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Gold and associated industrial heavy minerals in the Icy Cape District: White River to Icy Cape, Alaska, USA

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Synopsis

Portions of the Icy Cape placer Au district have been described and exploited since the early 1900s. Industrial studies of Au-bearing garnet-rich intervals established a 3.5 million troy ounce resource in the western half of the district. This estimate is not compliant with CIM and SME definition standards for Mineral Resources and Mineral Reserves. We note high variability in the textures of sediments and their heavy mineral (HM) content and composition in the district, probably as a function of the depositional environment. Sediments are medium- to fine-grained sands with a valuable HM assemblage that averages 26.0% in a range of 1.1–72.6%. Valuable heavy minerals (VHMs) garnet, magnetite, ilmenite, rutile, and zircon, but excluding Au, average 7.9% in a range of 1.0–37.6% of the HM assemblage. Trace quantities of uraninite, thorite, monazite, xenotime, and others are noted. Garnets have an average Y content of 726 ppm with a range of 0–2150 ppm. Energy-dispersive X-ray fluorescence confirms compositions commensurate with Ca, Al, and Mg silicates. We provide empirical analytical data and note high variability in the textures, HM content, and compositions as a probable function of depositional environment. Icy Cape District land and resources are owned by the Alaska Mental Health Trust Authority and managed by the Trust Land Office (TLO).

Keywords

placer gold, heavy minerals, beach sands, mineralogical characterization, depositional environment.

Introduction

The Icy Cape Heavy Minerals (HM) District in Alaska subtends more than 200 km^2 fronting the Pacific Ocean and backing to the foot of the Robinson Mountains at about 1700 m above sea level. We classify the district into geomorphic provinces; the eastern region as deltaic (Figure 1) and the western region as coastal plain (Figure 2), based on geomorphologic expressions. The coastal plain is entirely built up of unconsolidated outwash sediments and ancient beach sand deposits.

The area from the White River to Icy Cape has intermittently produced placer gold since the initial discovery in 1897. Gold production reports are nonexistent, but it is estimated that at least 16 000 troy ounces of gold have been mined from small-scale placer operations that concentrated on the active beaches and the White River sediments. It was not until the mid-1980s to the early 1990s that mining companies such as Noranda Exploration from Canada and Paraclete Resources from Australia began exploration for large-scale placer gold deposits. Paraclete Resources defined areas for gold placer mining as presented in Figure 2 and delineated a 3.5 million troy ounce resource (Rossetti, 1992). This resource estimate is a historical estimate and is not compliant with CIM and SME definition standards for Mineral Resources and Mineral Reserves.

Placer Au occurs primarily as fine-grained (averaging 0.250 mm in diameter) flat and rounded plates and is strongly associated with garnet-rich layers (inset in Figure 2). Test work demonstrated recoveries in excess of 93%, at an estimated 81% purity (Trust Land Office document archives).

In 1996 the land and minerals ownership of the Icy Cape land block was transferred from the State of Alaska to the Alaska Mental Health Trust Authority. The land and mineral resources are managed by the Trust Land Office (TLO). Natural resources between mean high tide and three nautical miles (5.56 km) offshore are managed by the State of Alaska. The nature and distribution of HMs in offshore sediments is unknown.

Over the next decade the TLO will develop timber resources in the heavily vegetated region of the coastal plain and delta regions. This will allow synergy with mineral resources development strategies.

Background

The first published systematic study of HMs in the region is one of titanium mineral

