DETERMINING THE BIOGENICITY OF MICROFOSSILS IN THE APEX CHERT, WESTERN AUSTRALIA, USING TRANSMISSION ELECTRON MICROSCOPY.

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Introduction: For over a decade, the oldest evidence for life on this planet has been microfossils in the 3.5 Ga Apex Chert in Western Australia [1]. Recently, the biogenicity of these carbon-rich structures has been called into question through reanalysis of the local geology and reinterpretation of the original thin sections. Although initially described as a stratiform, bedded chert of siliceous clasts, the unit is now thought to be a brecciated hydrothermal vein chert [2]. The high temperatures of a hydrothermal environment would probably have detrimental effects to early non-hyperthermophilic life, compared to that of a shallow sea. Conversely, a hydrothermal origin would suggest that if the microfossils were valid, they might have been hyperthermophilic.

Apex Chert controversy. The Apex Chert microfossils were originally described as septate filaments composed of kerogen similar in morphology to Proterozoic and modern cyanobacteria [1, 3]. However new thin section analysis shows that these carbonaceous structures are not simple filaments [2]. Many of the original microfossils are branched and have variable thickness when the plane of focus is changed. Hydrothermal alteration of organic remains has also been suggested for the creation of these strange morphologies [4].

Another point of contention lies with the nature of the carbon material in these proposed microfossils. Kerogen is structurally amorphous, but transforms into well-ordered graphite under high pressures and temperatures. Raman spectrometry of the carbonaceous material in the proposed microfossils has been interpreted both as partially graphitized kerogen and amorphous graphite [2, 5]. However, these results are inconclusive, since Raman spectrometry cannot adequately discriminate between kerogen and disordered graphite [6].

There are also opposing views for the origin of the carbon in the Apex Chert. The carbon would be biogenic if the proposed microfossils are indeed the remains of former living organisms. However, an inorganic Fischer-Tropsch-type synthesis is also a possible explanation for the formation of large-aggregate carbonaceous particles and could also account for the depletion of ^{13}C observed [2].

Methods: Previous studies of the Apex Chert have focused on petrographic analysis, stable isotope analysis, and now Raman spectrometry. However there are some benefits for using the more time-intensive methods of transmission electron microscopy (TEM). There are TEM techniques for imaging and determining both crystal structure and composition, all at the nanometer scale. High-resolution images can directly show local crystal structure, and may be used to differentiate between graphite and amorphous carbon, or kerogen. The two techniques for determining chemical composition are energy dispersive x-ray spectrometry (EDS) and electron energy-loss spectrometry (EELS).

As electrons pass through the sample, they can interact with it either elastically or inelastically. Inelastic collisions will cause the electrons in the beam to lose some of their energy, creating an energy spectrum within the transmitted beam. Dispersing the beam with a magnetic prism produces an electron energy-loss spectrum. Ionization edges appear on the spectrum when electrons lose energy to promote bonding electrons into empty orbitals, giving information on bonding within the material.

Graphite and Kerogen in TEM. Both graphite and amorphous carbon affect the high-energy loss portion of the EELS spectrum at the carbon K-edge (Fig. 1). The differences between the two spectra are due to differences in carbon-carbon bonding. Due to more ordered crystal structure and regular bonding, the spectra of both ordered and disordered graphite show a sharp π* peak followed by a wide, flat-topped σ* peak. At the front edge of the σ* peak is another sharp peak called the "A" peak [7]. The spectrum for amorphous carbon, however, only has a small π* shoulder, a sloping σ* peak, and no "A" peak [7]. These spectra are different enough to be able to distinguish the two carbon phases.

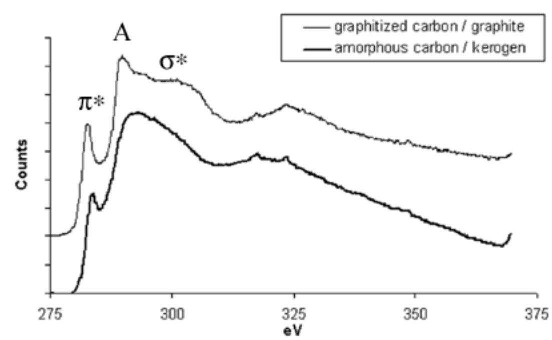

Figure 1. EELS spectra of carbon in Apex Chert and graphitized carbon, which are similar to the EELS spectra of amorphous carbon and graphite, respectively.

