregon Resources Corporation (ORC) [Weatherby, 2009] and the technical memo prepared by the Oregon Department of Environmental Quality [Mason, 2009]. This report is prepared at the request of the Bandon Woodlands Community Association and outlines, in my professional opinion, remaining and emerging concerns with ORC's plans to mine chromite and other materials from sand deposits along the central Oregon coast near Bandon. Topics are addressed individually below:

### Monitoring Well Sampling and Sample Preservation

It is not clear from ORC's technical memo [Weatherby, 2009] how groundwaters were sampled and preserved. While EPA standard methods for analysis (i.e., EPA 6010, EPA 6020) are cited, the actual methods for well sampling are not clearly outlined (e.g., were samples filtered? If so, were they filtered in the field?). This makes interpretation of reported results difficult. For example, total metals [Table 2 in Weatherby, 2009] analysis shows alarmingly high concentrations of aluminum, well above the chronic surface water criteria of 87 ( $\mu\text{g/L}$  or ppb) (<http://www.epa.gov/waterscience/criteria/wqctable/>, accessed June 16, 2009), however, the dissolved analysis [Table 3 in Weatherby, 2009] show concentrations below these criteria. This is commonly observed when colloidal clays are included in metal concentration analysis, implying that "total" concentrations were measured on unfiltered samples. For the remainder of this document, we will assume that "total metals analysis" was performed on samples that were not filtered and "dissolved metals analysis" was performed on samples that were passed through a filter, and will further assume the filter has a 0.45 micron pore size.

If we are correct in our assumptions, there are concerns about the conclusions drawn [Weatherby, 2009]. Comparing analytical results from unfiltered samples with drinking water standards [e.g., Table 2, Weatherby, 2009] ignores the fact that drinking waters are also subject to copious filtering (e.g., the strict turbidity standards serve to ensure this occurs: <http://www.epa.gov/safewater/contaminants/index.html>, accessed June 16, 2009). Operationally, these turbidity standards are closely equivalent to passing the sample through a 0.45 micron filter. While we cannot check our assumptions, it seems some of the observed water chemistry concentrations (e.g., the high "total" iron and aluminum) result from the measurement of colloidal material in the water.

As Mason [2009] points out, the larger concern is that as the manganese oxidation of chromium is a surface reaction, and addition of basic material to unfiltered samples could create conditions favorable for the oxidation of Cr to the hexavalent form. The dependence of chromium oxidation reaction rate on pH is unclear and raising the pH does not seem to quicken the reaction in simple systems [e.g., Fendorf and Zasoski, 1992 and the cites therein]. Therefore, it is not clear that the detected hexavalent Cr necessarily resulted from sample preservation with NaOH. The more troubling aspect of the sampling conducted by ORC is that standard methods for the measurement of hexavalent Cr (e.g., US EPA 218.6, [http://www.epa.gov/waterscience/methods/method/files/218\\_6.pdf](http://www.epa.gov/waterscience/methods/method/files/218_6.pdf), accessed June 16, 2009) should be utilized and cited. Method 218.6 clearly dictates that samples should be filtered before preservation, eliminating the potential for oxidation of trivalent Cr in the sample. In addition, method 218.6 also calls for measurement of the hexavalent Cr in the sample within 24 hours of

collection. Such filtering and time lines are not clearly documented in the ORC report. *The lack of filtration or a deficient sample storage protocol could cause the reported hexavalent Cr concentrations to be artificially low.* With colloidal material in the sample, there is the potential for reduction of hexavalent Cr, leading to under-reporting. In addition, once stored for periods longer than 24 hrs, the potential for reduction of hexavalent Cr in these samples increases.

Given the challenges one encounters in the correct determination of hexavalent Cr concentrations, regardless of methods used, it is wise to include field blanks and particularly spikes in the sampling plan. This can help remove the ambiguity that can arise (e.g., the discussion above). If the laboratory is consistently accurate in measuring spikes and spiking is done correctly, the hexavalent Cr concentrations can be considered more reliable than those reported by ORC.

