Variations in the style of thrust faulting in the South Wales coalfield and mechanisms of thrust development

Hathaway, T.M.; Gayer, R.A.

Geoscience in South-West England

Published: 01/01/1994

Publisher's PDF, also known as Version of record

Read at the Annual Conference of the Ussher Society, January 1994

VARIATIONS IN THE STYLE OF THRUST FAULTING IN THE SOUTH WALES COALFIELD AND MECHANISMS OF THRUST DEVELOPMENT

T.M. HATHAWAY AND R.A. GAYER

Hathaway, T. M. and Gayer, R. A. 1994 Variations in the style of thrust faulting in the South Wales Coalfield and mechanisms of thrust development. *Proceedings of the Ussher Society,* **8,** 279-284.

Variscan compressional deformation in the western and central coalfield of South Wales is dominated by thrust faulting. Opencast extraction records and field data have shown the existence of distinct levels of thrust development as isolated structures and basal detachments within imbricate systems.

Two areas have been studied where the thrust faults exhibit similar features which have formed by different propagation mechanisms. At Nant Helen opencast site major thrusts are separated by smaller isolated structures, which apparently do not link to a basal décollement below the site. The isolated thrusts are adduced to have formed due to fluid over-pressuring and mechanical anisotropies in the rock sequence. In the Ffyndaff district deformation at the Ffyndaff opencast site is characterised by a series of foreland propagating thrusts linked by a detachment below the Nine Foot Seam, whereas to the west at Rhigos and Dunraven the detachment rises to a higher level and is interpreted as a gentle eastwards dipping lateral ramp.

T. M. Hathaway and R. A. Gayer, Laboratory for Strain Analysis, Department of Earth Sciences, University of Wales, Cardiff; PO Box 914, Cardiff CF1 3YE.

INTRODUCTION

The Variscan front has a west-north-west — east-south-east trend within the British Isles with the coalfields being the eroded remnants of basins that have been deformed in post-Early Stephanian times during the Variscan Orogeny. The South Wales Coalfield is part of one such basin and forms an east-west-trending asymmetrical syncline verging northwards.

The dominant early compressional structures are folds with associated thrusts trending east-west in the western and central coalfield and north-east to south-west in the eastern area (Figure 1). These are cut by normal faults trending north-west to southeast in the eastern coalfield and north-south in the western and central coalfield. These cross-faults represent an early extensional phase; some have undergone late inversion during post-Westphalian contraction, and others have an earlier dextral strike-slip history when they may have acted as lateral thrust ramps. Two major belts of east-north-east — west-north-west disturbance cut the coalfield, the Swansea Valley Fault Zone, and the Neath Fault Zone which are though to represent

