THE DEVELOPMENT OF THE VOSKHOD CHROME PROJECT IN KAZAKHSTAN

N. A . Barcza, M. Boyes, N.R. Clarke, C. Johnson, and A.J. van der Merwe

Oriel Resources plc 1 Red Place Mayfair, London, W1K 6PL England
E-mail: nabarcza@orielresources.com, mboyes@orielresources.com, nclarke@orielresources.com, cjohnson@orielresources.com, avandermerwe@orielresources.com

ABSTRACT

Oriel Resources has with the support of SRK (Cardiff) and DRA and Mintek (South Africa) carried our a Definitive Feasibility Study (DFS) to recover high grade chrome ore from its Voskhod deposit very close to Chromtau that is near to Aktobe in Kazakhstan. Voskhod is a large podiform ore body that contains nearly 20 million tons of chromite grading about 48% Cr2O3 and with a Cr/Fe ratio of over 3/1. Selected bore hole core samples were obtained from the confirmation drilling programme during the DFS phase of the project in 2005 for pilot plant test work to design the mineral beneficiation plant.

The chrome ore is characterised by four main types, namely high grade lumpy and chip sized ore, high-grade fine ore, lower grade (subordinate) lumpy ore and lower grade fine ore. Gravity separation tests carried out by Mintek showed that the large density difference between the high grade (at over 3.7t/m3) and lower grade ore (at less than 2.97t/m3) should ensure very good separation in the DMS drum and DMS cyclone stages resulting in high recoveries of Cr2O3 - rich chromite ore products. Very high chrome ore grades of up to 64% Cr2O3 and Cr/Fe ratios of 4 to 1 were obtained at an 80% mass yield from selected samples of lumpy and chip ore size fractions. The overall predicted recovery from the design work on the mine and plant is expected to be closer to about 70% of the ROM (Run of Mine) feed.

DRA has completed the design of the mineral processing plant to recover about 900 kt/a of chrome ore from the 1.3 Mt/a of ROM feed. The plant has been sized to handle up to 1.5 Mt/a and will also be able to address the variability in ore feed as different regions in the deposit are mined. The lumpy high-grade product and the chips size fraction is expected to grade around 48% Cr2O3 and the fine concentrate between 56 and 58% Cr2O3 The ratio of products is expected to be about 70, 15 and 15 percent respectively but will vary to some extent during the expected 20 year life of the mining operation based on including the associated adjacent Karaagash deposit together with the Voskhod deposit. The prediction of the product split from the processing plant depends on many factors such as the geology, mineralogy, mining, handling and metallurgical processing.

An overall process flow model has been developed that covers the ROM ore, the various types of chrome ore feed to the mineral beneficiation plant, the projected products and the subsequent smelting of the chromite ores to produce High Carbon Ferrochromium. The model allows the optimisation of the quality of the chrome ore in terms of Cr2O3 content, Cr/Fe ratio and recovery to be studied. This information can also be evaluated in terms of the economic requirements for smelting High Carbon Ferrochromium (HCFeCr) at a given location. Oriel is planning to supply chrome ore to Ferrochrome plants mostly in China and Russia. The use of the model will assist to maximise the value of the Voskhod project to its owners and also assist the users of the chrome ore in selecting the appropriate supply quality to meet their needs for a given smelter operation. The smelting of high grade Voskhod ore requires a limited addition of about 5 to 7% quartz to flux the MgO and Al2O3 and about 25% coke as a reducing agent to produce an alloy containing from about 65 to 74% chromium depending on the Cr/Fe ratio.

1. INTRODUCTION

Oriel Resources plc (Oriel) an AIM-listed London-based company purchased the Voskhod chrome ore deposit located in western Kazakhstan in 2005 and established a company Voskhod Oriel to develop the mining of the chromite ore. The development of the Voskhod deposit, a new large chrome ore project, required a thorough technical and economic evaluation to justify the investment in the mining of the deposit and the beneficiation of the chrome ore into saleable products. The project is being carried out in three stages, the pre-feasibility or preliminary assessment study (PAS), the definitive feasibility study (DFS) and the implementation phase. The DFS was carried out for Oriel by SRK (Stefan Robertson & Kirsten in Cardiff) as the study manager. [1,2,3] DRA (Dowding Reynard & Associates of South Africa) was responsible for the process and plant design assisted by Mintek (South Africa) with metallurgical testwork and inputs to the process flow sheet design. The first two project stages have been completed and the detailed design for the construction phase was started in July 2006. This paper covers the work carried out during the DFS stage and in particular covers the geology, mineralogy, and metallurgical aspects of the Voskhod project. The geology, mineralogical, mining and metallurgical characteristics are necessary to determine the size and value of the deposit, to classify it as a resource and to design the mine and chrome ore beneficiation plant. Extensive confirmation drilling, core logging and sampling and metallurgical test work was carried out during the latter part of 2005 and much of 2006. The Voskhod deposit was shown to have an indicated chrome ore content of 19.51 million tons at a cut off grade of 20% Cr2O3 and an average grade of 48.47 % Cr2O3.

The Run of Mine Ore (ROM) production has been designed for an average Life of Mine (LOM) rate of 1.3 million tons per annum. The ROM feed to the chrome ore mineral processing plant will be beneficiated to produce a LOM average of about 900 kt/a of predominantly metallurgical grade products. The product spilt has been projected to be about 670 kt/a of lumpy (<100 >10 mm) high-grade chromite, about 130 kt/a chips (<10 > 1mm) and about 100 kt/a of fine concentrate (<1 mm). The estimated mine life is just over 14 years. Oriel has obtained the adjoining Karaagash deposit as an extension to the current mining lease that could extend the life of the project up to about 20 years.

