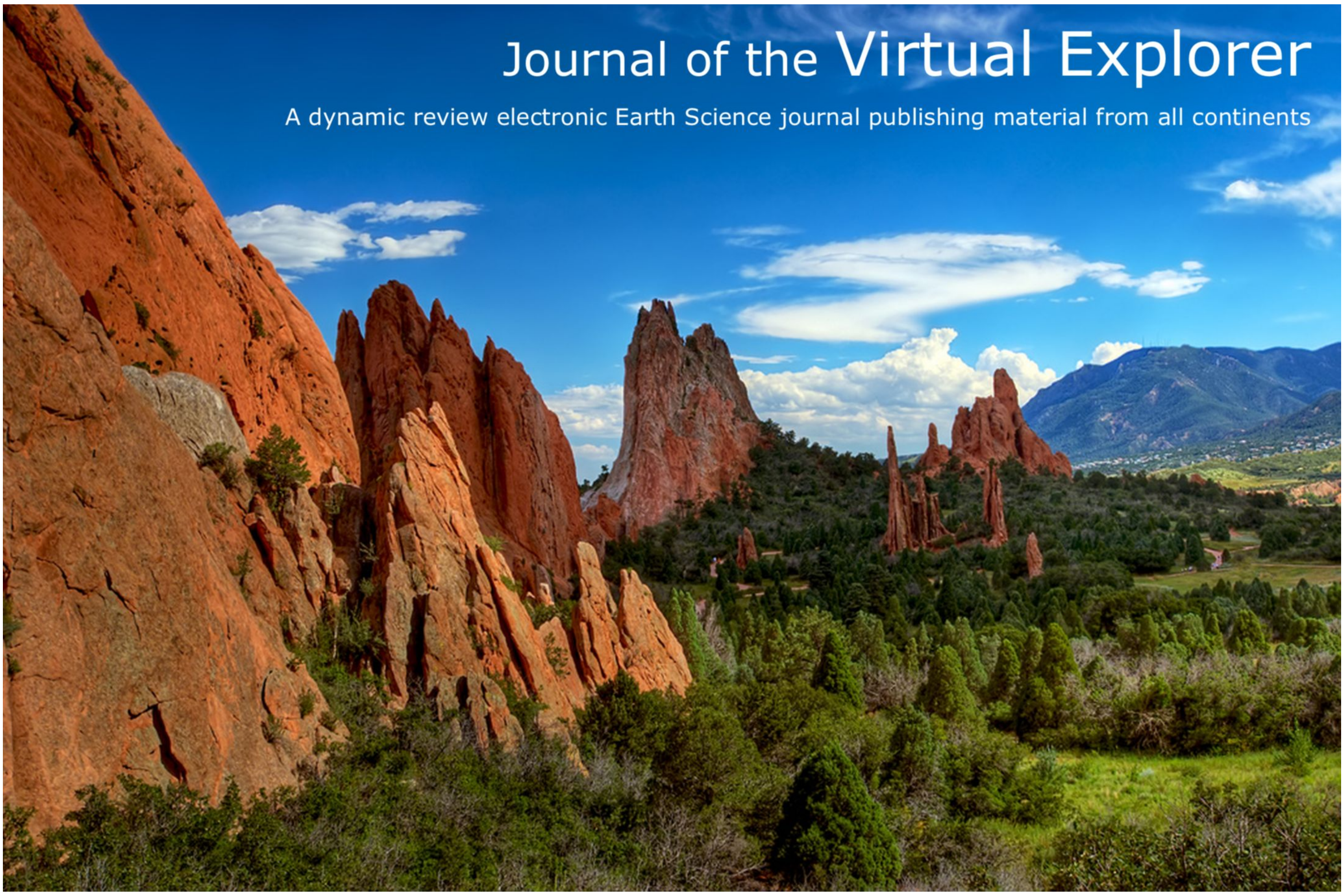

Discussion of Glen R.A. and Roberts J. 2012: Formation of Oroclines in the New England Orogen, Eastern Australia. In: Oroclines (Eds.) Stephen Johnston and Gideon Rosenbaum, Journal of the Virtual Explorer, volume 43, paper 3.

