RECORD 2020/9

LAYERED INTRUSION-HOSTED VANADIUM: A MINERAL SYSTEMS ANALYSIS

by
JN Guilliamse

Government of Western Australia
Department of Mines, Industry Regulation and Safety

Geological Survey of Western Australia

Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

RECORD 2020/9

LAYERED INTRUSION-HOSTED VANADIUM: A MINERAL SYSTEMS ANALYSIS

by
JN Guilliamse

PERTH 2020

Geological Survey of Western Australia

REFERENCE
The recommended reference for this publication is:
Guilliamse, JN 2020, Layered intrusion-hosted vanadium: a mineral systems analysis: Geological Survey of Western Australia, Record 2020/9, 5p.

ISBN 978-1-74168-897-9
ISSN 2204-4345

Published 2020 by the Geological Survey of Western Australia
This Record is published in digital format (PDF) and is available online at <www.dmirs.wa.gov.au/GSWApublications>.

Further details of geoscience products are available from:
Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Email: publications@dmirs.wa.gov.au
www.dmirs.wa.gov.au/GSWApublications

Cover image: Packing up the campsite in a claypan about 5 km south of Minilya in the southern Pilbara (photo by Olga Blay)

Contents

Figures

Layered intrusion-hosted vanadium: a mineral systems analysis

by

JN Guilliamse

Abstract

Layered mafic–ultramafic intrusion-hosted vanadium deposits in Western Australia account for the majority of Australia's vanadium resources, and include world-class examples at Speewah, Gabanintha, and Windimurra. The economic importance of such deposits warrants continued exploration and, to assist explorers, the Geological Survey of Western Australia has undertaken a mineral systems analysis to define critical and constituent processes controlling their genesis, and mappable proxies for these processes. Critical processes include: i) mantle-derived magmas as a source for vanadium; ii) mantle plumes to transport mafic–ultramafic magmas through the crust; iii) reduced, anhydrous magmas that delay Fe-oxide saturation and allowed vanadium to concentrate in the melt; v) chemical and mechanical processes to generate magnetite layers within layered intrusions; vi) preservation of the vanadium orebodies. A Mineral System Tree has been constructed for layered mafic–ultramafic intrusion-hosted vanadium deposits to document the link between critical geological processes and their recommended geographic information system map layers for exploration.

KEYWORDS: exploration potential, GIS, layered intrusions, mineral exploration, vanadium

Introduction

Australia's Critical Minerals Strategy (Commonwealth of Australia, 2019) defines a list of minerals that are considered strategically important to Australia, and outlines the Federal Government's policy framework for advancing our critical minerals industry through investment, innovation and infrastructure. Vanadium is one of the elements included on the critical minerals list, largely due to its potential use in renewable battery technology, as well as its use in steel alloys and in **superconducting magnets**.

Vanadium can occur in sandstone- or shale-hosted deposits, in vanadate deposits that form in oxidized zones of base metal deposits, and generally in trace amounts in other magmatic-hydrothermal deposit types (alkaline igneous intrusions, Alaskan-type mafic intrusions, porphyry copper, vein-hosted gold). However, by far the primary source of vanadium is large, layered, mafic–ultramafic intrusions (Kelley et al., 2017). Significant layered mafic–ultramafic intrusion-hosted vanadium deposits occur in: South Africa (Bushveld Complex); Sichuan Province, China (Panzhihua layered intrusion); the Ural Mountains, Russia (Kachkanar massif); Quebec, Canada (Bell River [Matagami] and Lac Doré Complexes); and Australia (Kelley et al., 2017). The majority of Australia's defined vanadium resources are in Western Australia, and 99% of these are contained within layered mafic–ultramafic intrusions, including world-class examples at Speewah (4712 Mt @ 0.3% V_2O_5), Gabanintha (131 Mt @ 0.9% V_2O_5), and Windimurra (235 Mt @ 0.49% V_2O_5) (Summerfield, 2019). Therefore, only the layered mafic–ultramafic intrusion-hosted vanadium mineral system is considered here.

Resource companies exploring for mineral deposits understand that particular commodities are commonly found in certain deposit types that result from specific geological processes. The companies therefore analyse geological datasets to identify the most likely locations where such processes occurred. The Geological Survey of Western Australia (GSWA) has created the **Mineral Systems Atlas** to deliver sets of geographic information system (GIS) maps tailored to exploration for particular commodities and mineral deposit types.

This Record describes the process of creating such a spatial dataset for the layered mafic–ultramafic intrusion-hosted vanadium mineral system, including the conceptual basis for the Mineral Systems Atlas and the results of a metallogenetic analysis of this mineral system. The analysis is based on current understanding of the characteristics of layered mafic–ultramafic intrusions and the critical processes for associated vanadium mineralization (e.g. Cawthorn et al., 2005; Kelley et al., 2017).