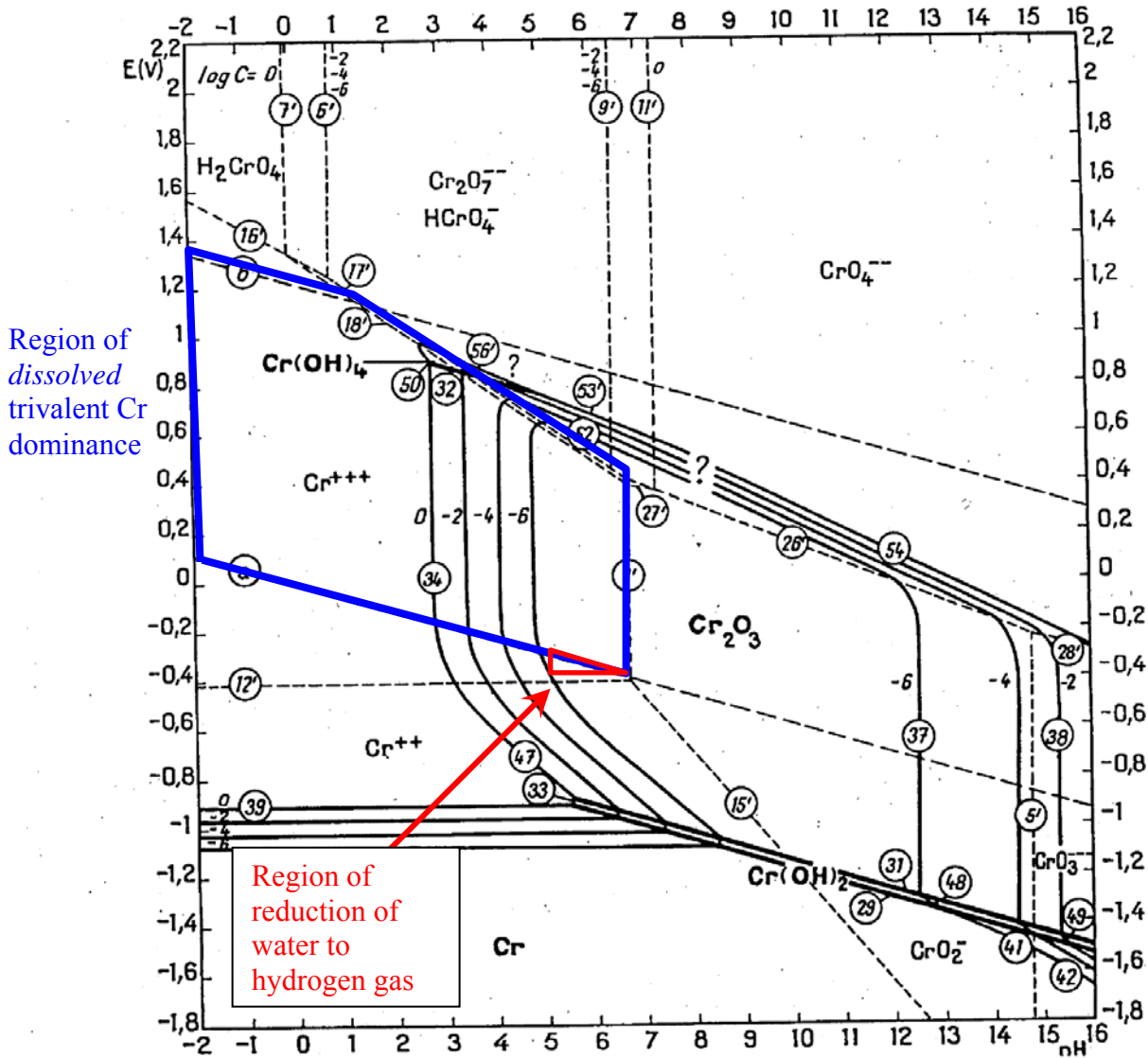
### Equilibrium Geochemistry

ORC uses equilibrium stability arguments [pg. 86, *Weatherby*, 2009] to suggest that Cr in the local groundwaters should not be oxidized based on groundwater chemistry. It is important to consider these arguments carefully. First, one must consider if the range reported is conceivable. For example, ORC overlays the relevant water chemistry ranges on their stability diagram of choice. However, this method results in the inclusion of a substantial area below the line delineating the threshold where reduction of water to hydrogen gas begins (Figure 1). These conditions are rare in near surface conditions and there is no indication of hydrogen gas in the well samples. Further, the majority of the observations fall within the region where dissolved trivalent chromium should be the dominant form of chromium based on this stability diagram (Figure 1). This means that dissolved trivalent chromium should be the most common species in the system. Therefore, as these wells are installed in chromite sands, there should be substantial amounts of dissolved trivalent chromium. The reported data in Table 2 and Table 3 indicate otherwise.

This discrepancy likely results from the fact that stability diagrams are generally based on geochemical databases and the database selected can alter the areas of chemical species dominance [for a nice illustration see: *Geological Survey of Japan*, 2005 <http://www.gsj.jp/GDB/openfile/files/no0419/openfile419e.pdf>]. In fact, the stability diagram seems to be taken directly from early pioneering work [*Pourbaix*, 1973]. This work did not have the benefits of access to more recent measurements of Cr behavior [particularly *Rai et al.*, 1987]. This likely explains the differences between the geochemistry as indicated by ORC on the stability diagram and that measured by ORC. It also illustrates some limitations of equilibrium stability arguments as predictions are based on partial knowledge of the system and will change as we continue to gather additional chemical data.