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Discussion of Glen R.A. and Roberts J. 2012: Formation of Oroclines in the New England Orogen, Eastern Australia. In: Oroclines (Eds.) Stephen Johnston and Gideon Rosenbaum, Journal of the Virtual Explorer, volume 43, paper 3.

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Abstract: This is a comment on and discussion of the model proposed by Glen and Roberts (2012) for the formation of oroclines in the New England Orogen, Eastern Australia *(view paper here)*. In particular, evidence is presented that shows that the Manning and Hastings Oroclines, an integral part of their model, do not exist.

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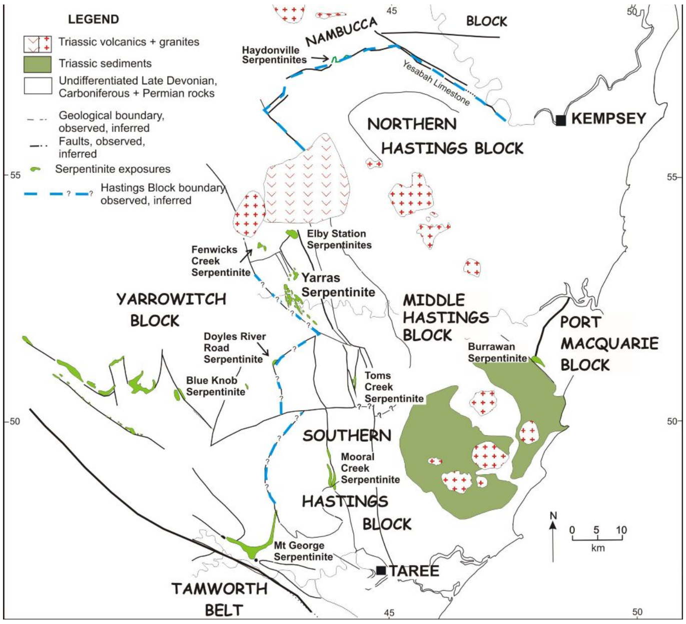
Introduction

The existence of oroclines in the New England Orogen (NEO) has been accepted by many authors and have been incorporated in models proposed for the development of the NEO (Cawood *et al.* 2011; Rosenbaum and Rubatto 2012 and references therein). However, the evidence for two of the oroclines, namely Manning and Hastings is not well established. This discussion will assess the regional aeromagnetics, the features in the northern Hastings Block, proposed hinge area of the Manning Orocline and the polarity of forearc-accretion complexes to show that the Manning and Hastings oroclines do not exist.

The aeromagnetic image they use to delineate the oroclines does not have the clarity or definition to support the presence of these structures nor does the distribution of the serpentinites. The latter are assumed to be the same age and their outcrop pattern is thought to outline oroclinal structures. However, there is no continuity in the outcrops of serpentinite between the fore-arc and subduction-accretion complex around the oroclines and the serpentinite bodies are of different ages (Figure 1). Further, the orientation of bedding and the pattern of folding in the Hastings Block are not consistent with passive, high angle rotation of bedding around an orocline.

Figure 1. Simplified map of the serpentinite outcrops in the Hastings Block portion of the Southern New England Orogen.



The possible position of the edge of the Hastings Block is shown by the blue dashed line. The serpentinite bodies do not form a continuous line around the edge of the Hastings Block as expected if they were all of one age and were passively rotated around an orocline.

The model for the development of the Manning and Hastings Oroclines proposed by Glen and Roberts (2012), involves the formation of the Parrabel Dome a structure they believe formed as an asymmetric, hanging wall anticline on the steeply, northeast-dipping, Bagnoo Fault. This is in contradiction to the field data collected by the authors that shows the bedding on the southwestern limb of the Parrabel Dome adjacent to the Bagnoo Fault is not steeply dipping. These data also show that thrusting required for the formation of the hanging wall anticline did not occur. Rather, this fault records a sinistral, strike-slip movement with the northeast side being down inconsistent with the required thrust history. Further, the Parrabel Dome plunges very gently northwest unlike that expected by rotation around a vertical axis as is normally the case with oroclines.

