A new industrial mineral sand mine near Coos Bay, Oregon

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Oregon Resources Corp. (ORC) has developed and permitted a new mining operation that incorporates a process design that will allow the unique paleo-beach placer deposits of southwestern Oregon to be extracted efficiently and economically, creating the only domestically mined source of a unique foundry grade chromite and specialty de-veining sand for precision casting. The operation will also provide an additional domestic source of garnet and zircon.

Engineering design has been guided by the variable geology and mineralogy of the paleo-beach placer deposits as well as the need for a dry tailing scheme that resolves a lack of water resources at the placer locations and at the same time eliminates the need for slurry settling ponds, typical of paleo-beach placer operations in North America.

Metallurgical study of the placer material was grouped into four distinct samples based on marine terrace deposition, geological facies and mineralogy. Because the metallurgical samples represented the extremes likely to be encountered in all future Oregon paleo-beach placers, the process design is highly dynamic and will successfully adjust to meet the production needs.

Water availability at the mining area is seasonal and will not support a traditional placer operation's water requirement needs for heavy mineral concentration. For this reason, ORC has developed a plan to construct the ore processing facilities near Coos Bay, where a municipal source of water is available. Raw ore will be transported from the mining sites approximately 32 km (20 miles) one way to the processing facility with return loads hauling tailings back to the active pit. The requirement to haul and reclaim dry tailings and limit the amount of water being purchased from the municipality has driven the design of a unique water reclamation system.

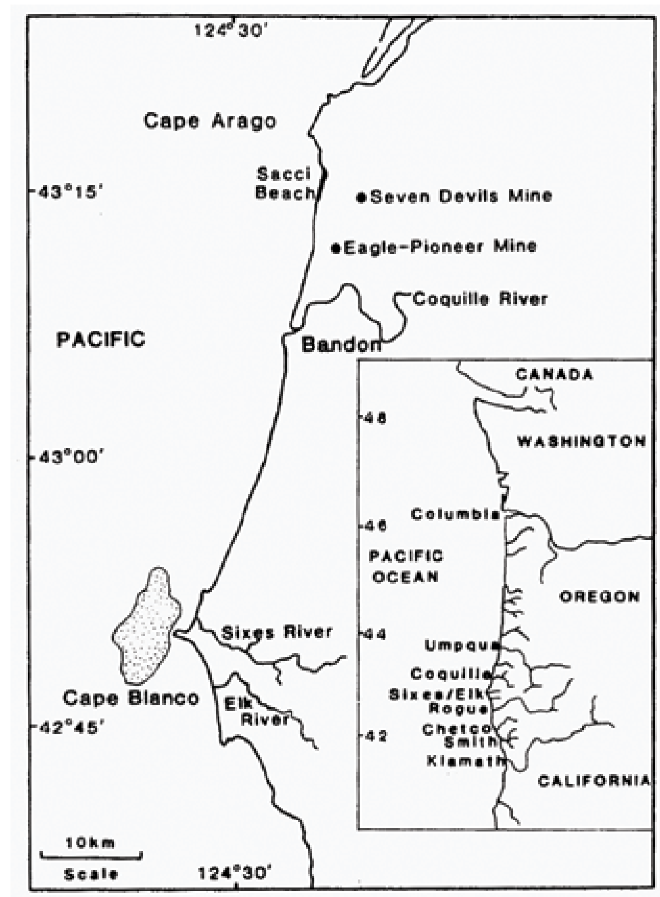
Background

Location and access. Economic concentrations of "black sand" or heavy mineral (minerals with specific gravity greater than 2.85) have been recognized and studied in marine placers from Coos Bay to the mouth of the Rogue River, a distance of approximately 121 km (75 miles) along the southern Oregon coast (Hornor, 1918; Griggs, 1945) (Fig. 1).

ORC will begin mining existing reserves approximately 32 km (20 miles) south of Coos Bay in a region known locally as Seven Devils. Ore will be trucked north to the processing site near Coos Bay on existing county and state roads, including U.S. 101.

Figure 1

Location map of southern Oregon with major sediment source rivers (Peterson et al., 1987).



The available facilities at the processing site include highway, rail, municipal water and electricity, natural gas and a deep-water port. At the time of this writing, the rail line had been abandoned, but was being pursued by the International Port of Coos Bay. It is anticipated that this will be serviceable at some time in the future.

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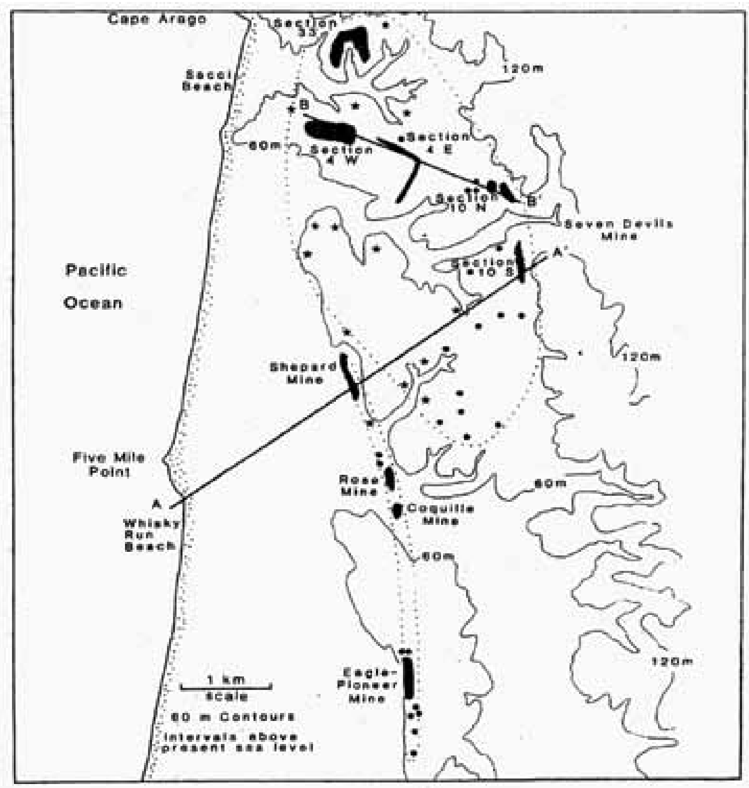
Figure 2

Detailed map of the study area with deposits. Cross section A-A' depicted (Peterson et al., 1987, with supporting data from Griggs, 1945).



