Early tectonic dewatering and brecciation on the overturned sequence at Marble Bar, Pilbara Craton, Western Australia: dome-related or not?

N.H.S. Oliver a,*, P.A. Cawood b

a Economic Geology Research Unit, School of Earth Sciences, James Cook University, Townsville, Qld 4811, Australia
b Tectonics Special Research Centre, School of Applied Geology, Curtin University, GPO Box U1987, Perth, WA 6001, Australia

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Abstract

Cataclastic breccias and hydrothermal fault arrays of likely c. 3400 Ma timing are well developed and exceptionally well exposed in the Marble Bar Chert Member of the Pilbara Craton. Brecciation involved centimetre- to metre-scale clast transport distances, in breccia zones up to 5 m wide, cutting the c. 60 m thick chert in a series of right-lateral fault zones. Our observations of downward facing pillow basalts, the geometry of the breccias, and oxygen isotope data for rocks and the breccia matrix suggest the rocks were at least steeply overturned on this flank of the Mt Edgar Dome prior to brecciation. The breccias are inferred to represent steep conjugate fault zones developed by local transtension. The history of overturning and brecciation predates the formation of dome-related regional foliation and metamorphism, and therefore occurred between 3460 and 3320 Ma, the established ages for deposition of the underlying Duffer Formation and intrusion of the Mt Edgar Batholith respectively. Local overturning of the Marble Bar sequence prior to both brecciation and the main phase of dome formation suggests a protracted deformation history for this segment of the Pilbara Craton. The transtensional movement along the breccias may be representative of strain accommodation accompanying an early doming phase, or could be a deformation event that developed independently of doming. Fluids involved in brecciation were most likely formation waters expelled from the cherts and basalts in response to overpressuring induced by the overturning and progressive burial. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Spectacular exposures of cataclastic breccia are preserved in the chert at the famous “Marble Bar” in the Pilbara Craton. The Marble Bar is a...
misnomer from early pioneering days, actually being a 50–70 m thick outcrop of banded chert, around which the Coongan River has created a series of permanent waterholes, and after which the nearby town of Marble Bar was named. This paper documents the breccias exposed at the Marble Bar, which record a complicated history of overturning, cataclasis and faulting, prior to the development of regional tectonic fabrics associated with doming and greenstone metamorphism.

Not only is the Marble Bar one of the world’s oldest breccia systems, brecciation occurs in finely bedded cherts, allowing approximation of clast movement and fragmentation paths, and an estimate of the overall flow direction (of matrix and clasts) within the breccias. One of the aims of this paper is to document the spectacular brecciation and speculate on brecciation processes. Secondly, the relationship of the bedded chert, the siliceous breccia, and adjacent, overturned pillow basalts, allows the reconstruction of the history of deformation and tectonic dewatering of the cherts, which represent part of the earliest history of deformation exposed in the Pilbara Block. Polyphase doming in the Pilbara has been recognised by previous authors (e.g. Hickman, 1983 Collins, 1989); others have identified areas with early normal faulting then thrust stacking (van Haaf ten and White, 1998), and possible nappelike tectonics (Bickle et al., 1985). This paper also aims to contribute to understanding some of the details of deformation features that predate the main phase of doming around the Mt Edgar Batholith, to attempt to clarify some of the issues remaining with the protracted, early Archean deformation history.

2. Pilbara geology

The Pilbara Craton consists of a series of early to mid-Archean granite domes enveloped by intervening greenstone belts, all unconformably overlain by late Archean to Paleoproterozoic strata of the Hamersley Basin (Hickman, 1983). The Marble Bar Chert Member lies with the dominantly volcanic Warrawoona Group greenstone sequence on the western flank of the domal Mt Edgar Batholith (Fig. 1, Hickman and Lipple, 1978). The group is divisible into the lower Talga Talga and upper Salgash subgroups separated by the Duffer Formation. In the Marble Bar region the group youngs to the west, lying on the east limb of the Warrawoona Syncline. The Marble Bar Chert Member occurs within the Towers Formation at the base of the Salgash subgroup. It accumulated at around 3460 Ma, based on U/Pb zircon dates of between 3471 ± 5 and 3463 ± 2 Ma for the Duffer Formation and 3458 ± 1.9 Ma for the Panorama Formation of the Salgash subgroup (McNaughton et al., 1993; Thorpe et al., 1992). Regional deformation and metamorphism are constrained to between 3320 and 3310 Ma, based on the age of pre-, syn-, and post-kinematic phases of the batholith (Williams and Collins, 1990; Collins and Van Kranendonk, 1999).

