

ASTER geoscience map of Western Australia

by

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Introduction

The public release of the ASTER geoscience maps of Western Australia, 2011 (14 in total, example shown in Fig. 1) represents an important benchmark. That is, it is the first and spatially largest public release of precompetitive geoscience information from the world's first and, to date, only operational, geoscience-tuned, global-mapping satellite system — the Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The release of the Western Australian ASTER geoscience maps, chiefly mineralogy, represents 20 years of successful collaboration between many national and international organizations (see Acknowledgements).

This paper introduces the opportunities ASTER geoscience maps can provide for mineral exploration at the continental to prospect scales. It also provides background information on the ASTER system, in that it explains how and why the derived ASTER geoscience products were designed to capture accurate (for its resolution) mineral information. The key message is that the value of this new precompetitive geoscience information is dependent on the geological–mineralogical models developed and applied by users. It also underlines the fact that ASTER was designed to provide only broad mineral-group information, and not the content and physicochemistry of specific minerals, which would require a much higher spectral resolution.

Background

The Mineral Council of Australia (2006) recognized that Australia is an attractive place to explore, in part because of its growing national coverage of publicly available precompetitive geoscience data, such as airborne radiometric and magnetic data.

However, the Council also recognized that a new generation of geoscience data and knowledge is required to help reveal hidden prospectivity, and to reduce risk in 'frontier areas' across Australia. This was recently echoed in the findings of the 2010 Theo Murphy Think Tank, 'Searching the Deep Earth' (Australian Academy of Science, 2010), which specifically recognized the need to solve issues such as building a national map of the character of the cover, and developing tools to recognize the 'distal footprint' or far-field signatures of giant ore-systems. However, the exploration community has not previously had access to national precompetitive mineral information maps.

Over the last 10+ years, there have been developments in a new generation of geoscience-tuned spectral sensing systems, operating from drillcore, field, airborne, and space platforms, all of which can, in theory, be used to provide mineral information, even in three dimensions (<<http://c3dmm.csiro.au>>).

This emerging mineral-mapping technology measures natural electromagnetic radiation, in wavelengths extending from visible light (0.4–0.7 μm) through to thermal infrared (TIR; 7–12 μm), which is reflected or emitted from the top few microns of a material. Importantly, this wavelength range spans atmospheric windows that allow the measurement of diagnostic spectral features for minerals significant to the characterization of primary geology, metamorphism, metasomatic alteration, and weathering effects (<<http://speclab.cr.usgs.gov/spectral-lib.html>>).

However, these diagnostic mineral absorption features are often very narrow, such that hundreds of channels are theoretically required to measure the complete wealth of available mineral information, not only including the abundances of specific minerals, but also their chemical and structural variations. Such systems are often called 'hyperspectral', and include the Australian airborne HyMap system (<www.hyvista.com>), CSIRO's HyLogging suite (<<http://www.csiro.au/Portals/Publications/Brochures--Fact-Sheets/hylogging.aspx>>), and a number of hyperspectral satellites scheduled to be launched starting 2015 (<www.isiswg.org>).

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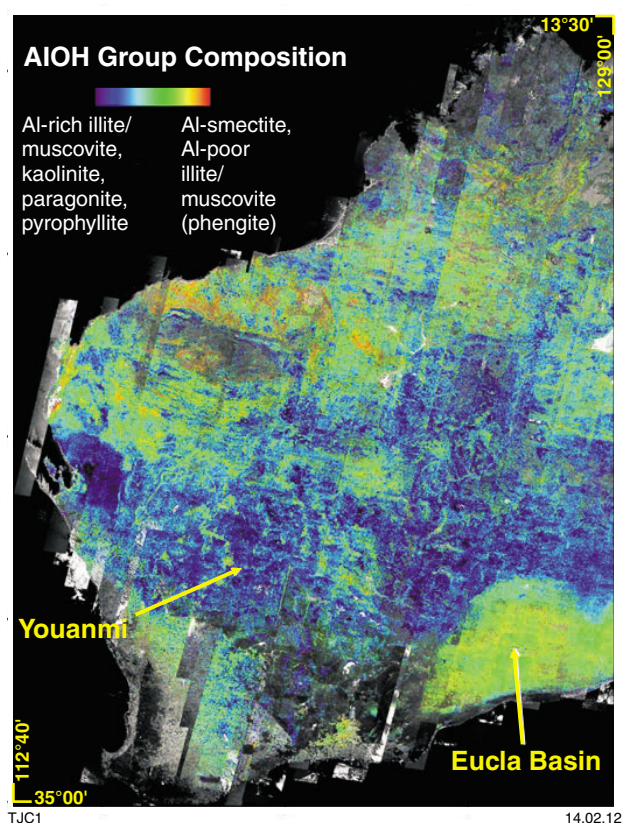