Mineral Systems Atlas

The GSWA Mineral Systems Atlas is an interactive GIS platform that collates and delivers map-based geoscience data layers filtered for specific relevance to understanding and exploring for mineral deposits in Western Australia. Atlas content is systematically defined by applying the mineral systems concept advocated by Wyborn et al. (1994) and McCuaig et al. (2010). This concept has two basic premises: firstly, that mineral deposits will only form and remain preserved where there has been a spatial and temporal coincidence of critical earth processes (geodynamic setting, lithosphere architecture, fluid, ligand and ore component reservoir(s), fluid-flow drivers and pathways, depositional mechanisms, postdepositional processes); and secondly, that the occurrence of these critical processes might be recognized from mappable geological features expected to result from them. It is these geological features ('targeting elements' or 'geological proxies') that can be extracted as digital map layers from geoscience datasets, and which may be used in GIS-based prospectivity studies.

GSWA classifies mineral systems and subsystems (deposit types) after the scheme proposed by Fraser et al. (2007). The analysis of any particular mineral (sub)system draws on in-house knowledge, existing literature, and collaborations with subject-matter experts. Structured queries are then used to extract relevant data from statewide GSWA geoscience databases, for those proxies that can be practicably produced. These queries operate directly on, and are dynamically linked to, primary GSWA geoscience data sources. Thus, no new data are acquired or created, although some information may be reformatted to meet the internal requirements of particular map layers. Furthermore, the queries are scheduled to automatically update the derived proxy map layers whenever new data are added to the primary databases. Users may therefore be confident that the data layers portrayed in the Mineral Systems Atlas are as up to date as possible. The Atlas is complemented by a Guide that documents the important characteristics of the different mineral systems, and the procedures for generating the constituent GIS map layers. This Guide may be revised from time to time when there are improvements in our understanding of particular mineral systems and additions of relevant geoscience data to the GSWA databases.

Layered intrusion-hosted vanadium mineral system

Layered mafic–ultramafic intrusions

Layered mafic–ultramafic intrusions are differentiated bodies of mantle-derived igneous rock that typically form large, ovoid to sill-like bodies (100s–1000s km^2 areal extent), which are emplaced into the crust (Ernst and Buchan, 2001). They are mineralogically layered and broadly gabbroic in composition, typically with a significant ultramafic component towards the base of the intrusion (Ashwal, 1993). Layered mafic–ultramafic intrusions form an important part of the plumbing system of Large Igneous Provinces (LIP) that result from massive upwelling of mantle-derived magma (Ernst and Buchan, 2001). They are also associated with intracontinental rift systems (e.g. the Duluth Complex, US; Severson, 1994) and convergent margins (e.g. Alaskan-style intrusions; Himmelberg and Loney, 1995). Layered mafic–ultramafic intrusions are an important host for deposits of chromite, platinum group elements (PGE) and vanadium (Cawthorn et al., 2005).

Critical mineralization processes

The primary source of vanadium is the mantle, where it was incorporated into mafic melts that formed initially by partial melting in rising mantle plumes or upwelling asthenosphere during lithospheric thinning. These melts then rose and were emplaced into the crust within intracontinental rift zones, where they could pond and fractionate (Allen et al., 1995; Ernst and Buchan, 2001; Cawthorn et al., 2005). Magmas with tholeiitic compositions experienced delayed onset of Fe-oxide saturation, which allowed vanadium to concentrate in the residual melt (Nebel et al., 2013). Upon Fe-oxide saturation, magnetite and ilmenite start to crystallize into discrete layers concordant with other igneous mineral layering, preferentially sequestering vanadium in solid solution within their structure (Kelley et al., 2017). The formation of this distinct magnetite and ilmenite layering is poorly understood — proposed mechanisms include liquid immiscibility, mineral settling, and increases in oxygen fugacity and pressure (Cawthorn et al., 2005; Kelley et al., 2017).

As an aside, relatively small-volume, subduction-related, Alaskan-style intrusions generally have a higher water content than large-volume, rift-related magmas. This higher water content causes early magnetite crystallization and suppresses a 'magnetite crisis', limiting the ability to form an economic vanadium deposit (Himmelberg and Loney, 1995).

