# HYPERSPECTRAL MAPPING OF EARTH'S EARLIEST HYDROTHERMAL ACTIVITY IN AN ARCHEAN GRANITE-GREENSTONE TERRANE

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## 1 Introduction

As part of a joint Commonwealth Scientific and Industrial Research Organization (CSIRO)–Australian Centre for Astrobiology (ACA) project to map hydrothermally altered minerals in the East Pilbara Granite-Greenstone Terrane (EPGGT), mineral maps of epithermal activity in two regions of volcanic successions have been compiled using an airborne hyperspectral dataset. The differing mineral suites suggest epithermal activity characterized by high and low sulphidation, possibly at the Archean seafloor or in a shallow marine environment.

### 1.1 Motivation

In 2005, NASA will launch a hyperspectral visible/near infrared-short wavelength infrared-infrared (VNIR-SWIR-IR) instrument called the Compact Reconnaissance Infrared Spectrometer for Mars (CRISM) onboard the Mars Reconnaissance Orbiter (MRO) mission. In order to increase the probability of this mission encountering a Martian geobiological event of interest, this project is studying some of the oldest, best-preserved volcanic successions with life signs on Earth, at the Pilbara Craton, Western Australia. Three water-related signs of interest exist in the target terrain:

a. pillow basalts,
b. stromatolites, and
c. serpentinized ultramafics.

The discovery of any of these water signs on Mars would be of great significance for the understanding of the geological development of the planet and verifying the existence of an extant or extinct Martian biosphere.

## 2 Geological Setting

The study area discussed herein lies in a region called the North Pole Dome (NPD) (see Figure 1), a succession of ovoid shaped volcanic units surrounding a central monzogranite, interpreted as a syn-volcanic laccolith (Van Kranendonk, 2000). The volcanic units form part of the 3.5-3.3 Ga Warrawoona Group, and include ultrabasic komatiite, mafic and felsic units (Brown *et al.*, 2004a) that dip 30–70 degrees away form the central monzogranite. A summary of the stratigraphy of the Warrawoona Group, along with associated fossil and stromatolite assemblages, is given in Table 1.

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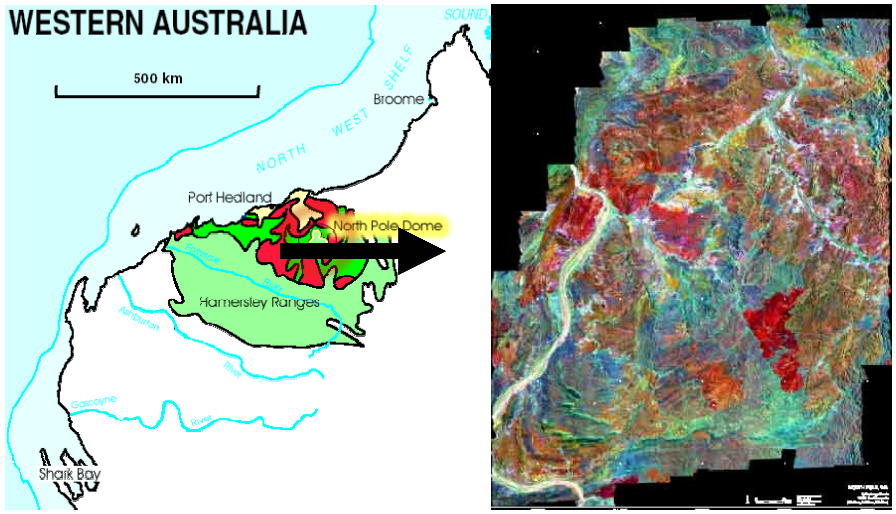


Figure 1 – Location map for the North Pole Dome and overall dataset. Central latitude and longitude of the dataset are 119°E 21°S. Dataset is approximately 27 km wide and north is up.