Figure 1. Western Australian ASTER geoscience map of AIOH Group Composition.

ASTER

Japan's ASTER imaging system was launched onboard the USA's TERRA satellite platform in December 1999 (www.ersdac.or.jp; <http://asterweb.jpl.nasa.gov>). ASTER was included on this multisensor platform in large part because it provided a 'zoom' optical lens (15–90 m pixel resolution for 60 x 60 km wide scenes) for MODIS (Moderate Resolution Imaging Spectro-radiometer — 250–1000 m pixel resolution and a 2330 km wide swath). Both ASTER and MODIS are multispectral systems with 14 and 36 bands, respectively. MODIS was designed to measure parameters such as: concentration of atmospheric gases, like water vapour and ozone; chlorophyll absorption in photosynthesising biomass; and kinetic temperature. In contrast, ASTER was designed to map the Earth's land-surface composition (below 80° latitude), especially its mineral-group information, such as aluminium-clays, iron oxides, carbonates, and silica. That is, each ASTER band in the 1–12 μm region was positioned over a diagnostic spectral feature for a mineral group, such as ASTER Band 6, positioned at 2.2 μm to capture Al–OH bond vibration absorption in dioctahedral silicates like kaolinite, illite, and montmorillonite.

CSIRO's ASTER geoscience processing

In theory, only 15 independent parameters can be measured or mapped with ASTER's 14 available spectral bands though CSIRO's processing methods. These processing methods are based on developing multiple parameters and masks for each geoscience product, allowing additional geoscience products to be generated. Notes for the Version 1 ASTER geoscience products (Cudahy, 2011) show how each is generated, potential complications to their content, and examples of how they can be used geologically. The ASTER product notes also provide information about the qualitative and, in some cases, quantitative accuracy of each geoscience coverage. For example, in the absence of any vegetation, the RMSE (root mean square error) of iron oxide content is 11%, and that of aluminium-clay content is 5% (Haest et al., in press). Both green and dry vegetation complicate the accuracy of these interpretations, although future versions of the ASTER geoscience output are expected to reduce this error (Rodger and Cudahy, 2009).

Version 1 of the Western Australian ASTER geoscience maps only use ASTER's nine reflected bands (bands 1–9, spanning the 0.4 – 2.5 μm wavelength region) as suitable independent validation data were not available for the five TIR bands. To enable the validation of the shorter wavelength products, CSIRO used the national archive of the Hyperion satellite hyperspectral (covers the 0.4 – 2.5 μm wavelength region) imagery. In brief, the processing of the ASTER raw data (radiance-at-sensor) into geoscience coverages involved corrections and statistical cross-calibrations for instrument, solar irradiance, geometric, atmospheric, vegetation, and overlapping mineral absorption effects. The Western Australian ASTER mosaic used 1500 scenes, selected from CSIRO's archive of greater than 30000 Australian scenes (sourced from Geoscience Australia, ERSDAC, NASA, and USGS). The final 14 digital Western Australian ASTER geoscience maps were then divided up into 1:1 000 000 scale map sheets (at ~100 Mb each map product) and converted to GIS-compatible formats (see below).

Version 1 of the ASTER geoscience map of Western Australia comprises three types of ASTER geoscience products, namely:

- Mineral group content, absorption depth relative to band/s outside of the absorption — ideally a continuum
- Mineral group composition, related to absorption geometry (wavelength)
- Mineral group index, which is sensitive to the material type, but not specifically its content or composition.