Ultimately, it does not seem that ORC was attempting to pick an optimal stability diagram, as their illustration somewhat undercuts their argument that trivalent Cr should be largely insoluble. Regardless, additional information is essential in these sorts of discussions. When making equilibrium arguments, the database used to construct the stability diagram must be specified, in addition to any alterations of constants in the database. Further, if we are relying on equilibrium process to attenuate the hexavalent Cr, it is essential to measure quantitatively the parameters as specified by Palmer and Puls [1994] including: 1) Is there sufficient reductant in the system to reduce the Cr(VI) currently generated and any potential increases in Cr(VI) generation following mining activity; 2) Is “the time scale required to achieve the reduction of Cr(VI) to the target concentration...less than the time scale for the transport of the aqueous

Cr(VI)” to the local surface waters and domestic drinking water wells.; 3) Will “the Cr(III)... remain immobile”, particularly in groundwater flow paths down gradient from the mining sites. Additionally, the system must be examined for flushing of accumulated Cr(VI) (please see the section below).



**Figure 1** ORC stability diagram with the region of water reduction to hydrogen gas and the region of dissolved Cr(III) dominance highlighted.

### Monitoring Well Placement

All monitoring wells were installed to sample aqueous chemistry conditions in the formations to be mined [Weatherby, 2009]. While this is an effective strategy for characterizing geochemistry in the actual ores that ORC proposes to mine, it does not provide information about how the hexavalent Cr [e.g., Weatherby, 2009] in these groundwaters moves through the local

system or how groundwater chemistry evolves as it moves toward local receiving waters or domestic wells. For example, while groundwaters in the heavy sands may be reducing [Weatherby, 2009], there is little information about the redox status of groundwaters below the perched aquifer systems. If the hexavalent Cr detected in these wells escapes from the perched aquifer systems, there is little information to predict the fate and transport of the hexavalent Cr in the natural system. *Additional monitoring wells along relevant flow paths are necessary to characterize and monitor the system and any mining activity.*

### Sampling of Springs & Domestic Wells

As aquatic biota in local surface waters seem to be particularly at risk (hexavalent Cr was detected in concentrations of ~7 ppb, just below the 11 ppb chronic surface water quality criteria and the 16 ppb acute surface water quality criteria), sampling of local springs discharging to surface waters seems like a quick, easy way to evaluate the potential for hexavalent Cr, either contemporary concentrations or concentrations altered by mining activities, to reach sensitive surface waters.

Further, due to the substantial costs involved in accessing new drinking water sources, a baseline characterization of domestic wells seems particularly prudent. While these wells likely do not tap the perched aquifers these monitoring wells are installed in, ORC has not ruled out the potential for movement of Cr(VI) contaminated water through longer flow paths to other aquifers. For example, while they assume that local surface waters will intercept any groundwater discharge and protect some of the documented domestic wells, there is no documentation of whether the surface water gains or loses discharge, an important indication of direction in ground and surface water interactions. Therefore, the recommendation that all domestic drinking water wells be characterized for Cr(VI) concentration before mining activities begin should be reiterated. Such a characterization protects both the residents of the Bandon Coast and ORC.

### Hydrologic Flushing

Another danger in relying on equilibrium modeling is that natural systems are not always at equilibrium. One of the most important mechanisms to consider along the Bandon Coast is hydrologic flushing [Burns, 2005], particularly as this area lies in a climate with strongly seasonal precipitation [e.g., Avila et al., 1992]. Hydrologic flushing describes a situation where an anion is generated in local soils and sediments on a continuous basis. During rain events this material is incorporated into storm flow and moves rapidly through the soil matrix. Anions, like chromate ( $\text{Cr}^{(\text{VI})}\text{O}_4^{2-}$ ) and nitrate [Creed et al., 1996], move particularly well through soil materials as both the soils and the ions are negatively charged and therefore do not interact. During storm flow and particularly during the beginnings of storm flow, significant peaks in anion concentration can occur. While ORC has attempted to characterize groundwaters in the actual sand deposits, we have little understanding of soil water geochemistry or surface water chemistry during precipitation events. Therefore, if chromate ions are accumulated in soil waters throughout the summer and flushed during the beginning of the rainy season, chromate concentrations substantially above those observed here and potentially above the 16 ppb acute surface water quality criteria could reach local receiving waters. As the presence of chromate was not confirmed when the original report was written, this topic was not raised. However, with Cr(VI) present in groundwaters at concentration near the freshwater quality criteria, chromium dynamics near the beginning of the wet season should be characterized before, during, and after mining activity (e.g., sampling of springs and monitoring wells during early wet season

flow). While the flushing of chromate ions has not been observed in the literature, this results solely from this being the first attempt to examine such behavior.

