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Vanadium Potential in Alberta

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Abstract

Global demand for vanadium is expected to increase over the next several years, primarily for its use in high-strength steel, aerospace alloys, and large-capacity batteries. The most promising sources of vanadium in Alberta are oil sands waste, oolitic ironstone, and metalliferous black shale. Vanadium occurs naturally in the bitumen phase of oil sands and becomes concentrated in petroleum coke (petcoke), petcoke fly ash, froth treatment tailings, and refinery wastes during processing and refining, with petcoke and petcoke fly ash as the largest readily available sources of vanadium. Recent estimates, based on 2017 production values, suggest that between 34 000 and 39 000 tonnes of vanadium are concentrated through oil sands and in situ bitumen processing each year in Alberta. The Alberta Geological Survey is currently collecting and compiling data on oil sands and oil sands–associated wastes to enhance public understanding of the distribution of vanadium and other critical elements in these geological and industrial waste materials.

Significant vanadium concentrations have also been reported in oolitic ironstone of the Bad Heart Formation in northwestern Alberta. The Clear Hills iron-vanadium deposit has an estimated indicated resource of 1.116 million tonnes of vanadium pentoxide. Further work is needed to estimate the grades and tonnages of vanadium in the surrounding areas, which show anomalously high concentrations of vanadium.

Finally, vanadium occurrences have also been identified in metalliferous black shale of the Exshaw, Loon River, Second White Specks, and Shaftesbury formations. Resource estimates completed in the Birch Mountains region in northeastern Alberta suggest an indicated resource of 12 562 tonnes of vanadium pentoxide in the Buckton zone, with a further inferred resource of 188 484 tonnes. The adjacent Buckton South zone is estimated to have an inferred resource of 88 489 tonnes of vanadium pentoxide. Vanadium anomalies observed elsewhere in the Asphalt zone of Birch Mountains, northwestern Alberta, Jura Creek, Mount Gass, and Crowsnest Pass warrant further investigation.

This publication provides a high-level overview of Alberta's vanadium potential from the review of existing data and reports, particularly Alberta Geological Survey Special Report 113, *Critical Metals in Alberta: Preliminary Evaluation of Vanadium and Nickel Potential in Alberta Bitumen and Bedrock*.

1 Introduction

Vanadium has been identified as a critical mineral by the Canadian government and is in demand on a global scale for metallurgical, catalytic, ceramic, electronic, and chemical applications (U.S. Geological Survey, 2024; Natural Resources Canada, 2025). Vanadium is most commonly used to manufacture high-strength steel and is an essential component of alloys for the aerospace industry. In recent years, vanadium has been growing in importance as a global shift towards electrification and renewable energy has driven unprecedented demand for the long-term, stable, and large-capacity energy storage offered by vanadium redox batteries (Kelley et al., 2017). Recent and ongoing research to characterize vanadium potential suggests that Alberta has economically significant vanadium enrichment, with the potential to become a significant vanadium producer through strategic development of this valuable commodity from multiple sources (Figure 1; Burkus et al., 2023).

Vanadium is a transition metal present in the Earth's continental crust at a concentration of 97 parts per million (ppm; Rudnick and Gao, 2003), comparable to the average crustal abundances of zirconium and chromium. The economics of vanadium recovery are dependent on a multitude of factors, such as the current market conditions, deposit type, local and regional geology, and the processing technology available. However, in general, vanadium concentrations of at least an order of magnitude greater than average crustal abundance are required for economic recovery from ore (Simandl and Paradis, 2022). Throughout this report, a minimum cutoff grade of ~1000 ppm is used to identify possible occurrences of vanadium, consistent with the methodology used to identify prospective areas shown on the Alberta Geological Survey's (AGS) Minerals of Alberta map (Lopez et al., 2020).