Mineral systems analysis

The objective of a mineral systems analysis is to define the critical and constituent processes responsible for metallogenesis, the targeting elements that might represent the occurrence of such processes, and the mappable proxies for the targeting elements (i.e. the GIS map layers). Such analyses can be conveniently summarized in graphical form in a 'Mineral System Tree'. Figure 1 shows this for the layered mafic–ultramafic intrusion-hosted vanadium mineral system. Critical processes for the layered intrusion-hosted vanadium system include: i) voluminous mantle-derived magmas that source vanadium from the mantle; ii) mantle plumes or intracontinental rift zones to transport magma into the crust; iii) anhydrous magmas that delay Fe-oxide saturation and allow vanadium to concentrate in the melt; and iv) sufficient uplift and erosion of overlying crust to expose the layered intrusions and orebodies, but not destroy them. The occurrence of these critical processes may be manifested by a variety of geological 'targeting elements', which themselves might be directly mappable, or instead be represented by one or more geological proxies (Fig. 1), each of which can potentially be fashioned into a GIS map layer in the Mineral Systems Atlas (Fig. 2). GIS layers for all mappable proxies can theoretically be generated using appropriately structured queries of relevant georegistered geological databases, although in practice, some proxies cannot currently be represented because the required databases are inadequate, incomplete or absent.

Examples of some mappable proxies for the layered intrusion-hosted vanadium system are provided in Figure 2. Queries used to produce these layers are documented in the **Guide to the Mineral Systems Atlas**.

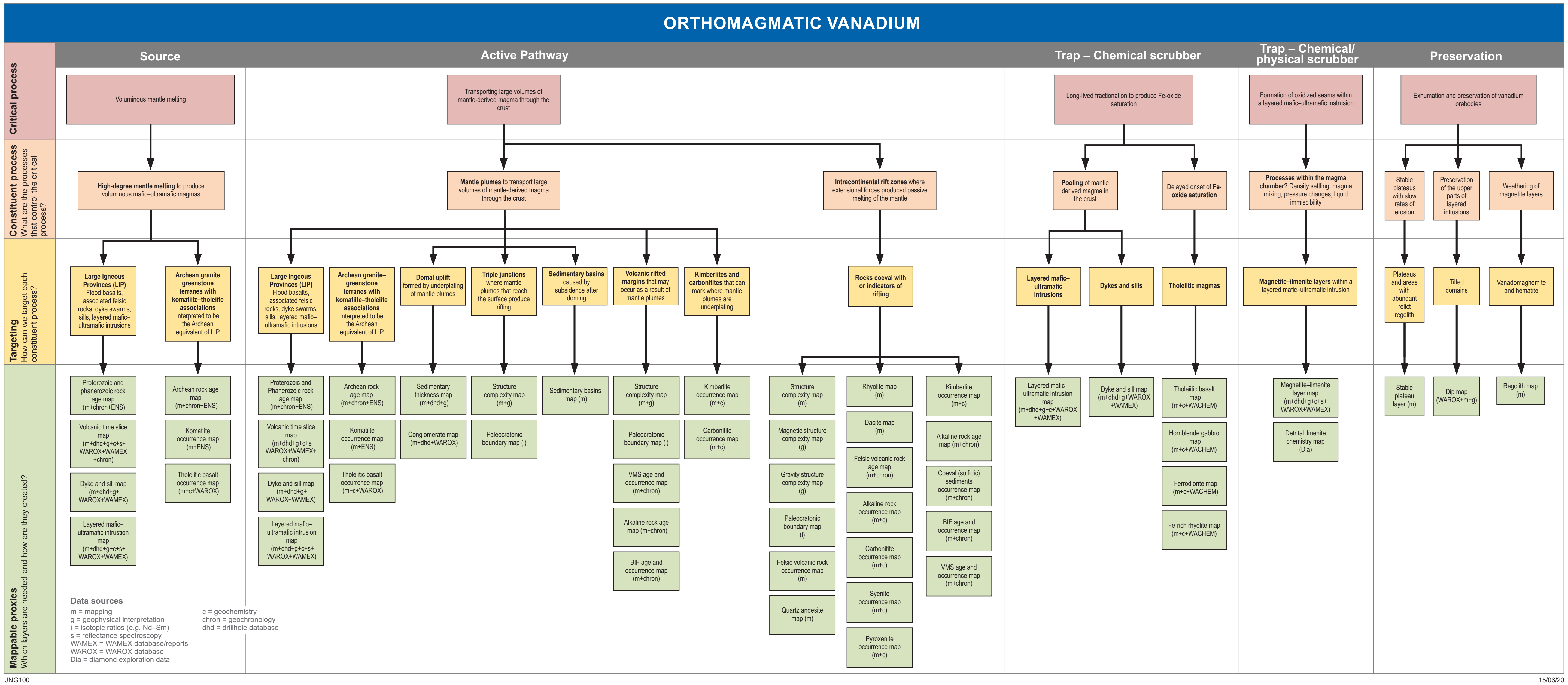

Figure 1. **The Mineral System Tree is the graphical display of a mineral systems analysis showing the link between critical and constituent processes, and their recommended targeting features and GIS layers. Abbreviations: BIF, banded iron-formation; ENS, Explanatory Notes System; WACHEM, Western Australia geochemistry database; WAMEX, Western Australia mineral exploration reports database; WAROX, Western Australia field observation sites database**