### Recommendations

Based on the concerns outlined above, it is my professional opinion that:

1. All future sampling to characterize hexavalent chromium should utilize proper methods for the determination of hexavalent Cr (whether EPA 218.6 or the Ball adaptation [*Ball and McCleskey*, 2003]) and clearly document adherence to method specifics. Moreover, field blanks and spikes should be utilized to ensure the effectiveness of this field sampling.
2. When making equilibrium stability arguments, geochemical databases should be clearly identified and stability diagrams carefully interpreted. Further, if making such arguments, the following criteria [based on *Palmer and Puls*, 1994] should be quantitatively measured and met:
  - a. There is sufficient reductant to reduce the Cr(VI) currently generated and any potential increases in Cr(VI) generated following mining activity
  - b. “The time scale required to achieve the reduction of Cr(VI) to the target concentration is less than the time scale for the transport of the aqueous Cr(VI)” to the local surface waters and domestic drinking water wells.
  - c. “The Cr(III) will remain immobile”, particularly in groundwater flow paths down gradient from the mining sites.
3. As recommended in my original report, “Groundwater monitoring wells should be installed down gradient of all mining locations to monitor total and hexavalent Cr concentrations in groundwater systems downstream of the operations.” This will allow characterization of geochemical conditions in the larger groundwater system and allow characterization of changes in transport of Cr from the mining sites before, during, and after mining activities.
4. Sample local springs down gradient of proposed mining sites for hexavalent Cr concentrations at baseline conditions and during any mining activities. This will allow evaluation of impacts on local surface water biota, biota that seem particularly at risk given hexavalent Cr concentrations detected in a relatively limited sampling of local groundwaters.
5. In particular, evaluate whether or not chromate is flushed to surface water systems during precipitation events, with an emphasis on early wet season periods. This will clarify the uncertainty surrounding potential impacts of mining activity on hexavalent chromium in non-equilibrium conditions.

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## Geochemical Risk and Chromite Mining Activity on the Bandon Coast

The Oregon Resource Corporation recently began the process of applying for permits to allow the mining of chromite sands from the Bandon, OR area. The Bandon Woodlands Community Association has solicited this document to characterize potential risks posed by mining activities and the associated disruptions to local hydrologic systems. This document outlines recent findings regarding the environmental geochemistry of chromium that raise concerns about consequences arising from the mining activity. Based on the literature summarized herein, I suggest monitoring and testing should be implemented as part of the planned mining activity, to protect both the citizens of the Bandon Coast and the Oregon Resource Corporation.

### Chromium Aqueous Chemistry

Chromium (Cr) is a trace, transition metal (atomic number 24, average US soil concentrations 53 ppm [*Shacklette et al.*, 1971]). Chromium's behavior in environmental aquatic systems is dictated by the valence or oxidation state (essentially the electrostatic charge on the atom). Cr atoms can have charges (or valence states) ranging from -2 to +6, though under Earth's atmosphere and in environmental conditions, Cr generally carries a charge of +3 or +6. These electrostatic charges correspond to the common names for chromium species, "trivalent" Cr (Cr<sup>III</sup>) and "hexavalent" Cr (Cr<sup>VI</sup>), respectively. While Cr is the same core material in each state, the valence state controls the number of oxygen atoms bonded with the Cr atom. This difference in oxygen atoms results in strongly contrasting environmental behavior. Table 1 summarizes these contrasts.

**Table 1** Summary of Cr species characteristics and behavior

<i>Cr Species</i>	<i>Cr<sup>III</sup> (trivalent)</i>	<i>Cr<sup>VI</sup> (hexavalent)</i>
Common Species	Cr <sub>2</sub> <sup>III</sup> O <sub>3</sub> (s), Cr(OH) <sub>3</sub> <sup>0</sup> (aq), Cr(OH) <sub>2</sub> <sup>+1</sup> (sorbed)	Cr <sub>2</sub> O <sub>7</sub> <sup>2-</sup> (aq), CrO <sub>4</sub> <sup>2-</sup>
Solubility	Low in non-acidic waters (pH>4.5)	Very soluble, can pass through cell membrane
Interaction with soils	Bonds strongly with iron oxide surfaces, making Cr <sup>III</sup> relatively immobile in soil.	Very mobile in soil due to the negative charge of anionic form and the negative charge of the soil materials (clays, etc.). If there is sufficient organic material or ferrous iron in the soil, Cr <sup>VI</sup> will rapidly reduce.
Interaction with biota	Essential micronutrient important in the metabolism of sugars.	Can pass through soil membranes and oxidize intercellular material, including genetic material

Understanding the risks associate with Cr requires an understanding of the environmental transitions between these two oxidation states. For many years, based on the pioneering work of Bartlett and James [e.g., *Bartlett and James*, 1988], Cr was thought to exist predominantly in the Cr<sup>III</sup> state in environmental conditions without direct inputs of Cr<sup>VI</sup> from human activities. Hexavalent Cr will rapidly reduce (i.e., transform) to Cr<sup>III</sup> when it encounters organic material, reduced iron, reduced sulfur, and other common environmental materials. In addition, until



Fendorf and Zasoski [1992] demonstrated the ability of manganese oxides to oxidize Cr<sup>III</sup> to Cr<sup>VI</sup> in laboratory experiments, there were assumed to be few or no non-human influenced processes that produced hexavalent Cr in environmental conditions. Therefore, before recent research results emerged [Ball and Izbicki, 2004; Chung et al., 2001; Gonzalez et al., 2005; Oze et al., 2007; Robles-Camacho and Armienta, 2000], it was assumed that very little hexavalent Cr was created naturally, and if it were, the Cr would be rapidly transformed back to the much more benign form.