History. The southern Oregon marine placers have garnered the interests of miners since 1852, when present day beaches were exploited for gold. The beach deposits were small and irregular in nature and were easily washed away by the major storms the coast endures during the winter months (Hornor, 1918).

In the 1920s, deposits at the beach were followed upstream to their paleo-beach terrace origins (Pardee, 1934). These terrace placers were mined, but with little success, as the cost of mining and processing was greater than at the present day beach deposits.

The greatest effort to understand and delineate the paleo-beach terrace placers came during World War II. As the need for a domestic source of steel hardening chromite was evident, the heavy mineral bearing placers of southwestern Oregon were investigated by the U.S. Geological Survey (USGS), under guidance from the Oregon Department of Geology and Mineral Industries, which began exploration drilling of the paleo-beach terraces in 1940 (Griggs, 1945). This work was part of the broader investigation of strategic mineral deposits and would ultimately supply much needed chromite for the war efforts.

The first mining efforts began in 1943 by Humphreys Gold Corp. and Krome Corp. (Griggs, 1945). Black sand concentrates averaging roughly 25 percent Cr_2O_3 were produced at the mining sites by wet gravity processes and trucked to the Defense Plant Corp.'s separation plant near Coquille, OR, where the black sand was further concentrated to approximately 40 percent Cr_2O_3.

Humphreys Gold Corp. developed and used the revolutionary helical spiral separator for the purpose of concentrating the heavy mineral of the Oregon paleo-beach placers (Allen, 1943). This methodology is still used in hundreds of mining applications from placer mining to coal processing.

Geology

Regional geology. As with any marine placer deposit, one must understand the source of the economic minerals, the transport mechanisms, segregation and depositional systems, and preservation of the deposits.

The heavy mineral deposits of the southwestern Oregon placers are sourced from the metamorphic and ultramafic rocks of the Klamath Mountains (Twenhofel, 1943). The Klamath Mountains are located in southwestern Oregon and northwestern California. Within the metamorphic and ultramafic terrain exist alpine-type podiform chromite deposits. Several small operations have attempted to exploit these deposits with little success, given the podiform variability (Libbey, 1963).

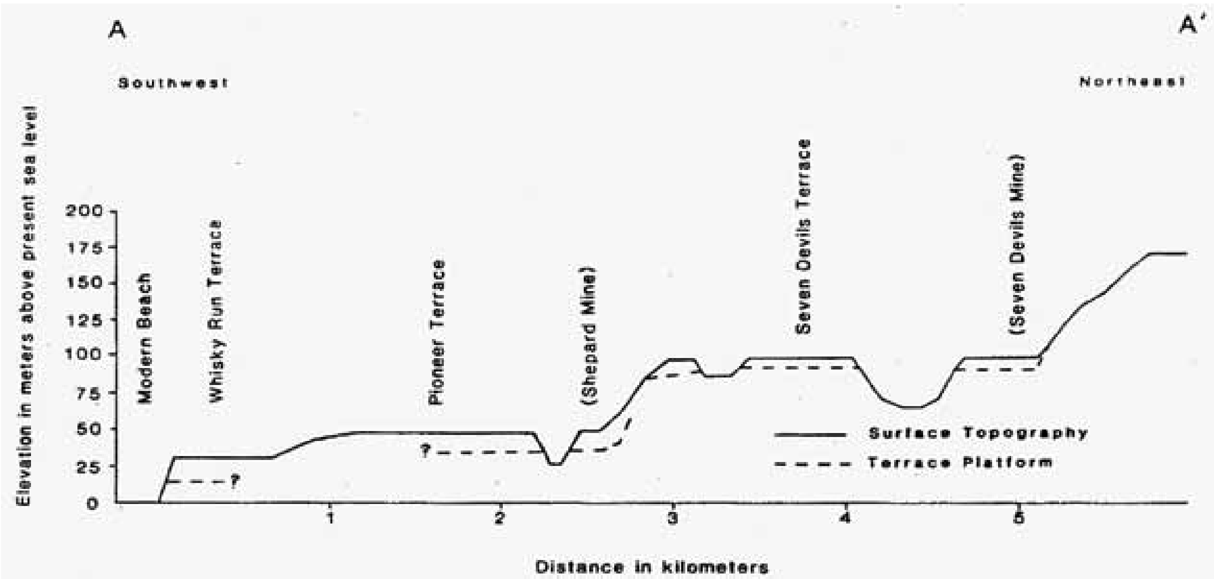
Several major rivers including the Chetco, Rogue, Elk, Sixes and the Coquille drain from the Klamath Mountains to the Pacific Ocean (Kulm et al., 1968). Mineral grains in currently identified paleo-beach placer deposits have been chemically analyzed with ion microbe analysis to demonstrate that their sources are indeed the existing rivers whose watersheds begin in the Klamath Mountains and in the regions of the alpine-type podiform chromite deposits (Peterson et al., 1986).

Once the sediments reach the Pacific Ocean, predominant longshore currents transport the sediments northward. Headlands along the paleo-coastline reduced the energy of the currents and allowed for the preferential removal of dense particles according to Stokes Law (Peterson et al., 1986). Currently, deposits of heavy minerals are forming off the coast of southern Oregon, following the same mode of deposition adjacent to prominent headlands (Cape Blanco) (Kulm et al., 1968). Another characteristic of the Oregon coast is the fierce storms and high-energy wave action that occurs along the beaches. This high-energy environment is sufficient to segregate the dense from light minerals and is amplified during storm events.

