Two-stage degassing of the Archaean mantle: evidence from the 3.46 Ga Panorama volcano, Pilbara Craton, Western Australia

by

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The NORTH SHAW 1:100 000 sheet area of the Pilbara Craton is famous for hosting the world's oldest stromatolites in (silicified) carbonate- and sulfate-bearing horizons interbedded with volcanic rocks of the c.3.46 Ga Warrawoona Group. Previously, the origin of carbonate–sulfate deposits has been interpreted as due to evaporative precipitation from shallow seawater (Lambert et al., 1978; Buick and Dunlop, 1990). However, a conformable relationship of these beds on felsic volcanic rocks in one setting, their association with growth faults in another, and the presence of magmatic carbonate in the vent of the 3.46 Ga Panorama felsic volcano, combine to indicate a genetic relationship between volcanism, carbonate–sulfate deposition, and early life (Glasby, 1998).

The best place to observe these relationships is in the North Pole Dome (Fig. 1), where three distinctive carbonate–sulfate units were deposited between c. 3.49 and 3.46 Ga (Richards et al., 1981; Thorpe et al., 1992). The lowest unit is the Towers Formation, which comprises up to three beds of chert–barite–gypsum within a graben underlain by growth faults. Growth faults were filled by chert–barite dykes that form a radial boxwork set emanating from the core of the dome. In the bedded sequence, gypsum and barite occur both in bedded deposits and as diagenetic minerals. The occurrence of barite mounds over terminations of the growth faults (Nijman et al., 1998), of barite in the growth fault dykes, and of bedded barite and gypsum (Buick and Dunlop, 1990; Nijman et al., 1998), combine to indicate an exhalative origin for some of the sulfates. A previous suggestion that barite–chert dykes were formed by later doming (Buick and Dunlop, 1990) is unlikely because the dykes are restricted to below the Towers Formation, and because thickness variations of bedded deposits relate to the growth faults. An exhalative origin for sulfates is confirmed by identical magmatic $\delta^{34}S$ values of +3.6 ± 0.5‰ for both bedded and discordant barite (Lambert et al., 1978).

The second unit, which is barren of stromatolites, consists of lower and upper felsic tuff beds, bounding an 8 m-thick sequence of cross-bedded to massive carbonate-altered tuff. Petrographic textures indicate that the carbonate is largely of replacement origin, but this is difficult to reconcile with the observation that the carbonate horizon is bound above and below by unaltered felsic volcaniclastic rocks.

The overlying Strelley Pool Chert, which contains abundant and widespread stromatolites, occurs on felsic volcaniclastic rocks of the 3.46 Ga Panorama Formation. The Strelley Pool Chert is up to 20 m thick, and consists of thinly bedded carbonate, beds with gypsum-crystal rosettes, and wavy-laminated rocks interpreted to have

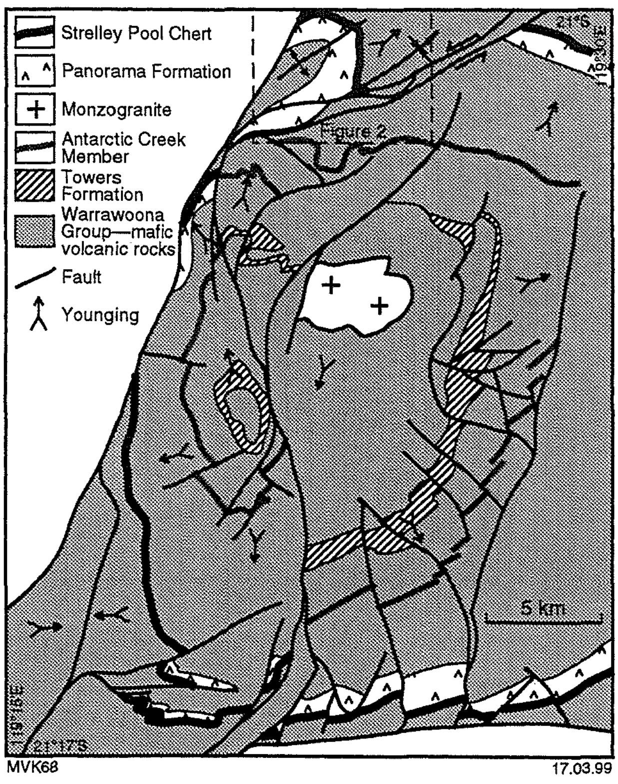

Figure 1. Carbonate/sulfate-bearing horizons of the North Pole Dome

formed by the transformation of anhydrite to gypsum. In some places, the wavy-laminated rocks and beds with gypsum or aragonite crystal splays have been replaced by diagenetic carbonate (ferroan dolomite and/or ankerite), indicating both a depositional and a replacement origin for the carbonates. The presence of evaporitic solution breccias at specific stratigraphic levels indicates periodic supratidal exposure, whereas evidence of wave action at other stratigraphic levels suggests periodic shallow-marine conditions (Buick and Dunlop, 1990).

The key to the origin of carbonate–sulfate assemblages and their relationship to felsic volcanism lies in the Panorama felsic volcano, which has been tilted by late folding to provide a cross-sectional view (Fig. 2). The volcano comprises a vent of unsorted breccia that is rimmed by, and cuts through, an apron of jaspilitic banded iron-formation. Adjacent to the vent is a kilometre-thick volcaniclastic apron, over which the Strelley Pool Chert is absent. The volcaniclastic rocks comprise, from base to top, bedded carbonate and jasper, volcaniclastic debris flows with abundant jasper fragments, finer grained volcaniclastic rocks with local pumiceous beds, and cross-bedded volcaniclastic siltstones. Proximal to the vent, volcaniclastic rocks contain abundant carbonate (ferroan dolomite ± ankerite) in the matrix, and are locally cut by metre-wide carbonate dykes. Distal to the vent, an almost identical sequence lacks carbonate. Within the vent, the unsorted felsic volcanic breccia is cut in three places by small, dark-brown carbonate plugs, the smallest of which is 1m in diameter and packed with angular jasper fragments, texturally identical to flanking debris flows.

