Discussion

Comment on “Evidence for multiphase deformation in the Archaean basal Warrawoona group in the Marble Bar area, East Pilbara, Western Australia” by van Haaften, W.M., White, S.H., 1998
Precambrian Research 88, 53–66

M.J. Van Kranendonk a,*, A.H. Hickman a, W.J. Collins b

a Geological Survey of Western Australia, 100 Plain St., East Perth, WA 6004, Australia
b Department of Geology, University of Newcastle, Newcastle, NSW 2308, Australia

Accepted 31 May 2000

1. Introduction

van Haaften and White (1998) presented kinematic data from shear zones within the Talga Talga Anticline of the Marble Bar belt to invoke a regional thrust-accretion tectonic origin for the East Pilbara Craton. By examination of small-scale, local faults, they inferred five phases of regional deformation, of which an early ESE-directed thrusting event which reactivated ca. 3450 Ma normal faults, and a NE-directed transport event at ~ 3300 Ma, were interpreted to be the most important. van Haaften and White (1998) state that a lack of radially plunging lineations in the Talga Talga Anticline and the presence of thrust-sense kinematics in bedding-parallel shear zones indicate that the Talga Anticline could not have formed through the solid-state diapiric rise of the Mount Edgar Batholith as suggested by Hickman (1984) and Collins (1989). Rather, they interpret the Talga Talga Anticline to be a thrust culmination formed as a result of three phases of east-to north-eastern directed crustal shortening. The early thrusting was interpreted to have occurred during the accretion of a so-called ‘East Pilbara terrain’, as originally suggested by Krapez (1993).

Further, van Haaften and White (1998) use the presence of thrusts, and a re-interpretation of the previous geochronology, to suggest that the volcanic stratigraphy of the Marble Bar belt represent an imbricate lithotectonic sequence. They conclude that ‘the Talga Talga Anticline is an unsuitable area for the type section of the lower Warrawoona Group’, that the conformable stratigraphic scheme proposed by...
Hickman (1983) for the Marble Bar belt is ‘...probably not correct...’, that it is a tectonically inverted, downward-younging sequence, and that ‘the contention of Krapez (1993) that the formations in the lower Warrawoona Group... constitute a lithotectonic complex is confirmed’ (van Haaften and White, 1998).

We are concerned with the study by van Haaften and White (1998) because it contains a number of misleading statements and inferences, several omissions of previously published data, significant errors in logic, and a critical lack of knowledge regarding the types of structures found in diapirs which they use to counter the diapir model. In particular, we would like to take issue with the following main points.

2. Stratigraphy

The possibility of tectonic duplication of Warrawoona Group stratigraphy in the Talga Talga–Marble Bar area was addressed by Glikson and Hickman (1981). Detailed geochemical traverses across the stratigraphy of the Marble Bar belt revealed progressive vertical geochemical trends with no evidence of large-scale repetitions or inversions, and basaltic formations at different stratigraphic levels were found to be geochemically distinctive.

The contention of van Haaften and White (1998) that the McPhee Formation is a mylonite zone and not a stratigraphic formation is countered by the data in Hickman (1983), which presents a detailed stratigraphic section for the McPhee Formation based on diamond drilling data. Although the formation is sheared and locally tightly folded (Hickman, 1983; Collins, 1989), it contains a variety of lithology (including interlayered komatiite, chert, and basalt breccia) distinctly different from overlying and underlying tholeiitic basaltic formations. As discussed in Section 3, the absence of any quantitative magnitude of displacement means that the high shear strain and reverse sense of kinematics within the McPhee Formation and the other ‘major’ bedding-parallel shears do not unequivocally support a regional thrusting event.

3. Structures

According to van Haaften and White (1998), the ‘Duffada shear zone’ and adjacent layer-parallel faults within the McPhee Formation are interpreted as ‘major thrusts’, yet they provide no evidence that significant displacements are involved. Figure 8 of van Haaften and White (1998) indicates that the important second phase of ESE–WNW ‘thrusting’ would produce thrusts transecting the stratigraphy, but no evidence is presented that the ‘major thrusts’ cross-cut stratigraphy. Without such evidence, the ‘thrusts’ cannot be used to infer that stratigraphic duplication or tectonic inversion has occurred.

