Journal of Structural Geology, Vol. 14, No. 7, pp. 887 to 890, 1992
Printed in Great Britain

0191-8141/92 $05.00+0.00

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The age of cleavage development in the Ross orogen, northern Victoria Land, Antarctica: evidence from $^{40}Ar/^{39}Ar$ whole-rock slate ages: Discussion

R. H. Findlay

Tasmanian Department of Mines, P.O. Box 56, Rosny Park, Tasmania 7018, Australia

(*Received* 28 *October* 1991; *accepted* 3 *April* 1992)

In their valuable paper detailing the $^{40}Ar/^{39}Ar$ systematics of the Robertson Bay Group and the Millen Range schist of northern Victoria Land, Wright & Dallmeyer (1991) discuss briefly the structural geology of the complex boundary between the Bowers and Robertson Bay terranes and conclude the following.

(1) The S_1 schistosity in the Millen Range schist and the regional, upright NW-trending slaty cleavage of the Robertson Bay Terrane formed at 500 Ma during the Ross orogeny.

(2) A subsequent deformation associated with thrusting produced the S_2 crenulation cleavage in the Millen Range schist.

(3) The thrusting involved west-over-east transport.

Wright and Dallmeyer's description of the structural geology is brief to the point of confusing workers not familiar with the local geology. As this is one of perhaps three key areas for interpreting the structural evolution of northern Victoria Land during and after the Ross orogeny, it is essential to clarify the ambiguities created by Wright and Dallmeyer's structural interpretation. Therefore in this Discussion, I present necessary corrections to the map given by Wright & Dallmeyer (1991, fig. 1), discuss the relationship between S_2 and thrusting, and discuss the vergence of thrusting.

MAP CORRECTIONS

A detailed geological map of the Millen Range region is presented as Fig. 1; Fig. 2 is a map of the key Turret Ridge–Crosscut Peak region showing the structural data collected by me in 1981–1982.

The 'Millen Thrust' discussed by Wright & Dallmeyer is, from their fig. 2, the same structure as that mapped as the Crosscut Peak Thrust (see Figs. 1 and 2) by Findlay & Field (1983) and Findlay (1987a) and it is not the Leap Year Fault, as indicated in their figure. The Leap Year Fault strikes through the nevé west of the Millen Range into the eastern ridge of Mt McCarthy (J. D. Bradshaw & M. G. Laird personal communication 1982) and is not exposed in the Millen Range.

A steep, probably reverse fault (Findlay & Field 1983, Findlay 1987a) separates the Millen Range schist from Roberston Bay Group rocks in Turret Ridge (Fig. 1). This fault strikes either along the line of Wood Glacier or into Handler Ridge where Bradshaw *et al.* (1985) and Wright & Brodie (1987) describe a reverse fault separating the Handler Formation of the Robertson Bay Group from rocks of the Millen Range schist correlated (Bradshaw *et al.* 1985) with the Sledgers Group (Bowers Supergroup) to the west. In Wright & Dallmeyer, these Bowers Supergroup correlates are placed in the Robertson Bay Group and the fault is not included.

As will be described below this, the Handler Fault, is distinct from the Crosscut Peak Thrust, which it cuts in the east ridge of Crosscut Peak and where it was recognized as the 'Lillie Fault' (Findlay & Field 1983, fig. 6).

RELATIONS BETWEEN S_2 AND THRUSTING–REVERSE FAULTING

According to lithologic similarities only (Findlay & Field 1983, Bradshaw *et al.* 1985, Findlay 1987a) the Millen Range schist consists of the variably strained low-grade metamorphic derivatives of the adjacent Cambrian to Tremadoc Bowers Supergroup and Robertson Bay Group rocks. Jordan *et al.* (1984) and Wodzicki & Robert (1987) confirmed Findlay & Field's interpretation that this tectonic amalgam forms a 10–25 km wide belt extending between the Bowers and Robertson Bay terranes for approximately 300 km to the Southern Ocean.