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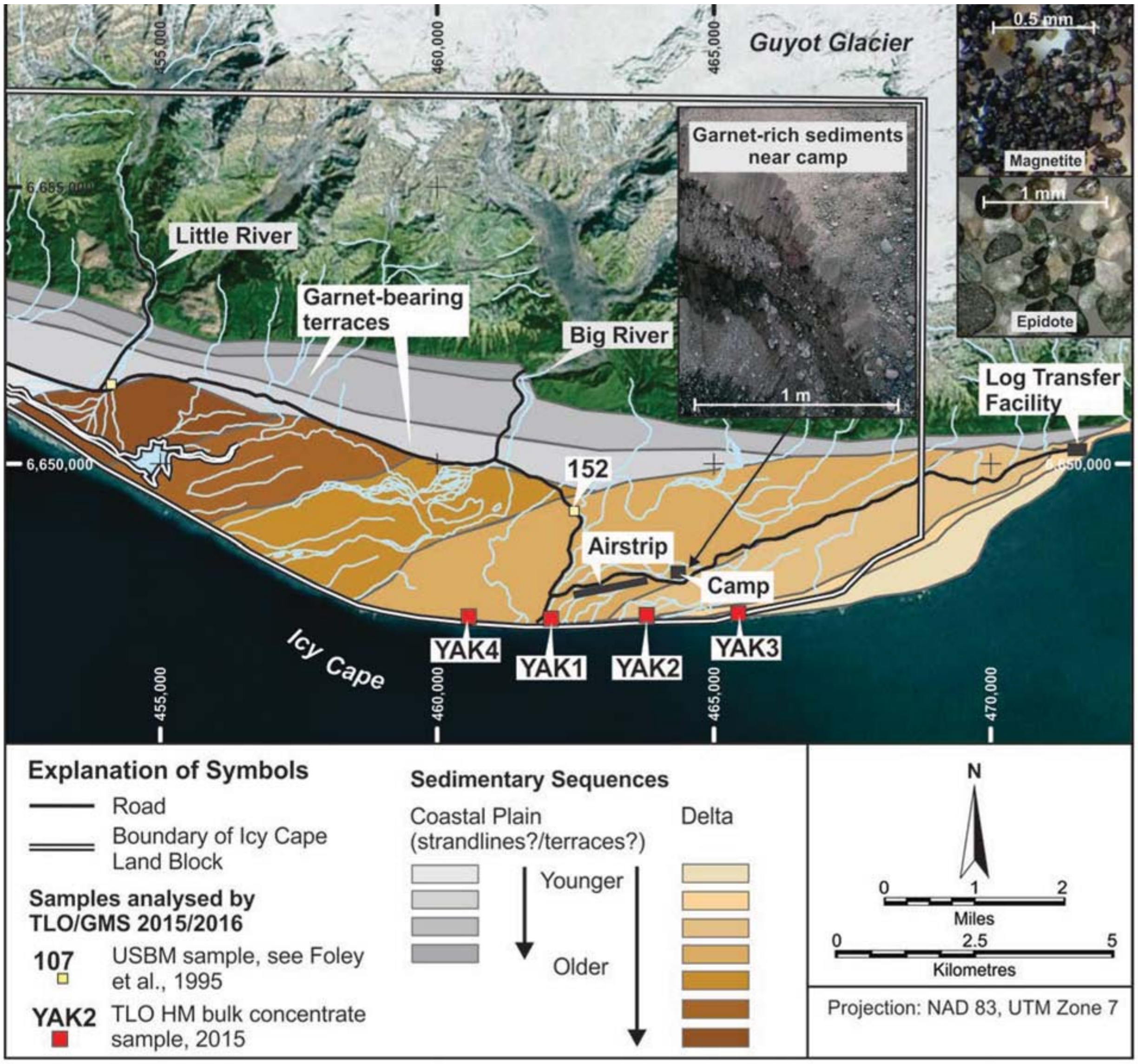

Figure 1—Sample locations and sedimentary sequences in the eastern Icy Cape District

resource potential by Foley *et al.,* (1995). They sampled at about 2 km intervals traversing the modern beach environment using solid-stem power and hand augers in the intertidal zone, beach face, and back beach, and channel sampling of wave-cut beach terraces. Samples collected during that study averaged 1.5 m intervals ranging to 9.6 m in depth. Foley *et al.,* (1995) estimate 0.57% valuable heavy minerals (VHMs: 0.49% ilmenite; 0.05% rutile; 0.03% zircon) with a range of <0.1% to 2.9% VHMs in modern shoreline sands of a portion of the district west of the Little River. Foley *et al.* note that dynamic depositional processes result in large variations in grain size distribution and in HM content. These large variabilities make the determination of statistical central tendencies difficult. Median and modal values are better measures of this tendency, but we present mathematical averages bracketed by ranges.