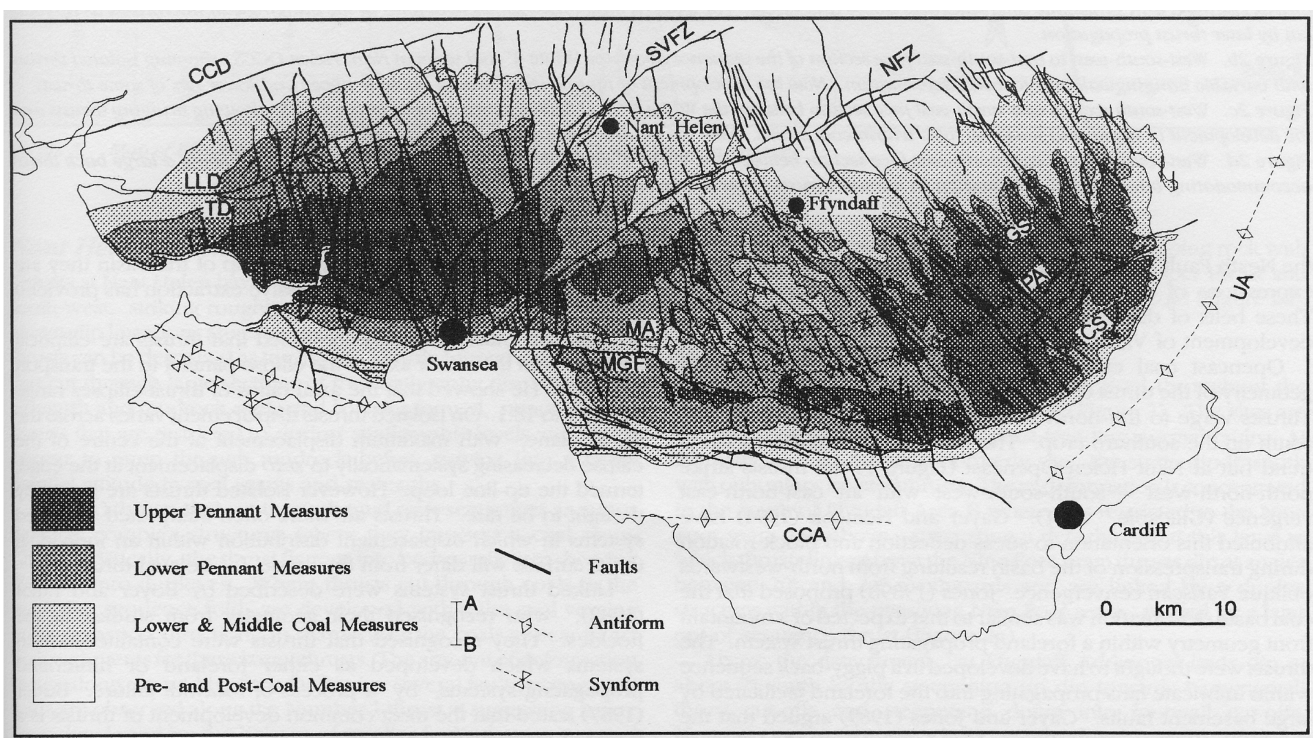

Figure 1. Map of the South Wales Coalfield (After BGS 1:50 000 range geological map) showing the main structural elements and the location of Nant Helen and Ffyndaff OCCS. CCD=Carreg Cennen Distrubance, LLD=Llanon Distrubance, TD=Trimsaron Distrubance, SVFZ=Swansea Valley Fault Zone, NFZ=Neath Fault Zone, MA=Maesteg Anticline, MGF=Moel Gilau Fault, CCA-Cardiff-Cowbridge Anticline, CS=Caerphilly Syncline, PA=Pontypridd Anticline, GS=Gelligaer Syncline and UA=Usk Anticline.

