The Upper Cretaceous Bad Heart Ooidal Ironstones: An integrated mineralogical-sedimentological-ore characterization

Jon Sliwinski*, Chris Gunning and Kathryn Sheridan
SGS Canada Inc., Lakefield, ON
jon.sliwinski@sgs.com

and

Barry Caplan, Bruce Smith
Ironstone Resources Ltd., Calgary, Alberta

Summary

The samples in this study are from a minette-type oolitic iron deposit in the Peace River district of NW Alberta. The deposit is located in the upper Cretaceous Bad Heart formation. In the Clear Hills region the Bad Heart formation consists of oolitic ironstones interbedded with shales and sandstones.

Ironstone and SGS have undertaken a significant amount of mineralogical testing to develop an integrated mineralogical-sedimentological-ore characterization.

Introduction

Cretaceous minette-type oolitic ironstones of the Bad Heart Formation, Clear Hills region, Peace River district of NW Alberta were initially discovered in 1924, and have since been the subject on numerous reports and publications. However, the first serious investigations only began in 1953 after the Phillips Petroleum Company encountered an “oolitic hematite” while drilling the Phil C No. 1 well at 08-23-090-05W6, about five kilometers south of the Rambling River ironstone outcrops.

A total of 245 core holes were subsequently drilled and initial reserve estimates were determined to be 206 million tons proven, 627 million tons probable and 186 million tons possible. Despite the large reserves, the deposit was deemed uneconomical in light of the prevailing steel prices and processing technology. Interest in the Clear Hills deposit was renewed during the mid to late 1970s when groups funded by the Alberta and Canadian governments undertook projects to determine if advances in mineral processing technology could be applied to the deposit (Petruk et al. 1974). At that time, the limits of technology, infrastructure and other economic factors made this deposit less economically viable than the more traditional banded iron (BIF) deposits.

Further work in the late 1990s by the Alberta Geological Society (Olsen et al. 1999) included significant geochemical surveying that identified several potential co-products, most notably in Rambling Creek oolitic sandstones in which vanadium averaged 0.22% V_2O_5 and zinc 0.06 % ZnO. Olsen et al (1999) also found elevated levels of As, Co, Cr, Mo, Mn, Ni, Pb, Sb and W.

Several depositional environments have been proposed for the Bad Heart formation and a number of genetic models suggested for the origins of the iron oxides. However, to date, no integrated sedimentological - ore characterisation study has been undertaken. By gaining a thorough understanding of the sedimentology, petrology, mineralogy and geochemistry of the oolitic facies, it is possible to improve reserve estimations, and thus gain a better understanding of the full economic potential of the deposit.

Therefore, a mineralogical and geochemical testing program was undertaken to identify the main iron mineral species, quantify their abundance and determine the deportment of other elements of potential interest such as vanadium, nickel and arsenic. This was integrated with a palaeo-depositional environment study to improve the understanding of the internal geometry of the deposit, the potential resource development and also guide future exploration for potential co-products.

Analytical Methodology

Ironstone Resources Ltd. undertook a diamond coring program during the winter of 2008 collecting 53 core holes, of which 47 intersected the ooidal ironstones giving a total of 1,265 meters of iron bearing core. The cores were quartered with one quarter was sent to the SGS Mineral Services in Lakefield, Ontario, for mineralogical and for process metallurgy testing.

For the mineralogical testing, 1-2 cm thick intact pieces or “cookies” were collected at selected intervals for detailed mineralogical analysis. The cores were subsequently divided into half meter intervals and crushed to +65 mesh to make composite samples for geochemical and mineralogical analyses.

This study focused on the oolitic sandstones that consisted of ooliths, siderite and phosphate clasts, and a silica matrix described as ferruginous opal containing microscopic goethite (Petruk et al. 1977a). The samples also contain detrital grains of quartz, minor feldspar and sparse localized sulphides.

Several analytical methods were applied to the samples collected, including high definition mineralogical analysis by QEMSCAN^{TM}, SEM-EDX/WDX (Scanning Electron Microscopy - Energy and Wavelength Dispersive Spectroscopy), Electron Microprobe and Optical microscopy methods, XRD analysis, and geochemical analysis by XRF and ICP-MS. Data was also collated from previous works published by the Alberta Geological Society.