Foley *et al.*, (1995) note that the HM fractions contain polymineralic grains, 'rock fragments', interlocked grains of magnetite, pyroxene, plagioclase, sphene, and ilmenite. They note the extensive deltaic sediments at Icy Cape, and their reconnaissance Ti, Zr, and Au assays for samples from this area indicated that VHMs are present. Trace quantities of platinum group metals (PGMs) are associated with the placer gold (Foley *et al*., 1995, Table 3).

Formerly confidential industry assessments of Au shown in Figure 2 (TLO document archive) note the sands contain other potentially recoverable minerals. Of these, zircon, garnet, and ilmenite are the most likely recoverable, with PGMs regarded as a possibility. The PGMs are apparently associated with magnetite. These reports also note that rutile is present and should be evaluated as a potential by-product of the proposed gold operations.

The stratigraphy of the coastal region (coastal plain and delta) is not well known. Corporate models are based on the major unconsolidated sediment types, which are classified according to lithological character and origin. The sediments comprise well-sorted sand and gravel formed at or near the present beach and on former beaches, including strandlines elevated by Holocene tectonic uplift; well-sorted dune sand on or near the present or former beaches; interbedded mud

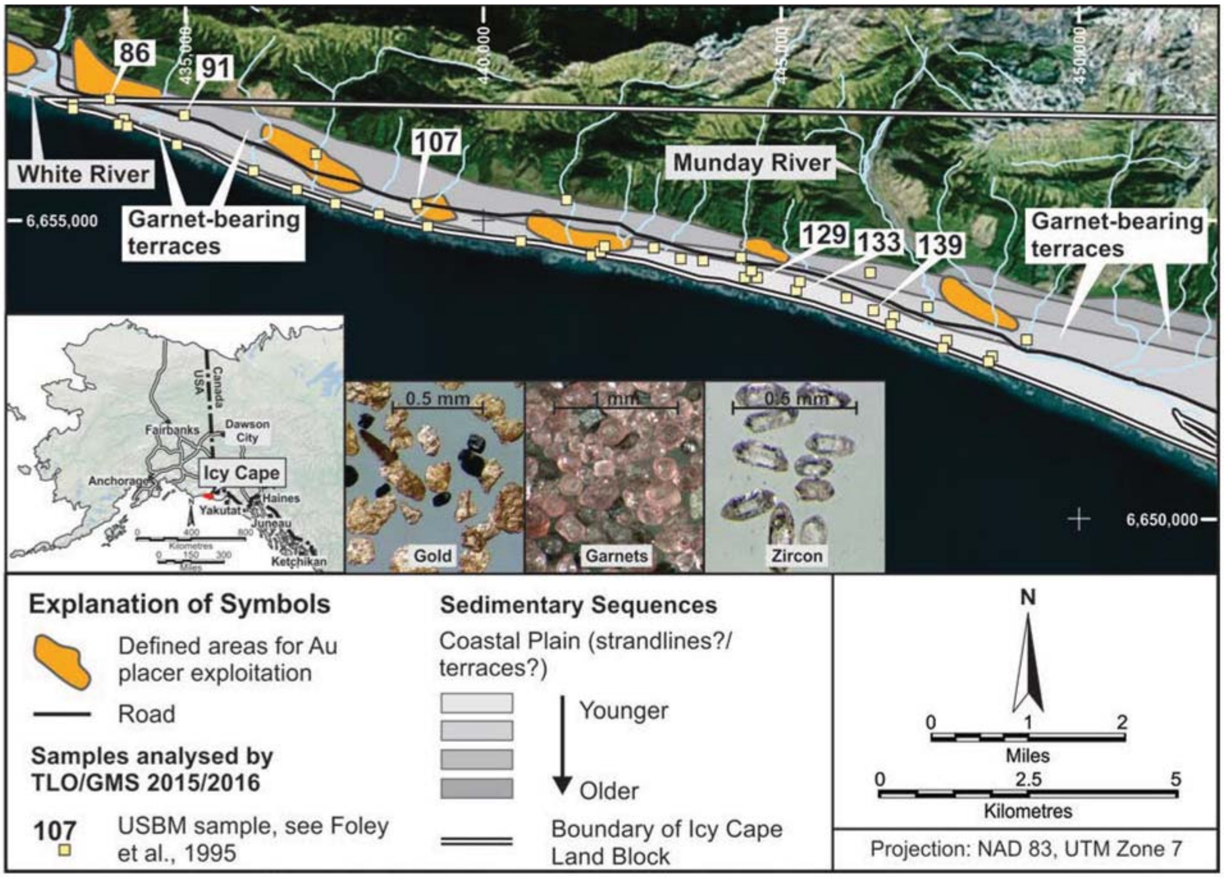

Figure 2—Sample locations, sedimentary sequences, and outlined areas for gold placer mining in the western Icy Cape District