Direct dating of the Marble Bar Cherts was attempted by Minami et al. (1995) who recorded Sm/Nd ages of 3200 ± 300 Ma for red (or black) and white banded cherts and 2500 ± 200 Ma for yellow-grey cherts associated with quartz veins.
These ages contain a large error and at least the younger age probably relates to post-doming hydrothermal disturbance of the sequence. The older age is within error of the ~3460 Ma depositional ages of enclosing sequences (Thorpe et al., 1992; McNaughton et al., 1993), but is also within error of the ~3320 Ma age of doming associated with the Mt Edgar Batholith (Williams and Collins, 1990). The geochemical data for the cherts along with initial ε-Nd values of ~+1.0 suggest derivation of depositional and/or post-deposi-
and cut by asymmetric boudinage structures and shear zones with green fuchsite alteration of the enclosing metabasalts (Fig. 3). These shear zones and foliation subparallel to bedding are inferred to represent the main ductile deformation phase recorded in the Marble Bar Belt and adjacent Warrawoona Syncline. Notwithstanding ongoing controversy on the role of the batholiths in the deformation history of the province, this fabric most likely developed during the main phase of doming associated with the Mt Edgar Batholith to the east.

Higher in the sequence in the Towers Formation, on the immediate northeastern side of the Marble Bar Chert Member, basalts are locally altered and foliated (4a), showing moderately well developed near-vertical foliation that strikes subparallel to the bedding (but dips differently, see below) in the adjacent cherts. The contact is parallel with the bedding in the chert, and is inferred to be conformable. Alteration is most intense in the basalts adjacent to the Marble Bar Chert Member, and involves the production of epidote–white mica–silica alteration replacing pyroxene and feldspar (green alteration and clasts), in a black, siliceous matrix. These breccias extend out from the adjacent chert (Fig. 2). The foliation in the basalt anastamoses around the altered basalt clasts, suggesting that foliation development postdated both the alteration and the brecciation that affected these basalts. We correlate the foliation with the regionally developed S1 of Collins and Van Kranendonk (1999) on the basis of orientation and lack of complex foliation overprinting in the lower grade parts of the greenstone belts.

In contrast, pillow basalts from the Apex Basalt

Fig. 4. Metabasalts of the Towers Formation and the Apex Basalt, and their contacts with the Marble Bar Chert Member of the Towers Formation. (a) Photograph and (b) line drawing showing the overturned contact between silicified metabasalts (top) and the Marble Bar Chert Member of the Towers Formation, exposed along the brecciated contact indicated at point 7 in 2; field of view 1.2 m across. The clasts and matrix are both deformed and aligned in the foliation, inferred to be produced by ductile deformation during emplacement of the Mt Edgar Batholith. Clasts in the basalt breccia are yellow-green in colour, reflecting sericite–epidote alteration produced during brecciation (see main text). (c, d) Photographs showing pillow structures in the Apex Basalt exposed approximately 5 m southwest of the main Marble Bar Chert Member, at point 1 in 2. Pillow shapes and cusps indicate younging towards the top of the photographs, away from the chert contact; pen for scale.
On both banks of the bar, exposure is approximately 90% in the chert, with several three-dimensional in situ blocks of rock elevated above the main water-worn platform, and irregular subvertical walls stepping up to 3 m high adjacent to the main river bed. The chert is dominated by centimetre-scale beds of interlayered red, grey, white and rare black finely crystalline silica, with overturned bedding dipping 45–70° to the northeast (Fig. 5). Colouration is due to differing amounts of very fine-grained iron oxide impurities, with some subtle grain size variations visible microscopically. Individual beds are continuous for up to 10 m or more along the strike (Fig. 5), and at scales broader than this they are invariably cut by high-angle faults or breccia zones. In addition, some layers are affected by crosscutting patchy alteration, which normally takes the form of discolouration to grey or white fine-grained silica, from the original darker greys or reds (6a).