Finally, once the economic heavy minerals

Figure 3

Generalized cross section of the southwestern Oregon paleo-beach terraces (Peterson et al., 1987).



are in place and concentrated, the deposit must be preserved. Such industrial mineral placers around the world typically show preservation by high sea level stands and subsequent regression, leaving behind the coastal remnant. The Trail Ridge deposit, which stretches from Florida to the Carolinas, represents such a depositional model. Economic heavy minerals have been mined from this ridge since the late 1940s to the present. It is suggested by Peterson et al., 1986, that the southern Oregon paleo-beach terraces were formed by a transgressive sequence that encroached approximately 5 km (3.1 miles) inland from the present-day beach followed by regression, high sea level stand and a subsequent progradational beach forming sequence, thus forming the overall geomorphology of the region into a stair-step sequence leading down to the present day beach (Peterson et al., 1987).

Terrace geology. Although several terraces exist, ORC's operation currently is developing reserves within the Seven Devils and Pioneer terraces (Fig. 2).

The Seven Devils terrace has been suggested to be 124,000 years old (Pleistocene) (Adams, 1984). The terrace has been uplifted to an elevation of 75 to 85 m (246 to 279 ft) above present sea level and is inland 5 km (3.1 miles), roughly parallel with the current beach. The Seven Devils terrace can be traced from approximately 11.3 km (7 miles) south of Cape Arago to Cape Blanco to the south, a distance of approximately 50 km (31 miles). Griggs (1945) suggests that the terrace is truncated to the east by normal faulting, leaving a sharp contact between the terrace sands and an older Tertiary mudstone (weathered to clay in most areas). To the west, the terrace is eroded by the subsequent formation of the younger Pioneer terrace (Fig. 3).

Peterson, et al., 1987, interpreted stratigraphic sections studied within the Seven Devils terrace to represent a transgressive sequence. Deposition on the Seven Devils terrace represents the nearshore to inner shelf deposition of the transgressive sequence. Exploration drilling by Krome Corp. and ORC indicate the presence of additional tensional faulting in the nearshore environment that increased the thickness of the sediment package. As a result, typical nearshore orebodies (North and South Seven Devils) have mineral-

Figure 4

Grain structure comparison (Hoyt, 2009).

ANGULAR VERSUS ROUNDED GRAIN STRUCTURE

ANGULAR GRAINS		ROUNDED GRAINS
MORE	BINDER REQUIRED	LESS
LOWER	HEAT TRANSFER	HIGHER
HIGHER	PERMEABILITY	LOWER
HIGHER	METAL PENETRATION	LOWER
ROUGH	CASTING FINISH	SMOOTH
LOWER	RECLAMATION YIELD	HIGHER

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Table 1

Bulk sample location and mineral information.

	Bulk sample ID			
	SH	**WB**	**S7D**	**N7D**
Drillhole samples	83	358	470	172
Total bulk weight (lbs)	1,634	2,351	8,248	5,190
Terrace represented	Pioneer	7 Devils	7 Devils	7 Devils
Deposits represented	Shepard	Westbrook West Bohemia Sec 10, 33	South 7 Devils	North 7 Devils
% Heavy mineral (sg > 2.85)	62.3	21.9	43.4	34.8
% Chromite	14.5	10.3	18.9	11.9
% Garnet	10.1	1.0	6.0	1.7
% Zircon	1.2	0.6	1.8	1.2
% Epidote/clinozoisite	30.5	12.3	18.6	20.9
% Staurolite	1.5	0.4	0.3	0.7
% Ilmenite	1.0	1.1	4.3	0.5
% Leucoxene	0.5	0.5	0.3	0.8
% Rutile	0.2	0.2	0.5	0.4
% Magnetite	0.0	0.1	0.4	0.1
% Misc. Light "heavies"	3.6	0.4	1.0	0.9

SH = Shepard, WB = Westbrook, S7D = South Seven Devils, N7D = North Seven Devils

ized sand depths from surface to maximum of 30 m (98 ft), while averaging 15 m (49 ft). Typical of the nearshore deposition, the delineated reserves are characterized by a basal conglomerate of well-rounded rocks and agates overlaying the weathered Tertiary mudstone (Baldwin et al., 1983 and ORC drilling). Coarse sands overlay the conglomerate and include some of the highest concentrations of heavy minerals, in some cases up to 95 percent. These higher-grade units typically reflect lags created under high-energy storm sequencing. Upsection, a general fining upwards exists, representing the transgressive nature of the ocean. Heavy mineral concentrations are recorded throughout the entire sequence, but there is no doubt that as the transgressive sequence progressed and energy shifted from high breaker/swash zone to seaward energies, segregation and concentration waned. In stark contrast to the lower zones of deposition, the upper zones typically contain 2 to 10 percent heavy mineral. Authigenic clays derived from feldspars and other weathered minerals exist within the deposits and represent 10 to 15 percent of the ores within the nearshore environment. Bioturbation does exist in the form of branching tubes typical of nearshore environments (Hunter, 1980).

West of these deposits on the Seven Devils terrace, ORC has further delineated the Westbrook (Sec. 4E), West Bohemia (Sec. 4E), and Section 33 deposits. These deposits are shallow in nature, located at or near surface to maximum depths of 9 m (30 ft) and averaging 6 m (20 ft). As is the case with the previously described North and South Seven Devils deposits, the western deposits along the Seven Devils terrace demonstrate a transgressive sequence, as suggested by Peterson et al. Similarities include the sequencing from basal Tertiary mudstones/clay and conglomerate unconformity followed by coarse sand deposition with higher concentrations of heavy mineral continuing upsection to lower energy sands. The primary difference between the two sets of deposits being the total depth of the deposited package of sand. The North and South Seven Devils deposits are narrowly bounded by north-south trending faulting, whereas the westward reserves on the Seven Devils terrace are broad, laterally continuous representations of full scale beach deposition and transgression.