I have described in full detail elsewhere (Findlay 1987a) the two fabrics ($_MS_1$ and $_MS_2$) and associated folds in the Millen Range schist and the single fabric ($_RS_1$) and associated folding in the Robertson Bay Terrane. Wright & Dallmeyer confirm my observations that production of $_MS_2$ involved pressure solution. No correlate of $_MS_2$ has been recognized in the Robertson Bay Group rocks east of the Handler Fault (Findlay 1987a), although Findlay & Field (1983) discussed the possibility that $_RS_1$ and $_MS_2$ could be correlates according to their common general orientation (see Fig. 1).

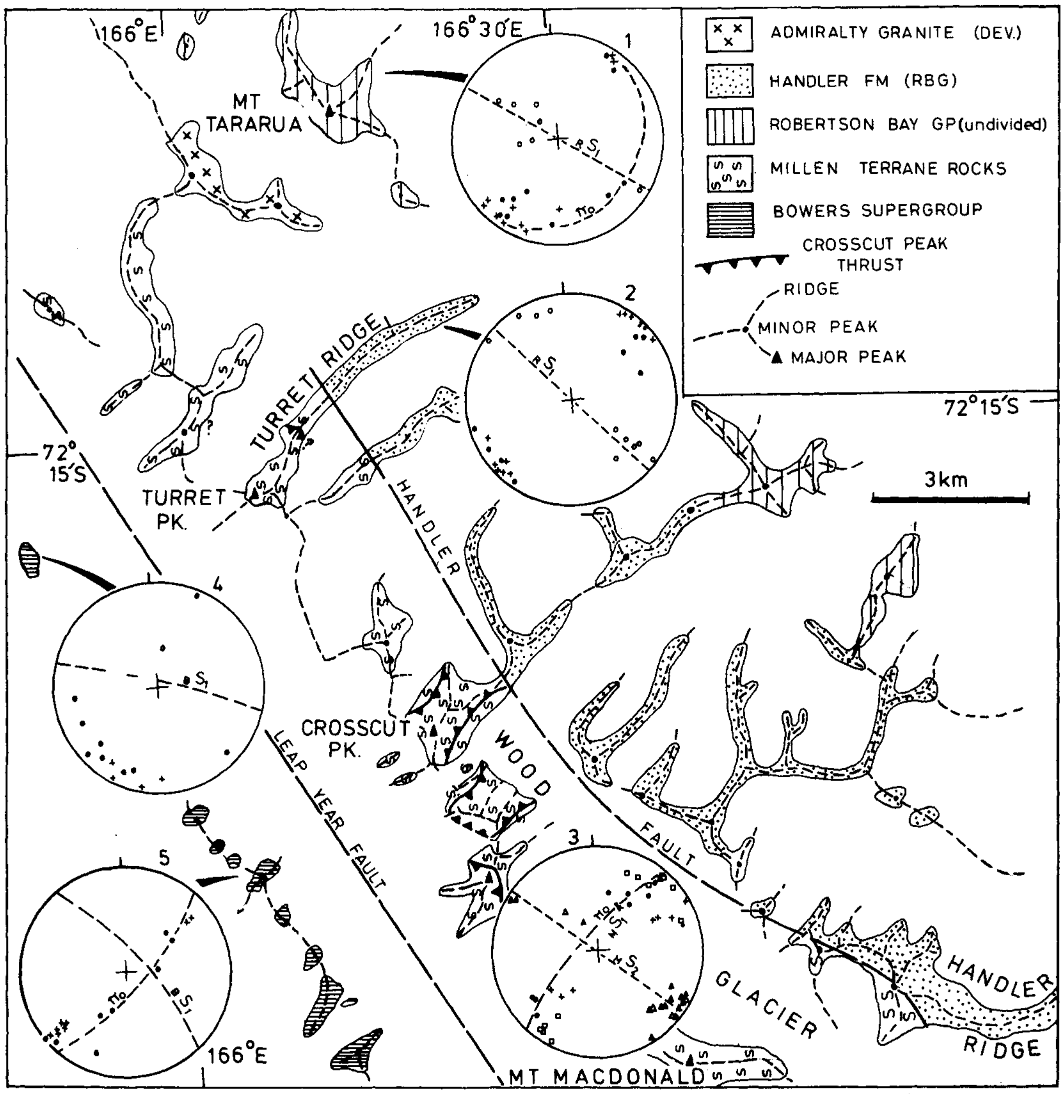

Fig. 1. Geological map showing distribution of Robertson Bay Terrane, Millen Range schist and Bowers Terrane rocks in the area of discussion. Structural observations, not previously published, are presented as lower-hemisphere equal-area stereographic projections. Net 1—Mt Tararua region: solid circles, poles to bedding; crosses, poles to $_{R}S_1$; open circles axial lineations ($_{R}L_1^0$) and fold axes ($_{R}B_1^0$). Note the variation in fold plunge in the $_{R}S_1$ axial plane; here, fold interlimb angles are as low as 25° (see Findlay 1987a, figs. 9 and 10). Net 2—Turret Ridge: legend as for net 1. Net 3—Millen Range: solid circles bedding; crosses $_{M}S_1$; open squares $_{M}S_2$; open triangles $_{M}L_2^1$; closed triangles $_{M}B_2^1$. Net 4—Bowers Terrane: legend as for net 1, except crosses are $_{B}S_1$. Net 5—Bowers Terrane, legend as for net 4. Note parallelism between $_{R}S_1$, $_{B}S_1$ and $_{M}S_2$; see Findlay & Field (1983, p. 110 where this coincidence is discussed).