There is no structural evidence in the subduction-accretion complex sequences of the Manning Orocline similar to that in the accretion-subduction sequences that define the Texas and Coffs Harbour oroclines. Finally, ocean-pointing vectors used by Glen and Roberts (2012) to determine the polarity of the fore-arc /accretion complex sequences and thus provide evidence for the Manning and Hastings Oroclines, are untenable in the Port Macquarie Block because the subduction-accretion sequences are older than those in the Tablelands Complex.

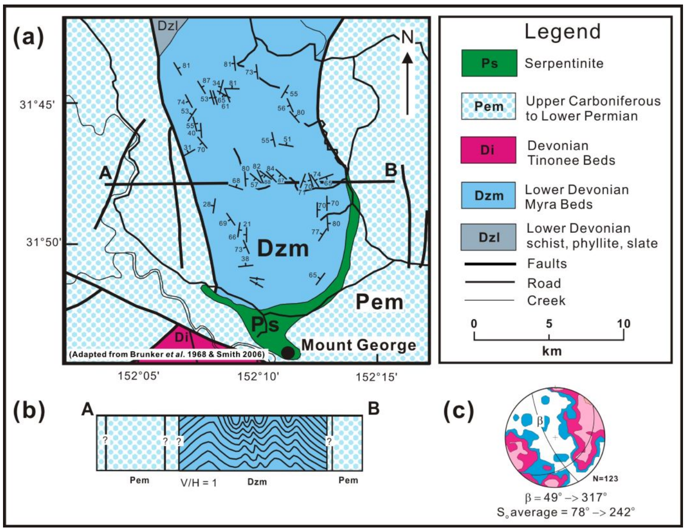
Detailed below are observations based on field data collected by the authors and data of other authors, that argue against the existence of the Manning and Hastings Oroclines.

Field observations

(1) Mapping by Laurie (1976) indicates that the Devonian to Carboniferous sequences south and southeast of the Mt George area are disrupted by N-S, NNE, E-W and NW trending faults. Bedding within the fault bounded blocks do not define an oroclinal structure, rather steeply dipping homoclinal sequences of varying orientation and uncommon N-S, NW and E-W trending, shallow plunging folds. The NW trending folds and faults appear to be related to the sinistral movement of the Manning Fault zone in the southern part of the area.

(2) The bedding in the subduction - accretion complex rocks north of Mt George where the hinge zone should be located, are variable but overall strike NNW and do not define a steeply-plunging macroscopic fold as expected for an orocline (Figure 2). The subduction-accretion complex rocks are deformed by moderately-plunging, tightly folded mesoscopic folds (Figure 2). Further, the structural grain south of Mt George in the hinge zone is oriented west-north-west, parallel to the Manning Fault in this region and does not bend around as expected for an orocline.

Figure 2. Mesoscopic folding of the Myra Beds north of Mt George.



a) Simplified geology map of the area north of Mt George in the so called hinge zone of the Manning Orocline.

