Imbrication of a Reference Section: Re-evaluation of the Adaminaby Beds at El Paso, Dalgety, New South Wales

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ABSTRACT. Re-examination of a reference section through the Adaminaby beds at El Paso, west of Dalgety in southern New South Wales, does not support the conventionally held belief that rocks here form a simple Upper Ordovician homoclinal sequence which dips and youngs to the west. Rather, there has been thrust interleaving of a Lower Ordovician turbidite-chert sequence with an Upper Ordovician black shale sequence. The El Paso area thus lies in a thin-skinned thrust belt which was first recognized in the Delegate area 60 km to the south and which also extends north and east of Dalgety. Recognition of this thrust style of deformation at El Paso has led to the redefinition of the stratigraphic section here, which contains only a single Upper Ordovician black shale, the Warbisco Shale, and a single Lower Ordovician sequence which is redefined as the Adaminaby Group.

INTRODUCTION AND BACKGROUND

GEOLOGY

Granitoids and Ordovician metasediments constitute the major elements of the southeastern part of the Lachlan Fold Belt between Canberra and the Victorian coastline (Fig. 1a). In contrast to the vast amounts of data collected on the granitoids, there are few data available on the Ordovician metasediments which go under a variety of formal and informal stratigraphic names such as "coastal greywacke facies", "inland facies", Mallacoota beds, Foxlow beds, Adaminaby beds, Nungar beds. This paper focuses on low-grade Ordovician metasediments in the greater Snowy Mountains area, stretching from Canberra southwards through Dalgety and Delegate to the Victorian coast (Fig. 1a), and presents new structural and palaeontological data which clarify stratigraphic and structural relations through a critical part of the Adaminaby beds.

Ordovician sedimentary rocks of the greater Snowy Mountains region are particularly poorly known. In northeastern Victoria, a sequence of Ordovician turbidites and black shales is known merely as "undifferentiated Ordovician", (e.g., on the TALLANGATTA 1:250,000 sheet). Across the border in New South Wales, the name Adaminaby beds has been used for a similar sequence of turbidites, black shales and cherts. The name Adaminaby beds was first used by Adamson in 1951, superseding the name Stony Creek-Barney's Range sediments of Mulholland (1941), but was only introduced into the literature by Fairbridge (1953). Adamson (1953) subsequently used the name as well. Graptolitic black shales were used to assign a Late Ordovician age to the unit (e.g., Hall 1952), but lithological and age relations were incompletely known. Although a type section has never been defined for the Adaminaby beds, the name was presumably taken from the old township of Adaminaby which was inundated by Lake Eucumbene in the late 1950s.

More recent mapping of the Adaminaby beds has been carried out by White et al. (1977) and by Owen and Wyborn (1979). Although White et al. (1977) concentrated on details of the granitoids on the BERRIDALE 1:100,000 sheet, they did report (p. 19) that in the El Paso area "a section [of turbidite, chert and black shale] which has escaped strong deformation and in which a chert bed occurs slightly higher in the succession than a prominent black slate horizon". It was only in this area of "overall simple structure" (p. 95) — in the west-dipping limb of a north-plunging anticline (see Fig. 1b) — that they were able for the first time to define a stratigraphic section for the Adaminaby beds.
Figure 1.a. Regional geological map (modified and much simplified from Pogson 1972 and VandenBerg 1988) showing major geological elements in the southeastern part of the Lachlan Fold Belt. Note that faults have not been shown and that the southern part of the I-S Line is shown, where it corresponds with the Yalmy-McLaughlin Creek Fault Zone (YFZ). The location of the El Paso area is shown by the hatched box.

Figure 2. Map of the El Paso area from Browne (1979) showing his subdivision into three separate "stratigraphic" black shale units separated by turbidite - chert units. See text for discussion. Location of figure 3 is indicated by box.
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REFERENCE
Black Shale band (Warbisco Shale)
Turbidite sequence / Chert band
Thin-bedded mudrock-rich sequence
Ordovician stage locality
Stratigraphic contact
Contractional fault (thrust)
Anticline
Syncline
Small scale fold
Bedding strike and dip
Creek, river
Track
Adaminaby Group

El Paso
BLACK SHALE BAND (V)
BLACK SHALE BAND NO.3
BLACK SHALE BAND NO.2
BLACK SHALE BAND NO.1

NOT MAPPED

T.N.