Figure 2 shows this distinction for the AIOH group, where content and compositional information plot along different trajectories for minerals either rich or poor in Al–OH vibrational bonds. Thus, an *AIOH Group Content* (ASTER bands: $[5+7]/6$) mask of more than two units is required

to more accurately map the composition of those pixels that contain AIOH minerals, such as kaolin, muscovite, and phengite. Without this mask to remove pixels with no apparent AIOH clay absorption, the resultant 'composition' image will show colour information for all pixels, but with much of this information incorrect. This explains why most ASTER mineral maps have many black (null data) pixels.

ASTER geoscience data access

The Western Australian ASTER geoscience maps are available to the public digitally, either as GIS-compatible images (e.g. in TIF and JPG format) or in image-processing software formats (e.g. BSQ with headers). The BSQ files are useful for those who want to set local colour stretches or apply filters to remove noise. The statewide ASTER mosaics were divided into 1:1 000 000 map sheets, with individual file sizes reduced to approximately 100 Mb each. The complete dataset, including the BSQ data (approximately 500 Gb), is available from the Department of Mines and Petroleum's Information Centre, as an external drive. The image (TIF and JPG format) data can be downloaded directly from CSIRO's website (<<http://c3dmm.csiro.au>>) and can be viewed on the Auscope Discovery Portal (<<http://portal.auscope.org/portal/gmap.html>>).

Geological demonstrations

The real value of these ASTER geoscience maps can be unlocked by applying geological models that accurately account for the mineralogical attributes of regolith cover, as well as the alteration footprints related to mineralized systems. That is, the maps are more than just colourful pictures for traditional photo-interpretation, although the *CSIRO Landsat TM Regolith Ratio* map was designed for this purpose. Instead, the ASTER mineral-group content, composition, and index products were specifically designed to capture both the potential of the ASTER spectral band configuration, and the quantitative information it can provide for mineral exploration purposes.

The ASTER geoscience product notes (Cudahy, 2011) provide more details on application, but as an example here, a useful exploration consideration could be mapping redox (reduced–oxidized) gradients (Neumayr et al., 2008), which can be gauged using the following ASTER coverages: (1) *Opaque Index*, which is sensitive to reduced rocks like graphitic shales, magnetite, and, if present at the surface, sulfides; (2) *Ferrous Iron Index*, which is sensitive to reduced iron (Fe^{2+}) bearing silicates (e.g. actinolite) and carbonates (e.g. ankerite, siderite); and (3) *Ferric Oxide Content*, which is sensitive to oxidized (Fe^{3+}) iron in the form of oxides (hematite and goethite) and sulfates (e.g. jarosite).

Figure 1 shows how the ASTER geoscience maps reveal mineralogical patterns at the continental scale. In this case, the ASTER *AIOH Group Composition* map shows patterns that reflect bedrock geology and/or climate.

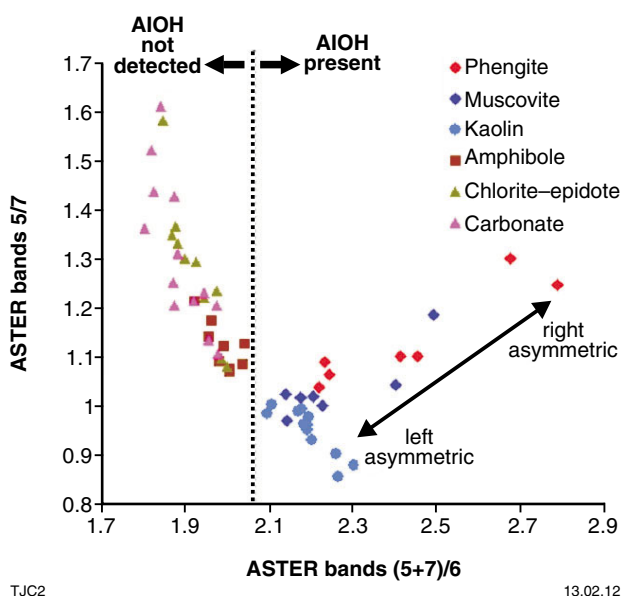


Figure 2. Scattergram of the ASTER-derived AIOH Group Content ($(B5+B7)/B6$) versus the AIOH Group Composition ($B5/B7$) products, for a selection of pure minerals from the ENVI USGS mineral spectral library. From Cudahy et al. (2008).