The mineral processing plant has been designed and is being constructed by DRA. Mintek conducted test work on four selected core samples and provided the design information for the process flow sheet to DRA. The beneficiation plant will be owned and operated by Voskhod Chrome a 100% owned subsidiary of Oriel. The three chromite product size fractions will be supplied largely to markets in Russia and China where there is significant growing demand and considerable scope to place all of the products. Although high grade lumpy ore is preferred by most Ferrochrome plants the use of significant proportions of chips and limited quantities of fines are acceptable to small furnaces (typically 10 to 15 MW) such as those operated by many Chinese and some Russian producers.

Some prospective producers have or are planning to install the facilities to agglomerate ore fines and small chips by briquetting or if fine enough (typically 90% minus 74 microns) by pelletising. The ability to predict the product split and product quality is based on a good understanding of the geology, mineralogy and mining as well as the use of appropriate techniques for logging of core samples. The product split information allows the marketing and sales of the chrome ores to be planned well ahead of the commencement of the mine and mineral processing plant operations. This advanced information will also assist Voskhod Chrome and its customers to plan for the supply of optimum blend of feed materials. The relative proportion of the chromite products are expected to vary during the life of the mine and the ongoing exploration ahead of mining will continue the inform the predicted product spilt ratios as well as the respective grades achievable from the mineral processing plant. The initial core logging was done primarily to provide confirmation data for the resource definition but did not provide sufficient data for accurately predicting the product split. Logging of new cores especially from the area to be mined in the early years has been carried out based on careful consideration of the different mineral types and their physical characteristics. This information has allowed a more realistic estimate of the product split to be made and will allow for better planning of the overall Voskhod project. The physical and chemical characteristics for the different ore types also allow the optimum smelting criteria to be specified.

2. GEOLOGY, MINERALOGY AND MINING OF THE VOSKHOD CHROME RESOURCE

The Uralian belt of Russia and Kazakhstan contains numerous ultramafic ophiolite massifs. The ophiolites were originally formed from a depleted mantle source in an oceanic environment in the Uralian palaeo-ocean during Palaeozoic times. The Kempirsai massif of Kazakhstan, one of the largest of the Uralian ophiolite complexes, is located approximately 85 km east of Aktobe near to the small town of Chromtau, in northwest Kazakhstan. It covers an area of around 2000 km2 and extends for 90 km from north to south, and 32 km from east to west. It is made up of a complete ophiolite sequence of: (1) mantle harzburgites, dunites, lherzolites and podiform chromitites; (2) layered olivine gabbros; (3) a sheeted dyke complex; (4) pillow lavas of mid-ocean ridge affinity; and (5) late stage dykes and intrusions composed of wherlite, pyroxenite and gabbro. The Kempirsai Massif is cut by a large north south trending shear zone related to the Main Ural Deep Fault. On the south eastern side of this lineament the sequence of exposed mantle rocks is referred to as the Main Ore Field (MOF).The MOF contains giant deposits of economic low-Al, high-Cr chromite and extends over a distance of 22 km north-northeast from the town of Chromate. It comprises dunite, harzburgite, chromitite and rare lherzolite lithologies and reaches a thickness of 16 km. The chromitite deposits occur in two bands which are parallel to the north northeast-south southwest trending axial plane of the major anticline within the MOF block. The ore bodies are lens shaped, enveloped by serpentinized dunites, and are often offset and dismembered by east-west trending faults.

2.1 The Voskhod Deposit

The Voskhod deposit is believed to have formed by the intrusion of late stage residual chrome-rich magmatic fluids at the intersection of east/west and north northeast structures. Voskhod lies within the eastern zone of the MOF together with up to 80 other deposits. The deposit is a lens-shaped body blind to the surface which dips to the northeast at 35-40º, it has a length of 600 m in this direction, a width of 170-360 m and a thickness of between 2 and 123 m (average 39 m), in the south west the hanging wall of the deposit is intersected at 98m below surface deepening to 450m in the north west.

2.1.1 Geological Model for Voskhod

The orebody can be divided on structural grounds into three areas: the Main Zone (MZ), the Northeast Extension (NEX) and the SouthEast Extension (SEX). The footprint area of all three areas totals 139,600 m2. Although the orebody has a lenticular form, its upper and lower contacts are highly irregular. The median plane of the orebody drops from a depth of approximately 102 m in the Southwest, to 452 m in the Northeast over a distance of 655 m, indicating an average dip of close to 28 degrees.

2.1.2 Mineralisation Descriptions

For the purposes of logging and sampling mineralisation, five main chrome ore types were identified:

Massive Chromite (MCR) comprises reddish brown material with grain size 0.5-3 mm and with >90% chrome spinel. The matrix is interstitial, and where present at <1- 2% the rock has a specular metallic appearance. Typical grades are >55% Cr2O3.

Powdery Chromite (PCR) is MCR that has disaggregated due to stress or dissolution of the serpentine matrix. It is generally very high grade with grain size variable from very fine silt to 1-2 mm sand. The presence of groundwater, leaching and oxidation has in some instances resulted in fine chromiferous muds.