Scale 1 km

0

Track

0

Scale 1 km

V=H

? Ramp in postulated imbricates or in floor thrust

? blind or emergent thrusts

BAND NO.1

BAND NO.2

BAND NO.3

D.1

A.1

A.2

A.3

ORDOVICAN

ORDOVICAN OR PRE ORDOVICIAN

18820
Figure 3. Map (Fig. 3a) and section (Fig. 3b) showing reinterpretation of part of the El Paso area along the Snowy River in terms of an imbricate splay system involving the Upper Ordovician Warbisco Shale and the Lower Ordovician Adaminaby Group. Stage names in the Upper Ordovician are as follows: Gi = Gisbornian; Ea = Eastonian; Bo = Bolindian. In Fig. 3b, position of floor thrust is uncertain. See text for explanation. Figs 3c-3d explain derivation of the structural model, starting from Fig. 3c which presents the raw field data. Fig. 3d is workable. As explained in the text, Figs 3e and 3f are not.
PREVIOUS INTERPRETATION OF THE EL PASO SECTION

The El Paso section is centred just east of the confluence of Kara Creek and the Snowy River, and lies some 10 km west of Dalgety on the BERRIDALE 1:100,000 sheet. The stratigraphy here was first described by White et al. (1977) and subsequently by Browne (1979). White et al. (1977) described the stratigraphy in this area as consisting of three turbidite-chert sequences separated by two black shale bands (Fig. 1b). They used graptolite identifications by Sherrard (in Hall 1956) and Wain (unpublished) to assign ages to these units. The eastern turbidite sequence plus the eastern black shale band were assigned to the Eastonian (middle Late Ordovician) and the western black shale plus the western turbidite sequence, extending west to the Barneys Range Fault, to the Bolindian (upper Late Ordovician) and Llandovery (Early Silurian).

Subsequent mapping and study of the graptolites by Browne (1979) refined the previous stratigraphy and the age control in the El Paso area. Browne mapped out the two black shale bands and the three turbidite-chert sequences of White et al. (1977). In addition, he recognised an additional black shale further east in the Beloko area (Fig. 2). These three black shale bands and the intervening turbidite-chert sequences were regarded as separate stratigraphic units and were given member status. From his graptolite identifications, Browne also concluded, like White et al. (1977), that these rock units form part of a west-dipping and — younging sequence in the Adaminaby beds. He suggested that the Bolindian part of the sequence extends from the "El Paso Shale Member" westwards to the Barneys Range Fault, and that the underlying Eastonian part of the sequence comprises three turbidite-chert members ("Beloko Sandstone Member", "Bulgundara Sandstone Member", "Dimboola Sandstone") interbedded with the eastern two of his black shale bands ("Range View Shale Member" and "Werralong Shale Member").

RESULTS OF THE PRESENT STUDY

Our present interpretation of the geology of the El Paso area is summarized in Fig. 3, and is based upon reconnaissance mapping and fossil collecting along the
Snowy River, as well as examination of most of Browne's collected material. Although additional work still needs to be undertaken, our studies are sufficiently detailed to demonstrate that major problems exist with the previous interpretations of the geology in this area. In presenting the results of our own work below, we refer to the black shale bands in the area shown on figure 3 by number, counting from east to west. This is because one of our conclusions is that the black shale bands are structural repeats of a single stratigraphic unit, and therefore should not be given different stratigraphic names.

Black Shale Band No 1 and Adjacent Turbidites

Black shale band No 1 corresponds to the eastern black shale of White et al. (1977) and the "Werralong Shale Member" of Browne (1979). It consists of two portions, both of which are hornfelsed: a lower part, several decametres thick, of siliceous shale and chert, and an upper part, greater than 300 metres thick, of low-outcropping black to grey shale with perfect lamination and fine parting. Dips are steep to subvertical and strikes swing from 340° in the south to 020° in the north adjacent to the Snowy River. Mesoscopic folds of uncertain geometry are also present.