Results

Composition of the Ooids

Typical ooidal ironstones consist of concentric layers of the iron rich clays chamosite of bertheriene. The Clear Hills ooids are unique in that they contain an iron oxide goethite with a iron clay. Previous mineralogical analysis work indicated that the ooids were composed of goethite and nontronite layered in varied amounts (Petruk et al. 1977a).The ratio of goethite to nontronite varies. Thus, some ooids consist of almost pure goethite, whereas others are comprised of almost entirely nontonite. More recently (Olsen et al. 1999) vanadium has been found to occur in economically significant levels.

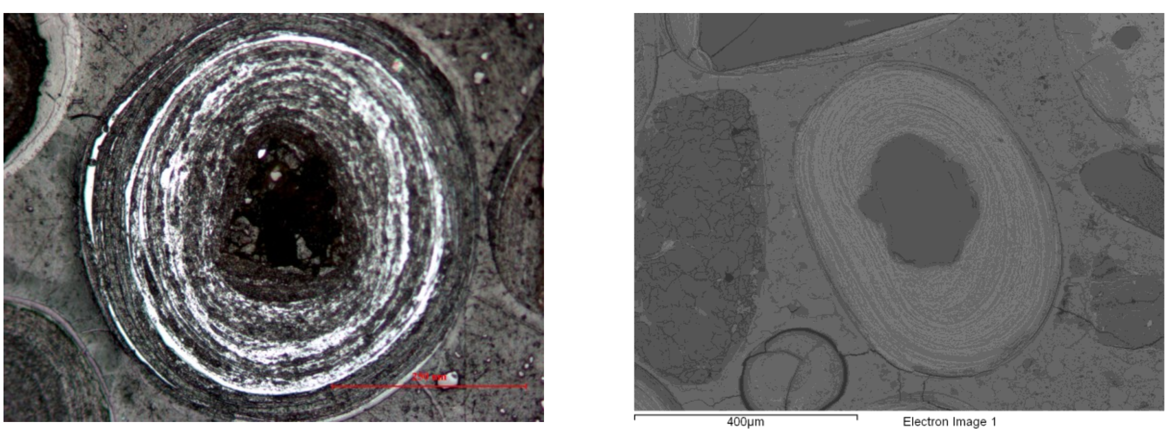

Figure 1: Left, Optical microscope photomicrograph right, a SEM image showing, both showing the layering texture of a typical ooid.

Nontronite $(Ca_{0.5},Na)_{0.3}Fe^{+3}{}_2(Si,Al)_4O_{10}(OH)_2$• nH_20 is a phyllosilicate mineral that may have originated in two possible ways:

Diagenetic - Berthierine $(Fe^{+2},Fe^{+3},Al,Mg)_{2\text{-}3}\,(Si,Al)_2O_5(OH)_4$ that is derived from a highly weathered terrigenous lateritic soil may have undergone low temperature diagenetic alteration with a 1:1 layer silicate of the serpentine group (Brindley, 1982). The serpentine group minerals may also be the source of Cr, Mn, Co and Ni, and such a geological system would also be expected to contain an above average Mg concentration within the rocks.

Authigenic- Numerous authors have documented the deposition of primary nontronite from underwater hydrothermal seeps and white smokers possibly in a bio-catalytic reaction (Bischoff 1972, Koehler et al. 1994, Ueshima & Tazaki 2001)

The cores of the ooids are variable and consist primarily of quartz, as well as feldspars, phosphates, iron oxides, broken pieces of older ooids and other clastic fragments. McDougall (1954) was the first to note that the deposit contained more quartz than typical for Minette or Clinton type ooidal ironstones. This was further supported by Collom (1999) who documented highly angular, crystal-clear quartz grains at the centre of many ooids. Collom et al (1999) suggested that these grains may have been derived locally from volcanic glass as opposed to being fluvially transported, thus avoiding mechanical weathering.