Wright & Dallmeyer (1991) assert that $_{M}S_2$ developed in association with their Millen Thrust. Wright & Dallmeyer (1991, p. 678) state, "The Robertson Bay Terrane structurally underlies the Bowers Terrane". From their fig. 2 it may be assumed fairly that Robertson Bay Terrane rocks are separated from the Bowers Terrane by the 'Millen Thrust' and that this is the same structure as the Crosscut Peak Thrust. Wright & Dallmeyer (1991) confirm that no equivalent of $_{M}S_2$ occurs in the Robertson Bay Terrane, and they assert that, "A variably penetrative cleavage S_2 developed in association with this [Millen Thrust] thrust and overprinted the pre-existing S_1 cleavage". That is, it may be fairly interpreted that Wright & Dallmeyer (1991) consider $_{M}S_2$ formed during movement on the Crosscut Peak Thrust, and that they think the Crosscut Peak Thrust separates underlying singly deformed Robertson Bay Group rocks from Bowers Supergroup rocks containing two fabrics.

Two observations indicate that the Crosscut Peak Thrust is older than $_{M}S_2$. Firstly, in Crosscut Peak the $_{M}F_2$ folds fold the thrust (Fig. 1 and previous references), and this thrust does not separate multiply-deformed rocks from singly-deformed beds as may be inferred from Wright & Dallmeyer (1991). Rather, a nunatak in the Joice Icefall, and which forms part of the underlying plate, is formed of rocks showing clear evidence for both $_{M}F_1$ and $_{M}F_2$, including the $_{M}S_2$ cleavage. Secondly, the mylonite forming the sole of Crosscut Peak Thrust is cut and crenulated by $_{M}S_2$ (e.g. as in University of Tasmania sample 62552 collected by me from the thrust plane), and thus the Crosscut Peak Thrust is older than $_{M}F_2$.

Therefore the Millen, or more correctly the Crosscut Peak, Thrust does not separate multiply-deformed Bowers Terrane rocks from singly-deformed Robertson Bay Terrane rocks. Furthermore, as there is a geometric