To the east, black shale band No 1 grades downwards into a thin-bedded, non-carbonaceous siltstone-shale sequence which dips and youngs west (e.g. 020°/50°W) and which itself passes downwards into a strongly jointed and hornfelsed sandstone sequence which also dips and youngs to the west. The western (upper) boundary of black shale No 1 is faulted (Fig. 3). This boundary fault lies generally parallel in strike to bedding in the footwall black shale, but in the immediate hanging wall in the turbidite sequence to the west, the fault cuts across an antiglinal hinge defined by rotated beds of poorly sorted sandstone and mudrock.

Numerous fossils occur in black shale band No 1 and whilst preservation is very poor because of hornfelsing, it is sufficiently good to permit identification of the most diagnostic species. The thin siliceous portion at the base of the band contains abundant Pygodus serra and Pygodus anserinus conodonts which is an unusual association since ranges of these two species do not normally overlap. The only other place where this association occurs is in the Nemagraptus gracilis Zone (lower Gisbornian, Gi1) in central Victoria (Cas and VandenBerg 1988). Late Gisbornian graptolites (Gi2) occur low in the black shale proper (Dicranograptus ramosus, Climacograptus bicornis bicornis, C. b. tridentatus, Orthograptus calcaratus acutus), and are followed several decametres higher by early Eastonian graptolites of Ea1 or Ea2 age (Dicranograptus hians, Climacograptus caudatus). The thick upper part of black shale band contains the Ea3 index fossil Dicranograptus kirki in addition to mainly long-ranging or unidentifiable graptolites.

Black Shale Bands Nos. 2 and 3 and Adjacent Sequences

Black shale band No 2 occurs as scree fragments on the south bank of the Snowy River, but forms low, grey to black outcrops some 100 m to the south between two gullies (Fig. 3a). Laminations have steep to subvertical dips with a regional 040°-050° strike. Steeply plunging tight to isoclinal folds, some with faulted hinges, are present at decametre scale, and show eastward vergence. The eastern, basal margin of black shale band No 2 appears to be conformable with an underlying sandy turbidite sequence, the upper part of which dips and youngs to the west above an east-vergent fold pair (cf Browne 1979). In contrast, the upper or western boundary of this shale band is a fault. The best evidence for faulting is seen in the truncation of a prominent chert band in the hanging wall turbidite-chert sequence which trends 030°-040°/50°W just south of the Snowy River, but becomes disrupted farther south as it rotates eastwards into an antiglinal hinge which is cut off at the western contact of the black shale band (Fig. 3a).

Although black shale band No 2 is locally tightly folded, graptolites indicate a relatively thin and incomplete Upper Ordovician section which youngs to the west and which overlaps with band No 1 in age (Fig. 3a). Siliceous siltstone along the eastern part of band No 2 is Gisbornian in age — it contains Climacograptus bicornis bicornis. Early Eastonian graptolites (Dicranograptus hians, Climacograptus caudatus) occur about 15 m higher up in black shale,
and Late Eastonian species (*Orthograptus quadrimucronatus*, *Leptograptus?* sp.) occur near the top.

The key feature of the turbidite-chert sequence west of black shale band No 2 is the chert itself, which consists of centimetre-thick beds of pale-weathering black chert with bioturbated muddy partings containing conodonts. Although most of these conodonts are long-ranging, the presence of *Spinodus spinatus* restricts the range from upper Darniwillian to earliest Gisbornian. The presence of this west-dipping Lower Ordovician chert above the Upper Ordovician black shale band No 2 (which dips and youngs to the west) constrains the boundary fault between them to be contractional in nature: that is, a high angle reverse fault or a thrust.

Black shale band No 3 lies to the west of (and therefore overlies) the chert-turbidite sequence briefly described above. The best outcrop occurs in a small creek (Fig. 3a), but outcrop is generally poor, mostly consisting of small floaters and chips of strongly silicified grey siliceous shale associated with quartz veining. Graptolites have been almost totally effaced, and only one small identifiable specimen was found—an *Orthograptus pageanus* which indicates an Early Eastonian age.

Band No 3 is overlain to the west by yet another turbidite sequence. Cursory examination showed at least one east-vergent fold pair and a mesoscopic fault with west-over-east displacement. Poor outcrop prevented clarification of the relationship with black shale band No. 3.