The Pioneer terrace is the younger of the two terraces in which ORC has been delineating reserves. The age of the terrace is approximately 103,000 years old and represents a progradational beach sequence formed at high sea level stand (Adams, 1984). The stratigraphic sequence of the Shepard deposit, the only reserve currently delineated by ORC on the Pioneer terrace, is similar to that of the Seven Devils terrace deposits and generally represents deposition at what would be the final stages of the transgressive sequence (Peterson et al., 1987). A basal conglomerate of well rounded rocks and agates exists above an unconformable layer with the same Tertiary mudstone encountered on the Seven Devils terrace deposits, followed by a nearshore/swash zone depositional sequence of coarse sand and higher concentrations of heavy mineral. Once again, this higher energy zone served to concentrate the heavy mineral during periodic storm and wave events. Upsection is found in the same fining upward sequence along with lowered concentration of heavy mineral resulting from lower energy environments associated with the transgressive sequence. The Pioneer terrace deposit differs from the previous terrace deposits in that it is capped by aeolian dune sequences that represent the end of transgression and the early stages of beach progradation (Peterson et al., 1987). While this aeo-

Table 2

Bulk sizing, desliming and oversize data.

	Bulk sample ID			
	SH	**WB**	**S7D**	**N7D**
% pit oversize (4 mesh, +4.75 mm)	1.3	4.0	3.1	2.6
% plant oversize (-4, +18 mesh, -4.75, +1.0 mm)	2.1	6.1	4.8	4.0
% slimes (-230 mesh, -63 µm)	6.7	14.8	14.0	14.8
% passing deslime to gravity circuit	89.9	75.1	78.1	78.6
Screen analysis of deslimed gravity circuit feed	100	100	100	100
+20 mesh (850 µm)	0.0	0.1	0.0	0.1
-20, +30 mesh (600 µm)	0.2	2.7	0.8	0.4
-30, +40 mesh (425 µm)	0.7	8.4	1.9	1.1
-40, +50 mesh (300 µm)	5.6	28.3	6.9	8.1
-50, +70 mesh (212 µm)	26.6	29.4	29.1	41.2
-70, +100 mesh (150 µm)	43.4	17.8	33.7	30.7
-100, +140 mesh (106 µm)	18.9	8.1	20.5	13.0
-140, +200 mesh (75 µm)	3.7	3.3	5.5	3.7
-200, +230 mesh (63 µm)	1.0	1.0	1.7	1.9

SH = Shepard, WB = Westbrook, S7D = South Seven Devils, N7D = North Seven Devils

lian sand does contain heavy mineral, it is not in economic concentrations within the Shepard deposit study area.

Mineralogy and products. Economic minerals from the southern Oregon paleo-beach placers currently being marketed by ORC include chromite and zircon products for foundry applications and garnet for waterjet cutting medium. Other recoverable minerals include ilmenite, magnetite, staurolite, kyanite, sillimanite, rutile, leucoxene, gold and platinum (Hornor, 1918 and Griggs, 1945). Ilmenite, leucoxene, rutile, magnetite and small amounts of chromite are combined into a fourth product called High-Iron, a foundry deveining solution. Not only do the total concentration of these economic minerals vary with depositional facies, there is also a degree of variability found in overall assemblage between the Seven Devils and Pioneer terraces. Constant among all of the terraces, however, is the degree of sphericity and rounding as well as the natural sizing and sorting (Hoyt, 2006).

The deposits located on the Seven Devils terrace (North and South Seven Devils, Westbrook, West Bohemia, West Section 10 and Section 33) contain higher concentrations of chromite and zircon in the heavy mineral fraction than does the Shepard deposit located on the Pioneer terrace. Full ore reserve (not metallurgical bulk sampling) analysis performed by ORC indicates that concentrations of chromite within the Seven Devils terrace ranges from approximately 33 to 43 percent, in contrast to only 23 percent on the Pioneer terrace (Drew, 2008). The same can be said of zircon, which averages between 1.5 and 2.9 percent within the Seven Devils terrace and only 1.4 percent on the Pioneer terrace. Alternatively, the Pioneer terrace shows greater percentage of garnet, at 12.6 percent versus 4.6 to 9.8 percent on the older Seven Devils terrace (Drew, 2008). These differences in mineral assemblage reflects the differing sources supplying the system at the time of deposition. Peterson et al. (1986) has shown several unique river sources supplied the deposition at varying stages of terrace development, yielding the shifts in mineralogy.

Constant throughout both the Seven Devils and Pioneer terrace deposits is the general physical nature of the heavy mineral. The chromite, garnet, zircon and High-Iron sand grains from the southern Oregon paleo-beach placers are highly rounded and moderate to highly spherical (depending on original crystal form) (Hoyt, 2006, 2009). The grains have also experienced a narrowing of particle size distribution by the wave action of the Pacific Ocean.

In direct comparison tests to market foundry grade chromite from the Republic of South Africa (typically angular crusher fines from ferrochrome operations) the ORC chromite performs favorably:

- The rounded grain structure and naturally smooth polish of the ORC chromite grains reduces the total surface area that requires binders in the foundry mold. This lowers costs while maintaining the strength of the mold.
- The reduction in mold binder lowers the decomposition gasses and emissions during the casting process.
- The rounded grain shape and narrow particle size distribution of ORC chromite allows for a tighter packing of grains in the mold. Increased grain-to-grain contact during binding yields superior tensile strengths and enhances the ability to transfer heat from the casting.
- Clay coatings eliminated during processing.

Oregon Resources Corp. chromite product

Table 3

Heavy mineral concentrate sizing from bulks.

Screen	SH	WB	S7D	N7D
	Bulk sample ID			
+20 mesh (850 μm)	0.0	0.0	0.0	0.0
-20, +30 mesh (600 μm)	0.0	0.3	0.1	0.0
-30, +40 mesh (425 μm)	0.0	1.1	0.4	0.2
-40, +50 mesh (300 μm)	3.1	8.6	0.8	2.1
-50, +70 mesh (212 μm)	29.0	28.9	12.4	20.7
-70, +100 mesh (150 μm)	39.5	34.3	39.4	39.3
-100, +140 mesh (106 μm)	16.2	11.8	29.8	26.4
-140, +200 mesh (75 μm)	12.2	13.9	16.2	10.9
-200 mesh (-75 μm)	0.0	1.1	0.8	0.5

met or exceeded the results of zircon in all foundry tests as well, making it a viable, lower cost alternative. Currently, ORC has memorandums of understanding for product sales with HA-International, IGC Technologies and Possehl Erzkontor GmbH.