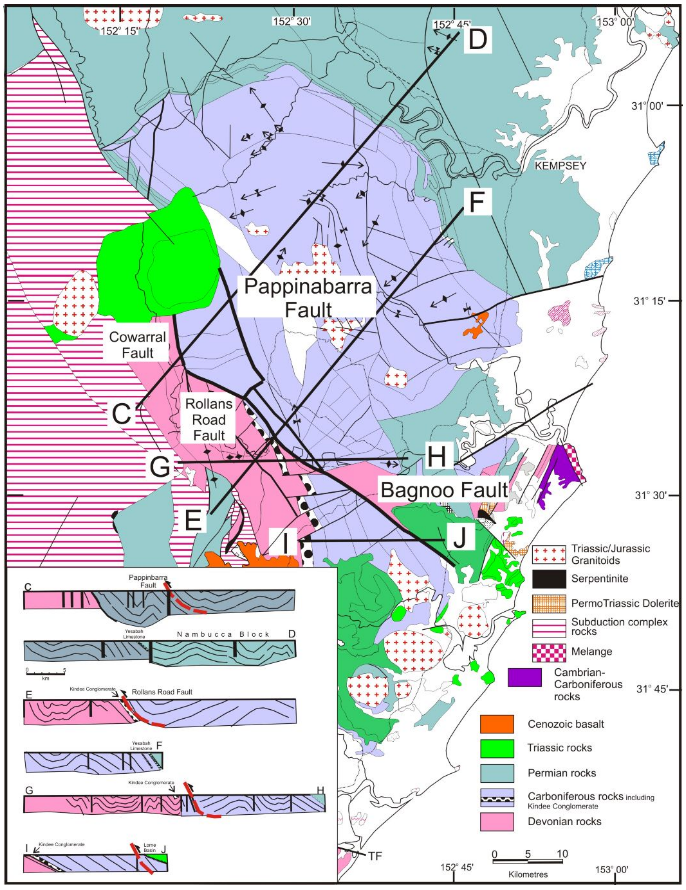
The variably oriented but overall north-northwest striking, steeply southwest dipping Myra Beds are tightly folded on a mesoscopic scale. They are not folded around a steeply-plunging axis of rotation as expected in the hinge zone of an orocline. b) Cross section of the Myra Beds showing tight, mesoscopic folding as observed in the field. c) Contoured, lower hemisphere projection of poles to bedding for the Myra Beds consistent with an overall moderately northwest-plunging structure rather than a steeply plunging structure expected in the hinge of an orocline.

(3) The age of the Majors Creek Formation has been changed from Namurian (Roberts *et al.* (1995) to Visean in their paper. No evidence is given to support this re-assignment. This is important as the Hastings and Myall blocks show a similar change to dacitic volcanism and shallow-marine to continental deposition in the Namurian, suggesting they were in similar positions relative to the arc.

(4) The model proposed by Glen and Roberts (2012) for the development of the Hastings Block (in their appendix; p35-38) is not consistent with the observed geology. The Bagnoo Fault does not show evidence for thrusting as required by their model, rather sinistral strike-slip movement with the northeast side downthrown (Feenan 1984; Spackman 1989; Offler unpubl.). Further, the Parrabel Dome is considered by Glen and Roberts (2012) to be asymmetric with a steeply dipping, southwestern limb and more gently dipping northeast limb.

The 1:100,000 data set on which this interpretation is based is a subset of the whole data set for this structure which is based on 1:25,000 sheets. Using the data recorded on the 1:25000 sheets, cross sections across the Parrabel Dome clearly show that it is an open, symmetrical structure (Figure 3).

Figure 3. Simplified geology map of the Hastings Block with cross sections to show the shape of the Parrabel Dome.



The dashed red line in each of the cross sections corresponds to the position and probably shape of the Bagnoo Fault as proposed by Glen and Roberts(2012). The Parrabel Dome is seen on these cross sections as an open, upright structure with a number of smaller folds across its crest. It is not an asymmetric hanging-wall anticline above the Bagnoo Fault as proposed by Glen and Roberts (2012).

Map Interpretation

Aeromagnetic imagery

Neither the Manning or Hastings Oroclines are clear on the grey scale 1VD aeromagnetic imagery (Figure 1C in Glen and Roberts 2012). The proposed oroclines have been highlighted by a dashed blue line but it is not obvious that the position of this line corresponds to a clear boundary between sequences of different aeromagnetic signature.