Table 1 – Stratigraphic column of Warrawoona Group units present at the North Pole Dome (Van Kranendonk, 2000). Dates are derived from U-Pb isotopes from zircons in the units and are accurate to approximately 3 million years; from Thorpe (1992).

| *Age (Ga)* | *Unit* | *Fossil assemblages* |
|---|---|---|
| | Euro Basalt | |
| 3.458 | Strelley Pool Chert | Well-preserved conical stromatolites (Hofmann *et al.*, 1999) |
| | Panorama Formation | |
| | Apex Basalt | Microfossils within Apex Chert (Schopf, 1993) |
| 3.470 | Duffer Formation | |
| | Dresser Formation | Domical stromatolites and microfossils (Walter et al. 1980; Awramik 1983) |
| | Mt Ada Basalt | |
| 3.515 | Coonterunah Group | |

## 2.1 Hydrothermal Alteration

Submerged hydrothermal vents have been posited as a possible setting for the genesis of life (Nisbet and Sleep, 2001). In the search for signs of life in early Archean terrains, such as the Pilbara, hydrothermally altered zones are an attractive location to commence looking. In addition to the ability of hydrothermal activity to sustain life, it also has the capability of preserving life signs (Walter and Des Marais, 1993). These principles would be as true for life on Mars as they are for life here on the early Earth.

### 2.1.1 Dresser Formation

There are two primary hydrothermal events in evidence at the North Pole Dome. The first event, terminating at the Dresser Formation, is characterized by subvertical black cherts leading up to a palaeo-surface, now replaced by chert, at the top of the Dresser Formation. The black cherts were first proposed as sedimentary features (Dunlop and Buick, 1981) but have now been interpreted as hydrothermal conduits (Nijman *et al.*, 2001), and carbon isotope geochemistry has led some researchers to propose them as an early niche for life (Ueno *et al.*, 2004). Barite accompanies the black chert throughout the unit, and has been proposed as a syn-depositional exhalite product of the hydrothermal system (Van Kranendonk and Pirajno, in press). Domical stromatolites have been found at the extremities of Dresser Formation. This has led to some researchers suggesting the Dresser Formation was an early habitat of life (Groves *et al.*, 1981).

The style of alteration at the Dresser Formation is quite distinct from that found at a later horizon within the NPD, at the Strelley Pool Chert (SPC) level.

### 2.1.2 Strelley Pool Chert

The 3.2 Ga Strelley Pool Chert is a stromatolitic marker chert unit found in several regions throughout the Eastern Pilbara (Lowe, 1983). It outcrops distinctively at the outer extremities of the NPD, on top of the felsic Panorama Formation. It consists of carbonate and silicified stromatolites, black and white injection cherts and a succession of silicified clastic horizons. It is overlain by the pillow basalts of the Euro Basalt unit.

The presence of stromatolites (Hofmann *et al.*, 1999) and black and white injection cherts has lead some to propose a hydrothermal-based biosphere in the Early Archaean. This has been disputed (Lindsay *et al.*, 2003) but is an intriguing possibility. The underlying Panorama Formation is in places altered pervasively to pyrophyllite, and several sericite-rich veins lead up to the SPC level, cutting vertically through the underlying Apex and Panorama Formations. These will be discussed further below.

## 3 Methods

A VNIR-SWIR hyperspectral dataset covering 600 sq. km of the NPD region was collected on 22 October 2002. The dataset was collected with the HyMap instrument (Cocks *et al.*, 1998), which is analogous to the AVIRIS instrument. The Pilbara coverage was collected as 14 swathes, each 2 km wide. The instrument was flown at approximately 2.5 km, or 8200 ft above mean sea level (AMSL). Spectral coverage was between 450–2500 nanometers in 126 contiguous bands. The date of the collection was timed to coincide with the end of the local dry season, in order to minimize vegetation coverage. The spatial resolution of the dataset is approximately 5 m per pixel along track.

Mineral maps were produced using the continuum-removed SWIR region by applying the “spectral feature fitting” method in the ENVI software (www.rsi.com). Representative spectra were identified using a combination of spectral library comparison and ground testing through fieldwork. Hand samples were collected with the assistance of a PDA and GPS unit and were analysed using PIMA (portable infrared mineral analyzer: hand-held spectrometer), petrographic thin section, X-ray diffraction (XRD) and X-ray fluorescence (XRF).