Process design

Bulk sample selection and preparation. A total of four bulk samples for metallurgical test work and plant design were collected by the ORC team (Table 1) and delivered to Outotec (USA) Inc. for characterization. Criteria for selection included marine terrace deposition, geological facies and mineralogy.

Upon selection, the bulks were collected using existing drillhole samples.

To accomplish the goal of creating a set of bulk samples that best represented the known minable resources, the ORC team divided the Seven Devils from the Pioneer terrace deposits. Based on previous work by Griggs (1945) and Peterson et al. (1987), the mode of depositional (facies) changes between both terraces and the mineral sourcing variability present at the time of deposition was enough to warrant concurrent metallurgical investigation of the two terraces.

At the time of bulk preparation, only the Shepard deposit within the Pioneer terrace had been delineated and drilled out, thus the requirement for only one bulk sample. The Shepard deposit on the Pioneer terrace also represents the largest shift in mineralogical assemblage, specifically the Seven Devils terrace deposits, however, it included multiple deposits delineated and drilled out by ORC. A total of three bulks were selected within the Seven Devils terrace on the basis of, first, location relative to the eastern boundary of deposition, a north-south trending normal fault scarp described by Griggs (1945) to be the equivalent of a sea cliff. The North and South Seven Devils deposits are located at the base of this scarp and are notably thicker in total sand deposition than the Westbrook, West Bohemia and West Section 10 and 33 deposits. Secondly, the North and South Seven devils deposits were bulked separately based on the relative amount of lower grade, uneconomic sand deposited in the final stages of the marine transgression at maximum ocean depths. While both deposits would have contained such deposition, the South Seven Devils deposit was partially mined during WWII, thus removing the upper sections of deposition that is still preserved at the North Seven Devils deposit.

The Westbrook, West Bohemia, West Section 10, and Section 33 deposits are all part of the Seven Devils terrace transgressive sedimentary package that has been dissected by erosion and mass wasting. These deposits are represented by one bulk sample resulting from the drilling at the Westbrook deposit.

Bulk samples were collected by splitting 1.5 m (5 ft) drillhole interval samples previously collected and warehoused by ORC. A small sample was retained, while the remainder was placed in 208 L (55 gal) drums. Samples for bulking were selected on the criteria that greater than, or equal to, 4 percent chromite be present in situ. This cutoff is typically considered by ORC to be of economic value. Interbedded lenses of less than 4 percent chromite were included in the sampling, thus representing the realistically mined deposit (Tables 2, 3).

Mining and ore grade control. The sample characterization summarized in Tables 1, 2 and 3 were homogenous samples produced from a drill program undertaken in 1991 by ORC. The goal of the 1991 drill program was to verify the findings of previous drilling studies and not necessarily to define the vertical and horizontal economic pit boundaries. Subsequent exploration programs in 2007 defined vertical and horizontal economic pit boundaries. The most recent drill studies indicate that grade varies, not only by deposit, but also vertically within the same deposit. For example, the heavy mineral content of S7D can from vary from 10 percent at the surface to > 70 percent at the bottom of the deposit.

The heavy mineral variations dictate the first design consideration, ore feed, grade control. Grade control will be accomplished by mining method. Mining will begin by establishing a low point at the edge of the deposit. Bulldozers will push diagonally through the vertical plane, taking slices of material from the entire vertical plane (top to bottom) with each push.

Grade control is especially important in the wet process. The wet process incorporates spirals where slurry is pumped to the top of the spiral and flows down the spiral in a corkscrew fashion. While descending the spiral, the minerals sort into distinct bands of materials of similar densities. Similar minerals are concentrated by splitters, which physically direct like bands of material onto the next processing step.

Feed grade should be made as consistent as possible in order to keep the width of the bands as uniform as possible. The position of the splitters is adjustable and the spiral circuit does have several reprocessing loops but the system would not be able to stabilize heavy mineral concentrate (HMC) recovery and grade with variations ranging from 10 to 80 percent (S7D). Figure 4 illustrates a typical spiral cross section. Dense materials, depicted by darker particles on the inside (right side), produce a distinct band. Stabilizing the feed grade produces a consistent band width of concentrate. The splitter would be positioned at the boundary between dense and non-dense material. Stabilizing feed grade stabilizes band width and makes maximizing recovery and stabilizing HMC grade possible.

Ore and tailings transportation. Typically, wet concentrators are located close to the deposit to minimize the transportation cost of getting ore to the wet concentrator and moving tailings back to the reclamation pits. Tailings are usually transported to reclamation areas by pumps moving slurry at 30 to 40 wt percent solids.

The -230 mesh material (slimes), portion of tailings are usually difficult to dewater and, for this reason tailings, are frequently pumped to a series of settling ponds where heavy equipment is used to work the coarse and fine material back together. Handling tailings this way is often difficult, as a series of collection ponds is usually required to allow the suspended solids enough time to settle, so the water fraction can be reused as process water.

Due to high ore grade, topography, zoning issues and lack of existing utilities and available process water at the mine site, both the wet and dry processing facilities are to be located separate from the mine site. The processing facilities will be located approximately 32 km (20 miles) from the mine site.

Typical thickened tailings slurry (thickened slurry at 40 wt percent solids) could not be successfully trucked back to the reclamation site. Project success rests on ORC's ability to dewater tailings so that it can be handled with standard, over the road, belly dump trucks.

Tailings dewatering and process water treatment. ORC, working together with FLSmidth Dorr-Oliver Eimco, has developed a unique solution to the challenge of tailings dewatering. The goal of the test work was to produce tailings that

Figure 5

Typical spiral cross section.

contained no free water, could be successfully transported, off loaded and contoured immediately.