Both White et al. (1977) and Browne (1979) showed only one black shale band in the western part of the El Paso area (the "El Paso Shale Member" of Browne 1979), and we are thus uncertain whether that band corresponds with band 2 or 3. Browne's map does suggest that his western band corresponds with band No 3, but this could be due to a misplot. Bolindian graptolites occur in a black shale band north of the Snowy River at locality v (Fig. 3a), part of Browne's (1979) "El Paso Shale Member" (Fig. 2), but correlation with shale bands south of the Snowy River is uncertain.

**INTERPRETATION**

While the observations reported above are based on a reconnaissance study only, they indicate that the geology of the El Paso area is considerably more complex than hitherto suspected. The new data cast serious doubt on the previous interpretations that the Ordovician rocks at El Paso form a coherent sequence which dips and youngs to the west, and instead strongly suggest that the rocks in this area can only be interpreted in terms of a sequence of Lower and Upper Ordovician rocks which has been structurally repeated by thrusting.

The key to our interpretation is the presence of black shale bands 1, 2, and 3. All these bands are similar in lithology and overlap in age. Unlike the previous interpretations, which regarded the black shale bands as separate stratigraphic units in an Upper Ordovician sequence, we regard them as repetitions of the same stratigraphic unit, the Upper Ordovician Warbisco Shale, defined originally in East Gippsland by VandenBerg (1981) (see VandenBerg et al. in prep and also Cas and VandenBerg 1988). In some black shale bands in East Gippsland, VandenBerg et al. (in prep.) have been able to map out a basal cherty interval which they call the Sunlight Creek Formation, and this correlates in age and facies with the siliceous Gisbornian basal parts of bands 1 and 2 at El Paso which are not separable at map scale. The biostratigraphic evidence for structural repetition of the Warbisco Shale in the El Paso area is very convincing. Bands 1 and 2 span almost the same biostratigraphic interval, from the Gisbornian (Gi1 or Gi2) to at least the Upper Eastonian. Further evidence that only a single black shale unit is involved comes from examination of Browne's own graptolite collections which shows that, rather than being of different age, his two western black shale bands contain a complete overlap of graptolite zones ranging from the Gisbornian (probably Gi2) to mid-Bolindian (Bo3). Take the middle black shale first. The "basal Werralong Shale Member at NUMBLA [GR]560580, Beloka Creek" (Browne 1979) contains a mixture of late Eastonian (Ea3) and Bolindian forms (including *Paraorthograptus pacificus*, index fossil for Bo3). About 3 km further northeast along the same band ("Werralong Shale Member, Snowy River,"
BERRIDALE 569613)" the graptolites are early Eastonian (Ea2). At NUMBLA 565585, the "Werralong Shale Member" contains Ea3 graptolites, including *Pleurograptus linearis*. For the westernmost black shale, the "El Paso Shale Member" at BERRIDALE 554615 contains Bo1 and Bo2 graptolites. At BERRIDALE 555614, the same band contains Ea3 and Ea4 graptolites.

Returning to the section along the Snowy River, the mapped data not only preclude an interpretation involving a homoclinal dipping and younging sequence, they also preclude an interpretation involving tight or isoclinal folding. This is best seen with reference to figures 3c-3f. Given the conclusion that only one stratigraphic black shale unit outcrops in the El Paso area, figure 3c presents, in stylised fashion, the elements of the structural problem set by having to join up the separate black shale bands within the constraints set by the new mapping, by youngings in the Warbisco Shale in shale bands Nos 1 and 2, and by the documented and inferred ages for the turbidite-chert sequence. Note that while only one Lower Ordovician date has been obtained from this latter sequence during this reconnaissance study, this Lower Ordovician age almost certainly applies to all the turbidite-chert sequences. This view is based on the presence of other cherts in the El Paso area east and west of band No 1 (see Fig. 2) which are similar in lithology to the dated chert which lies west of band No 2, and on the lithological similarity of turbidites associated with these cherts to those lying west of band No 2. These cherts are also comparable to cherts interbedded with turbidites which outcrop over a wide area of the greater Snowy Mountains area and from which earliest Gisbornian to Darriwilian ages have recently been obtained (e.g., in the Delegate area, Glen et al. 1989, VandenBerg et al. in press, and east of Cooma, I. Stewart written comm. 1989, pers. comm. 1990). The problem posed in Fig. 3c is answered in Fig. 3d which presents the only workable solution — one requiring the presence of contractional faults on the western side of each black shale band, putting Lower Ordovician on top of Upper Ordovician. Because the black shale bands must link up and join into the one stratigraphic unit at depth, the bounding faults must also link as well as flatten at depth. That is, they are west-dipping thrusts, splaying off a shallowly dipping floor thrust at depth, as shown in the true scale cross section of figure 3b. Solutions which use folding only (Figs 3e, 3f) do not work: they cannot explain the constant westerly youngings of the black shale bands Nos 1 and 2, and they cannot explain the documented presence of Lower Ordovician to the west of band No 2 in Fig. 3e, nor the inferred presence of Lower Ordovician west of band No 1 in Fig. 3f.