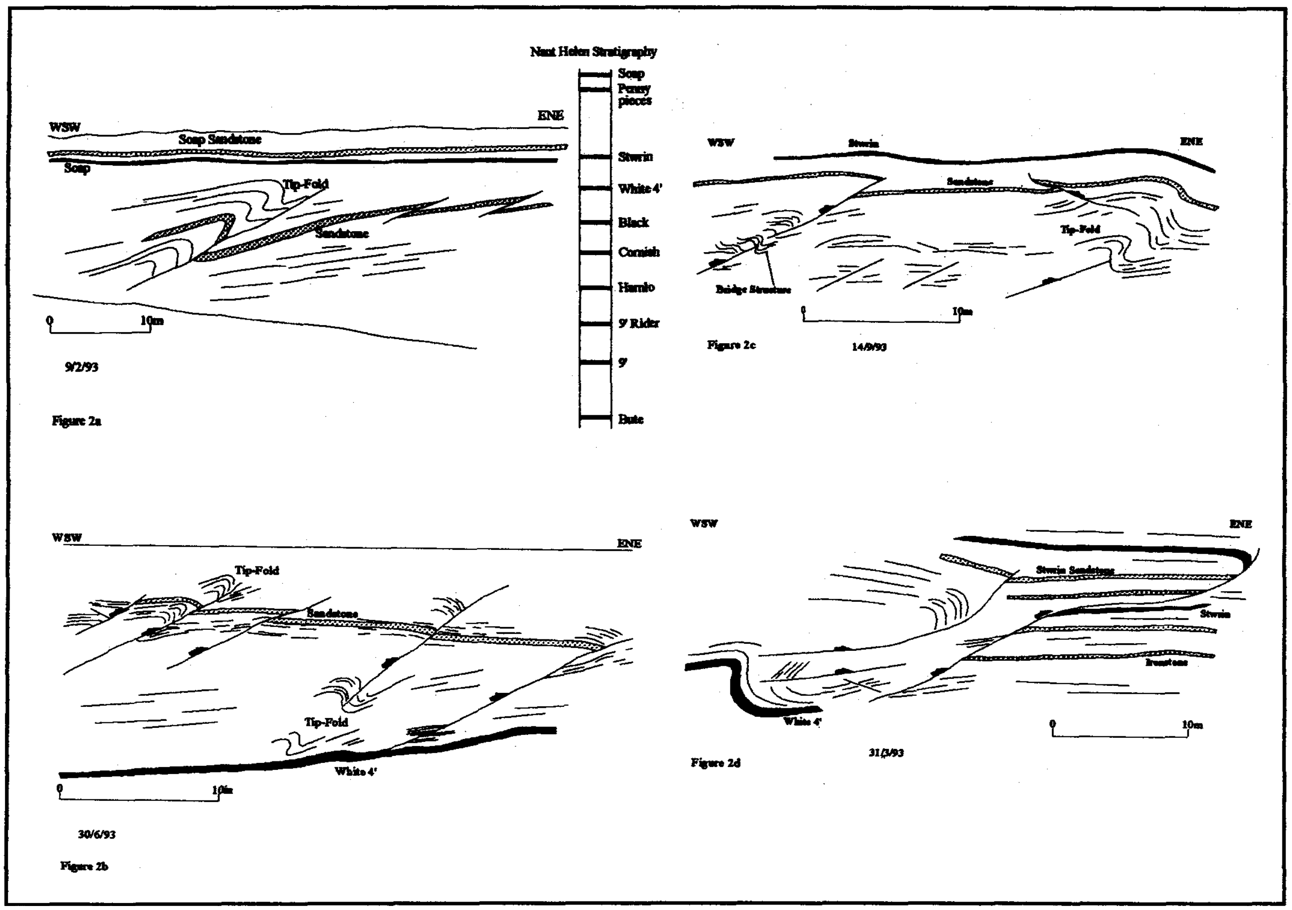

Figure 2a. West south-west to east-south-east face section of the sequence between the Stwrin and Soap seams at Nant Helen OCCS showing isolated thrusts cutting a thin sandstone and mudrocks above and below. The western most thrust shows tight folds in the hangingwall interpreted as tip-folds cut by later thrust propagation.

Figure 2b. West-south-west to east-south-east face section of the sequence above the White 4' coal seam at Nant Helen OCCS; showing isolated thrusts with variable hangingwall and footwall deformation. Note the development of tip fold structures at both the upper and lower tips of some thrusts.

Figure 2c. West-south-west to east-north-east face section between the White 4' and Stwrin seams at Nant Helen OCCS, showing bridging thrusts and the development of upper and lower tip folds within coal seams. Note the mudrock sequence shows little deformation.

Figure 2d. West-south-west to east-north-east face section between the White 4' and Stwrin seams at Nant Helen OCCS, showing a large back thrust accommodating hangingwall deformation in a lower thrusts. Note the development of a tip-fold between two bridged thrusts.

the surface expressions of basement lineaments with a Caledonoid trend. These belts of disturbance are thought to have influenced the development of Variscan structures in close proximity.

Opencast coal extraction records reveal the detailed 3-D geometry of the thrust deformation not seen by surface mapping. Thrusts verge to the north in the northern coalfield and to the south on the southern crop. There is a general east-west strike trend but at Nant Helen Opencast (Figure 1) the thrusts strike north-north-west — south-south-west with an east-north-east vergence (Gillespie, 1991). Gayer and Nemcok (1994) have attributed this orientation to stress deflection and block rotation during transpression of the basin resulting from north-westwards oblique Variscan convergence. Jones (1989b) proposed that the coal basin deformation was similar to that expected of a mountain front geometry within a foreland propagating thrust system. The thrusts were thought to have developed in a piggy-back sequence within imbricate fans propagating into the foreland facilitated by large basement faults. Gayer and Jones (1989) argued that the Mod Gilau fault greatly influenced the development of northward propagating linked thrusts.

The Variscan thrusts in the South Wales coalfield are exposed at numerous stratigraphic levels within the coal and mudrock sequences of the productive coal measures (Westphalian A-C) in opencast mines. On the northern outcrop of the basin they are the predominant structures. Progressive extraction has provided a 3-dimensional picture of the, thrusts.