Sample characterization and flowsheet development testwork by Outotec (USA) produced both fine and coarse tailings samples from each deposit. Dewatering testing at FLSmidth commenced with sample characterization and a standard flocculant screening matrix. The fine material was not difficult to flocculate using any flocculant with high molecular weight and low anionic charge density. Flowsheet development by Outotec, indicated the feed to the thickener would contain 7-10 wt percent solids. Static 2,000 mL (676 oz) cylinder tests were conducted using feed samples with 7-10 wt percent solids, as expected, results were poor. Feed conditions with solids of 7-10 wt percent, produced high flocculant dosage requirements, slow settling rates, poor supernatant clarity and low underflow densities (45-50 wt percent). Subsequent tests were conducted where the feed solids were reduced to <5 wt percent. Reducing the feed solids also dramatically reduced flocculant consumption (on a lb flocc/ton dry solids basis) and improved supernatant clarity. However, settling rates and underflow densities were not dramatically improved. Next, coarse tailings were mixed with the fine tailings in ratios of 1:1 to 4:1 (coarse:fine), adjusted back to 5 wt percent, and static 2,000 mL (676 oz) cylinder tests repeated. The result of mixing coarse and fine material, diluting the feed and using proper flocculant dosages was dramatic. The resulting flocculated particles were formed at nearly their ultimate density and settled very fast. Additionally, underflow densities of 65 wt percent were achieved. The underflow was essentially a paste. So to be sure it could be pumped, rheology work was conducted. Yield stresses vs. solids concentrations were measured. Bingham yield stress values of ~100 Pa at 65 wt percent solids were considered to be acceptable. Supernatant quality was also excellent, averaging 70-90 ppm TSS but never exceeding 130 ppm TSS (very clean for process water at a mineral sands operation). Recovery at minerals sands operations often suffers with dirty process water. Fine valuable mineral and dirty process water often result in a smearing of the concentrate on the spiral and result in lower recoveries and HMC grades.

Dewatered tailings will make operations at the mine site much simpler. Because ORC will not place tailings by pumping slurry, there is no need for a complex system of tailings booster pumps or to build and manage a series of settling ponds.

At 65 wt percent solids, the thickener underflow is not acceptable for over the road transport in belly dump trucks, as it has the consistency of tooth paste and would fluidize in a moving truck and possibly leak. As a result, further dewatering is required.

Pressure filtration tests were conducted unsuccessfully on underflow samples containing less than 1:1 coarse:fines ratios (very slow filtration, low cake solids). Acceptable results were achieved when the coarse:fine particle size ratios approached 4:1. Vacuum filtration tests were also successful at the higher ratio. Vacuum filtration has the advantage of being a continuous operation, does not require intermediate holding tanks, multiple units or a pug mill for breaking up cake. It was determined that adding coarse dry mill tailings and additional flocculant to the thickener underflow, vacuum filtration would produce a dewatered tailing material suitable for transport and reclamation. Adding coarse material to the fines is not only crucial for thickener performance but also makes vacuum filtration possible by producing a more porous cake. The coarse material provides pathways for the water to migrate, much the same as body aid would. By adding coarse tailings, vacuum filtration produced cake with a minimum of 82 wt percent solids and no free water. The dewatered cake at 82 wt percent resembles wet sand and passes paint filter tests, can be successfully transported and immediately contoured at the reclamation site.

Figure 6 illustrates the approach to managing water and tailings. Fines from the desliming cyclones are combined with coarse tailings from the wet mill and filtrate from the tailings filter, conditioned with flocculant, diluted using supernatant (internal, not shown) and fed to the thickener. The thickener overflow is recycled to the process water tank. The thickener underflow is conditioned with additional flocculant and mixed with more coarse material from the dry mill, and dewatered on the horizontal vacuum belt filter. The oversize separated at the wet screen is added to the cake and stacked as dewatered tailings ready for transportation and reclamation.

Dewatered tailings will make operations at the mine site much simpler. Because ORC will not place tailings by pumping slurry, there is no need for a complex system of tailings booster pumps or to build and manage a series of settling ponds. The operating mine footprint will be very small (one pit). ORC will be able mine and perform reclamation concurrently in the same pit due to the absence of water. The water make up requirement at the process facility is very small. The only paths to lose water at the process facility is the difference in moisture contents of the feed and the tailings, and water vapor lost at the fluid bed dryers preceding the dry mill. The process water make up requirement is < 3.15L/s (< 50 gpm).

A third piece of equipment, known as a horizontal vacuum belt filter, will be provided by FLSmidth and positioned between the spirals and HMC storage (Fig. 6). The HMC dewatering filter will increase the solids content of the HMC from approximately 80 wt percent solids, up to 95-98 wt percent solids. Usually, HMC is stockpiled on a concrete pad and allowed to drain. Solids contents of 90-95 wt percent are common with this method, depending on particle size distribution, process water viscosity and drainage time. Filtered HMC containing half the water content of typical HMC is expected to require approximately half the fuel (less efficiency losses). Fuel cost savings at 2008 natural gas prices are expected to pay for the cost of the filter in approximately 1.5 years. Additionally, if stockpiled HMC is low due to operational upsets, the dewatered HMC can be directly fed to the dryers without throughput or additional fuel requirement penalties.

Solid waste exemption. Tailings, even though being returned to their origin, required a solid waste exemption from the Oregon Division of Environmental Quality (ORDEQ). This exemption details the composition of the tailings and designates the material as clean fill, thus permitting the reclamation of the tailings as previously described.

The only process chemical use planned was polyacrylamide flocculant for slurry thickening and final tails filtering. The Oregon DEQ expressed reservations about the small amount of unreacted residual acrylamide (chemical formula: C_3H_5NO) in the flocculant remaining from the manufacturing process. Flocculants typically have residual acrylamide concentrations ranging from nil to a maximum 1,000 ppm. The ORDEQ's concerns related to possible residual acrylamide concentrations in drinking water that at some future date could flow through the tailings sand.

ORC retained Argo Consulting LLC (Wilsonville, OR), a mining consultant, to support the development of an effective chemical oxidation route that could be implemented in operation to reduce the residual acrylamide to non-detect levels.