Previous Studies: The Gunflint Formation in Canada is a well-accepted microfossiliferous chert. Kerogen is found associated with Gunflint microfossils and is distributed along quartz grain boundaries [8]. EELS spectra of the kerogen are identical to that of amorphous carbon [8].

Results: The Apex Chert is full of carbonaceous material, and this residual carbon is distributed along quartz grain boundaries and at triple junctions (Fig. 2), similar to the Gunflint kerogens. High-resolution images show that the carbon has no crystal structure. EELS spectra of this material shows the distinctive amorphous carbon profile (Fig. 1), suggesting it is kerogen. This spectrum can be compared to a spectrum of graphitized carbon under similar microscope conditions, which shows a definite graphite profile (Fig. 1).

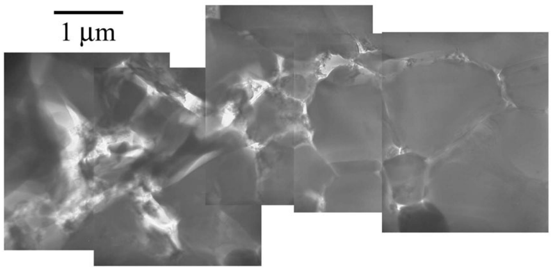

Figure 2. TEM image mosaic of Apex Chert kerogen (white) distributed along the boundaries of quartz grains (gray).

Kerogen is also found inside fluid inclusions in quartz crystals (Fig. 3). These inclusions form perfect hexagonal negative crystals that are completely or partially filled with visibly amorphous material. EDS analysis shows that the material inside the inclusions is in fact kerogen. Kerogen inside fluid inclusions suggests that organic matter was suspended in a fluid when the quartz precipitated.

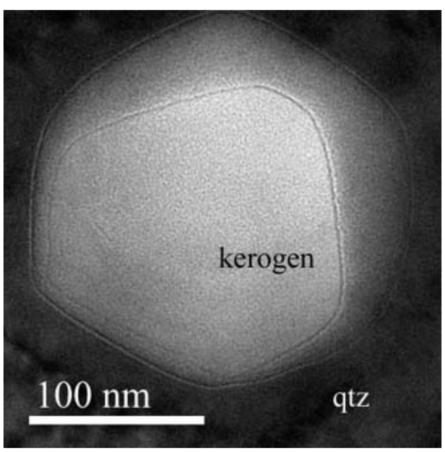

Figure 3. Kerogen within a fluid inclusion in a quartz crystal. This hexagonal inclusion is completely filled with amorphous carbon.

Discussion: The presence of kerogen within fluid inclusions agrees with a hydrothermal origin for the chert, however it does not rule out biogenicity. Three possible scenarios arise for the formation of kerogens in the Apex Chert:

(1) Hyperthermophilic organisms occupying thermal springs were silicified and later altered by hydrothermal pore fluids, which transported some of the organics to fill fluid inclusions in quartz crystals. These fluids would also have altered the microfossils to form the strange morphologies that are observed [4].

(2) Biogenic organic matter was transported from a nearby microbial community by hydrothermal fluids. The Apex Chert microfossils would not be true microfossils, but still would contain biogenic kerogen. This agrees with the abundance of kerogens throughout the chert. Microfossil-like morphologies would be created when a microbe was not fully degraded.

(3) The Apex Chert does not contain any biogenic material. The high temperatures in the hydrothermal fluids led to a Fischer-Tropsch type synthesis of large organic molecules, which agglomerated into larger kerogenous particles that could resist degradation by diagenetic processes [2].

Conclusions and Future Work: The kerogen within the Apex Chert is amorphous, not graphitized as recent researchers have suggested [2]. However, kerogen inside fluid inclusions implies a hydrothermal origin for the chert, which agrees with the recent geological remapping of the area [2]. Kerogen has been transported by hydrothermal fluids, complicating the problem of determining biogenicity. In this study, no kerogen was clearly part of a morphologically defined microfossil; so additional TEM analysis of the carbon associated with the proposed microfossils is necessary.

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