This thrust interpretation of the El Paso area is further reinforced by the presence of yet another Eastonian black shale band — the "Range View Shale Member" of Browne (1979) — which is deformed along its western margin and which outcrops east of black shale band No 1 (Fig. 2). These two eastern shale bands are separated from each other by another turbidite-chert sequence which is cut out to the south as the two bands merge (Browne 1979). If the sequence were simply west-dipping and west-younging, this "Range View Shale Member" should be older than band No 1. However, it is not, for its age overlaps that of the other bands. Graptolites from a quarry at Beloko within this easternmost band (see Fig. 2) indicate a late Eastonian (Ea3) age and include *Dicellograptus flexuosus*, *Diplacanthograptus spiniferus*, *Normalograptus tubuliferus* and *Orthograptus quadrimacronatus*.

The geometry of our thrust interpretation at El Paso is illustrated in Fig. 3b, in which east-verging, west-dipping imbricate thrusts splay off a flat or gently dipping floor thrust or detachment which lies at an unknown depth or stratigraphic level within the Lower Ordovician sequence (or even below it). These splay thrusts lie parallel to bedding for long distances in their footwalls (footwall flats) where they are localised by the mechanically weak Warbisco Shale and lie at low angles to bedding in the hanging wall (hanging wall ramps) where they are associated with fold propagation folds. Footwall ramps also occur at depth in the thrust system, where the imbricate thrusts ramp up through Lower Ordovician strata lying above the floor thrust. Other splay thrusts are probably also present in the El Paso imbricate fan, but because fine biostratigraphic control cannot be achieved in the monotonous turbidites, we can only recognise thrusts where they
juxtapose Upper Ordovician black shale against Lower Ordovician turbidites and cherts. Indeed, the different thicknesses of Lower Ordovician packets between the repetitions of Warbisco Shale (Fig. 3b) suggest that either different stratigraphic levels of detachment occur in different thrust sheets, and/or that additional thrusting occurs in the Lower Ordovician section. Emergent or blind thrusting probably accounts for the presence of small black shale slivers mapped by Browne (1979) in the turbidite-chert sequence in the southern part of the El Paso area (Fig. 2).

DISCUSSION AND REGIONAL IMPLICATIONS
Stratigraphy

This paper has shown that the rocks in the El Paso area do not form a coherent west-dipping and younging sequence through part of the Adaminaby beds but consist of an interleaving of a single Upper Ordovician black shale with a single Lower Ordovician turbidite-chert sequence. We adopt the name Warbisco Shale for the black shale unit, because its lithology, age and fauna, are identical to the Warbisco Shale in its type area. The Warbisco Shale is a constituent of the Bendoc Group (new name) which outcrops over much of the greater Snowy Mountains area, and comprises two formations — the Upper Ordovician Warbisco Shale (with a basal Darrwillian to Gisbornian Sunlight Creek Member identifiable in some areas), and a Bolindian to ?earliest Silurian mudrock sequence which includes the Akuna Formation and the Gungoandra Siltstone (Glen and VandenBerg 1987, Glen et al. 1989, Glen et al. in prep.). The name Adaminaby beds is therefore restricted to the Lower Ordovician turbidite-chert sequence, and is upgraded to group status since current work indicates it contains several units at formation status (Glen et al. in prep.). Further work in the area will enable us to define a type section. New stratigraphic names for the BEGA 1:250,000 sheet will be described by Lewis et al. (in prep.).