Orbicular Chromite (OCR) comprises aggregates of grains of chrome spinel 2-5 mm in diameter in a matrix of altered serpentine, giving the rock a 'spotty' appearance. Chrome concentrations typically range 75 - 90% with grades typically in the range 45-55%. Locally, classic orbicular textures are present, some of which demonstrate an ovoid form.

Vein Chromite (VCR) consists of patches or lenses of high-grade chromite 10-20 cm wide, often surrounded by a rim of serpentine and then a more diffuse zone of bleached host rock. Typical grades range from 20 - 30% Cr2O3. The lenses lie dominantly in the footwall of the massive chromite.

Disseminated Chrome (DCR) generally represents low-grade mineralisation in that the chromite occurs as disseminated gains or blebs within diffuse patches in the host dunite.

2.2 Chromite Analyses

Three holes from the 2005 drilling programme were sampled in detail in order to determine the variability of the composition of the chrome spinels within massive chromites and disseminated chromites in serpentinized dunites. The samples came from the Northeast Extension (NEX), west of the Main Zone the east of the Main Zone respectively and from the west side of the orebody. The chrome spinels from massive chromites have a very constant composition in the range 62.48 to 64.63% Cr2O3 with an average of 63.66% Cr2O3. The disseminated chromites have a much more variable composition with Cr2O3 values ranging from 18.39 - 62.99% and Al2O3 values ranging from 7.33 - 50.17%. The lowest Cr2O3 values and highest Al2O3 values occur in the Harzburgite and the higher Cr2O3 values with the lower Al2O3 values occur in the chrome-spinels in the dunites. Additionally over 700 chemical analyses from core samples were evaluated and the relationship between the chrome ore composition and Cr2O3 content was derived. This was done to allow estimated compositions for the predicted product split fractions to be determined. Figure 1 displays the relationship between Fe2O3, Al2O3, SiO2, MgO composition and the Cr2O3 content present within the mineralogical structure.

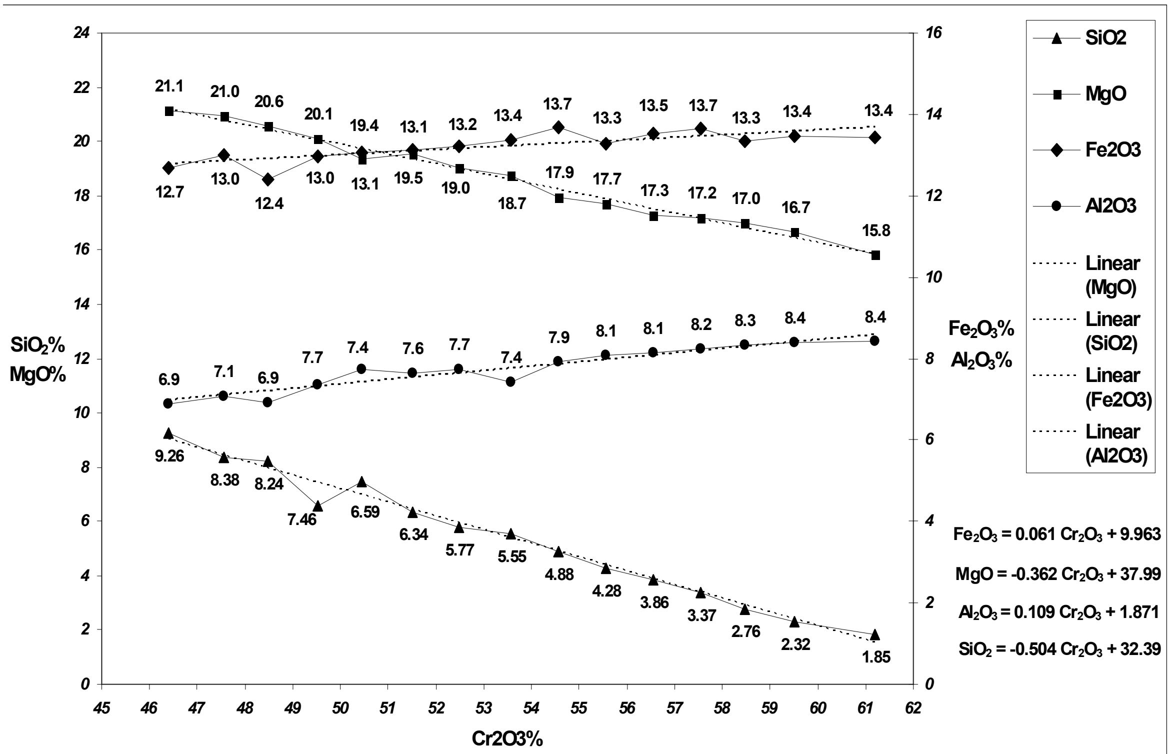

Figure 1: The Calculated Chemical Composition of the Chrome Ore as a Function of the Cr2O3 Content Based on the Proportion of Gangue Present in the Ore and from Varying Degrees of Beneficiation to Remove Gangue Materials.

2.3. Mining of the Voskhod Deposit

The Voskhod deposit will be accessed by a 1.2km 5.1m by 4.7m inclined ramp. Horizontal development drives will be used to access the orebody and developed on a 20m sub level spacing. Due to the continuity and consistent thickness of the orebody a bulk tonnage sub-level caving mining method will be utilised for ore extraction. Full production capacity of 1.3 Mtpa is forecast to be achieved by early 2008. The chrome ore will be hauled directly to the Run of Mine (ROM) stockpile where it will be separated into different storage areas based on it's physical properties and chrome grade before being fed to the metallurgical beneficiation plant.