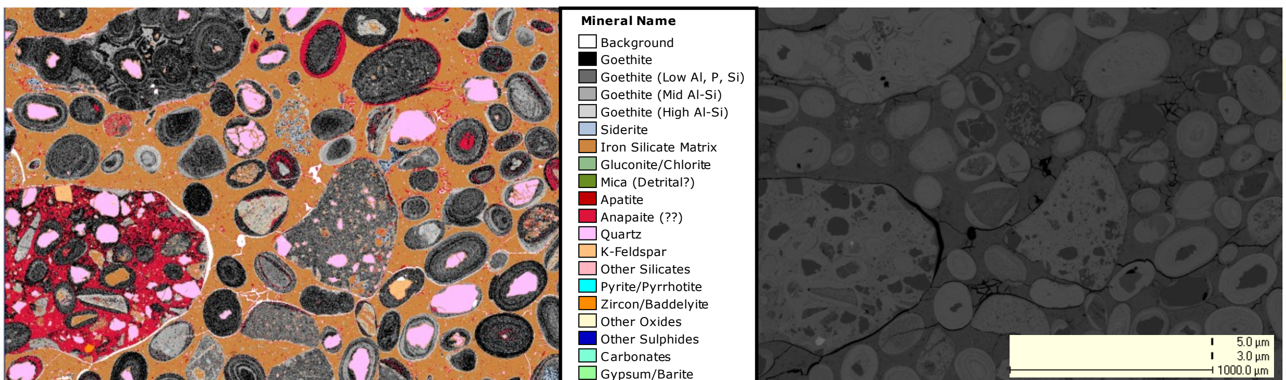

Figure 2: QEMSCAN^TM false colour image (left) mapped at 5 µm and the corresponding BSE (Back Scattered Electron) Image (right) from sample R04-C1

Vanadium

SEM-EDX and Electron Microprobe analyses yielded vanadium in the ooids. The average vanadium grade within the iron oxide ooids is 0.8% V_2O_5. The crystal structure of goethite can accommodate vanadium and the co-variance between iron and vanadium in the ooids adds further evidence.

Other Minerals

The QEMSCAN^TM and SEM examination identified a number of sulphide and REE minerals.. Previous studies have also reported significant amounts of gold in assay. While no discreet gold was noted in the original study, gold mineralogy was not part of the original scope of this project. Previous work (Craw & Leckie 1996, Lecki & Craw 1995) have documented gold in paleo-placer deposits in the upper Cretaceous rocks derived from sediments from the rising Cordillera which was exposed to more weathering during the Larimide uplift which began in the late Cretaceous. Alternatively gold may have been associated with hydrothermal fluids. While no discreet gold was noted in the original study, gold mineralogy was not part of the original scope of this project. Recently a limited number of gold assays provide encouraging results, and work is currently underway to identify the presence of gold within the deposit.