Work by Gillespie (1991) confirmed that thrusts are elliptical surfaces with the minor axis of the ellipse parallel to the transport direction. He showed that the axial ratios of thrust ellipses range from 3:1 to 18:1. On isolated thrusts displacement varies across the thrust plane, with maximum displacement at the centre of the ellipse decreasing systematically to zero displacement at the edge, termed the tip-line loop. However isolated thrusts are generally thought to be rare. Thrusts are more often interpreted as linked systems in which displacement distribution within an individual thrust surface will differ from the model for isolated thrusts.

Linked thrust systems were described by Boyer and Elliot (1982), who recognised their geometry from studies in the Rockies. They recognised that thrusts were contained within systems which developed as either foreland or hinterland propagating systems, by a process of footwall failure. Butler (1987) stated that the most common development of thrusts is a foreland-directed (piggy-back) series developing either as an emergent imbricate fan or a duplex structure. Thrust development in the South Wales Coalfield displays several unusual features, e.g. simultaneous movement on several detachments

(Frodsham *et al.,* 1993). This paper describes other atypical thrust phenomena. Unlike an idealised piggy-back development of thrusting, where thrusts cut up through the stratigraphy and propagate from a basal detachment, the thrusts observed in one area have developed as isolated structures with no basal detachments, or they have developed as secondarily linked imbricate systems.

STYLE OF THRUST DEFORMATION IN THE SOUTH WALES COALFIELD

The geometry of thrust deformation is described from two areas on the north crop. The first examples are at Nant Helen Opencast Coal site which is situated to the east of the Swansea Valley Fault Zone, bounded to the east by a north-west — south-east - trending normal fault, the Pwllau Bach Fault. The other area lies to the west of Hirwaun where thrusts have been investigated in three adjoining opencast coal sites. The investigation has been aided by use of British Coal extraction survey records that allows structures no longer available for study to be included.

by ductile flow within the mud rock, but where a thrust enters a coal there are zones of ductile deformation comprising sheared packages of coal separated by highly polished slip surfaces. Some of the type b thrusts show displacement decreasing both up and down-dip with high displacement gradients suggesting high tip-strains that are accommodated in the hangingwall by tight anticlinal structures that do not affect the overlying sequence (Figure 2a).

In both type a) and type b) the amount of accommodating deformation in the hangingwall and footwall both along the strike and down dip varies. Some thrusts have virtually no deformation in the hangingwall and footwall whilst others are characterised by close to tight folds (Figure 2b). The amplitude of these folds often varies significantly along the strike of the thrust, in one case changing from >5 m to zero over 25 m. In a third case the footwall is passive and deformation is dominant in the hangingwall. Large rollovers are often accommodated by south-west-directed back thrusts cutting through the limb of open hangingwall anticlines (Figure 2c). Many of the thrusts are connected down-dip by bridging structures which allow displacement transfer to higher or lower levels. The bridged areas