3. METALLURGICAL PROCESS PLANT PRODUCT SPLIT

3.1 Mintek Testwork

Mintek conducted metallurgical testwork on four core samples chosen by SRK from the drilling work on the Voskhod deposit. The objective of the testwork was to obtain confirmatory results to assist in plant design including maximising the chromite recovery, as well as confirming the hardness of the chromite rich product and other product fractions.

Cores were classified based on grade (High Grade, Medium Grade and Subordinate Grade) and competency (Powdery and Competent). Metallurgical testwork conducted on the material included comminution characterisation tests (on selected samples), separation (washability) testwork and shaking table testwork on the fines (<1mm). In addition, mineralogical examination of the cores was done as well as other sundry tests to further characterise the products and tail samples. The Mintek testwork followed the procedure as is shown in figure 2. The testwork provided confirmatory data and provided typical "washability" curves expected for the various grades. Comminution characterisation and mineralogy indicated that the HG material is very soft and that this material might easily break into the fines (<1mm) fraction during blasting, mining and handling.

The testwork indicated that desired product grades in the lumpy, chip and fines samples could be achieved with relative ease using gravity separation methods as a means of beneficiation and by employing the processing route proposed during the preliminary phase of the project. By employing this process the only losses would be the fines, although additional recovery could be achieved by employing a spiral circuit with a Rougher, Cleaner, Scavenger and Re-cleaner in closed circuit; thus without milling the material any further. The results indicate that the HG material is of very good quality and that the main aim of the Dense Medium Separation (DMS) plant would be to remove SO (Subordinate Ore) material from the feed, thus producing a saleable product. The logging of the cores reported lumps to fines ratios (mass %: mass %) of 62.3/37.7 and 50.2/49.8 for cores 12 and 13 respectively.

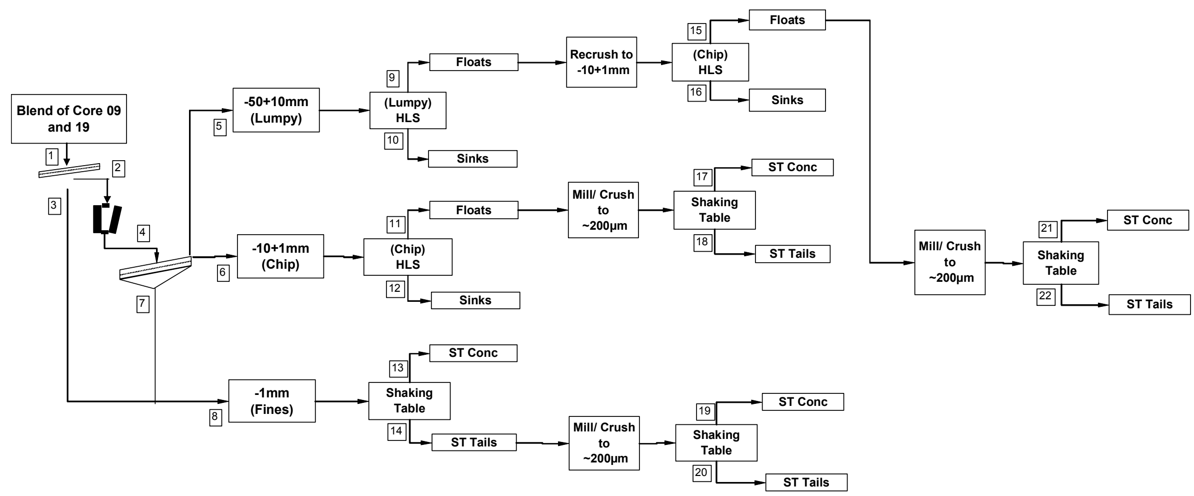

Figure 2: Overview of Mintek Testwork procedure to confirm the Voskhod process flwo sheet design

The secondary and tertiary processing stages did not add any significant increase to the final Cr2O3 recovery. Bond Rod Work Index testwork on the Cr2O3 rich product indicated the material as soft, which could affect the final lumpy product. In addition, tumbling tests conducted on the Cr2O3-rich product showed a significant fines (-1mm) generation at longer retention periods. Although the slimes fraction was small, the considerable reduction in top size indicates the material as friable. The lumps to fine ratio (mass %: mass %) obtained in this phase of work gave a range from 71.2/ 28.8 to 50.2/49.8. For conclusive tests on the hardness of the material more sample of the ore body would be required.

The prediction of the products from the Voskhod plant is critical to assessing market demand, potential purchasers, shipping costs and revenue. The product split will depend on a number of factors related to geology, mining and processing, many of which cannot be fully quantified at this stage and assumptions have been made based on the best available information. It is realised that the product split will depend on both the grade and size distribution of the material received at the plant, which are in turn influenced by the in-situ resource characteristics, mining method and deterioration of the feed during handling to the plant and within the process. Once the feed to the gravity sections of the plant have been defined based on the forecast feed size distributions, the product split can be predicted based on the metallurgical testwork washability results.

3.2 Estimation of Product Split

The ROM plant feed grade has been predicted from the mining plan on a quarterly basis and by relating the mining plan by domain and depth, an approximation of the feed ore split has be made. The split of feed to each process circuit has then been estimated using the assumed size distribution from mining and after crushing. "Washability"data has then been applied to determine a forecast product split over the LOM, which has been marginally adjusted to allow for the higher-grade feed to the spiral circuit and increased production of fines. Levels of silica, iron oxide, MgO and Al2O3 and have also been forecast from the "washability" data and a summary of the forecast product split over the LOM is presented in table 1.