The ‘Duffada shear zone’, as proposed by van Haaften and White (1998), is inferred to cause the ca. 5-km-thick Duffer Formation to override the ‘younger, ca. 4-km-thick, Talga Talga Subgroup’ (see Section 4). Thus, the vertical displacement would have to be at least 9 km, even if the fault were perpendicular to the stratigraphy. Since the observed shear is actually (sub-)parallel to the bedding, the proposed near horizontal displacement would have to be measured in 10’s of kilometres. Yet, at the contact, observations by one of us (AHH) reveal felsic tuffs with well-preserved graded bedding and distinctive lithological variations that persist undisturbed along a strike length of ca. 20 km, thus negating the possibility of significant shear.

The data presented by van Haaften and White (1998) actually suggests that displacement across the shears was probably minor. For example, the lowest fault in Fig. 4 of their study terminates to the ESE within an undescribed black blob, and therefore cannot have accommodated significant translation. In Fig. 5, they present evidence for thrust re-activation of a normal fault, but the evidence is restricted to a decimetre-scale set of arcuate fractures and what appears to be a small-scale, en-echelon vein array (?). However, Wheeler (1987), Hanmer and Passchier (1991); and Dubey, (1997) have all shown that drag folds of passive markers may be notoriously unreliable indicators of shear sense. This is exacerbated in the case shown in Fig. 5 by the fact that the curving features are fractures of unknown origin and ori-
entation with respect to the shear plane and thus should probably not be used to determine shear sense. Finally, the only thin section of a rock from one of the bedding-parallel ‘thrusts’ (their Fig. 6), is of a felsic volcanic schist with preserved ‘clasts’ of original igneous texture, that lacks any clear evidence for dynamic recrystallisation, nor for the development of mylonitic fabrics. Given the low grade of metamorphism in the area, the section is not from a strongly deformed rock that was involved in significant translation of adjacent rock units. A moderate displacement across the McPhee shear is supported by the data from Collins (1989) (Fig. 2), which shows that folds in the McPhee Reward area at a high angle to mineral elongation lineations and thus that folds were not fully transposed into the shear direction. In contrast to the Duffada shear zone, these rocks do contain mylonitic fabrics.

The ‘major shears’ identified by van Haaften and White (1998) in the Talga Talga Anticline have been confidently identified as thrusts by these authors, but technically they are high-angle reverse faults because they have dips $>30^\circ$. Although this distinction may appear pedantic, it is important because no data are presented that constrain in what orientation, or at what time, the shears were initially formed. This, in turn, has an important bearing on the interpreted mode of origin of these structures: whereas true thrust faults primarily form in response to horizontal compression, high-angle reverse faults may form in response to a variety of mechanisms, including diapirism as predicted by the centrifuge models of Ramberg (1967), and Dixon and Summers (1983) (see below). Furthermore, because the original orientation of the faults is unknown, it is pure speculation to state that ‘… horizontal transport along flats could be appreciable’ (van Haaften and White, 1998).

van Haaften and White (1998) also claim that the Talga Talga Anticline does not contain the pattern of radial lineations described by Collins (1989) and that, therefore, a diapiric model is untenable. However, the stereoplot of Fig. 3 in van Haaften and White (1998) does show a distinctly radial pattern of chlorite lineations across the N–S extent of the diagram, as does the regional pattern of lineations shown in their Fig. 1. A similar pattern is found around the entire Mount Edgar Batholith (Collins, 1989). Only the hornblende lineations from the ‘Duffada shear zone’ are uni-directional and co-linear, but these were measured from only a very small segment of the arcuate zone and therefore cannot be used to mitigate against a radial lineation pattern for the entire batholith or to support a regional kinematic model of uni-vergent shortening. The same criticism can be levied against the data presented for the McPhee Reward shear, which was measured from only the north, and NE-striking segments of the shear. Furthermore, a detailed examination of structures along the central part of the ‘Duffada shear zone’ revealed that they do not represent mineral elongation lineations as claimed by van Haaf ten and White (1998), but rather represent intersection lineations between bedding and an axial planar foliation to vertically plunging drag folds, indicative of a horizontal component of shear.