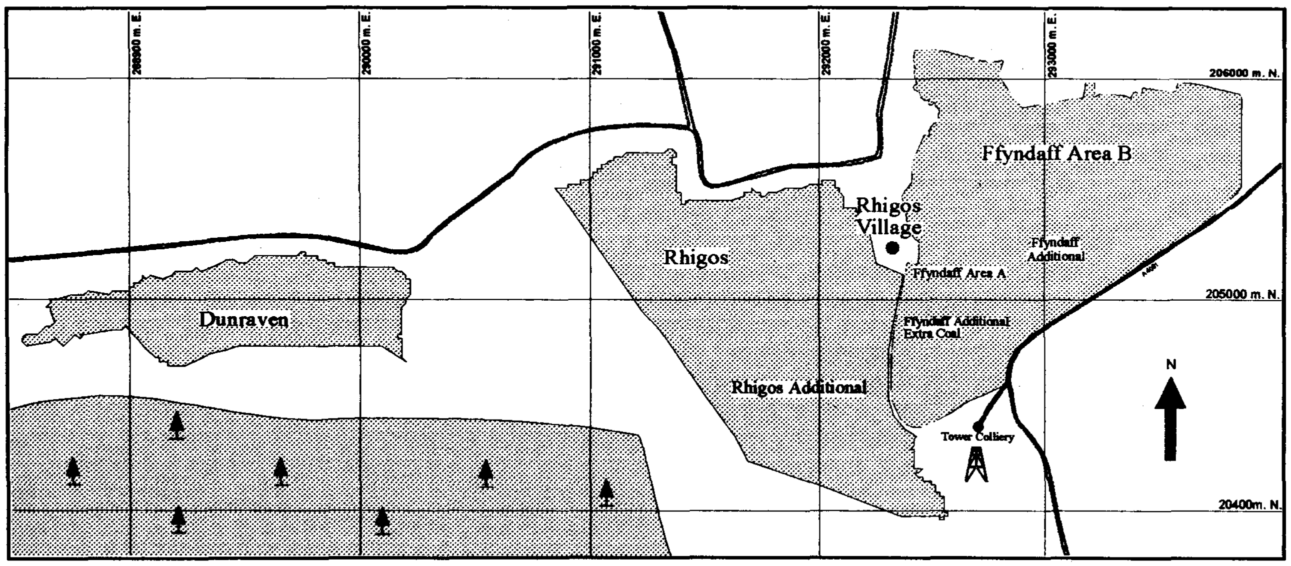

Figure 3. Map of Ffyndaff OCCS and the adjoining Rhigos and Dunraven opencast sites.

of dipping rock with upward facing cut-offs into the footwall of the upper thrust and horizontal beds into the lower thrust producing a fold (Figure 2d).

Nant Helen Opencast Coal Site

Thrusts at Nant Helen have an average dip of 22° towards the west-south-west, striking roughly north-north-west — south-south-east. Down-dip lineations are present on many of the fault surfaces. The thrusts can be described as two types: a) early formed major thrusts that cut through large sections of the stratigraphy displacing coal, seatearth and mudrock strata and b) later formed, minor isolated thrusts that are restricted to distinct stratigraphic levels and which appear to ramp through mudrock before curving into a layer-parallel attitude in coal seams and seatearths.

Type a) thrusts that cut through mud rock sequences as ramps develop complex structures where they intersect a coal seam. Characteristically, the thrust flattens into bed-parallelism shearing the coal into duplexes. Where thrusts cut through coals to the overlying sequence folds are developed within the coal verging in the transport direction. In many cases the coals appear to act as detachments for these larger thrusts. The amount of deformation varies along the width of the faults, i.e. several fault-propagation folds are observed along the Number 1 thrust at suggesting it may have developed by the linkage of smaller faults that propagated up and down dip to "capture" faults.

Type b) thrusts are restricted to the sequences between the higher seams of the site and do not cut the overlying or underlying coals. Strain is normally accommodated at the tip of the thrusts often consist

Ffyndaff Opencast Coal Site

This area comprises a number of sites worked throughout the 1980s and a new extension to the south (Figure 3). The sites are cut by major north-west — south-east-trending normal faults. At Ffyndaff Area B, the most northerly site, the strata dip 8° south with only minor isolated thrusts. Thrust deformation is concentrated in the south of Ffyndaff Area B where it is restricted to the Nine Foot seam and above, suggesting a detachment at this level to which thrusts link. Above the Nine Foot seam thrusts dip at angles between 20° and 24° southwards and are linked by a duplex structure within the overlying Nine Foot seam, roofed by a later out-of sequence thrust (Figure 4a).

Above the detachment, at Ffyndaff Additional beds dip at about 7° south locally steepening up dip towards hangingwall thrust cut-offs and steepening down into footwall cut-offs. However most thrusts show some development of both hangingwall anticlines and footwall synclines along their strike which are thought to represent either tip-folds or propagation folds, back thrusts are associated with these folds. Dips vary along thrust lengths and at the change of low dips to high