In 2023, vanadium production was dominated by China (68 000 tonnes), Russia (20 000 tonnes), South Africa (9100 tonnes), and Brazil (6400 tonnes; U.S. Geological Survey, 2024). Although there is no active vanadium mining in Canada, there are a number of exploration activities, primarily based in Quebec (e.g., VanadiumCorp. Resource Inc.'s Lac Doré project), Ontario (e.g., Brazeau prospect in southeastern Ontario), and Newfoundland and Labrador (e.g., ATHA Energy Corp.'s Moran Lake project), with occurrences documented in Alberta, British Columbia, Manitoba, and Nunavut as well. In the U.S., the only vanadium production is derived from processing waste materials such as spent catalysts and petroleum residues (U.S. Geological Survey, 2024). Global vanadium production has been steadily increasing over the past few years (Grand View Research, Inc., 2023). Based on data recently compiled as part of the AGS's Mineral Mapping Program, Alberta has prospective concentrations of vanadium in the following sources (Burkus et al., 2023):

- oil sands (Athabasca, Cold Lake, and Peace River oil sands regions)
- oolitic ironstone (Clear Hills deposit in northwestern Alberta)
- metalliferous, organic-rich, black shale (Birch Mountains, Rocky Mountains and Alberta Rocky Mountain Foothills, and northwestern Alberta)

2 Vanadium in Oil Sands

Alberta is one of the most significant oil-producing regions in the world. In 2023, the province produced 512 300 barrels per day (bbl/d) of crude oil and 3.41 million bbl/d of bitumen, and these values are expected to increase over the next decade (Alberta Energy Regulator, 2024a). Heavy crude and bitumen typically have elevated concentrations of sulphur and various metals, including vanadium, nickel, molybdenum, and rhenium, which are removed as contaminants during the processing, refining, and upgrading processes. Even though the original concentrations of vanadium in mined oil sands or in situ (thermally extracted) bitumen tend to be below the threshold for economic recovery, oil sands processing concentrates this commodity to prospective concentrations in petroleum coke (petcoke), petcoke fly ash, tailings, and asphaltenes (Table 1; Burkus et al., 2023). However, there is currently not enough data to calculate resource estimates and classify specific localities or waste streams as deposits.