Location of hinge zone

Although many authors support the presence of these oroclines, there is some disagreement amongst them as to the location of the hinge zone of the Manning Orocline. For example, Rosenbaum (2010) and Rosenbaum and Rubatto (2012) on the basis of the distribution of Permian granites, delineate a hinge zone approximately 60-65km west of that proposed by Glen and Roberts (2012) and Cawood *et al.* (2011) who locate the hinge zone near Mt George. As indicated previously, the authors provide no evidence to support the presence of the hinge zone near Mt George. Figure 2 shows a map, cross section and stereoplot of the area north of Mt George where the orocline should be located. The Devonian Myra Beds in this area are tightly mesoscopically folded but their map pattern is not consistent with a steeply northwest-plunging orocline. The location of the hinge zone proposed by Rosenbaum and Rubatto (2012) is just as contentious because it is based on the distribution of granites of the same age in their current position that is the result of faulting subsequent to emplacement (Landenberger *et al.* 1995). This has not been taken into consideration in their delineation of the fold hinge. Further, S_5 the last fabric to form within and adjacent to the Tia Granodiorite (Dirks *et al.* 1992) prior to oroclinal bending is not folded. Evidence for this should be present because this granodiorite body occurs in the hinge of the proposed Manning Orocline.

Serpentinites

The distribution of serpentinites has been used by Glen and Roberts (2012) to delineate the Manning and Hastings Oroclines. However, close examination shows that the serpentinites are not as continuous as required to outline these structures (Figure 1). For example, they do not wrap around the Hastings Block but rather form pod-like bodies near and sometimes away from the block boundary. Further, very few serpentinites are present on the northern margin of the Hastings Block, none on the northeast side of this block and here is no continuity with those in the Port Macquarie Block. Finally, the ages of the serpentinites and associated protoliths have not been established to be the same for all the exposures around these structures. For example, plagiogranites in the northern part of the Peel-Manning Fault System are of Cambrian age (U-Pb; 530 Ma; Aitchison and Ireland 1995) and hornblende cumulates at Glenrock Station and Pigna Barney, are of Silurian age (Rb-Sr; 425 Ma; Sano *et al.* 2004; U-Pb; 436 Ma; Kimbrough *et al.* 1993). By contrast, near Yarras on the western margin of the Hastings Block, plagiogranites are Devonian in age (Figure 1; U-Pb; 377 Ma; Aitchison and Ireland 1995) and serpentinites at Port Macquarie that are linked with those at Yarras (Figure 1C; Glen and Roberts 2012) are Silurian in age (K-Ar; 427 ± 8 Ma; Cr-rich white micas formed during serpentinisation; Och *et al.* 2010).

Determination of ocean-pointing vectors.

One of the approaches used by Glen and Roberts (2012) to show evidence for these oroclines was to determine the orientation of ocean-pointing vectors which is based on the spatial relationship between forearc basin sediments and subduction complex rocks. This is a valid approach if the sequences are the same age throughout but this is not so. The caption of Figure 1B implies that the rocks of the subduction-accretion complex in the Port Macquarie Block (PMB) are the same age as the subduction-accretion sequences in the Tablelands Complex. However, these rocks are of Middle-Late Ordovician age (Och *et al.* 2007) and thus older than the sequences to the west.

Furthermore, the deep water vector asserted to point east in the Hastings Block/Port Macquarie Block area (Figure 1B) depends on the sequences in both blocks being the same age or at least comparable ages. This is not the case as the rocks in the Hastings Block on the margin with the Port Macquarie Block are mainly Devonian in age (Mile Road Beds or Touchwood Fm, Pickett *et al.* 2009), whereas those of the PMB are (?) Neoproterozoic to Ordovician in age (Och *et al.* 2007). Therefore to define an ocean-pointing vector using rocks of different ages is not valid.

It is asserted (p.9) that Early Permian (Asselian and Sakmarian) rocks around the northern margin of the Hastings Block deepen northwards (across faults) into mainly Artinskian turbiditic strata of the Nambucca Block. However, the geology of this area is more complex than this interpretation suggests. For example, the early Permian (Asselian and Sakmarian) Youdale B and A units give way to the Artinskian Commong Formation that overlies the Yessabah Limestone. Above this limestone are the Warbro/Parrabel beds that are in faulted contact with the Nambucca Beds. This transition therefore, does not simply represent a deepening trend as evidenced by the presence of limestone in the Artinskian succession.