The contention of van Haaften and White (1998) that the Talga Talga Anticline is a thrust culmination lacks evidence for why such a structure formed, where it did, and why the polyphase Mount Edgar Batholith intruded successively into the same place over c. 150 Ma (Williams and Collins, 1990). Finally, the sequence of events depicted in parts a–d of Fig. 8 do not match the final, present geometry of the area, as shown in Fig. 8e.

4. Geochronology

The re-interpretation of available geochronological data which van Haaften and White (1998) (in Table 2) use as ‘supporting evidence’ for their supposed stratigraphic inversion of units within the Marble Bar belt is rejected for the following two main reasons. First, they simplistically and incorrectly assume that the younger zircon age data represents the depositional age of the formations, when some of the dated rocks are of intrusive or uncertain origin. Second, they ignore the published fact that hydrothermal/metamorphic zircon growth has been documented for the Mar-
ble Bar area and thus may be an equally likely explanation for the anomally young ages of some units proximal to the Mt. Edgar Batholith, as discussed by McNaughton et al. (1993).

The rock dated in the McPhee Formation by McNaughton et al. (1993) is a dolerite sill and thus cannot be used to constrain the stratigraphic age of the host formation. Zircons from the rock fall within 10% of concordia over the range 3.31–3.24 Ga, which are ages identical to those of known granitoid plutonism (Mount Edgar, Mucan and Corunna Downs batholiths: Williams and Collins, 1990; Nelson, 1998; M. Barley, 1998, personal communication) and contemporaneous felsic volcanism (Wyman Fm.: Thorpe et al., 1992; McNaughton et al., 1993) in the Eastern Pilbara. Based on this similarity, it is probable that the ages of zircons in the McPhee sill are the result of circulating igneous/hydrothermal fluids during granitoid intrusion, as originally suggested by McNaughton et al. (1993). Such an origin is supported by the highly altered chemical character of the ‘dolerite sill’, containing much higher SiO₂ (71.45%) and K₂O (3.3%), and lower MgO (0.78%) and CaO (0.41%) than any known basalt. The alteration is consistent with late- to post-Wyman (3325 Ma) alkali metasomatism and resetting of Rb–Sr systematics identified by Jahn et al. (1981).

An igneous hydrothermal/metamorphic origin for many of the younger zircon ages in the Marble Bar belt is supported by data from a sample of the felsic volcanic Duffer Formation, which were not discussed by van Haaften and White (1998). This sample yielded two distinct populations of zircon ages, at 3466 ± 4 and 3329 ± 4 Ma (McNaughton et al., 1993). Whereas, the first is within the error of three other dated samples of the formation and thus most likely represents its igneous age (3471 ± 5, 3465 ± 3, 3463 ± 2 Ma: Thorpe et al., 1992; McNaughton et al., 1993), the second is identical to a second period of widespread felsic magmatism throughout the East Pilbara (see above references) and thus probably grew during circulation of igneous/hydrothermal fluids related to this event. These data are important because the 3329 ± 4 Ma age for the younger igneous hydrothermal/metamorphic zircons in the Duffer Formation is identical to that of the oldest zircon (3326 ± 10 Ma) in the dated sample from the North Star Basalt, a single pillow from a greenschist-facies (chlorite–actinolite–albite–epidote) meta-basalt (McNaughton et al., 1993). Igneous zircons in basalts (particularly high-Mg tholeiites) are extremely rare, as zirconium saturation is not attained so it partitions into pyroxenes. Zircon is much more likely to grow during prograde metamorphism and/or alteration, once zirconium is released from the pyroxene structure and concentrated into circulating metamorphic fluids. Therefore, we suggest that the 3300 Ma zircon ages represent the time of greenschist-facies metamorphic recrystallisation. van Haaften and White (1998) are incorrect to say that the North Star Basalt is less than c. 3.0 Ga (the Pb–Pb age of the most discordant zircon affected by recent Pb-loss), as such an age is only known from epiclastic rocks stratigraphically much higher up in the Pilbara Supergroup.