## 4 Results

The dataset was delivered as radiance at sensor and was subsequently processed using the CSIRO-developed ‘Hycorr’ program, which is based upon the ATREM (ATmosphere REMoval) program, to give approximate surface reflectance. In addition, using the software program ENVI, the dataset was treated by a ‘continuum removal’ algorithm (Clark *et al.*, 1987). This enhanced the features in the 2.0-2.4 micron SWIR region, which are of most interest when detecting hydrothermally altered minerals.

Figure 2 displays representative continuum-removed spectra of five different hyodrothermal alteration minerals extracted from the HyMap dataset. Note the spectra appear similar in regions of the spectrum up to 2.0 microns. In the SWIR region, significant differences exist that enable them to be differentiated from each other.

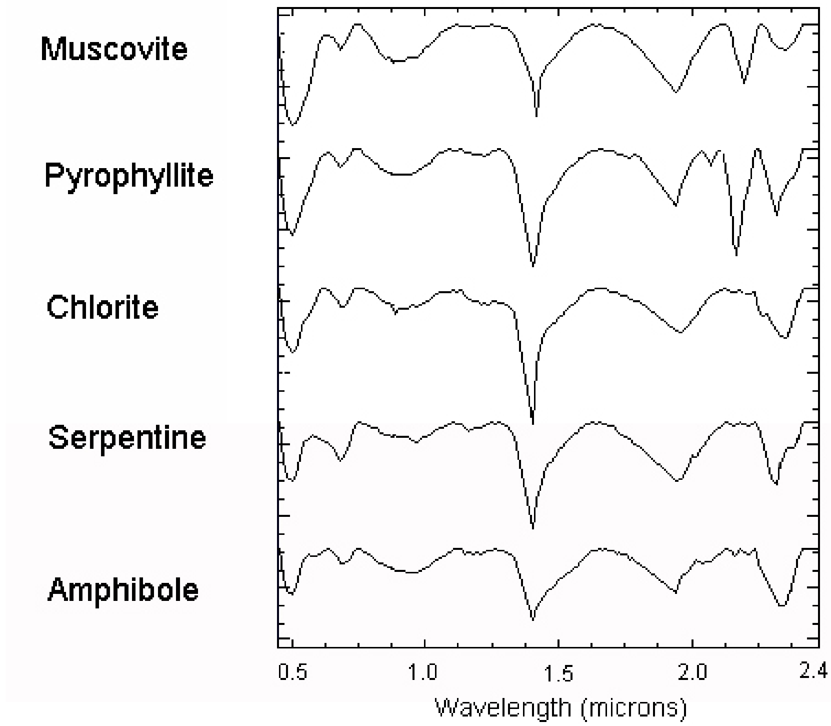


Figure 2 – Continuum-removed spectra of representative hydrothermal minerals extracted from the North Pole dataset. Each mineral is offset for clarity. Note differences between minerals are apparent in the 2.0–2.4 micron region.

Contrasting mineral assemblages were found at the Dresser Formation and Strelley Pool Chert levels; representative mineral maps are shown in Figures 3 and 4 below.

### 4.1 Dresser Formation

At the Dresser Formation level, it was possibly to discern an intense zone of sericitic alteration capped by a thin serpentinitic alteration layer, overlain by an intense chlorite layer. The region is also cut by several late quartz porphyry veins unrelated to alteration at this level. These are rich in sericite and are seen to cut through all horizons. From field mapping, it was determined that the intense sericitization was most likely due to pervasive and intense weathering of country rock basalts most likely affected through hydrothermal veins, now present as prominent black chert veins that cut through and terminate at a cap chert below the serpentine-rich horizon. The serpentine-rich layer was determined to be an ultramafic peridotite, most probably representing the basal layer of a komatiite succession (Brown *et al.*, 2004a). The overlying chlorite layer most probably represents seafloor alteration of the constituent basalts.

In addition to mapping the alteration minerals, black chert units that have been posited as feeder conduits for the Dresser Formation hydrothermal activity (Nijman *et al.*, 1998) can be seen clearly in the visible region of the spectrum, often due to thin Fe-rich veneers that preferentially coat the chert. These are visible as east-west trending lineaments in Figure 3.