For example, the alkaline regolith conditions associated with the underlying carbonate rocks across the Eucla Basin have promoted the formation of soils rich in aluminium-smectite (warm colours in Fig. 1). In contrast, kaolin-rich soils are developed in a belt extending from 25–30°S latitude (cooler blue tones in Fig. 1), which straddles different bedrock types, including rocks of the Yilgarn Craton, Albany–Fraser Orogen, and the silica-rich sedimentary basins north of the Eucla Basin. These relatively silica-rich bedrock units are often associated with neutral to acid conditions, which promote kaolin (and hematite) development. However, the drier conditions of the 25–30°S latitude belt is likely more important as a controlling factor, as the same or similar bedrock found in latitudes less than 25°S and greater than 30°S preferentially develop illite–smectite (and goethite), presumably because the climate is wetter. Importantly, these ASTER mineralogy data are consistent with river sediment studies (Gingele and de Deckker, 2004), soil type studies (<<http://www.asris.csiro.au>>), and a recent Australian clay map modelled from a national soil spectral-data archive (Viscarra Rossel, 2011).

At the prospect-scale, and using the same basic mineralogical models, Figure 3 shows how the *Ferric Oxide Composition* map can be used to map transported versus in situ materials for an area near Youanmi, in the Murchison region. Based on a model where hematite, poorly ordered kaolin, and a lack of primary minerals are the mineralogical evidence for transported materials (Anand and Payne, 2002; Cudahy et al., 2005), the black vector outlining the hematite-rich (red) area in Figure 3b