As thus redefined, the Adaminaby Group correlates with the Adaminaby beds in the Delegate area (Glen and VandenBerg 1985, 1987, White et al. 1989) and with the Pinnak Sandstone of East Gippsland (VandenBerg et al. in press). Work being carried out in the east Cooma and Bredbo areas by Glen et al. (in prep.) indicates that the turbidite-chert sequence there (Foxlow beds) is similarly Lower Ordovician in age and is also structurally interleaved with the Warbisco Shale. Relations between this redefined Adaminaby Group and the Boltons beds and Nungar beds most recently studied by Owen and Wyborn (1979) await further work.

Previous descriptions of the Warbisco Shale have come from the Delegate area (BENDOC and NUMBLA 1:100,000 sheets) in northeastern Victoria and southeastern NSW (VandenBerg 1981, Glen and VandenBerg 1985, 1987, Cas and VandenBerg 1988, White et al. 1989, VandenBerg et al. in press). In the Delegate area, the maximum thickness of the Warbisco shales is around 400 m (VandenBerg 1981, Cas and VandenBerg 1988), but because the formation is rarely preserved in a coherent sequence, the true thickness is difficult to estimate. In most outcrops there is structural repetition or omission of faunal zones or excision of the top of the shale by extensional faulting (Glen and VandenBerg 1987).

Structural Geology

The recognition that the structural style at El Paso is characterised by thin-skinned tectonics increases the areal extent of the thrust belt described from the Delegate area by Glen and VandenBerg (1987). These authors suggested that the zone of thin-skinned deformation is approximated by the distribution of the Llandovery Yalmy Group and its interleaving with the Upper Ordovician Warbisco Shale, and extends from the Delegate area west to the Indi-Long Plain Fault (see Fig. 1). This present work shows that the thrust belt can also be recognised in older rocks, and extends at least some 60 km north of Delegate into the Dalgety area. A key difference between the two areas is that thrust splays in the Dalgety area are localised in their footwalls by the Warbisco Shale (with Lower Ordovician being thrust over Upper Ordovician) whereas in most of the Delegate area, the splays are localised in their hanging walls by the Warbisco Shale which is thrust over Lower Silurian rocks. The exception occurs along the Yalmy - McLaughlan Creek Fault Zone west of Delegate (Fig. 1) where the splays are also localised by Warbisco Shale in the footwall.
Glen and VandenBerg (1987) regarded the Yalmy - McLaughlan Creek Fault Zone (Fig. 1), corresponding with the I-S Line of White and Chappell (1976), as the frontal part of their thrust belt. Subsequent work east of the I-S Line in the Combienbar area of East Gippsland (VandenBerg et al. in prep.), in New South Wales in the Cooma and Bredbo areas (Glen in prep.) and west of Bombala (McQueen et al. in prep.) indicates that the thrust belt does extend further east, although there is considerable evidence for an earlier, end-Ordovician deformation in some of these areas (Glen and VandenBerg 1987, Glen in prep.). In these areas, and also in the part of the thrust belt described from the Bungonia area east of Goulburn by Fergusson and VandenBerg (1990), the sole thrust again lies in the Lower Ordovician below the Warbisco Shale.

Our structural findings at Dalgety provide further evidence that the deformation style of the southeastern part of the Lachlan Fold Belt is characterized by upper and/or lower crustal detachments. Work by several authors (Fergusson et al. 1986, Glen and VandenBerg 1987, Gray 1988, Glen and Lewis 1990, Fergusson and VandenBerg 1990) all document a thin-skinned structural style for this part of eastern Australia. Out-of-sequence thrusting and movement on the detachments at different times account for the spread in ages of "orogenies" documented from the fold belt (Glen in prep.). These movements probably developed in response to an underthrusting event which commenced in the earliest Silurian (Scheibner 1983, Glen and VandenBerg 1985, Fergusson and VandenBerg 1990). This contrasts to the Alpine and Cordilleran orogens which developed by overthrusting involving major collisions and the upthrusting of large areas of high-grade metamorphic rocks.

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