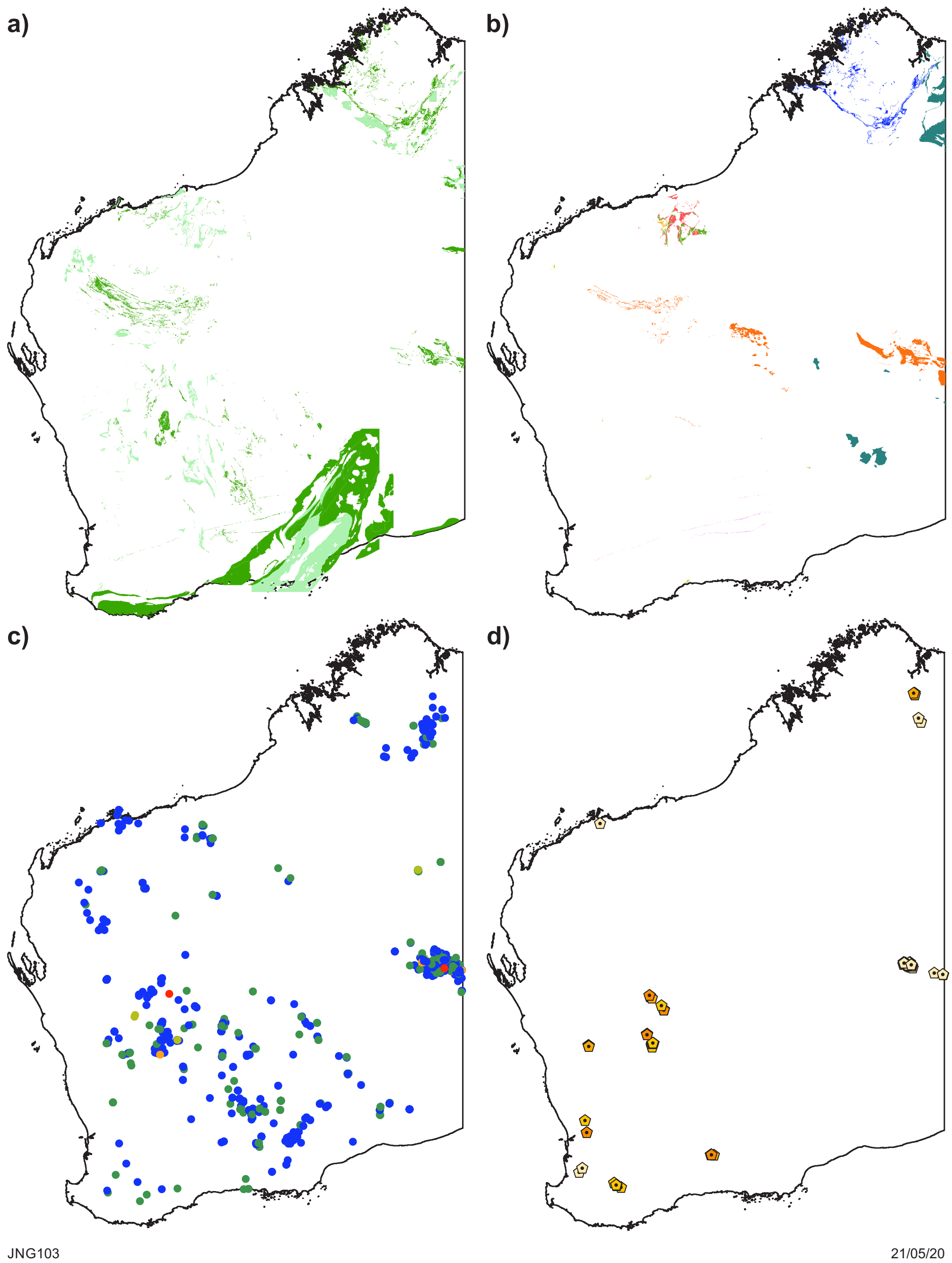

Figure 2. Examples of GIS map layers constructed to assist exploration for layered intrusion-hosted vanadium systems: a) distribution of gabbro, norite, and anorthosite in Western Australia, coloured by the likelihood of their presence in these areas (extracted from the GSWA 1:500 000 and 1:100 000 interpreted bedrock geology layers); b) distribution of LIP-related rocks in Western Australia, coloured by their respective LIP event (extracted from the GSWA 1:500 000 tectonic units layer); c) sample locations for gabbro, norite, anorthosite, magnetitite, and chromitite (excluding hornblende-rich equivalents), analysed for vanadium in parts per million (extracted from the GSWA geochemistry database); d) all recorded mines, deposits, prospects, and occurrences in Western Australia that contain vanadium as a target commodity; extracted from the mines and mineral deposits (MINEDEX) database. View the Mineral Systems Atlas online for descriptions of all map layers

References

Allen, DJ, Braile, LW, Hinze, WJ and Mariano, J 1995, The midcontinent rift system, U.S.A.: a major Proterozoic continental rift *in* Continental rifts: evolution, structure, tectonics *edited by* KH Olsen: Elsevier, Amsterdam, p. 373–407.

Ashwal, LD 1993, Anorthosites: Springer-Verlag, Berlin, 422p.

Cawthorn, RG, Barnes, S-J, Ballhaus, C and Malitch, KN 2005, Platinum-group element, chromium and vanadium deposits in mafic and ultramafic rocks, *in* Economic Geology 100th Anniversary Volume: 1905–2005 *edited by* JW Hedenquist, JFH Thompson, RJ Goldfarb and JP Richards: Society of Economic Geologists, Ottawa, Canada, p. 215–250.

Commonwealth of Australia 2019, Australia's Critical Minerals Strategy, 18p., <www.industry.gov.au/sites/default/files/2019-03/australias-critical-minerals-strategy-2019.pdf>.

Ernst, RE and Buchan, KL 2001, Mantle plumes: Their identification through time: Geological Society of America, Special Paper 352, 593p.

Fraser, GL, Huston, DL, Gibson, GM, Neumann, NL, Maidment, D, Kositcin, N, Skirrow, RG, Jaireth, S, Lyons, P, Carson, C, Cutten, H and Lambeck, A 2007, Geodynamic and metallogenic evolution of Proterozoic Australia from 1870–1550 Ma: a discussion: Geoscience Australia, Record 2007/16, 76p.