and sand containing much organic debris, which were formed on tidal flats, in bays or lagoons, and in clear lakes and swamps; and interbedded mud and poorly sorted to moderately well-sorted sand and gravel, which were formed on the floodplains or fans of streams on the outwash aprons of glaciers, including terminal and ground moraine and ice-rafted deposits. The thickness of the unconsolidated deposits on the coastal lowland and along the raised beach ridges is not known but is estimated to be of the order of tens of metres.

Current work

Our studies relied on methods, procedures, and techniques commensurate with those of the placer Ti-Zr-REE HM industry. Particle size distribution (PSD) analyses were conducted using US Standard stainless steel sieves and are reported for some bulk samples and for their HM fractions. An average mass of 120 g was separated in lithium metatungstate (LMT), a heavy liquid with a specific gravity of >2.96. Technical aspects are detailed by Foley *et al.*, (1995) and by Grosz, Berquist, and Fischler (1990).

A Frantz barrier magnetic separator was used to separate minerals in the HM concentrate into seven fractions. After a low field-strength (0.05 A) pass through the apparatus set at 15 degree forward- and 25 degree side-slopes, the HMs were concentrated according to their magnetic susceptibilities at 0.15, 0.25, 0.35, 0.50, and 1.00 A, yielding a nonmagnetic 1.00 A residue, and their weights were recorded. This approach recovered, for example, over 90% of the garnet into the 0.25 A fraction, over 95% of the rutile and zircon into the nonmagnetic residue, and epidote, pyroxene, and amphibole minerals into the intermediate fractions. Due to variations in chemical composition and the presence of inclusions and complex intergrowths, a particular mineral may report to more than one magnetic fraction. Magnetic fractionation reduces the number of mineral species in each fraction and thus facilitates qualification and quantification of the HM species.

Each magnetic fraction was examined by reflected and transmitted light microscopy. Modal mineralogical compositions were determined by point counts of at least 500 grains in combination with visual estimates of field percentage compositions. Mineral percentages were calculated on the basis of their weight in each fraction. The calculated weights of a mineral in the various magnetic fractions were then summed and divided by the total weight of the HMs. The densities of individual mineral species were not compensated for by this method. XRD, XRF, SEM, and microprobe analysis were used to confirm petrographic mineral determinations and to obtain detailed compositions.

In this paper, we provide PSD, HM content, modal mineralogical, and adjunct analytical data for samples. We also generated conductive, nonconductive, and trace element determinations, but these results are not included in this brief report.

More than 100 samples from Foley's (1995) study were retrieved from archives at the Geologic Materials Center in Anchorage, AK. From these, 87 samples averaging 275 g were collected by use of Jones splitters. Five samples of garnet-rich beach concentrate collected by the TLO in 2015 were also included. The average HM content of the 87 samples is 19.3% in a range of 0.7–72.6%. The PSD of these sands is predominantly between 0.149 mm and 0.297 mm. With the exception of a few beach samples containing significant amounts of very coarse sand- to gravel-sized material, samples were predominantly less than 0.595 mm and greater than 0.105 mm in particle size.

The analytical results for 21 samples representing seven locations as selected for this report are presented in Table I. They represent thicknesses of sediments above mean high tide, as modern beach sediments are outside the TLO property boundaries. Each location has defined sampling intervals. For example, samples SN 86.1 through SN 86.4 denote a core location with successively deeper sampled intervals. Sample numbers from Foley *et al.*, (1995) are present as map numbers for ease of cross-reference. Table I shows their locations (coordinates in metres, North American Datum 1983, UTM Zone 7), depth intervals in metres, and %HM (SG >2.96) expressed as a percentage of the bulk sample collected. Analyses of these widely distributed power-auger, hand-auger, and channel samples show an average 26.0% HMs in a range of 1.1–72.6%.