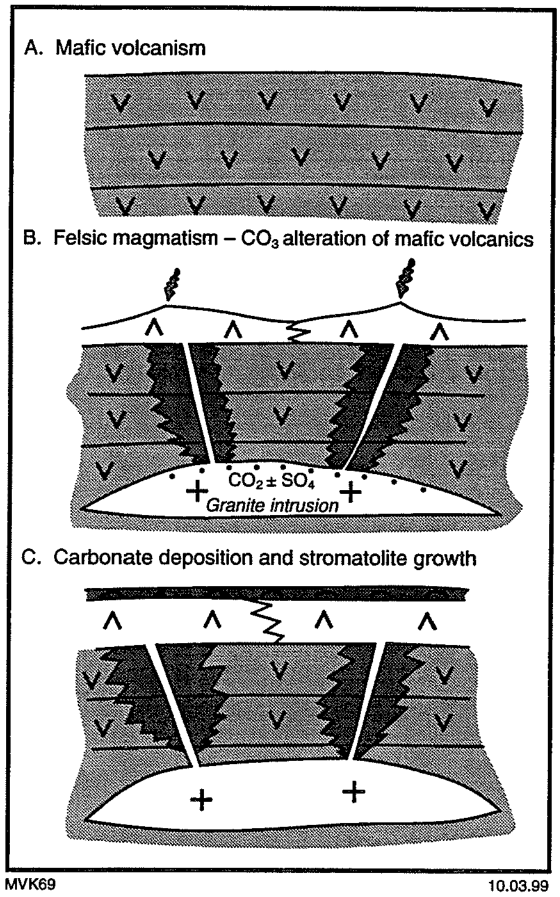

Figure 3. Model for carbonate/sulfate deposition during felsic volcanism

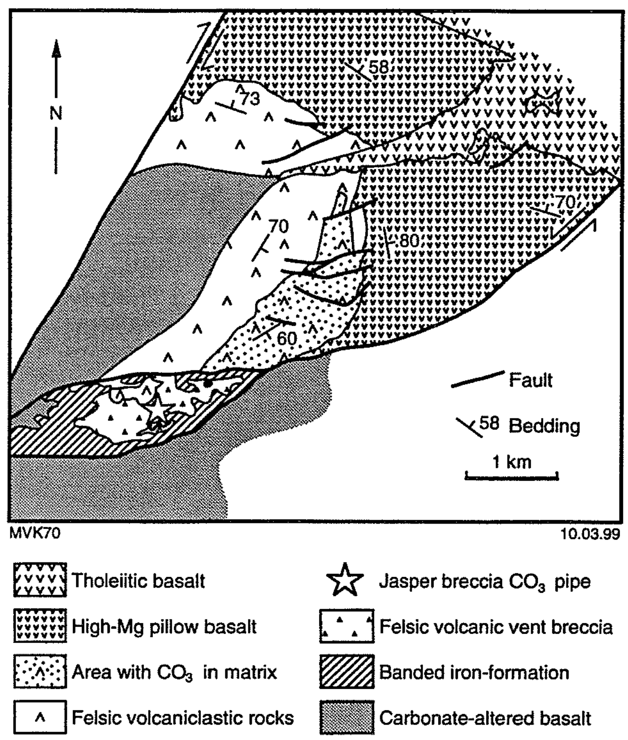

Figure 2. Geology of the Panorama volcano

Petrography of the breccia pipe shows that carbonate is restricted to the matrix and absent from included fragments of dacite and jasper. In the matrix, silica occurs both as a fine-grained component with rhomboid carbonate, and also as irregularly shaped, texturally-zoned, monomineralic patches between carbonate-bearing areas. The outer zone of silica in these patches forms radially fibrous crystals that nucleated on the terminations of carbonate rhombs. In the bigger patches, the fibrous zone grades into an inner zone of equigranular, granoblastic quartz. These textures are indicative of boiling fluids and of immiscibility between consanguineous carbonate-bearing and carbonate-absent fluids. It is thus clear that carbonate was an integral part of the matrix during magmatism, and not an introduced component during alteration. Additional evidence of a magmatic origin for carbonate is indicated by the fact that felsic feeder dykes to the Panorama Formation have a wide carbonate halo in host mafic volcanic rocks. Indeed, this carbonate alteration extends throughout the underlying pillowed mafic volcanic rocks, in sharp contrast to overlying mafic volcanic rocks that are far less altered.

This evidence suggests that Archaean carbonate is not derived solely through precipitation from seawater. Instead, it is proposed that the $CO_2 \pm SO_4$ in Early

Archaean Pilbara deposits was largely sourced from oxidized volcanic exhalations, and that these exhalations produced locally oxygenic conditions suitable for habitation by early microbial organisms. Whereas precipitation of carbonate–sulfate from seawater must have played a part in the formation of these units, it is argued that such unusually oxygenating conditions (i.e. Archaean seawater typically precipitated silica and had a lower partial pressure of sulfate than the present day; De Ronde et al., 1998) were locally developed in response to volcanic exhalations. A crustal melt origin for the Panorama Formation (Cullers et al., 1993) indicates that the carbonate–sulfate, and the iron around the vent of the Panorama volcano, were probably scavenged from older mafic volcanic rocks during melting and magma genesis. In this sense, carbonate–sulfate deposition in Archaean units reflects two-stage degassing of the Archaean mantle (Fig. 3).

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