Marker beds (at 1:200 scale) within the chert are dominated by “stick beds” (slump breccias of Hickman and Lipple, 1978; Hickman, 1983). These beds have conformable, parallel boundaries with adjacent beds, but internally are marked by the random distribution of red and grey bedding fragments in a paler matrix (6b), or by rare intra-layer angular folds and fold breccia. Because these textures are completely layer confined, they are inferred to be diagenetic structures formed by the compaction of partly consolidated silica gel under modest burial loads. Three or four of these beds can be traced across parts of the outcrops and provide the best evidence for the apparent movement sense on the faults and breccias. von Rad and Rösch (1974) have shown that the conversion of siliceous ooze to quartz chert in Mesozoic and Cenozoic seafloor sediments is a multistage process, requiring maturation over tens of millions of years (see Section 5.1). We suggest that the “stick beds” represent one of the intermediate lithification stages, whereby lithified chert was compacted until the recently lithified material collapsed and was then re-cemented by more siliceous ooze (see also Hickman, 1983). All subsequent discussion of breccias herein refers to the later, predominantly bedding-transgressive structures, except where specified in the final discussion.

4. Marble Bar breccias

The cherts are cut by two main types of fault and breccia material, predominantly at high angles to the bedding (Fig. 5):
1. irregular, wide breccia bands locally up to 10 m across comprising centimetre- to metre-scale angular clasts of banded cherts (and locally, basalt) in a predominantly dark grey to black, very fine-grained cherty matrix (6a,c,d), and
2. more regular, younger fault arrays, irregularly
Fig. 5. Detailed map of the area of chert, basalt and breccia indicated in 2, originally mapped at 1:200 on a 5-m grid with tape and compass. The darkness/density of the breccia symbol is a function of the matrix/clast ratio, with black areas being matrix dominant, and grey shading being clast dominant. Most clasts larger than 0.5 m across are mapped individually as shown; smaller clasts are not. Note the apparent dextral offset (in this view) across most black matrix breccia zones, the thinning and curvature of markers as the zones are approached, and the lack of penetration of the breccias into the Apex Basalt.
Fig. 6. Photographs of the Marble Bar Chert Member, breccias and veins. The pen points towards the northeastern (older) contact in all cases, and the overturned beds dip steeply away from the reader, and strike approximately 300 (see 5). (a) Typical contact between the banded (red-brown and white) chert (left) and the vein stockwork, showing silicification of some of the layers around the vein stockwork, identified by a clear front at point 1. Note the offsets along the white matrix breccia veins. (b) Typical “stick layer” (1), cut by black matrix breccia (2) and thin white breccia veins (3). (c) Black matrix breccia (right) cutting banded chert. The inferred total apparent movement trajectory in the clasts is indicated by correspondence and rotation of numbers 1 and 2. Note the possible partially silicified clasts just right of the pencil. Also note the thin white quartz veins in the thick dark chert band at the top. (d) Contact between banded grey, red and white cherts (top) and black matrix breccia (bottom), showing a small “scour” zone in the middle in which chert clasts from immediately adjacent wallrocks have moved over centimetre scales in the breccia. (e, f) Superb fault arrays associated with white quartz veins and breccia veins; apparent offsets indicated by correspondence of labelled layers. In both, note the local silicification/bleaching of the darker chert layers around the vein arrays, labelled 3.
spaced fracture cleavage, and breccia sheets with parallel to subparallel walls, with a white, crystalline quartz vein infill or (less abundant) breccia matrix (6 e,f).
4.1. Black matrix breccias

Breccias with very angular banded chert clasts in a dark matrix dominate the map expression of deformation in the chert (Fig. 5). Detailed mapping shows that they are commonly, but not always, associated with apparent right-lateral offsets that have distended the overall outcrop (Fig. 5).