Results

Medium- to fine-grained sands with locally significant coarse- or fine-grained components dominate the coastal plain and delta portions of the district. With the exception of a few samples of relatively very coarse sand to gravel-sized material, the particle size is from 0.6 mm to 0.11 mm. The PSDs of 21 sediment samples and some of the HMs are given in Table II. Note the high variability in size distribution of both bulk sediments and their HMs.

Mineralogy

The HMs of coastal plain and deltaic sediments in the district comprise a large and varied assemblage.

Table I

Analytical results for 21 bulk sediment samples showing sample locations, depth intervals sampled, and HM content

SN	UTM E	UTM N	From m	To m	Interval m	Wt% HM
86.1	433723	6657013	0.0	2.1	2.1	44.89
86.2	433723	6657013	2.1	4.0	1.9	33.82
86.3	433723	6657013	4.0	5.8	1.8	24.12
86.4	433723	6657013	5.8	7.3	1.5	72.58
91.1	434966	6656749	0.9	2.1	1.2	13.85
91.2	434966	6656749	2.1	4.0	1.9	64.91
91.3	434966	6656749	4.0	5.8	1.8	38.72
107.1	438874	6655268	0.9	2.7	1.8	38.87
107.2	438874	6655268	2.7	5.8	3.1	17.18
107.3	438874	6655268	5.8	6.7	0.9	10.44
129.1	444575	6654017	0.0	2.1	2.1	33.86
129.2	444575	6654017	2.1	4.0	1.9	12.88
129.3	444575	6654017	4.0	5.8	1.8	6.97
129.4	444575	6654017	5.8	7.6	1.8	1.50
129.5	444575	6654017	7.6	9.6	2.0	1.10
133	445248	6653788	0.0	0.8	0.8	21.27
139.1	446545	6653484	0.0	2.1	2.1	48.78
139.2	446545	6653484	2.1	4.0	1.9	10.92
139.3	446545	6653484	4.0	5.8	1.8	8.32
139.4	446545	6653484	5.8	7.2	1.4	2.91
152	462481	6649158	0.0	4.6	4.6	38.99

Table III shows the distribution of HMs in 21 samples. Magnetite (MAG), ilmenite (ILM), garnet (GAR), rutile (RUT), zircon (ZIR), others (OTH), and VHM, (MAG, ILM, GAR, RUT, and ZIR) are given as modal percentages of the total HMs. A value of 0.00 denotes <0.01%. Images of minerals are shown as insets in Figure 1 and Figure 2, and they are described in the following section. Small, flat (with irregular and/or curled edges) gold particles as well as uraninite and thorite particles were noted in many samples (example in Figure 1).

XRF analyses confirmed the chemical compositions commensurate with the relative abundances of Ca, Al, and Mg silicate minerals, which have not been examined for their potential value as abrasives, water filtration agents, drilling mud components, or other commercial applications.

Magnetite and ilmenite

MAG and ILM are strongly magnetic components of the HMs. They are technically best classified as oxides as they include

Table II

Particle size distribution (in mm) of 21 bulk sediment samples and some of their HMs. Blank cells have no data

