

Gamma-ray spectrometric and oxygen-isotope mapping of regional alteration halos in massive sulphide districts: an example from Panorama, central Pilbara Craton

David L. Huston¹, Carl W. Brauhart², Peter Wellman¹, & Anita S. Andrew³

The Panorama district, in the central Pilbara Craton (WA), is perhaps the best exposed, least deformed volcanic-hosted massive sulphide (VHMS) district in the world, and represents an ideal laboratory not only to study the genesis of such deposits but also to test the utility of exploration techniques. Recent studies there indicate that γ -ray spectrometric and whole-rock oxygen-isotope mapping effectively define regional- and local-scale alteration facies in VHMS districts. The application of simple K/Th ratios to γ -ray spectrometric data, acquired as part of AGSO's regional aeromagnetic survey of the Pilbara, defines a regional semiconformable zone of potassium depletion. This zone becomes transgressive below known deposits and prospects. Potassium depletion zones, which were detected remotely, correspond closely with zones of potassium mineral destruction mapped by Brauhart et al. (1998: *Economic Geology*, 93, 292–303). Similarly, oxygen-isotope mapping highlights the same semiconformable and transgressive zones as areas of low $\delta^{18}\text{O}$.

Two major (Sulphur Springs and Kangaroo Caves) and a number of smaller Zn–Cu VHMS deposits occur in the Panorama district at

or near the contact between the ca 3.24-Ga Kangaroo Caves Formation and the overlying turbiditic Gorge Creek Group (Fig. 16a). The Kangaroo Caves Formation consists of andesitic to rhyolitic volcanic rocks. It is intruded by the polyphase subvolcanic Strelley Granite, which is inferred to have acted as the heat source driving the hydrothermal circulation that formed the VHMS deposits and associated regional alteration zones.

The volcanic and granitic rocks have been altered into four broad assemblages (Fig. 16b):

- alkali feldspar–chlorite–calcite–quartz–pyrite ('background' spilitic assemblage),
- alkali feldspar–sericite–quartz,
- sericite–quartz, and
- chlorite–quartz.

The chlorite–quartz assemblage is closely associated with ore. It forms a semiconformable zone 0.1–0.2 km thick at the base of the volcanic pile; this zone becomes transgressive immediately below all known prospects (Brauhart et al. 1998: *op. cit.*).

Part I. Remote alteration mapping by γ -ray spectrometry

David L. Huston¹ & Peter Wellman¹

As the ore-related alteration assemblage of chlorite–quartz is characterised by a lack of potassium-bearing minerals, this alteration zone should be characterised by low potassium concentrations relative to the surrounding feldspar- and/or sericite-bearing zones. Over the past ten years, the quality of airborne γ -ray spectrometric surveys has improved dramatically, so that the absolute surface concentrations of potassium, uranium, and thorium can be estimated and gridded. Hence, airborne γ -ray spectrometry could effectively map feldspar- and sericite-destructive alteration zones, particularly in well-exposed areas such as the Panorama district.

As part of the joint AGSO–GSWA (Geological Survey of Western Australia) 'North Pilbara' project for the National Geoscience Mapping Accord, AGSO acquired γ -ray spectrometric data over the Panorama district in a 400-m-line-spaced aeromagnetic survey of the central and east Pilbara in mid-1996. A detector-specific calibration facilitated the raw data conversion to compositional data. As mass changes in hydrothermally altered rock are best viewed relative to immobile elements, potassium and uranium concentrations were ratioed to immobile thorium concentrations to produce images showing K/Th and U/Th.

Of these images, that showing K/Th mapped geological variations most effectively (Fig. 16c). Four broad zones with similar K/Th characteristics occur within the Strelley succession:

- a zone of intermediate values (0.14–0.20 % K/ppm Th) in the western (basal) part of the Strelley Granite,
- a zone of low values (0.08–0.14) in the eastern part of the Strelley Granite and the base of the volcanic pile,
- a narrow semiconformable zone of extremely low values (<0.08) in the lower part of the volcanic pile, and
- a zone of higher values (0.14–0.30) at the top of the volcanic pile.