Also pertinent to whether or not the Marble Bar belt represents a litho-tectonic sequence is the fact that the ages of the Duffer Formation (Thorpe et al., 1992; McNaughton et al., 1993) are consistently older than those for the stratigraphically overlying Panorama Formation (Hickman, 1983), dated as 3459 ± 9/−4 Ma in the type area of the North Pole Dome and 3454 ± 1 Ma in the Marble Bar belt (Thorpe et al., 1992; Williams, 1998). This relates to the c. 3449 Ma age cited by van Haaften and White (1998) for the Mount Ada Basalt, obtained from 30–50 m thick felsic schist ‘… of uncertain extrusive or intrusive origin’, concordant with the regional stratigraphy (Thorpe et al., 1992). This sample yielded only a small amount of zircon of which only two fractions were analysed, giving near-concordant ages of 3470 ± 3 and 3449 ± 3 Ma, interpreted as xenocrystic or inherited grains within a felsic sill (op cit.). However, there is no evidence to suggest that the felsic sill is an integral part of the formation as implied by van Haaften and White (1998). Instead, it is probable that the dated felsic horizon either represents a sill related to extrusive felsic volcanism higher up in the stratigraphy (Panorama Formation, with inherited Duffer Formation zircons), or a silicified
basalt in which igneous hydrothermal/metamorphic zircons grew during Duffer and Panorama felsic magmatic events.

What is interesting about the geochronological from the Marble Bar belt is that ages of zircons of probable hydrothermal origin become progressively younger down the stratigraphic section towards the batholith. We interpret this to reflect the effects of conductive heat from known magmatic episodes within the batholith and note that this is consistent with a diapiric origin of doming, as discussed below.

5. Discussion

The model presented by van Haaften and White (1998) for the structural evolution of the Talga Talga Anticline is rejected on the basis of published stratigraphic, geochemical and geochronological data that indicate the Talga Talga subgroup to be a conformable stratigraphic succession. Further, we have shown that the structural arguments presented by van Haaften and White (1998) in support of an origin of the Talga Talga Anticline as a thrust duplex culmination are not supported by field evidence. Moreover, their statement that lineations are not radially distributed in either the bedding-parallel shear zones studied in the Talga Talga Anticline, or around the Mount Edgar Batholith, is not correct, as it is based on incomplete data from too small an area. The use of selected data from small segments of the studied shear zones to interpret craton-wide directions of shortening/compression is viewed as invalid, and based on these objections, the model of Pilbara-wide contraction must, at this stage, be discounted.

None of the data presented by van Haaften and White (1998) are in conflict with a diapiric origin for the Mount Edgar Batholith and the Talga Talga Anticline, as presented in the studies by Hickman (1984) and Collins (1989). We acknowledge the presence of bedding-parallel shears in the Marble Bar belt, but this shearing is confined to slip along bedding where changes in lithology and rock competence occur (e.g. along fine-grained tuff in the basal Duffer Formation). Indeed, the formation of bedding-parallel shears along major stratigraphic boundaries is an expected consequence of doming, formed when originally horizontal greenstones are deformed into steeply dipping synclines between rising domes. Because diapiric doming was not a single event in the East Pilbara (Hickman, 1984; Collins, 1989), several episodes of movement, with varying senses of displacement and orientation of lineation development, can be expected on many of the shear zones flanking the domes.

The sequence of NW-directed extension and subsequent NE-directed reverse faulting in greenstones of the Talga Talga Anticline presented by van Haaften and White (1998) (Fig. 11c) is identical to that presented in Collins (1989), who ascribed them to diapirism. In this model, NW-verging isoclinal folds were interpreted to represent the products of gravity sliding off the rising dome and subsequent reverse faults to have formed during construction of the greenstones within the syncline. As noted by Collins (1989), the presence of recumbent isoclinal folds, thrust faults, and high-angle reverse faults are the expected products of diapirism, as predicted by the centrifuge models of Dixon and Summers (1983; Fig. 14) Ramberg (1967; Fig. 100). Furthermore, Collins (1989) pointed out four regional features of the geology around the Mount Edgar Batholith, which mitigated against the formation of these structures through horizontal compression.

In conclusion, we wish to re-affirm that the Talga Talga Anticline is composed of a little disturbed, generally coherent succession of dominantly volcanic rocks and that there is no evidence that it represents a lithotectonic complex, as claimed by Krapez (1993) and van Haaften and White (1998). As a result, the Talga Talga Anticline is retained as the type section of the lower Warrawoona Group.

References