A summary of the production on an annual basis is presented in figure 3, which shows an increase in total production from the early years of the mine life as higher-grade material is encountered. The quantity of fine concentrate produced also increases as more high-grade powdery ore is received at the plant.

Several assumptions have been made that could significantly affect the forecast products. These include the ore type split, size distribution from mining and after crushing and degradation and size reduction during handling. A further unknown is the degree of degradation of the ore during handling. This will result in the reduced production of lumps and the increased production of fines. Degradation of the ore into ultra-fines would result in an overall reduction in total product with the high-grade chromite in the ultra-fines / slimes fraction being lost directly to tailings.

Table 1: Forecast of average product split over LOM

Products	Production [tonnes]	Yield [% of Feed]	Cr_2O_3 %	Fe_2O_3 %	SiO_2 %	MgO %	Al_2O_3 %	Cr/Fe
Lump	9,567,541	52.29	48.0	11.0	11.9	20.6	7.6	4.3
Chip	1,805,195	9.87	48.0	11.0	11.9	20.6	7.6	4.3
Concentrate	1,398,314	7.64	57.0	12.5	< 3.0	17.2	8.2	4.5
Total	12,771,050	69.79						
Waste								
Lump Rejects	2,914,456	15.93	10.5	10.6	27.1	47.5	3.0	0.7
Chip Rejects	552,350	3.02	10.5	10.6	27.1	47.5	3.0	0.7
Fines	594,924	3.25	19.0	11.1	22.8	42.2	4.0	1.7
Slimes	1,465,523	8.01	41.1	10.8	12.2	23.6	6.2	3.7
Total	5,527,253	30.21	19.5	11.0	23.0	41.6	4.0	1.7

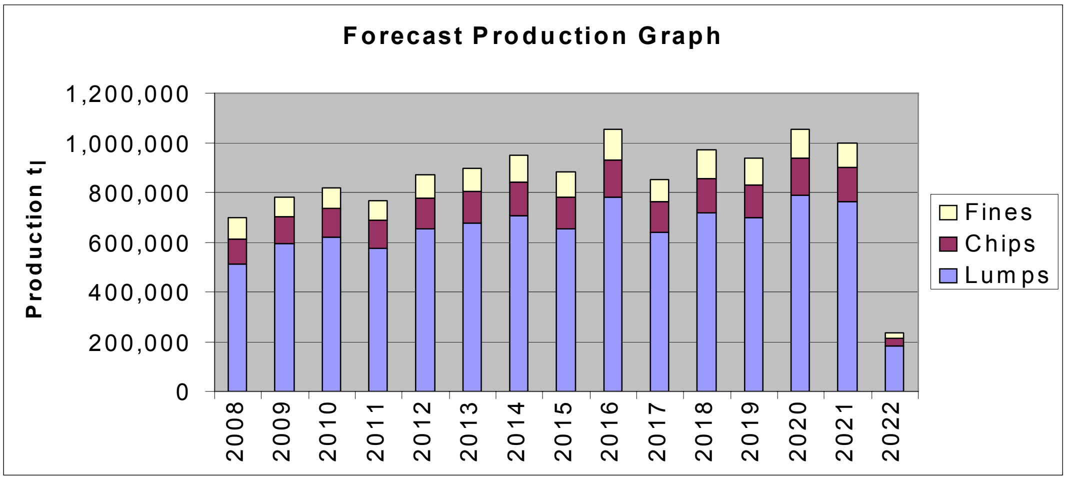

Figure 3: Forecast of Annual Production for the LOM

3.3 Mettalurgical Core Logging

The results from processing and metallurgical testing (Mintek 2005) indicated that i) ore grades between 46-52% Cr_2O_3 and ii) two key variations in the physical nature of the ore exist. The physical variations of the ore are categorised as competent ore or powdery fine ore. The powdery fine ore grades at approximately 60% Cr_2O_3 and cannot easily be recovered, the competent ore varies from massive ore which grades 55-60% Cr_2O_3 to weakly disseminated ore which grades at approximately 20% Cr_2O_3 (cut off grade). Table 2 illustrates the relationship between the types of chromite ore and the respective Cr_2O_3 content of the ore types.

Table 2: Ore type categories and associated Cr_2O_3 content

Categories	Cr_2O_3%	Fe2O3 %	SiO2 %	MgO **%**	Al2O3 %	Cr/Fe
Subordinate	20-40	11.18	22.31	41.5	4.07	2.6
Orbicular Chromite	Ave. 40	12.39	12.23	22.5	6.27	3.2
Hard Massive Chromite	55-60	13.30	4.66	17.2	7.92	4.2
Soft Massive Chromite	55-60	13.30	4.66	17.2	7.92	4.2
Sands and Gravels	55-60	13.30	4.66	17.2	7.92	4.2
Fines	>60	13.61	2.14	15.6	8.47	4.3

By recognising the difficulty in recovering the powdery fine ore it was essential to determine the percentage of all types of chrome ore, including the powdery chrome that could be recovered. There was insufficient existing data on the in-situ split of ore types to calculate the percentages. Consequently a new method of logging was developed and implemented to, i) accurately measure the mineralised intersections and identify the different ore types, their respective quantities and size distribution, ii) collect data that could be related back to assay results enabling the determination of the relative proportions of the different grades of Cr_2O_3 present in the resource, iii) collect data that could be modelled to calculate the feed size of the run of mine ore to be processed at the plant.