The matrix of the breccia varies from black to very dark grey in the central and northern part of the outcrops, to greener in the south, within a few metres of the (overturned) pillow basalt outcrop. These breccias also extend northwards into the overlying, overturned basalts, with green, sericite–epidote altered basalt clasts in the black matrix. In several locations, the breccia extends continuously across the chert/basalt boundary, with little visible change in matrix composition, but with a change in clasts from chert to basalt. On the southern contact, altered fragments of basalt in breccia extend a maximum of 1.5 m from the basalt contact into the chert, but the matrix changes colour from green (just on the basalt side of the contact) to green-grey to dark grey over approximately 2 m (location 10, Fig. 2). The brecciation thus did not involve large distances of clast transport, although the internal and external geometry of clasts indicates that there was some movement, and rotation, of clasts as they left their walls behind (6c). Movement of the clasts is inconsistent, some moving “up” (north), some “down”, and some laterally (with rotation), relative to the well defined bedding in the wallrocks. However, individual breccia sheets branch out towards the north, generally thicken in the same direction, and extend into the northern basalts, and not into the overturned ones in the south (Figs. 2 and 5). This suggests gross mass transport towards the north, at least of the matrix material.

Internally, the matrix consists of very fine-grained quartz with a weak alignment of opaque minerals, the alignment being subparallel to the breccia walls. The fine-grained, milled appearance of the matrix, together with the presence of ghost-altered clasts within, and on the margins of, the zones suggests the breccia matrix is a fault cataclasite which is dominated by altered rock fragments and milled chert rock. This interpretation is supported by the presence of zircon in the matrix which was detected by a preliminary ion probe accelerator–mass spectrometer examination using the CSIRO AUSTRALIS instrument (B. Hobbs, personal communication, 1998), as zircon is unlikely to have precipitated from a hydrothermal fluid at the low-temperature greenschist facies conditions which these rocks experienced. Sugitani (1992) has also documented that grey (black) cherts containing banded red and white chert blocks at the Marble Bar are depleted in FeO and generally contain more Al2O3, TiO2 and Zr than the blocks, indicative of a dominant altered rock component within the matrix. Enrichment in these “immobile” elements is also indicative of volume loss in the matrix material associated with the removal of more mobile components (e.g. Fe, Si) in solution. This data also supports the inference that the black matrix material is milled, altered rock, rather than being dominated by silica precipitated from solution as fracture infilling. However, evidence of at least some additional quartz precipitation from solution is indicated from thin, diffuse-bounded veinlets of quartz within the black matrix, but this is inferred to be subordinate in volume to a cataastically milled chert matrix.

Most apparent offsets across the black matrix breccias are apparently right lateral, but the specific movement vector is only poorly constrained by one observation of gently southerly plunging slickenfibres. A full fault solution was not possible due to the presence of only one planar marker orientation (bedding) in the chert. However, the thinning and slight curvature of the chert observed in plan view near the largest breccia sheets (Figs. 2 and 5) imply that the predominant slip vector was subhorizontal relative to the present geometry, with the slip vector approximately orthogonal to bedding in the plane of the dominant breccia orientation (presently northerly trending and steeply dipping). The greater displacement observed on the breccia bodies towards the north is also indicative of some degree of either décollement near the southern boundary, or rotational movement on the breccias. Interestingly, the displacement on individual breccia veins is also an approximate function of width, with an apparent
systematic increase in displacement as the veins widen (Fig. 5). The presence of folds in the southern part of the outcrop (Fig. 5) is inconsistent with the overall inferred shear sense for the breccias. These may be early, compaction related folds off which breccia veins have nucleated, or they may also be representative of a complex rotational strain history during brecciation.