	BULK SIZE DISTRIBUTION (Wt% retained)						HM SIZE DISTRIBUTION (Wt% retained)					
SN	0.595	0.420	0.297	0.250	0.149	<0.149	0.595	0.420	0.297	0.250	0.149	<0.149
86.1	0.7	1.6	10.5	13.9	70.2	3.2	0.1	0.4	4.2	5.3	84.4	5.6
86.2	4.6	3.8	17.2	17.6	53.2	3.6	0.9	0.8	3.6	10.1	79.7	4.8
86.3	10.8	6.1	21.7	17.9	40.2	3.3	2.8	1.8	9.6	7.2	77.1	1.5
86.4	12.5	6.3	21.4	17.5	39.0	3.4	16.9	0.7	2.6	2.1	49.4	28.2
91.1	3.8	2.6	6.8	10.3	65.6	10.9						
91.2	0.6	0.1	1.0	2.8	66.4	29.2						
91.3	2.5	2.6	10.8	10.8	70.5	2.8						
107.1	2.3	0.7	7.5	15.9	66.7	6.9						
107.2	0.5	0.9	11.9	20.2	64.2	2.2						
107.3	6.2	7.3	21.5	18.5	40.8	5.6						
129.1	0.1	0.3	10.2	23.3	65.2	0.8	0.0	0.0	0.9	1.3	95.0	2.8
129.2	2.4	3.2	18.7	25.6	48.3	1.8	0.0	0.0	4.4	8.6	85.0	1.7
129.3	4.0	2.9	17.8	23.0	51.7	0.7	6.2	2.3	4.5	9.0	67.9	10.1
129.4	1.2	1.0	6.7	11.3	52.5	27.2	19.7	3.9	12.1	9.1	53.0	2.2
129.5	0.1	0.4	8.6	17.4	72.2	1.4						
133	0.0	0.1	5.1	19.6	73.1	2.1						
139.1	1.8	3.0	20.4	24.6	47.6	2.7	0.0	0.0	2.0	1.7	3.2	93.0
139.2	1.8	2.3	19.9	24.4	50.6	1.0	2.8	1.4	12.3	10.6	38.6	34.2
139.3	2.5	3.5	21.6	25.1	44.7	2.6	1.5	2.0	2.5	59.9	31.3	2.9
139.4	2.0	0.7	7.2	15.3	68.0	6.8						
152	52.7	16.6	13.1	4.3	8.5	4.8						

Table III

Modal mineralogical composition of the samples in Table II

	MINERAL COMPOSITION (Wt% of HM)						
SN	MAG	ILM	GAR	RUT	ZIR	OTH	VHM
86.1	0.73	0.17	10.21	0.47	0.42	88.00	12.00
86.2	0.79	0.17	8.70	0.43	0.31	89.60	10.40
86.3	0.15	0.66	12.70	0.08	0.11	86.30	13.70
86.4	0.14	0.00	1.66	2.89	2.76	92.55	7.45
91.1	1.86	0.07	8.42	0.34	0.23	89.08	10.92
91.2	1.47	0.54	11.75	0.76	0.53	84.96	15.04
91.3	1.70	0.05	6.72	1.94	0.74	88.84	11.16
107.1	1.90	0.18	9.11	0.37	0.45	87.99	12.01
107.2	0.28	0.00	3.94	0.20	0.66	94.92	5.08
107.3	0.48	0.03	3.52	0.32	0.50	95.16	4.84
129.1	0.85	0.00	0.76	0.17	0.02	98.20	1.80
129.2	0.51	0.00	0.42	0.06	0.00	99.01	0.99
129.3	0.44	0.06	0.56	0.02	0.02	98.90	1.10
129.4	0.59	0.08	0.68	0.01	0.04	98.60	1.40
129.5	0.56	0.00	1.24	0.00	0.03	98.17	1.83
133	1.51	0.03	0.34	0.03	0.00	98.09	1.91
139.1	1.93	0.76	34.73	0.07	0.14	62.37	37.63
139.2	1.95	0.03	7.75	0.28	0.08	89.91	10.09
139.3	1.31	0.00	1.82	0.26	0.00	96.61	3.39
139.4	1.43	0.00	0.65	0.06	0.07	97.78	2.22
152	0.40	0.00	0.67	0.04	0.01	98.88	1.12

Ti-free iron oxides with sphene and amphibole inclusions, haemo-ilmenite, chromite, octahedral and rounded magnetite, and magmatic haematite-ilmenite-magnetite showing exsolution features at 2 µm to >50 µm scale. Sphalerite, pyrite, and REE-rich phases from 2 µm to 10 µm in size occur as inclusions in the oxide group minerals. Ilmenite is present in all samples but is not liberated (52.7% TiO_2), and it appears not to be suitable for pigment manufacture because of trace impurities that include Si, Cr, V, and Al (Foley *et al.*, 1995). Figure 3A shows a backscattered SEM image of a typical titaniferous magnetite with titanium-rich exsolution lamellae (thin black bands). Black spots are Al-rich spinel. Figure 3B shows intergrowth of magnetite and ilmenite. Black areas near the centre are hornblende inclusions. Oxides average 1.13% of the HM suite, with a range of 0.14% to 1.98% (Table III).