Off shore uplift

Based on their interpretation of seismic sections offshore from Newcastle and Sydney, Alder *et al.* (1998) and Breeze (2009) delineated three major structures, namely the Offshore Syncline, Offshore Uplift and Newcastle Syncline. They suggested that the Offshore Uplift has been thrust NNE over Permian strata in the Newcastle Syncline (Fig. 9B) and a similar overthrust relationship between the Offshore Uplift and Offshore Syncline (Fig. 9C). The features in these seismic sections do not have sufficient clarity to ascertain whether their interpretations are correct. A similar criticism could be levelled at the interpretation of the aeromagnetic data in this area by Glen and Roberts (2012) who state that the “core of the Offshore Uplift has similar properties to….the Carboniferous continental margin arc volcanics…” but no evidence is given to justify this interpretation.

Crustal Architecture

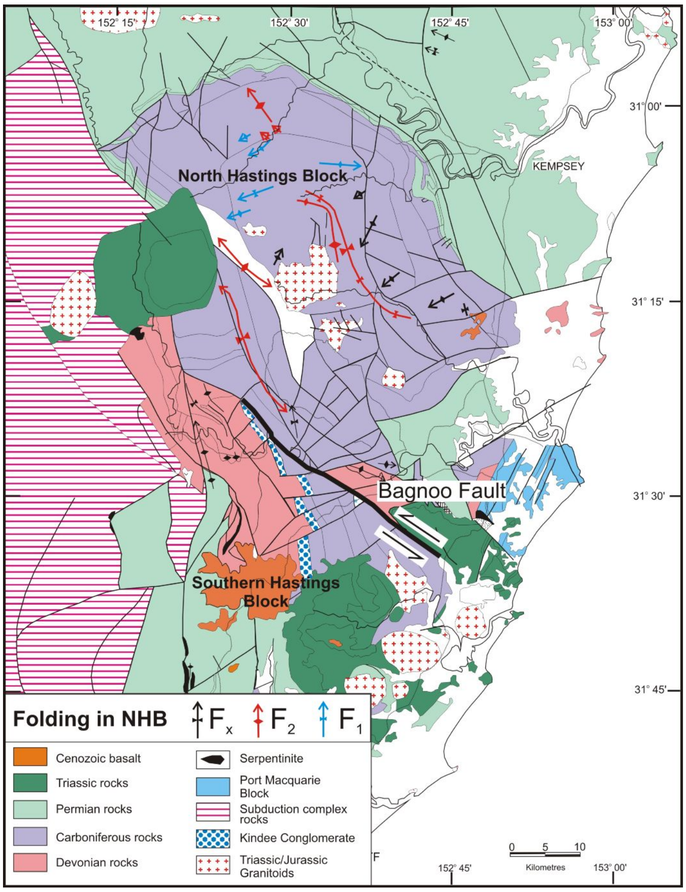
Several statements are made by Glen and Roberts (2012) in this section that we consider to be incorrect. These are discussed below.

(1) It is stated on p.14 that Late Carboniferous strata have dips of 35-50º and early Permian strata 28-60º. This is an over simplification because data collected from the Carboniferous strata in the area covered by the Kemps Pinnacle and Sherwood 1:25,000 sheets, show dips varying from 2º to 90º (av. = 34º; n = 253) for the Kemps Pinnacle sheet and 2º to 73º (av. = 26º; n = 176) for the Sherwood sheet (Lennox unpubl. data). By contrast, data for the early Permian on the same two sheets shows dips varying from 33º to 87º (av. = 54º; n = 27) for the Kemps Pinnacle sheet and from 24º to 87º for the Sherwood sheet (av. = 58º; n = 30). Clearly the Carboniferous rocks have a lower average dip than the early Permian sequences in the northern hinge area of the Parrabel dome.