4.2. White quartz vein arrays and related breccias

Quartz veins with both dextral and sinistral offsets developed synchronously and later than the black matrix breccias, as indicated by local overprinting relationships. Locally, the white veins form marginal zones adjacent to the black matrix breccia (6b). The veins characteristically form in swarms, with either a few or many millimetre- to centimetre-scale veins forming distinctive and spectacular fault zones (6e,f). The strike of the vein arrays is typically more orthogonal to bedding than for the black matrix breccias. Vein arrays may form horst-and-graben structures, or have sinistral or dextral offset, but, on average, they are dominated by sinistral offsets. The internal texture of the drusy to blocky quartz infill, with highly abundant growth zones and primary fluid inclusion arrays, contrasts with the fine-grained, cataclastic nature of the black matrix breccias. The preferential sinistral offsets and angles with the black matrix breccias could represent a conjugate relationship. More likely, they may have developed slightly later than the black matrix breccias under different fluid pressure and stress conditions (see below). They appear to accommodate bulk extensional strain parallel to the bedding, and are formed by infilling of fractures with a substantial tensional component.

5. Oxygen isotope data for rocks and breccias

Small samples were collected from the Marble Bar reserve for a limited oxygen isotope survey of rocks, veins and breccias. Oxygen isotope ratios were measured at Monash University, following Clayton and Mayeda (1963), using CIF3 as the oxidising reagent. Extracted gases were analysed as CO2 on a Finnigan Mat 252 mass spectrometer and are expressed relative to V-SMOW, with a laboratory precision of ±0.2‰, determined by reference to in-house and international standards. The results are shown in Fig. 7. The most pristine basalt sample is a dark green pillow metabasalt, sampled from the interior of one of the pillows. The $\delta^{18}O_{(SMOW)}$ of 12.5‰ is too high for unaltered metabasalt (typically ~6‰), and most likely reflects a component of low-temperature seafloor alteration (e.g. Gregory and Taylor, 1981), as suggested by the abundant presence of chlorite, epidote and white mica replacing primary pyroxene and plagioclase. Least affected chert returns values of 19‰, not atypical of Precambrian cherts (Knauth and Epstein, 1976). Basalt $\delta^{18}O$ values greater than 12.5‰ are found in:

1. a very restricted zone < 20 cm from the southeastern basalt contact,
2. altered basalt clasts transported a maximum of 1.5 m into the chert at the same contact, and
3. a broader zone of up to 5 m of silicification in basalts on the northeastern contact with the chert.

These zones of elevated basalt isotope ratios correlate well with a distinctive yellowish pale-green colour, developed in basalt clasts adjacent to both contacts but most prominent in the northeastern basalt where the surrounding black breccia matrix extends up to 5 m into the basalt.

Chert values less than 19‰ are found in clasts immediately surrounded by black matrix breccia, but away from the breccias they retain these elevated values. The value of the chert clasts and the matrix is also a function of the distance from the two basalt contacts (Fig. 7). There is a correlation between matrix colour and oxygen isotope ratio, with a distinctive greenish colour present in the matrix on the southern boundary, and dark grey to black in both matrixes in the main Marble Bar Chert, as well as in the breccia that extends into the basalts on the northeastern contact.

The overall asymmetry in the oxygen isotope ratios matches the outcrop asymmetry (Figs. 2 and 5). Alteration and isotopic variation from inferred precursor rocks is greatest in the areas of greatest brecciation. In the basalts, $^{18}O$ enrich-
ment is most extensive on the northeastern side, where silicification and brecciation is most intense. The most depleted chert value of 15.4‰ comes from 1.5 m above the southwestern basalt from a breccia clast surrounded by a yellow-green matrix.