It should be stressed that much of the environmental reduction and oxidation of Cr has focused on the behavior of Cr in soil systems. Groundwater systems are fundamentally different, particularly in terms of potential reductants. In general, organic material diminishes exponentially with depth in the soil column. Therefore, at the water table and deeper, unless there is close connection between the soil surface and groundwater (e.g., a wetland), there is limited organic material in groundwater. Further, if hexavalent Cr does reach groundwater, there is potential for transport of some distance via the groundwater system, particularly if the system is oxic. In addition, if chromium is oxidized and therefore created in or near the groundwater system by manganese oxides, there are limited opportunities to reduce the resulting hexavalent Cr. In this case there is also the potential for transport of Cr to relatively distant areas, including local receiving waters.

All assumptions underlying chromium risk analysis chromium must be correct to ensure the safety of residents in areas surrounding the proposed ORC mines and aquatic species downstream of these sites. That is, all of the following must be true:

1. Hexavalent Cr is not generated in the black sands of the southern Oregon Coast.
2. Alterations to local hydrology and stratigraphy caused by the mining activity do not change environmental conditions to enhance or create processes oxidizing Cr to the hexavalent state.
3. There is sufficient organic material and other Cr-reducing materials in the soils and sediments between the mine sites and drinking water wells/surface waters to transform any oxidized Cr to the benign, immobile trivalent state.

However, as discussed in the remainder of this document, these assumptions cannot be validated with currently available data. As a result, there is the potential for unforeseen consequences arising from mining activities that could increase risks to local residents and environmental systems.

### *Bandon Chromite Sands Mineralogy and Geochemistry*

According to Griggs [Griggs, 1945], the “black sands” of the Southern Oregon Coast originate from serpentinized bedrock in the Oregon Coast Range and Klamath Mountains. During deposition in Tertiary sandstones and in contemporary beach deposits, these materials have been concentrated by density sorting. Samples of sand taken from several of the mines open in 1945 have mineralogies as described in Table 2:

**Table 2** Mineralogy of Southern Oregon Coast Black Sands from Griggs [1945].

Mineral	Chemical Formula	Specific Gravity	Mine & Sample			
			Pioneer BS-1-G	Shepard BS-2-G	Shepard BS-3-G	Eagle BS-4-G
Quartz	SiO <sub>2</sub>	2.55-2.66	3	5.1	10.6	4.3
Olivine	(Mg,Fe) <sub>2</sub> SiO <sub>4</sub>	3.18-3.57	6	21.6	20.1	5.6
Pyroxene	Ca,Mg,Al,Fe,silicate	2.8 -3.7	2.8	23	13.6	5.3
Ilmenite	FeTiO <sub>3</sub>	4.44-4.90	2.8	8.3	6.4	6.4
Rutile	TiO <sub>2</sub>	4.18-5.13	0.3	0.5	0.2	0.1
Zircon	ZrSiO <sub>4</sub>	4.02-4.86	2.5	1.9	1.5	3
Garnet (% indicates sum of Almandite and Spessartite)			28.8	10.2	25.7	27.6
-- Almandite	Fe <sub>3</sub> Al <sub>2</sub> Si <sub>3</sub> O <sub>12</sub>	3.69-4.33				
-- Spessartite	Mn <sub>3</sub> Al <sub>2</sub> Si <sub>3</sub> O <sub>12</sub>	3.8 -4.3				
Chromite	(Mg,Fe)O·(Fe,Al,Cr)2O <sub>3</sub>	4.32-4.57	48.8	20.7	18.4	43.1
Magnetite	FeFe <sub>2</sub> O <sub>4</sub>	4.97-5.18	4.7	7	2.7	4.4
Epidote.	Ca(Al,Fe) <sub>3</sub> (OH)(SiO <sub>4</sub> ) <sub>3</sub>	3.07-3.50		0.2		
All others..			0.4	1.4	0.4	0.3
Total			100.1	99.9	99.6	100.1

These deposits contain substantial amounts of both chromium and manganese, creating the potential for interaction between manganese and chromium to generate hexavalent chromium. Moreover, the mixing of sediments and changes in hydrology associated with the proposed mining activity could enhance such oxidation and mobilization. However, as our understanding of the chemical mechanisms and environmental processes are limited, we cannot predict the consequences with much certainty. This uncertainty, coupled with the toxic nature of hexavalent Cr, dictates that a cautious approach to large scale disruption of hydrologic flow paths in the region should be followed.