Calculations at ORC's estimated flocculant use rates and highest expected residual acrylamide dosages showed that a maximum 72 kg/a (160 lb/year) of residual acrylamide potentially would report to the re-deposited tails, which will average 653 kt/a (720,000 stpy). This is a maximum of 46 μg/kg tails. For perspective, researchers have found that acrylamide naturally forms in fried foods at concentrations as high as 7,800 μg/kg (gingerbread). From a practical standpoint, acrylamide is carcinogenic as an acrylamide monomer product as used in industrial and manufacturing situations.

Health and food studies are under way in an attempt to establish whether the residual dietary acrylamide food levels are even a human hazard, as research to date has not found any carcinogenic link to dietary acrylamide. Considering that polyacrylamide flocculants are already approved for use in drinking water clarification, dewatering food plant waste that becomes animal feed, agricultural field erosion control and a myriad number of other applications that can lead directly and indirectly to human acrylamide ingestion, the ORDEQ regulator's concern at this point appears to be misplaced.

Acrylamide is a fairly reactive molecule and decomposes naturally in the environment by bacterial action, ultraviolet light, iron, natural mineral free radicals, organic acids (tannins, lignins), oxidizers, acids, bases and heat. There is a possibility that the residual acrylamide molecules would not even survive to tailings deposition but ORC would be in a very difficult position to prove this point without extensive and lengthy studies.

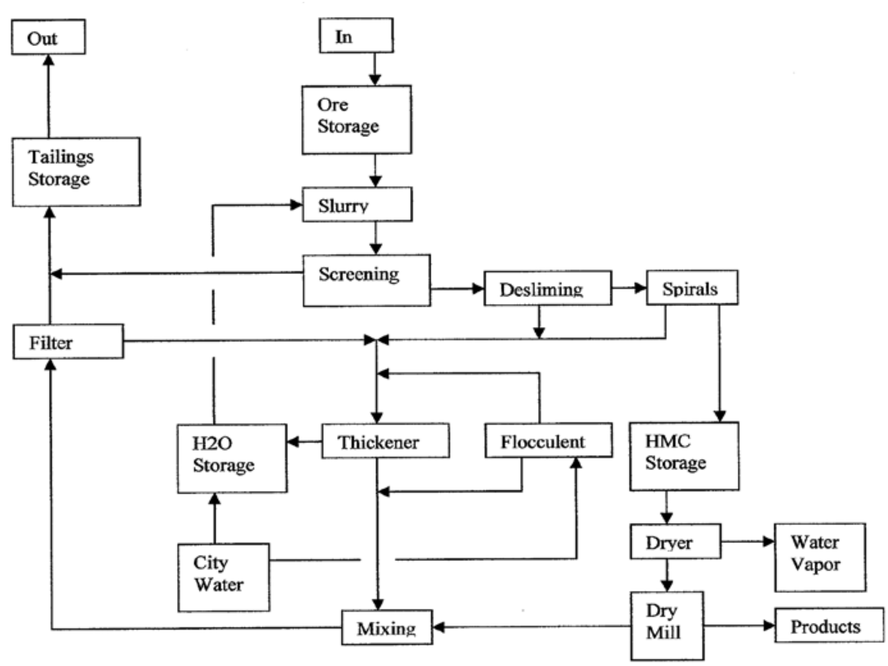
Various chemical oxidizers were considered as well as bacteria/enzymic treatment. In the lab process simulation studies, it was found that hydrogen peroxide dosed in the thickener and filter following flocculant solution addition at 0.025 percent w/w (slurry basis) dosage would reduce acrylamide to non-detect levels.

With these findings, the ORDEQ approved the permit with use of hydrogen peroxide to degrade acrylamide to nondetect levels. Hydrogen peroxide is readily available although it poses safety concerns that must be engineered into the system. Annual use rates will be approximately 204,000 kg/a (450,000 lb/year) of 35 percent peroxide liquid.

Zeroday Enterprises will be supplying the hydrogen peroxide and has been working with ORC on the system design installation with Solvay Chemicals support, which is providing the bulk storage tank. With the award of the process flocculant business, Zeroday is also providing their Z ChemGear dry flocculant mixing-feeding system and assisting with flocculant system plant design and installation.

Figure 6

Process flow diagram.



Characterization and circuit development. Considerable effort was made by ORC and Outotec to develop a robust process design. The goal of the design work was to produce a process capable of producing 63 kt/a (70,000 stpy) of high quality chromite foundry sand as well as secondary products (high-iron, garnet and zircon).

Producing and characterizing representative samples for each deposit was critical for understanding the range of processing requirements necessary to reach design goals. Simply taking all the drillhole samples and combining them into one large sample for testing would have resulted in a design not suited to any of the individual deposits

Table 1 demonstrates the wide variability of the presence heavy mineral, as well as finished products, by terrace as well as deposit. Table 1 illustrates that S7D contains almost twice as much HMC and chromite as WB. An inflexible design based on one deposit would have been inappropriate when mining in the opposite deposit. For this reason, the solids handling systems and wet plant capacity have an operating range of 63 to 127 t/h (70 to 140 stph). Table 1 also illustrates that SH contains approximately three times as much HMC as WB. A dry plant design based on an average HMC value would

Table 4

Permits required for mining and processing.

Permit	Permitted activity	Regulatory agency	Type	Application submitted	Permit received
Processing plant					
NPDES 1200 C permit	Construction stormwater	OR DEQ	Permit	September 2007	October 2007
Conditional land use permit	Site development and use	Cross country	Permit	April 2007	August 2007
NPDES individual permit	Stormwater discharge	OR DEQ	Permit	December 2008	December 2008
Mine operating permit	Ore processing	DOGAMI	Permit	April 2009	November 2009
Air contaminant discharge permit	Air discharges	OR DEQ, DOGAMI	Permit	February 2010	September 2010 (est.)
Mine sites					
Permit	**Permitted activity**	**Regulatory agency**	**Type**	**Application submitted**	**Permit received**
Radioactive waste exemption	Disposal of tailings	OR DOE	Exemption	May 2007	June 2007
Conditional land use permit	Site development and use	Coos County	Permit	May 2007	February 2008
Water pollution control facilities permit	Stormwater management	OR DEQ, DOGAMI	Permit	June 2008	September 2009
Solid waste exemption	Disposal of tailings	OR DEQ	Exemption	September 2009	October 2009
Mine operating permit	Mining	DOGAMI	Permit	June 2008	February 2010
401 certification	Mining	OR DEQ	Certification	February 2009	February 2010
Biological assessment	Mining	NMFS	Certification	October 2009	February 2010
404 permit	Impacts to wetlands	ACOE	Permit	May 2008	March 2010
Removal-fill permit	Impacts to wetlands	OR DSL	Permit	May 2008	March 2010