Fingers of low K/Th ratios extend from the narrow semiconformable zone of extremely low values to the Kangaroo Caves and Sulphur Springs deposits (Fig. 16c), as well as the smaller prospects. The overlying Gorge Creek Group is characterised by variable, although generally high K/Th ratios.

Comparison of Figure 16c with Figures 16a and 16b indicates that the K/Th ratio effectively maps not only primary geological features, but also the distribution of important alteration facies within the Panorama district. In particular, the semiconformable zone of extremely low K/Th ratios corresponds closely to the K-mineral deficient zones mapped by Brauhart et al. (1998: *op. cit.*). The discordant chlorite–quartz feeder zones underlying the VHMS deposits also are characterised by low K/Th ratios. The zone of higher K/Th ratios at the top of the volcanic pile corresponds to feldspar- and sericite-bearing alteration zones.

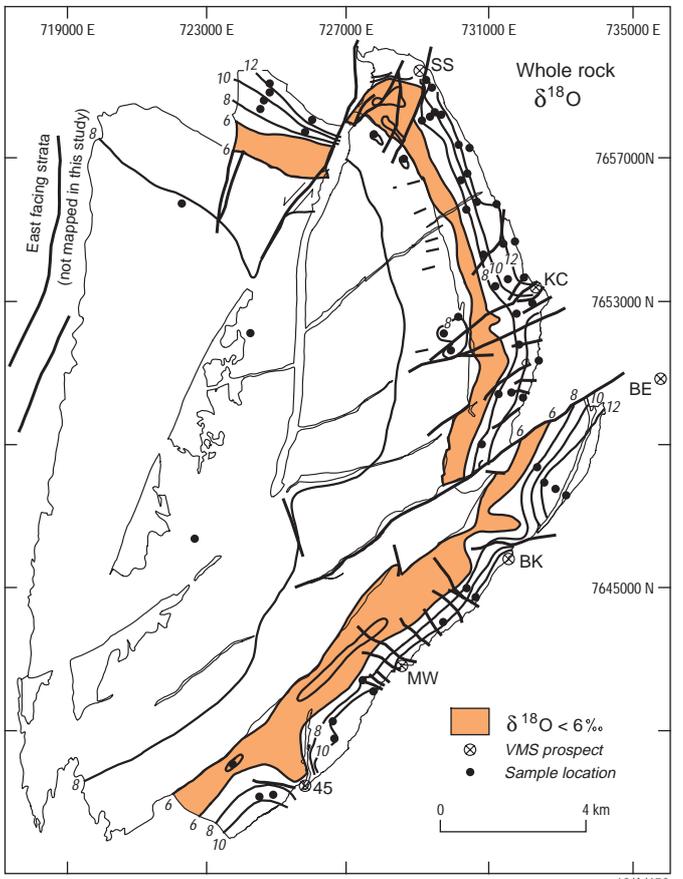
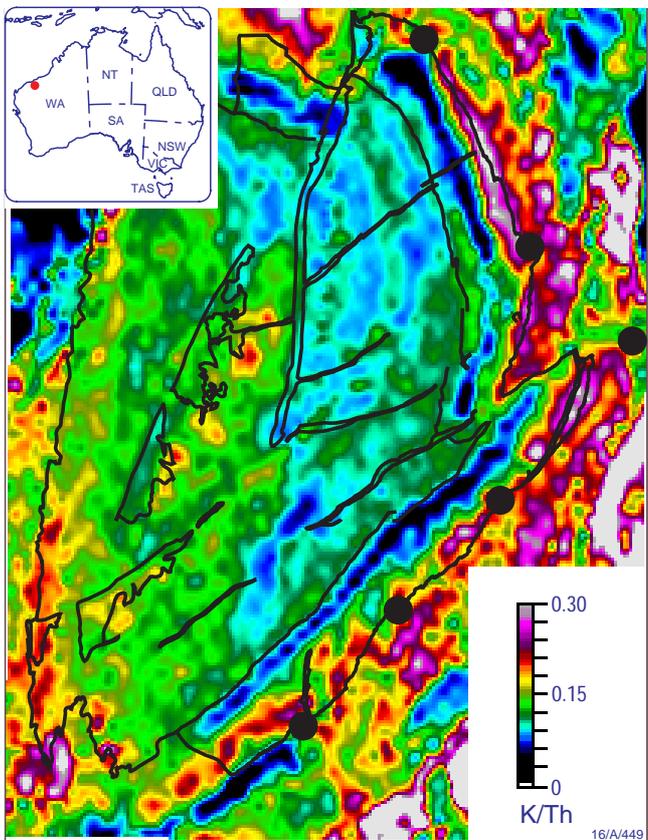
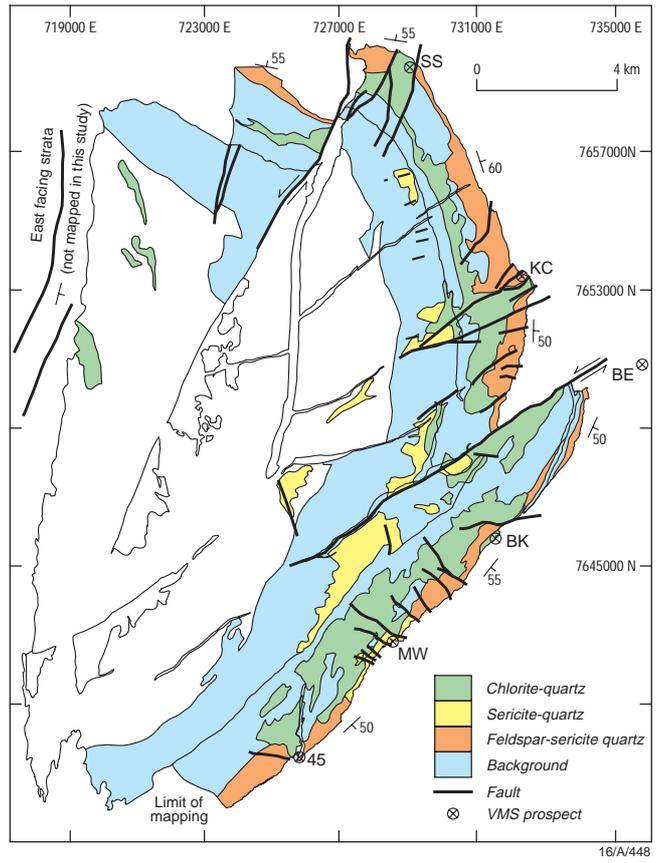
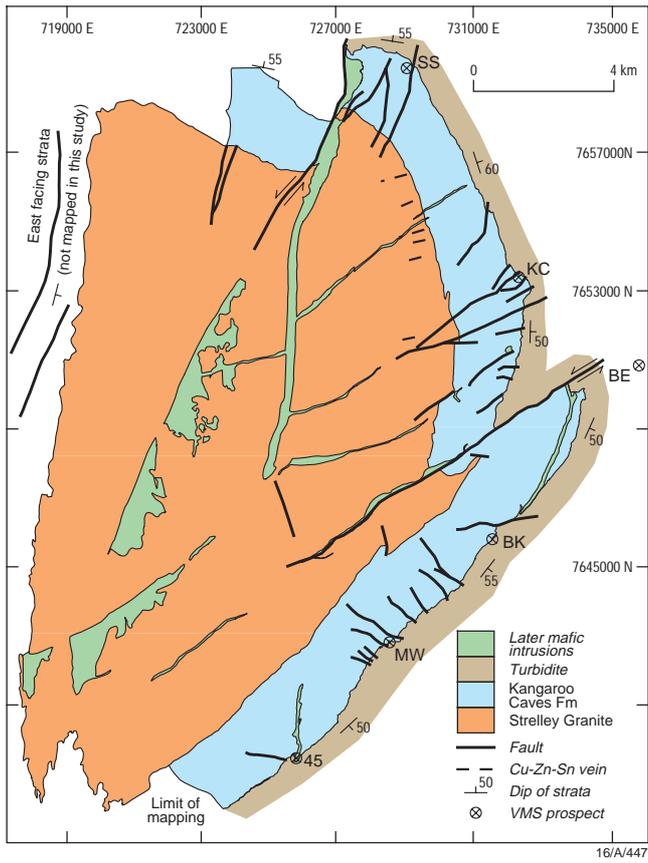


Fig. 16. Maps of the Panorama district showing (a, top left) geology, (b, top right) distribution of alteration facies, (c, bottom left) variations in the K/Th ratio from airborne γ -ray spectrometric data, and (d, bottom right) variations in whole-rock $\delta^{18}\text{O}$. Abbreviations of prospect names are as follows: BE = Berndts, BK = Breakers, KC = Kangaroo Caves, MW = Man O'War, SS = Sulphur Springs, and 45 = Anomaly 45 (partly modified after Brauhart et al. 1998: op. cit.).