A classification system, composed of 6 categories, was developed for the purpose of product split logging. The classification system, indicating that mineralised ore type categories can be related to the envisaged process products, is shown in table 3.

The results displayed graphically in figure 4 show orbicular chrome ore (41.1%) and hard massive competent chrome ore (33.4%) to be the most prevalent forms of mineralisation present in the resource, totalling 74.5% of the resource when combined. However slimes are the third largest chrome component accounting for 11.8% of the resource.

Table 3: Plant product types related to geological ore types

Ore Type	Processed Product
Subordinate	Chips
Orbicular Chromite	Chips
Hard Massive Chromite	Lumps
Soft Massive Chromite	Chips and fines
Sands and Granules	Chips
Powdery Chromite	Fines

The results demonstrate that 88.2% of the mineralisation falls into ore type categories that will report to chips and lumps. The results also indicate clearly that powdery fine chrome ore does not dominate the deposit. However contributing to 11.8% of the resource and having such a high grade (55 to >60% Cr_2O_3) a specialised method required for the recovery of this ore type should be considered further.

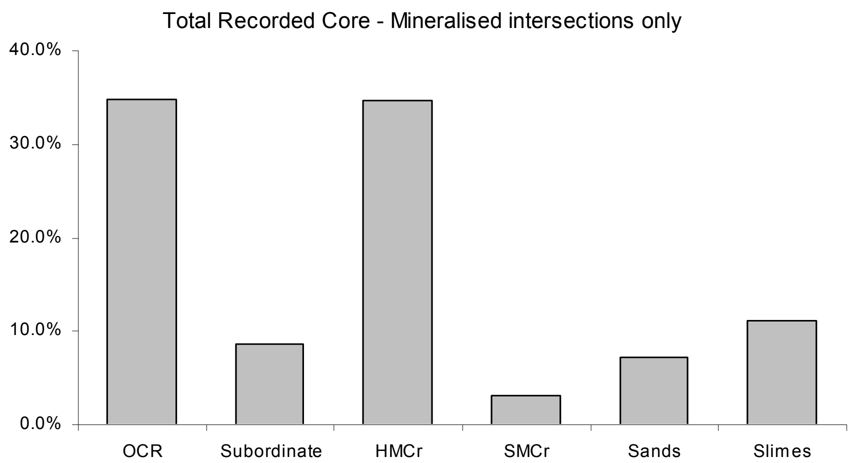

Figure 4: The Percentages of the Various Chrome Ore Types in the Voskhod Deposit

4. MINERAL BENEFICIATION - PLANT AND PROCESS

The Mintek test work programme commenced whilst the flowsheet development and conceptual plant design and layout by DRA was in progress. Mintek test results were then used to confirm the initial process design criteria assumptions.

4.1 Plant Feed Size Distribution

The Mintek test work was carried out on borehole cores and thus could not be used to provide plant feed sizing data for a 100mm material top size. This distribution was therefore initially estimated as by the Uralmechanobrnauka Process Procedure, which is based on similar ores from the region. [4] The bore cores contained significant quantities of friable material (up to 60%), designated "powdery ore" which contains as much as 45% <1mm material and 13% <38 μm. Empirical tests carried out by Mintek indicated that even if care is taken in the plant design and material handling, degradation of this ore type will occur readily during processing.

The plant design caters for a blend of ore types (maximum of 22% <1mm and 10% <50 μm slimes) and additional spiral and tails pumping capacity will be required if the capacity to process a greater proportion of powdery ore is necessary. The proposed design makes provision for the retrofit of additional spirals and tailings pumps to accommodate this should it become a requirement.

4.2 Dense Medium Separation

The Mintek tests confirmed that the bore core material separates relatively easily using dense medium (DMS) separation. It should be noted that although washability analysis was carried out individually on high, medium and subordinate grade portions of the bore cores, the material will be mined as a composite. The results, as shown below in figure 5, indicate low near gravity contents of less than 15% in all cases at the expected washing density range of between 2.9 and 3.3t/m3.

When applying a typical dense medium drum partition curve with an Epm of approximately 0.10 to the washability data a separation efficiency of approximately 98-99% may be estimated due to the low quantity of near gravity material. In this case the term separation efficiency means the proportion of the feed that is separated into the correct stream, based on density, not the efficiency of chromite separation. Epm is an abbreviation of Ecard Probable Moyen, which is an accepted method of measuring dense medium separation

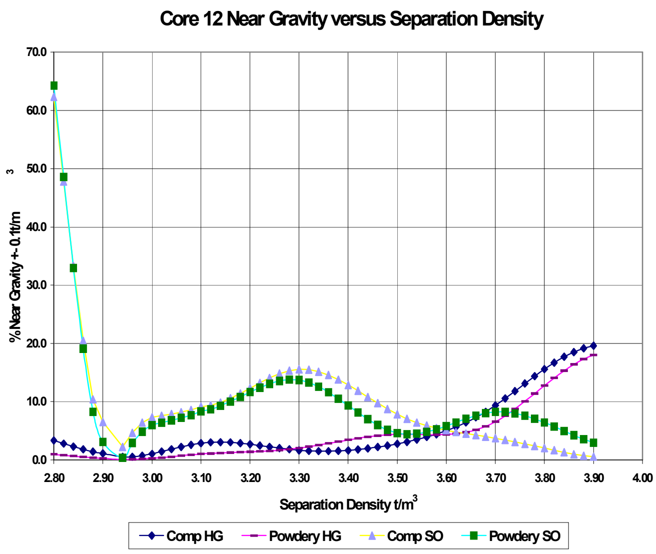

Figure 5: Near Gravity Material versus Separation Density for Core 12

efficiency - the lower the Epm, the higher the efficiency. Furthermore, the plant will be capable of operating up to a density cut point of 3.7t/m3.