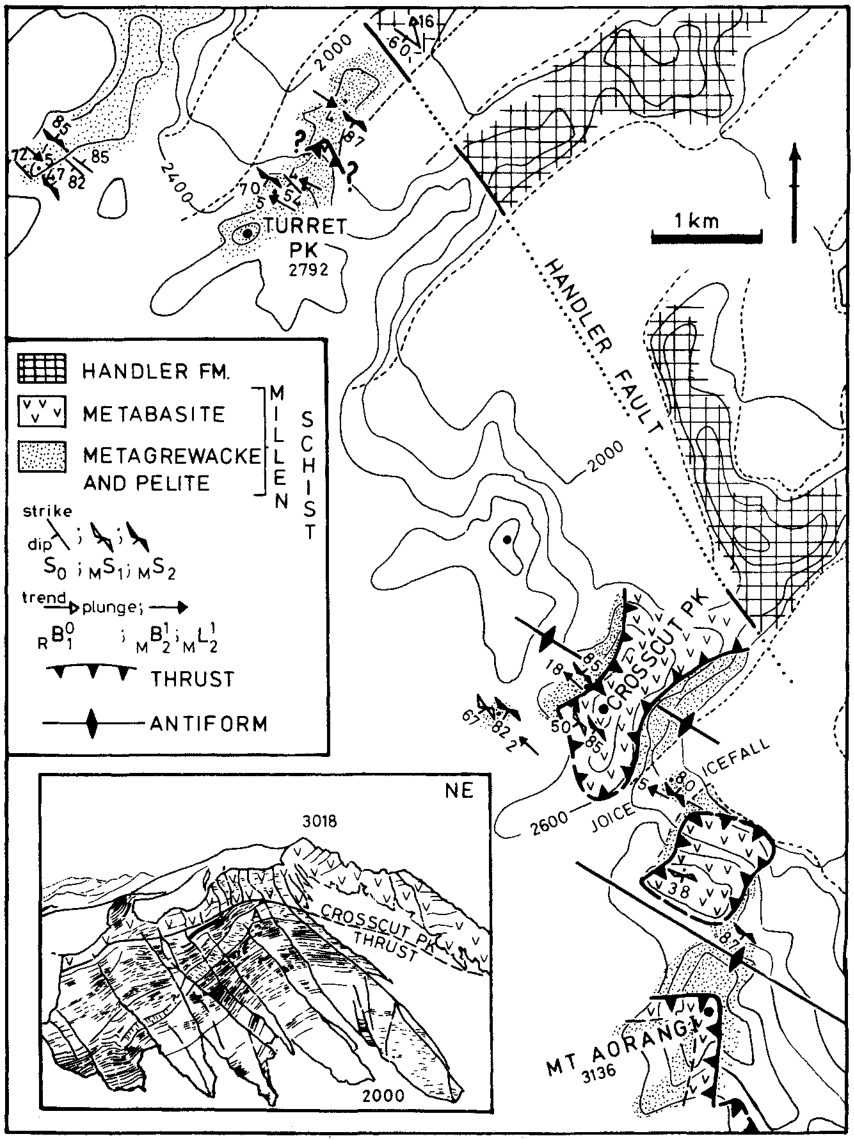

Fig. 2. Summary of structural geology in Turret Peak–Mt Aorangi region; inset shows southeast face of Crosscut Peak drawn from 35 mm transparencies taken from a helicopter above Wood Glacier and 300 mm telephoto slides from the easternmost part of Mt Aorangi. Above the thrust are weakly-bedded metabasites (v); below the thrust bedding is clearly defined; the thick W-dipping unit (A) below the thrust may be a metabasite, and it and bedding underlie the thrust discordantly. The simplest explanation for this geometry is east-over-west thrusting during ${}_{M}F_1$.

and spatial association between this thrust, ${}_{M}S_1$, and the ${}_{M}F_1$ folds (Findlay 1987a) it could well have been involved in the tectonic amalgamation which produced the Millen Terrane rocks; it would appear to be a syn-${}_{M}S_1$ structure; it is folded by ${}_{M}S_2$; and it is cut by the Handler Fault (Findlay & Field 1983, fig. 6, Findlay 1987a). That is, the Crosscut Peak Thrust could well have formed during the Ross orogeny as Wright & Dallmeyer (1991) confirm that ${}_{M}S_1$ formed during this 500 Ma old event.

VERGENCE OF THE 'MILLEN THRUST'

Since thrusting and reverse faulting was first reported in Bowers Terrane and Robertson Bay Terrane rocks (Findlay & Field 1983, Gibson & Wright 1984) these faults have been assumed to be solely related to collision between the Wilson and Bowers–Robertson Bay terranes during the Ross orogeny, despite evidence suggesting otherwise (see Findlay 1986, 1987a, 1988 for discussions). As all thrusts, with the exception of the folded Crosscut Peak Thrust, dip west most tectonic models have assumed westward-dipping subduction before collison. The report in Bradshaw *et al.* (1985) of E-verging *C–S* fabrics associated with thrusting in the Millen Range region (which, following Wright & Brodie 1987, must refer to the Handler Fault only) re-affirmed the supposition that all thrusting in northern Victoria Land was associated with the Ross orogeny and involved west-over-east transport (see Findlay 1987b, fig. 7, and compare to the earlier paper by Findlay 1987a, fig. 14).