The hydrothermal activity that produced the sericite alteration most probably occurred in a low-pH environment. The presence of large barite deposits within and surrounding the vein testifies to an oxidizing fluid, if one is to accept that the Archean environment was generally reducing (Ohmoto, 1997; Holland, 1999). These locally oxidizing conditions may have been created by a primitive biosphere living in the hydrothermal vents.

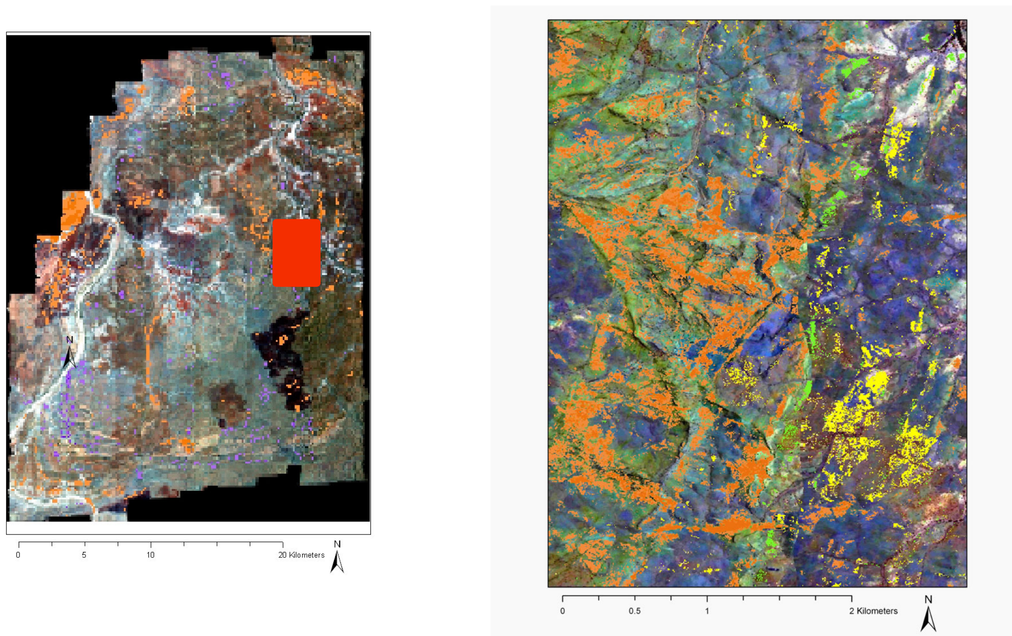


Figure 3 – Mineral map for the Dresser Formation region with context map on left showing coverage. Sericite is orange, serpentine light green (vertical strip in middle) and chlorite is yellow. East-west trending lineaments are massive black cherts, interpreted as feeder dykes for hydrothermal sites at the Dresser level (see text).

## 4.2 Strelley Pool Chert Mineral Assemblages

At the Strelley Pool Chert level, horizontal mineral assemblages of carbonate-chlorite are overlain by a thin but prominent sericite-pyrophyllite layer (at the Panorama felsic volcanic level), which is in turn overlain by a chlorite-rich layer. Sericite-rich veins grade into pyrophyllite and then terminate at the Strelley Pool Chert layer. Some layers within the Strelley Pool Chert display sericite signatures (Brown *et al.*, 2004b); however, there is no pyrophyllite within the Strelley Pool Chert.

It is hypothesized that this alteration style betrays the actions of an acid-sulfate hydrothermal system as described by previous researchers (White and Hedenquist, 1990). The presence of a thin continuous layer of pyrophyllite beneath a chert horizon and associated with sericite veins leading up to this horizon shows similarities with acid-sulfate Porphyry Cu argillic alteration, as portrayed in Figure 4 below (Bonham Jr. and Giles, 1983).