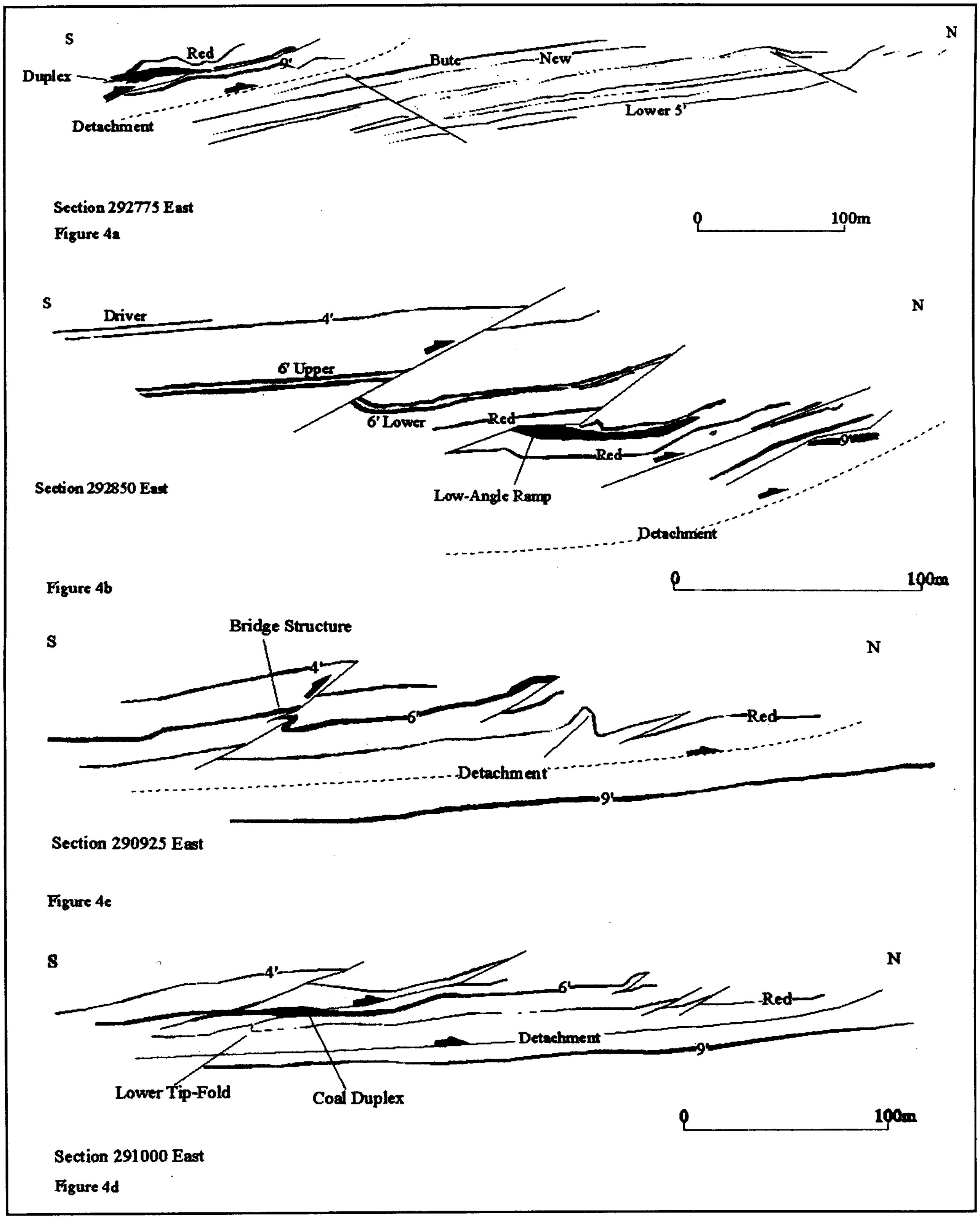

Figure 4a. Extraction section 292775E from Ffyndaff Area B, showing thrust deformation restricted to the Nine Foot seam and above. Note the duplex in the Nine Foot seam bounded in the roof by an out-of-sequence thrust.

Figure 4b. Extraction section 292850E from Ffyndaff Additional, showing the development of major thrusts with the development of weak hangingwall and footwall deformation. Note the large displacement associated with the low-angle ramp.

Figure 4c. Extraction section 290925E from Rhigos, showing a bridging structure in the Six Foot seam and the a prominent tip-fold in the Red seam.

Figure 4d. Extraction section 291000E from Rhigas, note the thickening of the Six Foot seam by coal duplexing and the associated thrust dying out at a lower tip-fold.