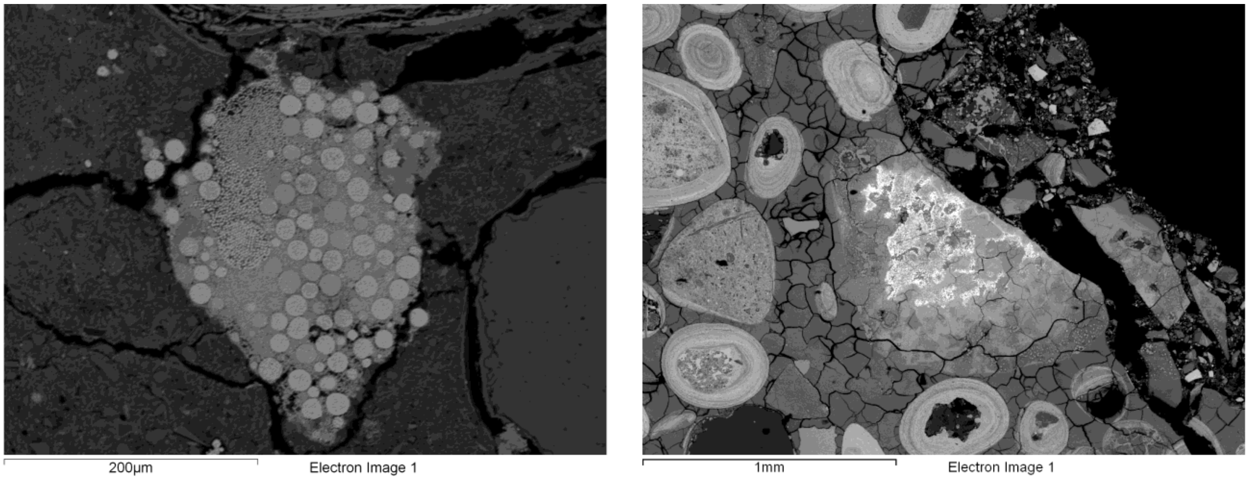

Figure 3: SEM images of framboidal pyrite (left) and a sulphide mineral (bright phase) containing nickel, cobalt, arsenic and iron.

Framboidal pyrite was abundant in the samples. The origin of framboidal pyrite is controversial, but most studies have proposed a biogenic origin by replacement of fossil organisms such as foraminifera, or sponge spicules. However, experimental work by Graham (1992) has shown that a reaction between sulfur grains from sulfur fixing bacteria takes place, and iron rich waters can produce an iron-sulphide gel, which can aggregate to form framboidal structures. Thus, the framboidal pyrite may not be biogenic and the involvement of sulfur fixing bacteria may also add to the evidence that this deposit is related to hydrothermal venting.

Galena, sphalerite, arsenopyrite are also present and appear to be diagenetic in nature. Monazite was identified as discreet, angular grains and occurs in ooid cores.

Bad Heart Geology and Stratigraphy

The Bad Heart Formation unconformably overlies the lower Marshybank and Muskiki formation and comprises two upward-shoaling allomembers. Each allomember grades upwards from laminated mudstones through highly bioturbated silty sandstones to ooidal silty sandstone and into an almost pure ooidal ironstone containing very few clastic grains. In the Clear Hills area, these oolidal sandstones form a series of NW-SE trending, elongated shoals, which are up to kilometers wide and tens of kilometers in length and up to 15 meters thick.

During the Lower Cretaceous, reactivation of the Peace River Arch, and specifically the Dawson Creek Graben Complex (DCGC), created a series of deep troughs, which strongly influenced the underlying strata. Donaldson et al (1998) have suggested this tectonic activity continued into the late Cretaceous and increasing pressure from the westward orogeny created a forebulge trending NW-SE. The formation of this forebulge and the reactivation of the DCGC were the main controls over the depositional environment during sedimentation of the Bad Heart formation.

In addition, the reactivation of the faults of the Peace River Arch may have provided the source of the exhaustive hydrothermal fluids responsible for the forming the iron oxide-nontronite ooids. If the exhaustive hydrothermal vents resulted in hydrothermal fluid flow along the reactivated faults in the DCGC, then this deposit may have experienced mineralization mechanisms similar to those of Sedimentary-Exhalative (SEDEX) ore deposits, Mississippi Valley – Type ore deposits (MVT) and Hydrothermal Dolomite (HTD) hydrocarbon reservoirs. However, the fluids did not find a suitable trap before reaching surface in this case. Thus, we would expect to find increased sulphide mineralization close to these hydrothermal vents.

Integrated model

While Ironstone is still compiling this data and further testwork has begun on new cores the new integrated model has been applied to early resource evaluations. Metallurgical testing has centered on producing an ooid concentrate that would provide a simple cost effective first step, while recovering the bulk of the iron and vanadium and reducing a significant amount of gangue minerals.

Conclusions

- The ooids are the product of a high energy shallow marine environment with limited clastic sediment supply, similar to modern Bahamian carbonate ooid shoals.
- Bad Heart iron oxides formed as the result of hydrothermal seepage, not due to diagenetic alteration of carbonate ooids or from iron rich sediments derived from a lateritic paleosol.
- The Bad Heart sedimentological structure is strongly controlled by synsedimentary tectonic activity, and particularly reactivation of the Peace River Arch, and the Dawson Creek Graben Complex (DCGC) during the Cordilleran/Servier Orogeny.
- The same tectonic activity provided the hydrothermal iron rich fluids responsible for the formation of iron oxide ooids, and possibly various trace elements.
- Hydrothermal processes responsible for the formation of the goethite-nontronite ooids may be similar to MVT type mineral deposits (Pine Point and HTD-TSR) based on models proposed by Reimer & Teare (1991) and Davies (1993) (Ladyfern, Peggo, Parkland, etc.).
- Localized sulphide mineralisation may yet be located near the site of hydrothermal vents.
- While past studies have deemed this deposit non-economic by incorporating a combined sedimentological / mineralogical data and with the additional value of so-products and application of the current metallurgical processing technologies, this deposit shows the potential to be economically viable in the present market.