(2) The authors claim that folds in the hinge zone of the Hasting Orocline plunge north (p. 35). However, this is incorrect because macroscopic F_1 folds in the hinge zone of the Parrabel Dome plunge east or west (Figure 4;

Lennox *et al.* 1999). Early almost east-west trending macroscopic folding in the northern Hastings Block is overprinted by northwest-southeast trending macroscopic folds as shown in Figure 4. All bedding readings for the Northern Hastings Block which incorporates the Parrabel Dome a D2 structure, indicate that overall this structure plunges gently northwest (11º → 302º).

Figure 4. Macroscopic folding in the Northern Hastings Block shows three generations of folds.



Early east-west macroscopic folds are shown in blue and have been refolded by northwest-southeast trending folds in red. The black coloured macroscopic folds on the northeast limb of the Parrabel Dome are probably third generation folds. The sinistral dip-slip movement observed on the Bagnoo Fault is consistent with the drag highlighted by the outcrop pattern of the Kindee Conglomerate shown south of the fault.

(3) According to Glen and Roberts (2012; p.15) the Bagnoo Fault shows thrust movement. However, our studies and those of other authors based on kinematic indicators and drag of units (e.g. Kindee Conglomerate in Figure 4) has revealed that sinistral, dip slip movement of 1-2km with down throw to the northeast has occurred (Figure 4; Feenan 1984, Spackman 1989).

(4) In Figure 7 of Glen and Roberts (2012), the trends of what are referred to as F_1 folds are shown with NW-SE trending axial plane traces and F2 with meridional trending axial planes. Collins (1991) considers that the meridional trending fold traces are related to D1 and NW trending fold traces parallel to the Hunter Thrust to D2 which is in contradiction to the interpretation of Glen and Roberts (2012). We favour the interpretation of Collins (1991) because E-W contractional deformation associated with the Hunter-Bowen Orogeny commenced at ~265 Ma and the thrusting with which the NW trending folds are associated post 254 Ma. This is based on the occurrence of tuffs of this age in the footwall of the Hunter Thrust.

(5) Figure 10 C. In this figure, cleavage in the accretion complex is shown to have formed initially in the Latest Carboniferous. This is contrary to the observations of other authors who have shown that cleavages of this age formed during the HT/LP event in sequences close to the ~300 Ma Hillgrove Suite intrusives. These cleavages are superimposed on earlier subduction-related cleavages (e.g. Morand 1982; Dirks *et al.* 1992) which in some sequences may be as old as 346 Ma (Phillips unpubl. results)

(6) P. 25. 1st paragraph. The early shortening is supposed to have been responsible for the "sporadically developed cleavage in the Tamworth belt". However, there are two cleavages developed in the Tamworth Belt, one that is parallel and strongly developed adjacent to the Peel-Manning Fault System (PMFS) that could be attributed to the E-W shortening associated with the Hunter-Bowen Orogeny and the second, oblique to the PMFS, that is due the sinistral movement on the PMFS (Cao and Durney 1993).

(7) In Figure 5, the Majors Creek Formation is shown as Visean in age whereas Roberts *et al.* (1995) indicates it is Namurian in age. This affects the correctness of Figure 3 where Namurian rocks should be shown in a pale pink colour (as per the Kullatine Fm) whereas the Majors Creek Formation on this figure is shown uncoloured (consistent with its proposed age in Figure 5 as Visean). Why is the Majors Creek Formation Visean rather than Namurian?

Discussion and Conclusion

There are a number of problems with the captions and figures which prevent readers assessing the veracity or otherwise of assertions in the text.

These include:

(1) The time-space plot in Figure 2 is extremely difficult to read as the lettering is too small. It is impossible to assess the various time slices in Figure 3 because the stage information on Figure 2 is unreadable. In addition, it is not clear where some of these columns are located on Figure 3 as they are not labelled nor their position marked on the figure.

This makes it difficult to assess the accuracy of Figure 3 as it is based on the information in this plot.

(2) P.13 Curvature of early Permian units. There is no Permian near point G. Point G could be moved to the NNE into the Werrikimbi Creek area (Hastings 1:250,000 GR6560 000mN, 430 000mE, Figure 3) where there are early Permian rocks (Bourke 1971).