Garnet

The garnet group was examined in more detail than other HMs as the co- or by-product potential of garnet was alluded to in the past but was not addressed. Garnet comprises an average of 6.02% of the HM suite with a range of 0.34% to 34.73% (Table III). Our analyses reveal that end-members almandine, pyrope, grossular, and spessartine (not including andradite and uvarovite) comprise 67%, 12%, 6%, and 15% respectively of the garnet group. We distinguish pink, orange, and dark garnets that are mostly euhedral to slightly rounded, with a crushed shard component. Figure 4 shows the principal types. Many garnets have varying amounts of inclusions that include monazite-(Ce) (up to 25 µm), pyrite (up to 50 µm), ilmenite (up to 50 µm), and xenotime (up to 20 µm). Microprobe analyses show garnets have an average Y content of 726 ppm with a range of 0 to 2150 ppm, with pink and orange types having the highest overall values. The reader interested in Y distribution in garnet-group minerals is referred to Jaffe (1951), Pyle and Spear (1999), references therein, and to subsequent publications.

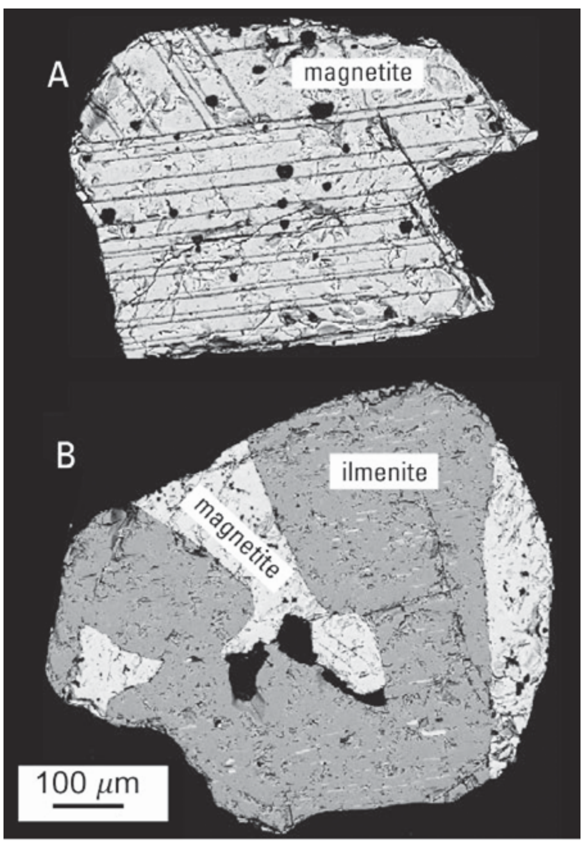

Figure 3—Backscattered SEM image of oxide mineral particles classified as magnetite and ilmenite (MAG and ILM; Table III)

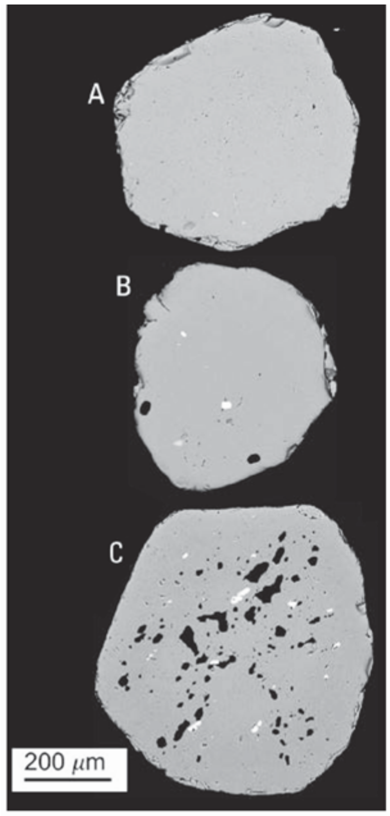

Figure 4—Backscattered SEM electron image of typical garnet particles (GAR, Table III) A: pink, euhedral; B: orange, rounded, with zircon (white) and quartz (black) inclusions; C: dark, rounded, with quartz (black) and ilmenite (white) inclusions

Rutile

The rutile group (≥90%TiO_2) includes rutile, anatase, and sphene. This group of minerals averages 0.42% of the HM suite with a range of <0.01% to 2.89% (Table III). Particles appear liberated and are finer-grained than other HMs, including gold.