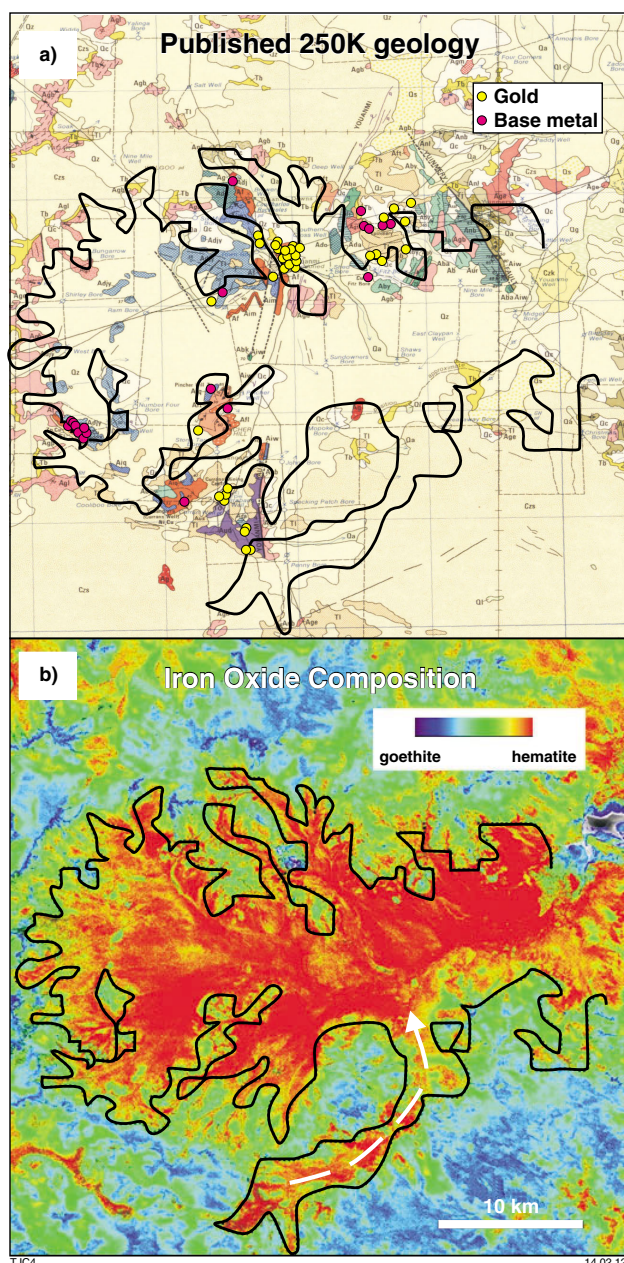


Figure 3. (a) Published 1:250 000 geology of the Youanmi area, with overlays of the gold and base metal occurrences, and a black vector marking the 'hematite-rich' areas shown in part b); (b) ASTER Iron Oxide Composition product, with hematite-rich in red and goethite-rich in blue. A 10 km scale bar is shown.

represents transported material within a drainage basin. This vector has then been overlain on the published 1:250 000 geology in Figure 3a, showing the following points: (1) there is generally good correspondence between ASTER data and the alluvium/colluvium mapped for a drainage basin; (2) the published 1:250 000 geology appears to have missed a major drainage channel extending from the south (dashed curved white arrow; Fig. 3b); and (3), not unexpectedly, all the known mineral occurrences were found in areas of exposed bedrock geology.

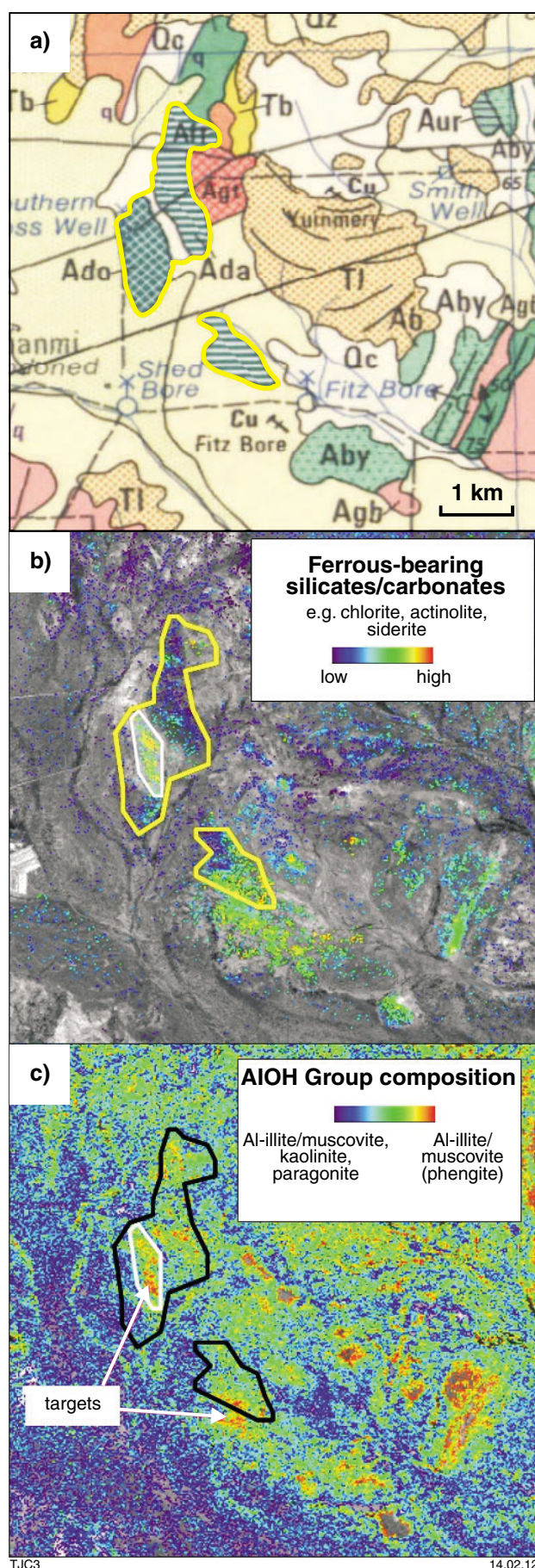
This example shows that characterization of the regolith maps can be quickly compiled using this type of spatial mineral information, provided there is a suitable model of the regolith available. This enables the accurate digital mapping of transported 'cover' versus exposed (albeit variably weathered) bedrock, which will assist in devising more efficient sampling and drilling programs. It also highlights the possibility to reveal new exploration targets, such as uranium-calcrete or gold-placer paleochannels.