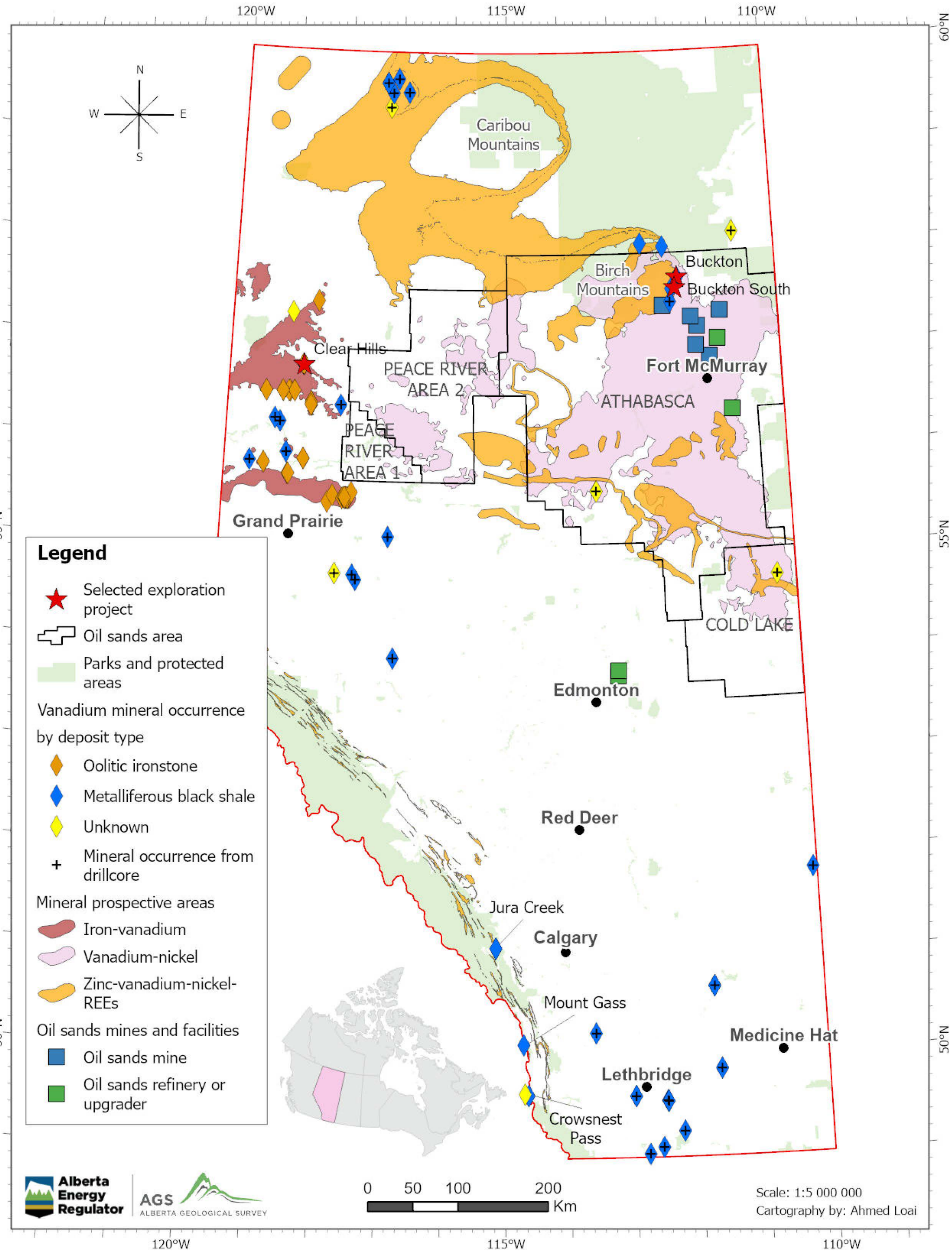

Figure 1. Vanadium deposits, occurrences, and prospective areas in Alberta, as well as oil sands sites with notable vanadium potential. Mineral occurrences are from surface materials unless noted by a cross, in which case they come from drillcore samples, sometimes at considerable depth. Mineral occurrences from Lopez et al. (2020) and Meek et al. (2023a, b). Mineral prospective areas from Alberta Geological Survey (work in progress). Abbreviation: REE, rare-earth element.

Table 1. Annual production volumes of various oil sands products and waste materials in Alberta, with reported concentrations of vanadium (V) in samples from various representative sources. Fluid tailings volume is total cumulative volume as of 2023. Abbreviations: AOS, Athabasca Oil Sands; CLOS, Cold Lake Oil Sands; PROS, Peace River Oil Sands; TSRU, tailings solvent recovery unit.

Material	2023 Production Volume (million tonnes)	V (ppm)	Sample Description
Mineable oil sands	675.9[a]	21.9–53.5[d]	Bulk oil sand (AOS)
		51[e]	Bulk oil sand (CanmetENERGY inventory)
Bitumen	187.3[b]	206–299[d]	AOS bitumen
		174–203[f]	AOS bitumen
		170[g]	CLOS bitumen
		180.1–257[g]	PROS bitumen
Crude oil	30.1[b]	70[g]	Heavy crude oil
		0.1[g]	Light crude oil
		0[g]	Light crude oil
Petroleum coke (petcoke)	12.0[a]	1100–1500[h]	Petcoke (fluid coking process)
		1600[i]	Petcoke (flexicoking process)
		1500–1900[j]	Petcoke (fluid coking process)
		1000–1400[k]	Petcoke (fluid coking process)
		1300–1400[l]	Petcoke (fluid coking process)
		1400–1500[l]	Petcoke (fluid coking process)
Burnt coke	1.3[a]	39 200–65 700[m]	Fly ash from delayed coke
		34 700–43 900[m]	Fly ash from fluid coke
Fluid tailings	1504.4[c]	490[e]	TSRU tailings
		197[e]	Mature fine tailings
		68[e]	Fluid fine tailings
		82[e]	Extraction middlings
		11[e]	Coarse tailings
Asphaltene		1763.4[n]	Asphaltene (AOS)
		820[o]	Asphaltene (CLOS)
Asphaltene char		2565.78–4225.55[n]	Asphaltene char (CLOS)

[a] Alberta Energy Regulator (2024b)
[b] Alberta Energy Regulator (2024b)
[c] Alberta Energy Regulator (2024c)
[d] Bicalho et al. (2017)
[e] Roth et al. (2017)
[f] Alberta Energy Regulator (2014)
[g] Anderson et al. (2015)
[h] Nesbitt et al. (2017)
[i] Jack et al. (1979)
[j] Har (1981)
[k] Zubot et al. (2012)
[l] Abdolahnezhad and Lindsay (2022)
[m] Jang and Etsell (2005)
[n] Mahapatra (2014); Mahapatra et al. (2015)
[o] Semple et al. (1990)

Recent estimates, based on 2017 production values, suggest that between 34 000 and 39 000 tonnes of vanadium are concentrated through oil sands and in situ bitumen processing each year in Alberta, with the majority of this element being concentrated in petcoke and petcoke fly ash (Burkus et al., 2023). Since 2017, both in situ and surface production of bitumen has increased by approximately 24% (Alberta Energy Regulator, 2024a) and, as a result, the processes that concentrate vanadium are likely concentrating more than these original estimates. In addition, elements associated with vanadium such as nickel, molybdenum, and rhenium have been identified as potential coproducts (Burkus et al., 2023).