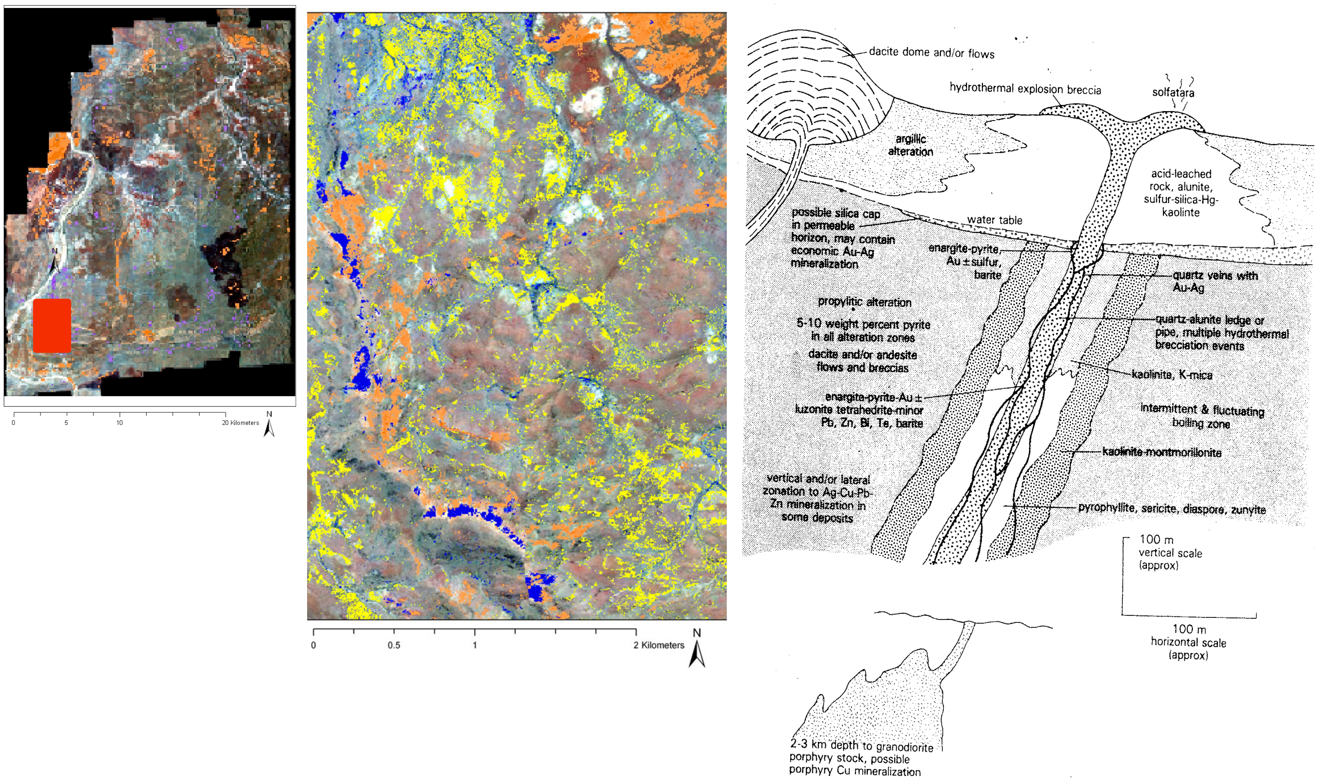


Figure 4 – Hydrothermal alteration at the Strelley Pool Chert level. Image on left shows coverage of central image. In central image, orange represents sericite, yellow chlorite and blue pyrophyllite. Image on right (from Bonham Jr. and Giles, 1983) shows typical mineral assemblages of an acid-sulfate epithermal vein.

## 5 Conclusion

This study into hydrothermal alteration amongst some of the best-preserved, oldest rocks preserved on this planet is continuing. Latest results are being published at the project website - http://aca.mq.edu.au/abrown.htm. Hyperspectral mapping has already demonstrated the ability to detect mineral assemblages that give vital clues to interpretation of the conditions within these hydrothermal systems.

In 2005, NASA will launch the hyperspectral VNIR-SWIR Compact Reconnaissance Infrared Spectrometer for Mars (CRISM) onboard the Mars Reconnaissance Orbiter (MRO). The instrument will have a spatial resolution of approximately 16 m in high-resolution mode (Murchie *et al.*, 2003). This will allow researchers to investigate signs of hydrothermal alteration using the critical SWIR region at scales approaching that expected for individual veins of an epithermal deposit. Application of the lessons learned from mapping volcanic terrains such as the Warrawoona Group in Western Australia will be of vital importance in informing the search for possible past or present habitats of life on Mars.

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