5.1. Discussion

On a gross scale, the correlation between the breccia matrix and the clast oxygen isotope ratios suggests that brecciation was largely in situ. This is supported by the observation that the maximum distance of basalt clast transport into the chert is 1.5 m (on the southeastern contact), and that the boundary between the chert and basalt along the northeastern contact is fairly sharp, irrespective of the presence of brecciation (Figs. 4a and 5). In detail, however, the geometric asymmetry of the black matrix breccias and the stable isotope data are inferred to represent a net flux of material (silica, water, oxygen) towards the north, relative to the present disposition of the outcrops. Given the younging direction, the northerly divergent nature of the breccias, and the extension into the northeastern basalts, it is likely that the sequence was already overturned during breccia formation (Fig. 8). Fluid overpressuring may have developed because of this overturning and then formed the breccias. Although we have not conducted extensive geochemical or fluid inclusion tests, it is likely they were deep basinal or even

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**Fig. 7.** Oxygen isotope ratios for basalt, chert, and matrix from the sample locations indicated in Fig. 2, projected along the line A–B, also in 2. The samples shown in Fig. 2 and labelled here in italics are against the points. Note the enrichment in $^{18}$O of the basalts (from the “precursor” value of 12.6‰) adjacent to the chert is most pronounced near B, where the breccia matrix extends several metres into the basalt. Along with the overall outcrop relations (mainly the relative degree of brecciation in the basalts on either contact and the shape of the breccia zones), these data are consistent with a flux of material from A to B.
Fig. 8. Sketch of the overall structural and stratigraphic relations indicating rocks were overturned prior to the development of a foliation in the metabasalts. An antiformal anticline would have older rocks in the core (in this case to the SW). Because these rocks young to the southeast, the present structure indicates an antiformal syncline to the southwest, which requires that at least one deformation event (that overturned the sequence) predates the formation of the upright foliation.

metamorphic fluids, as the rocks had already recorded diagenetic dewatering in the form of the “stick beds”. The system is “closed” over 10 m scales and broader (Oliver, 1996), in the sense that there is clearly substantial control on the isotopic composition of the breccia matrix imposed by the host rocks. Small volumes of fluids associated with the dextral faulting have passed through the basalt–chert–basalt sequence, with an inferred fluid flow vector to the north, and probably also upwards, as suggested by the divergent breccia geometry and the likelihood of upward fluid buoyancy (Fig. 8). In this orientation, the black matrix breccias would represent transtensional faults, accommodating all of the offset and most of the extension, with the white faults and veins being conjugates, accommodating the remainder of the extension with some antigoritic shear (Fig. 9). The faulting may have developed through an elastic response to overturning, or through a discrete episode of transtensional tectonics after overturning. Alternatively, if the white faults and veins postdated the black matrix breccia, they may have developed at higher fluid pressures and lower differential stresses (9b), consistent with progression from shear failure mode towards more tensile failure mode, and with an increase in fluid flux with time.

6. Timing and origin of brecciation

A relative history of basin evolution and deformation based on observations and data from the Marble Bar region integrated with regional geochronology is outlined in Fig. 10. Initial depo-
Fig. 10. Schematic time–event plot showing how the events determined at the Marble Bar are inferred to relate to regional events during the evolution of the eastern Pilbara. Several deformation phases or events are required prior to the main dome formation to explain the sequence.

An approximately 3460 Ma is a maximum (and probable overestimate) for the timing of lithification, and hence, of overturning and then brecciation. If processes of lithification in the present seafloor are a guide to rates of lithification in the Archaean, then the results of von Rad and Rösch (1974) would suggest complete lithification may not have finished until at least 3400 Ma. This would place both overturning and brecciation into a time window of 3400–3320 Ma, the latter being the age of intrusion and doming of the Mt Edgar Batholith.

A single predominantly ductile dome-forming event could not have produced the sequence of overturning, transtensional faulting, and regional deformation and metamorphism. Our data require at least a protracted history of deformation and doming. The steep foliation in basalts adjacent to the Marble Bar Chert overprints silicification, strikes at a high angle to all of the fracture-related fabrics in the chert, and transects the overturned basalt/chert boundary at the wrong angle, and with the wrong vergence sense (Fig. 8). This indicates that the Marble Bar sequence records a deformation history prior to the D1 dome forming event of Collins (1989), and this deformation involved overturning of the sequence followed by transtensional faulting. The brecciation is unrelated to widespread post-doming conjugate shears seen on regional maps.