Although previous work has demonstrated the potential of producing vanadium from oil sands waste, these studies tend to be focused on samples from a single site and often lack publicly available spatial information. More sampling and analysis work is underway to (1) assess whether critical elements are preserved in petcoke, petcoke fly ash, and tailings from a wide variety of sites under typical storage conditions, and (2) determine which host materials show the greatest potential for economic recovery of critical elements. The AGS has partnered with the Northern Alberta Institute of Technology's Centre for Energy and Environmental Sustainability to collect and analyze samples of oil sands and associated wastes to help answer these questions, as well as to enhance public understanding of the potential for vanadium and other critical minerals in the oil sands.

2.1 Petcoke and Petcoke Fly Ash

Petcoke and petcoke fly ash represent the largest, readily available sources of vanadium (Burkus et al., 2023), in terms of volume and vanadium content (Table 1). Petcoke is a carbon-rich solid residue produced as a by-product of refining crude oil and upgrading oil sands (Environment and Climate Change Canada and Health Canada, 2020). Some of the petcoke produced in the Athabasca Oil Sands region is burnt as fuel at refineries and upgraders, generating fly ash, but most is stored in stockpiles on site (Table 1). The compositions of petcoke and petcoke fly ash are dependent on the type of bitumen material and coking process used, and could vary from site to site (e.g., Jang and Etsell, 2005, 2006; Nesbitt et al., 2017; Table 1). Vanadium is generally the most abundant trace element found in petcoke and petcoke fly ash (Nesbitt, 2016) and it is relatively stable in these materials under neutral pH conditions, but can be released when exposed to oil sands process-affected water and acid rock drainage (Nesbitt et al., 2017; Swerhone, 2018; Abdolahnezhad, 2020; Abdolahnezhad and Lindsay, 2022). Vanadium is also likely to be released when petcoke is exposed to precipitation and oxygen (Nesbitt, 2016; Cilia, 2017).

More research is needed to compare petcoke and petcoke fly ash from different sites and assess the long-term potential for economic recovery of vanadium from these waste streams.

2.2 Tailings

There are three principal tailings streams generated during bitumen extraction at oil sands mines in northern Alberta: coarse tailings, fluid fine tailings, and froth treatment tailings (FTT; Lindsay et al., 2019). Froth treatment removes water and fine solids from the bitumen froth to yield cleaner bitumen, using either paraffinic or naphthenic solvents in the process. Paraffinic froth treatment precipitates asphaltenes—large, heavy, organic molecules that contain vanadium and other trace elements such as nickel (Nesbitt and Lindsay, 2017)–suggesting that vanadium is likely more abundant in paraffinic froth tailings than naphthenic froth tailings, and thus prospectivity is site dependent.

3 Rock-Hosted Vanadium Sources

In Alberta, most vanadium exploration has focused on oolitic ironstone and shale units in northern Alberta, resulting in the identification of three main deposits with calculated resource estimates (Table 2).

Table 2. Rock-hosted vanadium deposits in northern Alberta with available resource estimates. Abbreviation: V_2O_5, vanadium pentoxide.