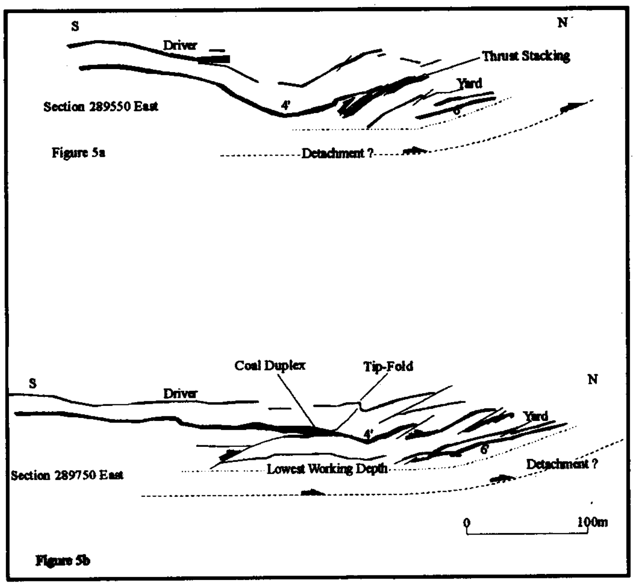

Figure 5a. Extraction section 289550E from Dunraven, showing an asymmetrical syncline in coal measures with thrust stacking concentrated on the steeper, northern limb.

Figure 5b. Extraction section 289750E from Dunraven, showing thickening of the Four Foot seam by duplexing and a tip-fold associated with the thrust.

dips, ramp folds develop in the area above the thrust (Figure 4b). Steeply-dipping ramps coincide with low displacement. Flats appear as local areas, associated with high displacement, connected by sidewall ramps.

Rhigos Opencast Coal Site

This site and the Dunraven site (Figure 3) are no longer worked and the analyses are based entirely on British Coal extraction sections. To the west of Ffyndaff Additional, Rhigos opencast site exhibits similar thrust styles and features to those seen at Nant Helen, with two major thrust systems (Figures 4c and 4d). The strata dip 3° to 4° southwards but locally steepen where thrusts cut coal seams. Cut-offs tend to face upwards rather than the usual hangingwall anticlines and footwall synclines as developed in Ffyndaff Additional. The two largest thrusts developed early (Owen and Weaver, 1983) whereas smaller thrusts developed later, whilst the larger structures were still undergoing movement, and many of the type b thrusts may have developed out-of-sequence.

Thrusts dip at angles between 20° and 24° southwards and strike approximately east-west. The two main thrusts cutting the site have generally low displacement gradients. They have large displacements in the Red and the Four Foot seams but have significantly less displacement where they enter the Six Feet seam and do not extend to the Nine Foot seam. Other smaller thrusts show higher displacement gradients (Figure 4c). The Six Feet seam is thickened by the development of a coal duplex and displacement is accommodated along several slip planes within the coal. The main thrusts show displacement decreasing downwards with a lower tip-fold developed in section 291000 (Figure 4d), suggesting that the thrusts have developed as isolated structures growing from a central nucleus and propagating radially to later link with a basal detachment. Fault bend folds developed in a lower thrust have deformed the upper and therefore older thrusts, indicating an in-sequence thrust development.

Dunraven Opencast Coal Site

Westwards along strike from Rhigos at Dunraven the strata dip steeply south on the northern limb of an asymmetric syncline. The fold developed pre-thrusting and verges northwards. Most thrusts are small and concentrate at the levels of one seam, stacking the coal seam. Two larger thrusts cut the site. The thrusts have developed preferentially on the northern limb of the syncline where the strata dip to the south, providing a mechanically preferential orientation for rock failure. The thrusts abut against a north-east — south-west-trending normal fault seen in the most westerly sections, downthrowing to the north-west. In the sections farther east the dip shallows and the cross fault, which is oblique to the sections, does not appear (Figure 5). The southern limb of the syncline dips shallowly and on the north limb steeper dips are caused by the ramping of the strata over the same detachment seen to the east. The thrusts dip at between 20° and 24° south with little evidence of extreme layer-parallel thrusting and thickening of seams by duplex development.

The thrusting appears to have developed in-sequence, but locally out-of-sequence thrusts and back-thrusts occur. Fault propagation folds are developed by a process of tip-folding (Figure 5b). Some thrusts show a downwards decrease in displacement.