Acknowledgements

We would also like to thank SGS Canada Inc. and Ironstone Resources Ltd. for supporting this work.

References

Bischoff, J. L., 1972, A Ferroan Nontronite from the Red Sea Geothermal System, Clays and Clay Minerals 20 217-223

Brindley, G.W., 1992 Chemical Compositions of Berthierines B – a review, Clays and Clay Minerals, 30 153-55

Craw, D., Leckie, D.A., Tectonic Controls on Dispersal of Gold into a Foreland Basin: An Example from the Western Canada Foreland Basin, Journal of Sedimentary Research Volume 66 (1996)

Donaldson, W. Steven, Plint, A. Guy, Longstaffe, Fred J., Basement tectonic control on distribution of the shallow marine Bad Heart Formation: Peace River Arch area, northwest Alberta, Bulletin of Canadian Petroleum Geology, 46(4) 576-598

Donaldson, W. Steven 1997, The Sedimentology, Stratigraphy and Diagenesis of the Upper Createaceous Bad Heart Formation, NW Alberta. Ph.D. Thesis, University of Western Ontario, 492p

Graham, U ., 1992, Formational Mechanism of Framboidal Pyrite on Sulfur Surfaces, Energia – CAER University of Kentucky, Center for Applied Energy Research, 3(5) 1-3

Köhler, B., Singer, A., Stoffers, P., 1994 Nontronite from Marine White Smoker Chimneys, Clays and Clay Minerals, 42(6) 689-701

Leckie, D.A., Craw, D., 1995 Westerly-derived Early Cretaceous gold paleoplacers in the Western Canada Foreland Basin, southwestern Alberta: tectonic and economic implications, Canadian Journal of Earth Sciences, 32 1079-1092

Mellon, G.B. 1962, Petrology of the Upper Cretaceous oolitic iron-rich rocks from northern Alberta; Economic Geology 57(6) 921-940

Olsen, R.A., Eccles, D.R., Collom, C.J., 1999, A Study of Potential Co-Product Trace Elements Within the Clear Hills Iron Deposits, Northwestern Alberta, AGS/AEUB Special Report 08, 190p

O'Connell, S.C., Dix, G.R. and Barclay, J.E. 1990. The origin, history and regional structural development of the Peace River Arch, western Canada., Bulletin of Canadian Petroleum Geology, 38A, 4-24.

Petruk, W., Farrell, D. M., Lauffer, E.E., Trembleay, R.J. & Manning, P.G. 1977a, Nontronite and ferruginous opal from the Peace River iron deposit in Alberta, Canada; Canadian Mineralogist 15(1) 14-21.

Petruk, W., Harrison, D.C. and Pinard, R.G., 1974, A Mineralogical Investigation of Samples from the Clear Hills Oolitic Iron Deposit, Peace River, Alberta; Canada Mines Branch Investigation Report IR 74-33, 21 p.

Petruk, W., Klymowsky, I.B. and Hayslip, G.O., 1977b, Mineralogical characteristics and beneficiation of an oolitic iron ore from the Peace River district, Alberta; CIM Bulletin, October 1977 p. 122-131.

Petruk, W., 1977, Mineralogical characteristics of an oolitic iron deposit in the Peace River district, Alberta; Canadian Mineralogist , 15(1) 3-13.

Reimer, J.D., Teare M.R., 1991, Reservoir development and resource emplacement in selected Paleozoic carbonates of northeaster British Columbia and northwestern Alberta. Canadian Society of Petroleum Geologists Convention, Abstracts 116

Ueshima, M., Tazaki, K. 2001, Possible Role of Microbial Polysaccharides in Nontronite Formation, Clays and Clay Minerals, 49(4) 292-299