Part II. Alteration mapping by oxygen isotopes

Carl W. Brauhart², David L. Huston¹, & Anita S. Andrew³

Although regional studies (e.g., Cathles 1993: *Economic Geology*, 88, 1483–1511) have demonstrated that the distribution of whole-rock $\delta^{18}\text{O}$ can define areas of high-temperature fluid flow in VHMS districts, such geochemical studies are not routinely integrated with geological and alteration mapping programs. To investigate the spatial relationship of whole-rock $\delta^{18}\text{O}$ to alteration facies, 188 fresh samples were analysed for $\delta^{18}\text{O}$ at the CSIRO Division of Petroleum Resources in Sydney.

Comparing Figures 16d and 16a reveals a steady decrease in $\delta^{18}\text{O}$ values from 12–14‰ at the top of the volcanic pile to less than 6‰ at the base. Beneath the Sulphur Springs deposit and the Breakers and Anomaly 45 prospects, pronounced discordant low $\delta^{18}\text{O}$ zones lead up to the mineralised horizon. At Kangaroo Caves and Man O'War, discordant low $\delta^{18}\text{O}$ zones are not well developed. Within the underlying Strelley Granite, $\delta^{18}\text{O}$ values are 6–8‰.

According to previous modelling of oxygen-isotope mobility in hydrothermal systems (e.g., Cathles 1993: *op. cit.*), the dominant control on $\delta^{18}\text{O}$ distribution (and alteration facies) is the temperature at which hydrothermal fluids alter rocks: whole-rock $\delta^{18}\text{O}$ decreases with the increasing temperature of fluid-dominated alteration. Hence, the $\delta^{18}\text{O}$ map shown in Figure 16d can be regarded as a crude map reflecting hydrothermal palaeotemperatures. Consequently, the semiconformable and transgressive low $\delta^{18}\text{O}$ zones are best interpreted as zones that have undergone intense high-temperature fluid flux. Moreover, zones of very high $\delta^{18}\text{O}$ are best interpreted as regions that have only reacted at low temperature, without interacting with high-temperature ore fluids. Hence, oxygen-isotope mapping can be used to establish zones of high-temperature *and* low-temperature fluid flow, information which can be used to focus exploration programs at regional and deposit scales.

Conclusions

The results of this study indicate that regional alteration facies in VHMS districts can be mapped effectively by remotely sensed γ -ray spectrometric data and by the distribution of whole-rock $\delta^{18}\text{O}$. Both techniques may be underutilised by the mineral exploration community. This study indicates that fairly straightforward processing of γ -ray spectrometric data can very effectively delineate regional alteration facies involving potassium metasomatism, particularly in well-exposed terranes such as the Pilbara Craton. Oxygen-isotope mapping effectively defines zones that underwent both low- and high-temperature reaction with hydrothermal fluids; this information can be used in mineral exploration both to focus on zones through which high-temperature ore fluids have passed and to exclude regions that have only interacted with low-temperature fluids.

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¹ Minerals Division, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601; tel. +61 2 6249 9577 (DLH), +61 2 6249 9653 (PW); fax +61 2 6249 9983; email David.Huston@agso.gov.au, Peter.Wellman@agso.gov.au.

² Centre for Teaching and Research in Strategic Mineral Deposits, University of Western Australia, Nedlands, WA 6009; tel. +61 8 9481 6259; fax +61 8 9322 3047; email sipa@iinet.com.au.

³ CSIRO Division of Petroleum Resources, PO Box 136, North Ryde, NSW 1670; tel. +61 2 9490 8743; fax +61 2 9490 8197; email Anita.Andrew@syd.dpr.csiro.au.