(3) P.12 The legend of Figure 4 does not explain what the red letter R or the green lines correspond to on the map.

(4) P.13; iii. The Merlewood Formation is not present on Figure 4 so it is not possible to assess the veracity of the statement on this formation in this paragraph.

(5) P.14 Most of the formations are not identified in Figure 5B which makes verifying the statements regarding these formations on p.13, extremely difficult. Most readers would not have time to access the relevant literature to enable identification of the relevant formations.

(6) P.12-13 (ii) The units in the Hastings Block corresponding to the lower part of the forearc basin are Tournasian zones 1b and 2, not Pappinbarra Formation or the lower part of the Hyndmans Creek Formation but the Nevann Siltstone and Kindee Conglomerate (Fig. 5B). The Pappinbarra Formation is Tn3, the Hyndmans Creek Formation is Visean and only a small part of the Boonanghi Beds are Tn2. Since most of the Boonanghi Beds are Tournasian 2 to Visean 2 or 3a, we do not know why these beds are coloured as Tournasian 2 (red colour) on Figure 3. This is clearly an incorrect assignment for these beds. The Rollans Road Formation is Fammenian to Tournasian 1b but is coloured red on Figure 3 as though it is all Tournasian zones 1b and 2.

(7) P.16 There is no legend for the different seismic units on Figure 6B. This could have been addressed by annotating these units. Further, the lettering on these units is unreadable and the figure illustrating them is out-of-focus. As result the annotation of the different units and the TWT scale is not readable. Thus there is no way of assessing the statements made on p.15 regarding the geology or the depths of the detachment.

(8) P.19 The identification of formations and the TWT in Figure 8A are difficult to read. In addition, the symbols for each unit and the depth in metres in Figures 8B and C are impossible to discern, apart from the period of their formation. This makes assessing the interpretation presented on p. 18, difficult. Although we accept that the text may provide a reasonable interpretation of these cross sections, this should be able to be tested through the provision of illustrations which are legible and clear.

(9) Roberts *et al.* (1995) rule out continuity between the Early Carboniferous sequences of the Tamworth Belt and Hastings Block (Boonanghi/Majors Creek Formations). If this is correct, Glen and Roberts (2012) have no basis for delineating an orocline.

(10) P. 13 The text claims the Namurian stage is represented by the Major Creek Formation. However, the rocks of the Namurian stage according to Fig. 5B, do not include the bulk of the Majors Creek Formation which is Visean in age. This is in contradiction to Roberts *et al.* (1995) who state the Majors Creek Formation is Namurian in age.

(11) P. 24 Figure 10D. No explanation is given in the legend for the WSW trending yellow lines. The legend suggests the different stages of the orocline formation are described in the text. Unfortunately the text does not explain that rectangular bodies of yellow represent Permian deposits or what the diagonal green lines in Figure 10F represent.

In conclusion we do not believe Glen and Roberts (2012) have provided sufficient data to prove that the Manning Orocline exists. Bedding in the subduction-accretion complex rocks in the Mt George area where the hinge zone should be located does not delineate a megafold (Figure 2). Further, the serpentinites are not continuous around both the proposed oroclines and do not have similar ages as would be expected in their model (Figure 1). The eastward ocean-pointing vector suggested for the Hastings/Port Macquarie block area depends on the sequences in both blocks being the same or of comparable ages but they are not. The age of the Majors Creek Formation within the Hastings Block has been changed from Namurian (Roberts *et al.* 1995) to Visean in Figure 5B without any supporting documentation. This has consequences for the map of chronostratigraphic elements throughout the forearc basin (Figure 3) and hence their interpretation.

The legends for some figures are incomplete (Figures 4, 6B and 7), formations referred to in the text are missing or the lettering in the figure is out-of-focus or has unreadable lettering for different units (Figures 2, 5A, 6B and 8). This makes it extremely difficult to assess the accuracy of statements made in the text.

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