4.3 Fines circuit

The bore cores did not provide a sufficient quantity of <1mm fines to carry out spiral test work. Shaking table and Mozley table test work confirmed that the fines are amenable to upgrading via gravity separation and the recommended use of spirals is applicable.

4.4 Unit Operations and Process Selection

A closed circuit jaw crushing has been proposed for the reduction of ROM material to the required plant feed size. The choice of crusher and the closed circuit arrangement has been specifically selected to minimize fines generation and maximize the quantity of coarse (lumpy) material. Closing the circuit allows the crusher to operate with the optimum closed side setting to produce the required nominal 100mm product, without over crushing.

Static bath dense medium separation (DMS) drum was recommended for the separation of lumpy product since it provides the required degree of efficiency and control. This option offers both operating and capital cost advantages as well as ease of start up benefits. The use of a dense medium separation (DMS) cyclone is proposed for the chip size fraction, as widely practiced in the mineral processing industry for beneficiation of chromite, manganese, platinum, nickel, and other hard rock ores. Provision has been made for a plant upgrade to beneficiate the dense medium tails should this prove economical (Mintek test work has shown expected tails to be 10% Cr_2O_3 - producing 48% Cr_2O_3 concentrate). The design allows for the retrofit of a re-crush and milling circuit as well as additional spirals as a means of further increasing recovery, should this be required.

No upgrading of the slimes fraction of plant feed (<50 µm) is envisaged initially and this material will be pumped with spiral tails directly to the slimes dam. The decision to implement slimes filtration and/or other means to treat this material, will obviously be driven by economics, depending on the long-term quantity and quality of slimes material as mined and the market potential for this potential product. The process has been defined into the following unit operations: ROM Receiving and Crushing, Feed Preparation, DMS Drum Module, DMS Cyclone Module, Spiral Module, Thickening and Slimes Disposal and Product and Discard Handling. The designs of the respective circuits has provided for the expected variability in ROM feed over the life of the project in that the three circuits can accommodate up to 80, 40 and 22% of the total throughput respectively.

4.5 Process Flow Sheet Optimisation

Further work is envisaged to look at upgrading the lower grade subordinate ore fraction. The modifications to that plant would include a conveyor to divert screen undersize (<10mm) to a mill feed stockpile. The naturally arising <10mm and the crushed DMS floats will thus report to the mill feed. DMS tails will be pumped to a new degree circuit, de-watered grits reporting to the mill feed stockpile and de-grit cyclone overflow to the mill circuit. The milling circuit would perform the duty of reducing the 10mm particle size to <0.85mm as well as liberating silica from chromite grains. This would be achieved using a ball mill in closed circuit with a wet screen. Minus 10mm material would be withdrawn from the mill feed stockpile at a controlled rate and conveyed to the mill feed chute where it would be pulped with circulating oversize (screen discharge) and water to the required milling density (60% solids by mass). The screen underflow (<0.85mm) would be pumped to the spiral plant which would have an increased number of starts and be suitably upgraded for the increased throughput.

5. SMELTING CHARACTERISTICS FECR AND MODEL

5.1 Refractory Index and Reducibility

Typical Voskhod ore analyses are compared to other regional chromite ores in table 4 below. Also included in the table is a value for the refractory index (R.I.). This index is a measure of the relative fluxing and total energy requirement to reduce a chromic ore to metal and can be used to compare the relative reducibility of ores. The higher the refractory index, the more difficult it is to reduce the ore. The index is calculated according to the formula

$$R.I.= (\%Cr_2O_3 +\%MgO+\%Al_2O_3)/(\%FeO+\%SiO_2)$$

Table 4: Ore analyses and refractory index comparison for various ores

Compound	Voskhod Lump, %	Voskhod Concs. , %	Kazchrome Concs. , %	Turkish Lump, %
Cr_2O_3	48.0	57.0	50,0	43.00
Fe_2O_3	11.0	12.5	13.3	14.74
CaO	0.07	0.07	0.6	0.80
MgO	20.3	17.2	20.0	21.50
Al_2O_3	7.6	8.2	11.3	11.00
SiO_2	8.5	3.0	7.0	11.50
P_2O_5	0.01	0.01	0.01	0.02
S	0.02	0.02	0.08	0.06
R.I.	4.1	5.8	4.3	3.0

The refractoriness of the Voskhod fines is within the 'difficult to reduce' range. The chemical analyses of typical raw materials that can be used in the reduction smelting of Voskhod ore are given in table 5 below. Coke analysis is from two potential regional suppliers (averaged) and a typical analysis for quartzite is indicated.