The vergence of thrusting in the Millen Range region has been discussed by Wright & Findlay (1984), Bradshaw *et al.* (1985), Findlay (1987a), Wright & Brodie (1987) and Wright & Dallmeyer (1991). It is clear from the work of Bradshaw *et al.* (1985) and Wright & Brodie (1987), whose work deals only with Handler Ridge, that the Crosscut Peak Thrust has been confused with the

Handler Fault at Handler Ridge. Therefore the eastward-verging kinematic indicators referred to by these workers and by Wright & Dallmeyer (1991) can only apply to the Handler Fault. This leaves open to discussion the vergence of the Crosscut Peak Thrust; as discussed by Wright & Findlay (1984) and Findlay (1987a) the thrust could well have an east-over-west sense of movement, contrary to the west-over-east sense reported on the possibly younger thrusts–reverse faults described elsewhere in northern Victoria Land.

Studies of thin sections of two oriented samples collected by me from the faulted base of the metabasite in the northeast face of Crosscut Peak and the ridge immediately southwest of Joice Icefall do not confirm a syn-S_2 *C–S* fabric, as implied for the 'Millen Thrust' by Wright & Dallmeyer (1991). Rather, these samples confirm that pressure solution was involved in the production of $_{M}S_2$; that $_{M}S_2$ is predominantly a flattening fabric as indicated by symmetrical pressure shadows around numerous circular objects present in the thin sections (such as those shown by Findlay 1987a, fig. 2); and that the vergence of the $_{M}F_2$ crenulations is consistent with their interpretation as vergence folds on the southwest limb of the Crosscut Peak Antiform.

The $_{M}S_1$ fabric is formed of principally actinolite, epidote, zoisite and opaques and in the rocks I have studied there are no syn-$_{M}S_1$ kinematic indicators which confirm either east-over-west or west-over-east movement on the Crosscut Peak Thrust.

CONCLUSIONS

Wright & Dallmeyer (1991) have confused two generations of faulting in the Millen Range region, and they have come to regard two clearly distinct faults as of the same generation. These are the probably syn-$_{M}S_1/_{R}S_1$ 500 Ma old Crosscut Peak Thrust and the younger syn- or post-$_{M}S_2$ Handler (reverse) Fault. With this interpretation their paper assumes considerably greater importance; as discussed by Findlay (1987a) the Ross orogeny occurred at about 500 Ma and involved production of: $_{M}S_1$, $_{M}F_1$ folds, the Crosscut Peak Thrust, $_{R}S_1$, $_{R}F_1$ folds and tectonic amalgamation of units within the Robertson Bay Group and Bowers Supergroup to produce the Millen Range schist. As discussed in Wright & Findlay (1984) and Findlay (1987a) this event may have involved east-over-west thrusting.

The second generation of faulting involved the Handler Fault, which post-dates $_{M}S_1$ and which Wright & Dallmeyer (1991) recognize as 'associated' with $_{M}S_2$. Adams & Kreuzer (1984) dated a reverse fault along the Bowers–Wilson Terrane boundary at 417 Ma. If this fault and the Handler Fault were contemporaneous, much of the present undated reverse faulting currently assigned to the Ross orogeny in northern Victoria Land could well be of Siluro-Devonian age, as could the $_{M}F_2$ folds in the Millen Range and perhaps the large open NW-trending folds affecting the Leap Year Group (see Findlay 1986, 1987a, 1988). That is, this 'Handler Event' could correlate with Siluro-Devonian structural events in the Lachlan Fold Belt of eastern Australia, rather than with the Cambro-Ordovician Ross orogeny.

As such an event has not yet been recognized in northern Victoria Land, Wright & Dallmeyer's paper could lead to a breakthrough in the structural interpretation of this region.

Acknowledgements—Dr E. Williams, Tasmanian Department of Mines, kindly acted as a critical sounding-board for my concerns.

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