Zircon

Zircon is present as fine-grained, clear, doubly terminated euhedral crystals and as crushed shard fragments with low U and Th content (<300 ppm combined). Figure 5 shows euhedral zircon (A) and a broken fragment of euhedral zircon (B). ZR comprises an average of 0.34% of the HM suite with a range of <0.01% to 2.76% (Table III). Some zircons contain chalcopyrite inclusions up to 20 µm, monazite inclusions up to 10 µm, uraninite inclusions up to 5 µm, thorianite inclusions up to 2 µm, and thorite inclusions in the order of 1 µm. Arsenopyrite is also occasionally present as inclusions. Zircons are finer-grained than other the HMs, including gold.

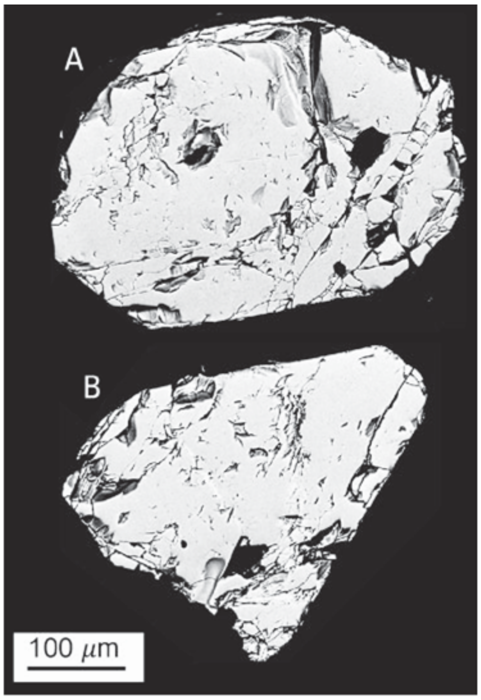

Figure 5—Backscattered SEM image of typical zircon particles (ZIR, Table III)

Other

For the purposes of this study, large and varied groups of HMs are classified as ‘others’ (OTH, Table III) and retained for follow-up analyses. This group accounts for an average 92.09% of the HM suite with a range of 62.37–99.01%. It includes dominant epidote, zoisite, clinozoisite, pyroxene, amphibole, olivine, serpentine, as well as unidentified opaque and non-opaque sand- and finer-grained particles made up of HM and non-HM fragments. Included in this group are very small but persistent traces of spinels, monazite, cassiterite, uraninite (100 μm particles), chromite (high Al/low Fe), thorite, thorianite, albite, barite, scheelite, and localized carbonate fragments.

VHMs

Reported VHMs reflect on potential as co- and by-product HMs from gold recovery operations. Excluding gold, VHMs average 7.91% of the HM suite in a range of 0.99–37.63% (Table III). Values are considered underestimates because the OTH group contains a larger, though lower-value, suite of industrial minerals than VHMs. Nonetheless, the VHM contents reach very high values in comparison to traditional titanium-zirconium deposits.

Conclusions

The Icy Cape District is host to a large and varied body of unconsolidated sediment with documented placer Au resources and associated HM resources that are primarily industrial in nature. We estimate the district to contain in excess of 1.7×10^9 t of resource-bearing sediments to 10 m depth. Our analyses confirm the potential for mineable HMs with associated Au concentrations. The geological framework, textural, mineralogical, and chemical data indicates a large, but as yet incompletely understood, resource potential for gold, garnet, and other HMs. Very large vertical and lateral variations in PSD and HM content and composition are noted, likely as a function of depositional environment. This, and supportive (and formerly proprietary) information, enhances knowledge of the factors controlling the potential commercial viability of HMs in the Trust Land area, and provides a better understanding of resource potential with a view to exploration and development. The TLO will conduct high-resolution aeromagnetic surveys of the district in 2016 and stratigraphic and resource drilling campaigns in 2017.

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