### Recent Recognition of Hexavalent Chromium in Groundwaters

The first to recognize the presence of natural hexavalent chromium was Frederick Robertson in his 1975 Masters thesis work at Arizona State University. Since, natural hexavalent Cr has been detected in a variety of groundwater systems. This report will focus on data from California, as the southern Oregon Coast shares California's strong seasonal climate and similar, and in many cases richer, Cr-source rocks. More important, California, in conjunction with the USGS, has begun state-wide monitoring of hexavalent chromium in groundwater [Bennett *et al.*, 2006; Fram and Belitz, 2007; Kulongoski *et al.*, 2006; Kulongoski and Belitz, 2007; Milby Dawson *et al.*, 2008; Wright *et al.*, 2005], following the discovery of natural hexavalent Cr in several California aquifers and the potential for generation of hexavalent Cr in California soils [Ball and Izbicki, 2004; Chung *et al.*, 2001; Gonzalez *et al.*, 2005]. It is assumed that the hexavalent Cr encountered in these groundwater systems results from the oxidation of trivalent Cr to hexavalent Cr by manganese oxides.

The California Groundwater Ambient Monitoring and Assessment Program (GAMA, see the citations above) results are important to consider when evaluating the risks associated with the mining of the chromite sands on the Bandon Coast. Table 3 summarizes the data from all published GAMA results. It includes the number of wells with measurable hexavalent Cr, the

total number of wells sampled, and the range of total and hexavalent Cr concentrations observed. There seems to be a loose affiliation between Cr rich source rock and groundwater concentrations (e.g., the Sacramento River drains Cr source rocks (part of the Klamath formations) and the Southern Sierra is poor in Cr source rock). Unfortunately, the Klamath region, the region most relevant to the Bandon Coast question (due to similarities in source rock composition), will not be evaluated until 2010. However, it is clear that hexavalent Cr occurs in groundwater throughout California and therefore it is likely that Cr<sup>VI</sup> exists in Oregon ground waters as well.

**Table 3** Summary of to-date Cr results from the California Groundwater Ambient Monitoring and Assessment Program.

<i>GAMA Region</i>	<i>Number of wells sampled</i>	<i>Wells with detectable Cr<sup>VI</sup></i>	<i>Cr<sup>VI</sup> concentration range (ppb)</i>	<i>Total Cr concentration range (ppb)</i>
San Diego (DS 129)	40	27	0.1 – 5.6	0.1 – 5.7
North San Francisco Bay (DS 167)	97	79	0.1 – 15.6	0.1 – 17.1
Northern San Joaquin (DS 196)	39	32	1 – 14 (estimated)	1 – 15 (estimated)
Monterey Bay/Salinas Valley (DS 258)	97	86	1 – 33	1 -33
Southern Sacramento Valley (DS 285)	47	24	8 – 70	8 - 67
Southern Sierra (DS 301)	28	17	1 – 9	1 - 11

In most cases, the concentrations of Cr<sup>VI</sup> detected by the GAMA studies are well below drinking water regulatory levels (the drinking water total Cr MCL is 100 ppb). However, the studies demonstrate that the assumption that hexavalent Cr is not produced naturally is clearly incorrect. Moreover, as we are only beginning to discover natural hexavalent Cr in our groundwater systems, we have limited geochemical theory available to predict levels of hexavalent Cr in groundwater. Ultimately, we have no basis to understand the consequences of landscape disruption associated with mining activity to hexavalent Cr concentrations in groundwater systems.

*Transfer of Chromium in Groundwater to Surface Water*

While groundwater contamination is a concern to human health, the potential discharge of hexavalent Cr enriched groundwaters to local surface waters also raises concerns about impacts to instream biota. For example, we know rivers discharging to the San Francisco Bay have hexavalent Cr concentrations in the parts per billion range, particularly during the wet winters [Abu Saba and Flegal, 1997]. These concentrations do not seem to correspond with human inputs [Abu Saba and Flegal, 1997] and therefore likely result from the processes discussed above. While values at the Bay itself are below concentrations of concern for in stream biota (i.e., USEPA surface water quality criteria of 11 ppb), these are measurements from the mouths of large river systems and are likely lower than concentrations in drainages upstream due significant dilution and in-stream reduction. Therefore, groundwater discharges directly to streams should be more concentrated and potentially higher than 11 ppb. This potential exposure raises concern as hexavalent chromium concentrations of 200 ppb are reported to be acutely toxic to salmon fingerlings and concentrations of 16-21 ppb inhibit growth in trout and salmon fingerlings [Eisler, 1986]. In-stream biota may have been exposed to very small quantities of hexavalent Cr in local waters for years. The question remains, will mining activities alter