Folding and faulting either predating doming or occurring during the initial stages of doming have been described by a number of workers. Zegers et al. (1996) record syn-sedimentary listric faulting and block rotation during accumulation of the Duffer Formation on the east flank of the Shaw Batholith which they related to extension off the flanks of the rising granitic dome. Bickle et al. (1980) and Bickle et al. (1985) describe recumbent folding and associated ENE thrusting west of the Shaw Batholith. Thrusting postdates the South Daltons Pluton dated by U/Pb zircon at 3431 ± 4 Ma (McNaughton et al., 1993). Nijman et al. (1998) document a variety of extensional and contractional syn-sedimentation features in the Coppin Gap greenstone along the north flank of the Mt Edgar Batholith. At least some of the structures, including thrust reactivation of exten-
sional faults, appear unrelated to and predate dome formation associated with batholith emplacement. In the Marble Bar greenstone just to the northeast of the Marble Bar, van Haften and White (1998) proposed early E–W extension during the formation of the Warrawoona Group followed by E-directed thrusting to form a large-scale ( > 10 km) antiformal culmination which is truncated and intruded by the Mt Edgar Batholith. They noted a similarity in the sequence of deformational events in the Shaw and Marble Bar regions, with early WNW–ESE extension followed by east-directed thrusting and suggested that these may be regional events in the East Pilbara. The proposal of widespread inversion by Bickle et al. (1985) is disputed by Hickman (1983) and Collins and Van Kranendonk (1999), on the basis of consistent younging indicators outwards from the domes, but our study confirms the complexity of pre-dome deformation noted by several other workers.

Kyanite occurs in higher grade, structurally lower greenstone sequences closer to the major granitic domes. Bickle et al. (1980) and Bickle et al. (1985) infer this to be a function of early thrusting and thickening prior to extensional collapse and doming. Collins and Van Kranendonk (1999), however, prefer a model of partial convective overturning to explain the distribution of kyanite and its relationships to the dome formation. These latter workers maintain that the thrusting referred to by Bickle et al. (1985) adjacent to the Shaw Batholith was localized and not representative of the deformation history of the Pilbara as a whole. Although we are uncertain of the regional significance of the overturning of the Marble Bar Chert, it is evident that deformation prior to the main phase of doming was not restricted to the western margin of the Shaw Batholith. The remarkable preservation of bedding in the Marble Bar Chert prior to transtensional faulting is perhaps inconsistent with the structures expected to develop during a wholesale inversion event. However, later deformation events cannot account for the structures observed because of the overprinting relationships (8), and also because the “S1” tectonic fabric developed in Marble Bar metabasalts is in a similar orientation to elsewhere in the Marble Bar belt. Our data could be interpreted as supporting the existence of a shallow-level inversion event that postdates sedimentation and lithification but predates dome formation, in the range 3400–3320 Ma. In this scenario, the apparently complicated deformation history must have involved a component of horizontal tectonics, not just the vertical tectonics proposed by Collins and Van Kranendonk (1999). Even if displacements are small, our work suggests the maximum principal compressive stress (σ1) during brecciation was subhorizontal. The thrust stacking documented by van Haften and White (1998) 15 km to the northeast may correlate with the overturning at the Marble Bar, but further mapping is required to clarify possible correlations, as the geometries are different. Major pre-dome recumbent fold closures such as those proposed by Bickle et al. (1985) are not evident in the sequence around Marble Bar.

A more conservative interpretation of our data suggests doming in this area could have involved more than one phase, producing locally overturned sequences prior to the main phase of ductile deformation associated with emplacement of the Mt Edgar Batholith. Collins (1989) proposed polydiapirism in the Pilbara Craton and it is possible that the main stage of intrusion of the Mt Edgar Batholith postdates an earlier history of diapirism (and overturning), as well as a number of structural processes accompanying diagenesis. Alternatively, a protracted history of doming around the Mt Edgar Batholith may have commenced with some structural disruption, overturning and then transtensional faulting, followed by further burial on the flanks accompanied by foliation development and peak metamorphism. The faulting represented by the Marble Bar breccias may have been an important strain accommodation structure during early doming processes.

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