OR DOE - Oregon Department of Energy
OR DSL - Oregon Department of State Lands
OR DEQ - Oregon Division of Environmental Quality
DOGAMI - Oregon Department of Geology and Mineral Ind.
ACOE - U.S. Army Corps of Engineers
NMFS - National Marine Fisheries Service (NOAA)

not have the capacity required when processing ore from a deposit with a lot of trash heavy mineral. For this reason, the dry plant is capable of operating 18 to 36 t/h (20 to 40 stph). The design process included a plant-wide bottleneck analysis. The need for a bottleneck analysis can be seen in the garnet content shown in Table 1. If the solids handling capacity for garnet circuit were sized for WB, the entire process could be either choked when not in WB or would result in garnet being wasted, as the excess would simply be thrown to tails because the capacity was not present to process it.

The 1991 drill program used an reverse-circulation drilling rig. For this reason, it is believed the pit and plant oversize will be greater than the values shown in Table 2. The design includes extra screen capacity for this concern.

Characterization results given in Table 2 demonstrate the need for a desliming circuit, as slimes contents that high would affect spiral recoveries as a result of the smearing effect previously mentioned.

A pilot scale test was conducted in August 2007. During the pilot test, 31 t (34 st) of finished chromite foundry sand was produced. The wet process was completed at ORC's facility. The dry processing was completed at Hazen Research in Denver, CO. Until the processing at Hazen was undertaken, the importance of the last two steps of the wet processing were not fully appreciated. Foundries require that quality chromite contain less than 1.0 wt percent clay coatings. Clay content is critical because it affects the binder requirement and mold strength. If foundries start with dirty chromite, the binder requirement is higher and the mold's tensile strength is lower. The last two steps determined by bench scale testing at Outotec were attritioning of the HMC and final rinsing and grade control using a Floatex hydrosizer. The attritioner liberates the clay coating on the HMC grains and the hydrosizer flushes it away while providing final grade control. When the pilot work was undertaken at Hazen, the exact pilot equipment to simulate the final steps in the wet process was not available and the final steps were simulated using alternative equipment. The chromite produced had excessive clay content, which was unacceptable for marketing purposes as the material had to be representative of full-scale production quality. Processing was halted until the appropriate equipment was available. The final material produced is low in clay (< 0.5 wt percent), has a low binder requirement and produces strong, high-quality casting molds that provide ORC a marketing edge over competitors.

Permitting and construction

Oregon Resources Corp.'s management team, along with consultants URS Corp. and attorney Stoel Rives (Portland, OR), successfully navigated the complex and challenging task of successfully permitting a new mine and processing facility in three years (Table 4).

The permitting process officially kicked off in 2006 with delineations of wetlands and surveys for threatened and endangered species. Concurrent with surveying activities, ORC applied for conditional land use permits in Coos County for the mining and processing sites. The mining sites are located in zoning for forestry, which in the Coos County Zoning and Land Development Ordinance, allows for outright exploration, but requires a public hearing in front of a planning commission to site a mining project. The planning commission can add conditions to the operation to aid in making sure it fits the intended land use. The processing facility is located on industrial zoned land, making the process fairly straightforward, as the intended use fits the zoning. Oregon land use law allows for challenges of decisions, so an appeal of a proposed mining site was not expected (the processing facility land use permit was not appealed). This process involves several stages of appeal. The first is to the Coos County commissioners, an elected three-member board. At this stage, the land use permit had additional conditions added to it and accepted by ORC. The next stage of appeal is to a three-member lawyer team at the state level referred to as the Land Use Board of Appeals (LUBA). The LUBA affirmed the decision of the Coos County planning commission and the elected commissioners, thus ending the appeal process and granting ORC the necessary permit to continue. Overall, this process for the mining land use permit took 11 months. In contrast, the land use permit for the processing facility was not appealed and took five months to receive.

The Oregon Department of Geology and Mineral Industries issues the Mine Operating Permit (MOP), which covers all aspects of mining. The Oregon Department of Geology and Mineral Industries also works closely with OR DEQ, OR DSL, etc. to aid in the general permitting process within those agencies. An additional MOP was required by DOGAMI to cover the processing facility site, as it is interrelated and codependent with the mining sites.

Several exemptions and concurrences were crucial in obtaining all permits, an example being the previously mentioned solid waste exemption. Without the exemption, ORC would have to classify its reclamation (filling and recontouring the pits with tailings) as a landfill operation. The radioactive waste exemption from the OR DOE was required as part of the tailings characterization and was crucial for the solid waste exemption. The biological assessment was required by NMFS, as the proximity to streams and potential Coho salmon habitat required further study.

The remaining permits are standard in the industry, including the Water Pollution Control Facility permit (OR DEQ), 401 Clean Water Act Certification (OR DEQ), 404 permit (ACOE), wetland and waters of the state removal/fill permit (OR DSL), and WPCF and NPDES (OR DEQ). The Air Contaminant Discharge Permit from ORDEQ remains outstanding, as issuance is being timed to coincide with the completion of the processing plant construction.

With permits in hand, construction began on the site in the first quarter of 2010. Heery International was engaged as project manager for ORC while construction will be completed by West Coast Contractors (site prep and grading, piling, concrete work), Mid-City Steel (structure fabrication), and CCC Group (structure erection).

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Conclusion

Oregon Resources Corp. has successfully navigated engineering challenges and permitting requirements and is on schedule to break ground at the mining sites in November 2010 and commission the processing facility currently under construction in January 2011. (References are available from the authors.) ■