Table 5: Typical raw materials, compositions in mass %

Material	Cr_2O_3	Fe_2O_3	SiO_2	MgO	Al_2O_3	CaO	P	S	C	Cr/Fe	Ash	Volatiles
Voskhod Lump	48.0	11.0	8.5	20.3	7.6	0.07	<0.01	0.02		4.3		
Voskhod Concs.	57.0	12.5	3.0	17.2	8.2	0.07	<0.01	0.02		4.5		
Severstal coke							0.03	0.60	84.8		13.0	1.5
Moscoke coke							0.06	0.60	84.8		13.0	1.5
Coke ash		17.9	48.6	2.5	6.2	24.8						
Quartzite		0.6	97.9	0.2	0.0	1.0	0.05	0.05				

5.2 Model Description and Example

An Excel™ spreadsheet that uses the variation in feed analysis and size distribution to the process plant as input variables and that then calculates the expected headgrade, product mass splits and yields, grades and recoveries per given time period, has been developed further through to a HCFeCr smelting model. The combined model can be used to calculate a mining, mineral processing and smelting schedule for a specific time period of production. A product offtake add-on to the model was developed as a first phase in which different scenarios of product distribution to potential offtakers (5 possible options) can be modeled to optimize sales profit, taking into account the product type and volumes produced per time period, required product grades and transport logistics to potential offtakers. A smelting model, using Pyrosim v1.56 software to calculate the metallurgical smelting parameters, was added as a second phase to the model. [5]

Example: A feed mix of 75:25 lump to agglomerated (chips-50%/fines-50%) is required for a 65MW SAF. The smelting model then uses the calculated processing plant product output (lump, chip and fines) allocated to a specific smelter for the selected time period, which in turn is calculated based on the mining and process plant production schedules for the same time period. The optimized ore distribution and related smelting parameters for this example is shown in table 6 and table 7 respectively (as calculated using the Excel[TM] model).

Table 6: Example of Distribution of Voskhod Ore Types per Quarter

	LUMP [t]	CHIP [t]	FINES [t]
EU#1 Offtaker A	59,999	9,963	9,963
EU#2 Offtaker B	30,000	10,000	10,000
EU#3 Offtaker C	30,000	5,000	5,000
EU#4 Offtaker D	30,000	Balance	Balance
EU#5 Offtaker E	Balance	0	0
	157,500	33,750	33,750

Table 7: Example of smeling parameters for Offtaker A based on the supply of Voskhod as per quarter

Total Ore Input [tpq] :	79,826		
HCFeCr Furnace #1			
ALLOY			
Output [tpq] :	38,940	kWh/t Alloy:	3,521
% Cr in Alloy :	70.20	Ore/Alloy:	2.05
% Fe in Alloy :	20.80	% Si in Alloy:	0.62
% C in Alloy :	8.50	% P in Alloy:	0.003
% S in Alloy :	0.068		
SLAG			
Slag/Alloy :	1.01		
% FeO in Slag :	0.53	% Cr_2O_3 in Slag:	7.1
% CaO in Slag :	0.55	% MgO in Slag:	40.3
% Al_2O_3 in Slag :	17.20	% C in Slag:	0.3
% SiO_2 in Slag :	27.5	MgO/SiO_2 in Slag:	1.5
% Cr Recovery :	95.8	Furnace Load [MW]:	65.0

Table 7: Example of smeling parameters for Offtaker A based on the supply of Voskhod as per quarter (Continued)

MWh available :	0	MWh Consumed:	137,106
Transformer Utilization [%] :			96.0

6. CONCLUSIONS

The Voskhod deposit has been extensively drilled and has been classified as a resource with an indicated chrome ore content of 19.51 million tons at a cut off grade of 20% Cr_2O_3 and an average grade of 48.47 % Cr2O3. The logging and testing of core samples generated from the exploration programme has also provided the data for the design of the mine and the mineral processing plant.

The characterisation of the cores into the various mineral types has provided the information necessary to estimate the projected ROM product split from the mining operation. This has been used in turn to project the product split from the metallurgical plant. There is expected to be considerable variability in the respective proportions of lumpy, chip and fine chromite over the life of the mine. The plant has therefore been designed to handle a wide range of product splits up to 80% lumpy, 40% chips and 22% fines. Provision to increase the amount of fines has been made if required. A powdery chrome-rich slimes fraction will deport to the tails but the recovery of this material will be investigated provided it can be justified. These slimes could be pelletised or dried and smelted in a DC arc furnace with the option of preheating.

A model covering the output from the mining operation, the throughput of the various streams in the plant and the smelting of the products has been developed to support the marketing and sales of the chrome ore and to optimise the overall development of the Voskhod project. High quality HCFeCr alloy can be produced from the Voskhod ore based on the high Cr/Fe ratio and the low sulphur and phosphorus contents.

7. ACKNOWLEGDEMENTS

Oriel Resources plc would like to thank the following for their valued role in the development of the Voskhod project, SRK Cardiff, DRA and Mintek South Africa and well as Bateman Minerals and Metals with aspects of the PAS stage of the project.

REFERENCES

[1] SRK Consulting Engineers, "Voskhod Feasibility Study 43-101 Summary Technical Report", (Private Communication), May 2006, (Private Communication)

[2] MINTEK, "Metallurgical Testwork on the Voskhod Chromite Ore", (Private Communication) February 2006,

[3] MINTEK, "Recovery Optimisation Testwork on the Voskhod Chromite Sample", (Private Communication) April 2006,

[4] Uralmechanobrnauka, "Process Procedure of Chromite Ore-Dressing of the Voskhod Deposit in the South-Kempirsye Chromite Area", (Private Communication) 2005

[5] Prof R T Jones (rtjones@global.co.za), PYROSIM, Mintek, Private Bag 3015, Randburg, South Africa, 2125