Himmelberg, GR and Loney, RA 1995, Characteristics and petrogenesis of Alaskan-type ultramafic–mafic intrusions, southeastern Alaska: United States Geological Survey, Professional Paper 1564, 41p.

Kelley, KD, Scott, CT, Polyak, DE and Kimball, BE 2017, Vanadium: Chapter U, *in* Critical mineral resources of the United States — Economic and environmental geology and prospects for future supply *edited by* KJ Schulz, JH DeYoung, RR Seal and DC Bradley: United States Geological Survey, Professional Paper 1802, p. U1–U36.

McCuaig, TC, Beresford, S and Hronsky, J 2010, Translating the mineral systems approach into an effective exploration targeting system: Ore Geology Reviews, v. 38, p. 128–138.

Nebel, O, Arculus, RJ, Ivanic, TJ, Rapp, R and Wills, KJA 2013, Upper Zone of the Archean Windimurra layered mafic intrusion, Western Australia: insights into fractional crystallisation in a large magma chamber: Journal of Mineralogy and Geochemistry, v. 191, no. 1, p. 83–107.

Severson, MJ 1994, Igneous stratigraphy of the South Kawishiwi intrusion, Duluth Complex, Northeastern Minnesota: Technical Report, NRRI/TR-93/34, 210p.

Summerfield, D 2019, Australia Resource Reviews: vanadium 2018: Geoscience Australia, Canberra, Australia.

Wyborn, LAI, Heinrich, CA and Jaques, AL 1994, Australian Proterozoic mineral systems: essential ingredients and mappable criteria, *in* Australian mining looks north — the challenges and choices *edited by* PC Hallenstein; 1994 AusIMM Annual Conference, Darwin, Northern Territory, 5 August 1994: Australian Institute of Mining and Metallurgy, p. 109–115.

RECORD 2020/9

LAYERED INTRUSION-HOSTED VANADIUM: A MINERAL SYSTEMS ANALYSIS

Guilliamse

This Record is published in digital format (PDF) and is available as a free download from the DMIRS website at <www.dmirs.wa.gov.au/GSWApublications>.

Further details of geolscience products are available from:

Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Phone: +61 8 9222 3459   Email: publications@dmirs.wa.gov.au
www.dmirs.wa.gov.au/GSWApublications

MINERAL SYSTEMS ATLAS