Name	Location	Deposit Type	Stratigraphic Unit(s) (formation)	Status	Extent (km^2)	V_2O_5 Grade (ppm)	Recoverable V_2O_5 (tonnes)
Clear Hills Ironstone deposit[a]	Clear Hills, northwestern Alberta	Oolitic ironstone	Bad Heart	Indicated resource	84	2000	1 116 000
				Inferred resource		Unquantified	Unquantified
Buckton zone[b]	Birch Mountains, northeastern Alberta	Metalliferous black shale	Second White Specks, Labiche	Indicated resource	1.5	659.9	12 562
				Inferred resource	20.4	606.4	188 484
Buckton South zone[c]	Birch Mountains, northeastern Alberta	Metalliferous black shale	Second White Specks, Labiche	Inferred resource	3.3	720.6	88 489

[a] Arseneau and Johnson (2012)

[b] Eccles et al. (2012, 2013a); Puritch et al. (2013)

[c] Eccles et al. (2013b)

3.1 Oolitic Ironstone

The most prospective area for relatively thick, shallow, oolitic ironstone intervals is in the Clear Hills region of northwestern Alberta, where this unit is approximately 10 m thick (Kafle, 2008). The Clear Hills iron-vanadium deposit is located approximately 80 km northwest of Peace River and includes the Rambling Creek, North Whitemud River, South Whitemud River, and Worsley zones. This deposit is a near-surface, flat-lying, oolitic ironstone bed hosted by the Bad Heart Formation. The 1.116 million tonne indicated resource for vanadium pentoxide (Table 2) is surrounded by an inferred resource for iron of 94.7 million tonnes with a recoverable grade estimate of 34.11% iron (Arseneau and Johnson, 2012), further work is needed to estimate the grade for vanadium. The AGS has identified multiple oolitic ironstone occurrences outside the inferred resource area (Olson et al., 2006; Kafle, 2008) indicating that the deposit may extend even farther to the east, west, and south. Other potentially favourable areas for vanadium exploration include the surrounding southern Clear Hills, Smoky River, Spirit River, Blueberry Mountain, and Rambling Creek areas, which have yielded elevated vanadium concentrations in previous sampling and analysis programs conducted by the AGS (Table 3; Kafle, 2008).

Table 3. Areas in northwestern Alberta with vanadium (V) geochemical anomalies in oolitic ironstone samples from the Bad Heart Formation (Kafle, 2008).

Location	Number of Samples	V (ppm)
Blueberry Mountain	4	316–960
Rambling Creek	24	554–1435
Smoky River	59	529–2093
Southern Clear Hills	41	506–2598
Spirit River	12	1053–2323

3.2 Metalliferous Black Shale

Vanadium is sensitive to changes in oxygen levels and tends to accumulate in fine sediments under low-oxygen conditions (Tribovillard et al., 2006), which prevail during the deposition of sediments that ultimately form organic-rich black shale. Vanadium occurrences have been identified in marine organic-rich shale and mudstone units of the Western Canada Sedimentary Basin (WCSB) in Alberta (e.g., Sabag, 1998; Dufresne et al., 2001; Prior et al., 2008; Rukhlov and Pawlowicz, 2011; Puritch et al., 2013; Rokosh et al., 2016; Lopez et al., 2020). Although these rocks extend across the province, they are most prospective in northern Alberta, where they occur at or near-surface and are more suitable for extraction. Zones of metal enrichment (including vanadium) have been observed in the Upper Cretaceous Second White Specks Formation in the Birch Mountains region (Sabag, 2008, 2010, 2012), in the Loon River and Shaftesbury formations in the Hay River and Steen River areas (Dufresne et al., 2001; Prior et al., 2008; Rokosh et al., 2016; Lopez et al., 2020), and farther south in the Exshaw Formation at Jura Creek, Mount Gass, and Crowsnest Pass (Rukhlov and Pawlowicz, 2011). Most exploration for this type of deposit has been concentrated in the Birch Mountains region. This region is the site of the Buckton and Buckton South zones, which have inferred resource estimates totalling 276 489 tonnes of vanadium pentoxide (Table 2). Several vanadium anomalies have been observed between these two zones and the adjacent Asphalt zone (Sabag, 1996). Given these observations and the fact that the host deposit is relatively flat lying and regionally extensive, it is possible that these three zones are connected. However, further drilling is necessary to confirm this hypothesis.

Recent work for the AGS's Mineral Mapping Program included the analysis of over 2000 sedimentary rock samples from across the province. Forty-two samples with vanadium concentrations exceeding 1000 ppm were identified in the Doig, Exshaw, Fernie, Loon River, and Second White Specks formations (Meek et al., 2023a, b; Figure 1). Several other samples with elevated vanadium concentrations were collected from the Banff, First White Specks, and Muskwa formations, as well as the aforementioned units (Meek et al., 2023a, b)

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