Figure 4 presents an example of how the ASTER mineral maps can be used to recognize 'metasomatic' alteration in naturally exposed greenstones. First, to set up the exploration model, a target host-rock for gold mineralization is selected to be a mafic rock, such as 'dolerite', which is consistent with the Golden Mile style of gold mineralization with superimposed potassium metasomatism and related iron-chlorite and 'sericite' development (Bateman and Hagemann, 2004). The known dolerites in the exploration area near Youanmi are highlighted by yellow vectors overlain on the 1:250 000 scale published geology (Fig. 4a). Figure 4b of the *Ferrous Iron in MgOH Group* map, shows that these mafic rocks comprise MgOH minerals (possibly including amphibole, chlorite, talc, serpentine, and/or carbonate), but that their ferrous iron contents vary from low (cool tones) to high (warm tones). This change in the Fe^{2+} content of the MgOH mineralogy can be a function of differentiation or layering within the mafic igneous rocks, or of cross-cutting hydrothermal alteration. The presence of Fe^{2+} -bearing chlorite could explain the pattern observed in the area highlighted by the white vector (Fig. 4b), making this area an exploration target as per the 'exploration model' being tested here. Note that the ASTER *FeOH Group Content* product should also be used to support this interpretation of chlorite.

Evidence for potassium metasomatism is offered by the *AlOH Group Composition* map (Fig. 4c), which has muscovite/phengite appearing as warmer tones. These tones appear over most of the highlighted dolerite units in the 1:250 000 scale published geology (Fig. 4a), and are also coincident with the area interpreted as chloritic (white vector; Fig. 4b). However, Cudahy (2011) notes that mixing with chlorite, carbonate, and dry vegetation can also influence the accuracy of the current *AlOH Group Composition* product, exaggerating warmer colours. Therefore, it is recommended that checks be made to help confirm the mineralogical interpretation, such as confirming (in this case) whether the 'muscovite/phengite' pixels also have high *AlOH Group Content*, low *FeOH Group Content*, and low *Green Vegetation Content*.

Figure 4b shows that this reduced 'fresh rock' signature extends >1 km to the southeast, over an area mapped as colluvium in the published 1:250 000 geology, and which is associated with copper mineralization. This provides an additional exploration target, as parts of this same area also contain muscovite-phengite (Fig. 4c).

This 'soft' geological modelling approach based on the ASTER mineral maps, can be transformed into 'hard' mathematical computer models reducing the need for visual, subjective interpretation, and capturing the intrinsic quantitative nature of these 'measured' data. This would



enable the rapid processing of large volumes of ASTER mineral maps, and other similar precompetitive digital spatial data, for regolith characterization and target generation in mineral exploration.

Closing points

This first public release of Australian ASTER geoscience products allows explorers in Western Australia to appreciate the geological value available from this new generation of 'geoscience-tuned' remote sensing data that can be applied from the continent to prospect scale. These data can be used for a wide range of mineral commodity styles, with their value essentially dependent on the geological models developed and tested by geoscientists. The National ASTER Geoscience map is scheduled for public release at the 34th International Geological Symposium, to be held in Brisbane, Queensland, in August 2012.

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Figure 4. (a) Published 1:250,000 geology of the Youanmi area, with yellow vector overlays showing the target host-rock, namely dolerite, used for a hypothetical exploration model; (b) ASTER product of Ferrous Iron in MgOH Mineral Group, which is used here to map distal alteration of Fe^{2+} chlorite and/or actinolite; (c) ASTER product of AIOH Group Composition, used to map areas of silicon-rich white mica (phengite), indicating proximal potassium-metasomatism.

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