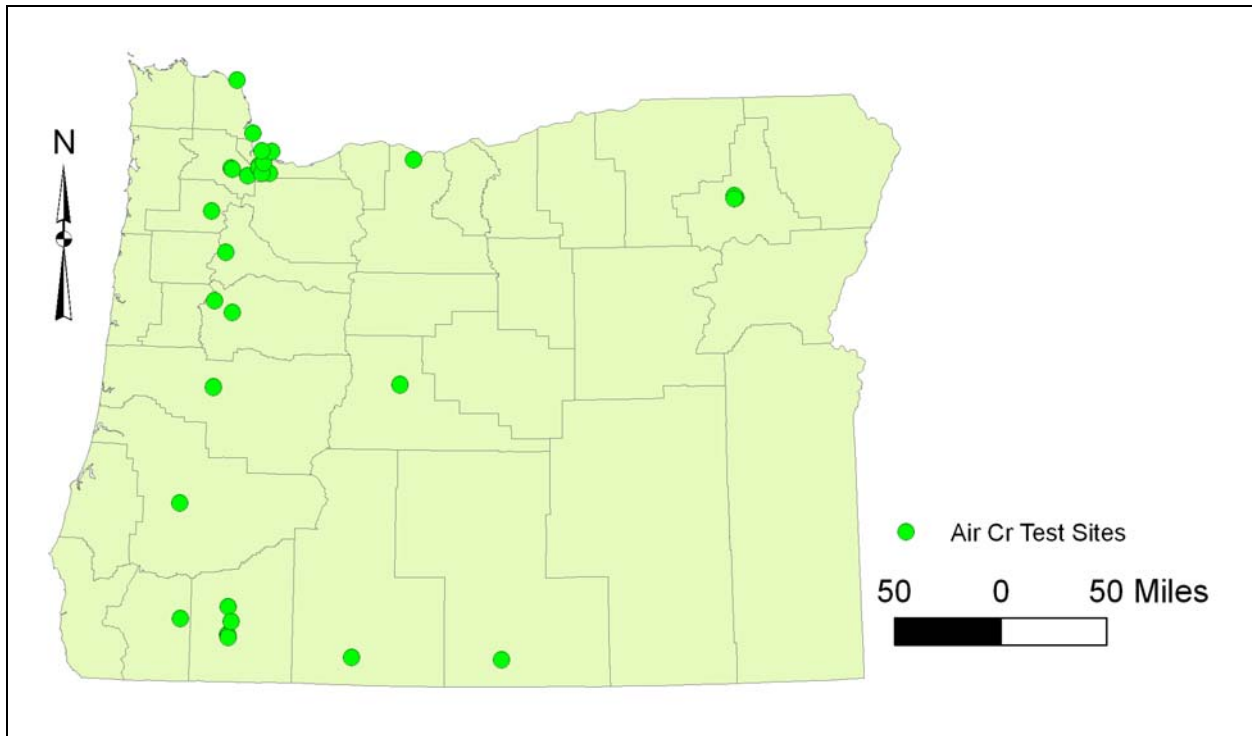
hydrologic processes to increase or prolong these exposures? As with hexavalent Cr in groundwaters, we do not have sufficient information to confidently answer this question.

### Chromium Toxicology

Chromium is a substance of concern primarily due to the strongly toxic behavior of hexavalent chromium. In terms of human exposures generated by mining activity, there are two pathways of particular concern, respiratory (via dust generated by earth movement, etc.) and orally (via drinking water). In terms of larger ecosystem effects, any discharge of hexavalent Cr enriched groundwaters to surface waters will expose all biota living in those waters to this toxic material. Risk associated with Cr exposures tends to be minimized in the toxicological literature due to the assumptions made about Cr environmental behavior. First, it is assumed that Cr is predominantly in the trivalent form in soil environments, minimizing the mobility of Cr. The ATSDR Toxicological Profile (pg. 295, [*Agency for Toxic Substances and Disease Registry (ATSDR), 2000*]) states in the Environmental Fate section, “In most soils, chromium will be present predominantly in the chromium(III) state. This form has very low solubility and low reactivity resulting in low mobility in the environment and low toxicity in living organisms.” Second, it is further assumed that most exposures to hexavalent Cr result from releases of human generated Cr. In the Public Health Relevance section of the ATSDR Toxicological Profile [2000, pg. 171], it states, “chromium(VI) in the environment is almost always related to anthropogenic activity.” However, as is outlined above, the recent environmental chemical research points to mobilization of Cr from environmental pools to groundwater and therefore the potential for unexpected mobility of and exposure to hexavalent chromium in environmental systems. Moreover, this potential transformation has led to the recent examination of how particulate Cr behaves once it enters the lung tissue [e.g., *Goldhaber et al., 2006*]. It is important to carefully evaluate the potential risks associated with mining activity in the Bandon, OR area in order to ensure that proper monitoring and, if necessary, abatement occurs.

### Inhalation Exposures Standards

The link between inhalation of Cr, particularly hexavalent Cr, and human health effects is well established. Federal agencies including EPA, OSHA, and NIOSH all regulate ambient air Cr standards. Oregon has measured airborne Cr in variety of forms in at least 37 locations (see Figure 1). However, most of these locations are located inland from coastal areas and are concentrated in relatively urban areas. Ultimately, airborne Cr concentrations (regardless of valence state) in the Bandon area are uncertain. While most of the Cr disturbed during mining will likely be in the trivalent form, there remains the potential to significantly increase dust levels and therefore airborne exposures to total Cr in the area, particularly in the dry summers. As a result, this exposure should be quantified, particularly as emerging work suggests that simulated human lung leaches (i.e., simulations of the liquids encountered in the human lung) can leach up to 1 ppm Cr from ultramafic soils, even when the Cr is in the trivalent state [*Goldhaber et al., 2006*].



**Figure 1** Map of locations tested for airborne chromium in Oregon according to the Department of Environmental Quality's Laboratory Analytical Storage and Retrieval (LASAR) system [*Oregon Department of Environmental Quality*, 2008].

### Drinking Water and Surface Water Quality Standards

The risks associated with chronic oral exposure to hexavalent Cr have led to the regulation of Cr concentrations in drinking water (the USEPA total chromium drinking water standard is 100 ppb. Some states, including California, have a total Cr standard of 50 ppb, in line with World Health Organization recommendations). Further, due to potential impacts to in stream biota, USEPA and Oregon Cr surface water criteria indicate Cr<sup>VI</sup> should be below 11 ppb. Groundwater Cr levels observed in California sometimes exceed the California drinking water standard and approach the USEPA drinking water standard. These groundwater Cr concentrations are routinely above surface water quality criteria. We do not have a baseline Cr concentration characterization of waters in the Bandon area, making the origin of any future Cr<sup>VI</sup> detected during monitoring uncertain.

### Summary and Recommendations

Based on the evidence presented in this document, it is my professional opinion that:

1. The geochemistry of the sand includes significant amounts of both chromium and manganese. This sand and the hydrogeologic flowpaths through this sand will be disrupted by the mining process. This disruption will include mixing of formerly separated sediments, large changes in local hydrogeology due to dewatering and disposal of the resulting water, etc.
2. Recent research results demonstrate that the benign trivalent chromium can be oxidized to the toxic hexavalent form by manganese oxides in environmental conditions.

3. Field studies in the United States, and particularly in California, have identified substantial concentrations of hexavalent Cr in groundwater systems. These concentrations can exceed the California total Cr drinking water standard and the USEPA surface water quality criteria. Further, this hexavalent Cr can reach surface waters, particularly during the wet Oregon winters.
4. We cannot accurately predict the impacts of disrupting the sediments and hydrogeology on the concentrations of hexavalent Cr in local drinking water wells or in groundwater discharges to local surface waters. Nor can we say how these activities will alter air quality.

Therefore, it is my professional opinion that the following monitoring should occur as part of the mining operation:

1. A baseline measurement of both total and hexavalent Cr in all potentially impacted drinking water wells and springs discharging to local streams should be made at least twice (in both winter and summer conditions) prior to the onset of mining activity. This will not only protect the consumers of drinking water and in-stream biota, it will also protect ORC if hexavalent Cr is measured in these wells after mining, as post-mining results can be compared with unambiguous pre-mining concentrations.
2. Groundwater monitoring wells should be installed downgradient of all mining locations to monitor total and hexavalent Cr concentrations in groundwater systems downstream of the operations. These wells, when regularly monitored (an appropriate sampling frequency should be developed based on local hydrogeologic conditions, particularly groundwater velocities), should provide early warning of any changes in dissolved Cr arising from mining activity. Again, these wells should be installed, developed, and sampled multiple times before mining activity begins to ensure proper pre-mining concentrations are characterized.
3. Once mining operations begin, potentially impacted wells and springs should be sampled and measured for total and hexavalent Cr at least annually, and more frequently if hexavalent Cr concentrations increase in these wells.
4. Following cessation of mining operations, monitoring wells should be sampled and Cr measured regularly over a time period several times the expected time period necessary for groundwater to move from the mine sites to the monitoring well. In addition, total and hexavalent Cr should be measured in potentially impacted domestic wells and local springs annually for a similar period (springs should be sampled in the wet season).
5. Dust monitoring. As inhalation exposures to chromium have documented human health impacts, baseline monitoring of ambient air quality, particularly in the summer dry season should be conducted during periods when mining operations are ongoing. The concentrations of both total Cr and hexavalent Cr should be measured during this period and the results assessed to determine the necessity of continued monitoring.

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