DISCUSSION

The initiation of thrusts as isolated faults rather than by foreland propagation of a linked thrust system is not a new idea. Eisenstadt and De Paor (1987) suggested that thrusts may have developed as ramps in layered sequences with competency contrasts, nucleating in competent bands, and Gillespie (1991) documented some examples from the South Wales and Ruhr coalfields. However, this account describes a series of isolated faults and related features that indicate how they may link.

At Nant Helen isolated thrusts at several levels cut and may have originated in strong sandstone before propagating into less competent mudrock. The evidence from Nant Helen suggests two categories of thrusts within the central area of the north crop. Initial compression produced the larger thrusts that cut and propagated through the competent sequence and have a relatively low displacement gradient. However, these larger thrusts may not have developed as isolated structures growing from a central nucleus. It is not clear whether the thrusts developed as ramps or flats, and it is difficult to tell if displacement decreases up or down the fault. The second category thrusts are characterised as having developed in inter-seam mudrock sequences, passing into a layer-parallel flat in the overlying coals, without affecting higher strata. However, there remains the possibility that these thrusts may be linked along strike by bridging structures. Displacement is lost rapidly with correspondingly high displacement gradients, and a large proportion of the shortening strain is taken up within the mud rock sequence. The detachment levels may be controlled by stratigraphy and thrusting is due to the mechanical anisotropy in the rock sequence.

At Rhigos, one of the large thrusts shows displacement in some of the sections decreasing down the fault to die out at a lower tip-fold. In sections farther along strike the thrusts cut down through the seam and would appear to link to the detachment. This implies that thrusts initiated as isolated faults and propagated both laterally and downward to link with a basal detachment. In doing this they appear to retain their elliptical shape during sideways propagation.

The process of development of isolated thrusts at Nant Helen cannot be attributed to Progressive Easy-Slip Thrusting (PEST) deformation described by Frodsham *et al.* (1993). Unlike PEST the thrusts at Nant Helen do not appear to fold higher sequences and simultaneous movement is not obvious. The restriction of thrusts to mudrocks would suggest varying pore fluid pressure throughout the stratigraphic sequence. At certain levels fluids were contained between coal seams allowing thrust faulting to occur. Percolating fluids may have passed along fault planes and cleat fractures (Gayer *et al.,* 1991) and could have become trapped between coal seams at the base of mudrock sequences.

The recognition of high displacement gradients and of large shortening strains fits with the fourth scenario of Vann *et al.* (1986), who described rapid loss of displacement along thrusts producing crustal-scale monoclinal folds. The rapid loss of displacement towards the tip implies large scale ductile shortening in the hangingwall rocks which should produce effects such as stratal thickening and steep cleavage. It also implies large-scale deformation above the tip of the basal detachment and faults splaying from the basal detachment.

CONCLUSIONS

1) Linked thrust systems within the South Wales Coalfield have developed either by thrusts propagating towards the foreland from basal detachments, or as isolated structures which may be linked along strike by bridge structures.

2) There have been at least two stages of thrust development at Nant Helen and in the Ffyndaff area.

3) Detachment levels are the result of mechanical anisotropy in the rock sequence accompanied by periods of fluid over pressuring within the strata.

4) Isolated thrusts may later connect to basal detachments or may remain isolated and restricted to distinct levels by fluid pressuring controls.

ACKNOWLEDGEMENTS

TH is supported by NERC/British Coal Opencast CASE studentship. The data used for analysis of thrusts was provided by British Coal Opencast.

REFERENCES

BOYER, S.E AND ELLIOT, D. 1982. Thrust systems. *Bulletin of the American Association of Petroleum Geologists ,* **66,** 1196-1230.

BUTLER, R.W.H. 1987. Thrust sequences. *Journal of the Geological Society,* **144,** 619-634.

EISENSTADT, G. AND DE PAOR, D.G. 1987. Alternative model of thrust-fault propagation. *Geology* **15,** 630-633.

FRODSHAM, K., GAYER, R.A., JAMES, J.E. AND PRYCE, R. 1993. Variscan thrust deformation in the South Wales Coalfield: a case study from Ffos Las opencast coal site. In: *The Rhenohercynian and Sub-Variscan Fold Belts*. Eds: R. A. GAYER and R. O. GREILING. Earth Evolution Science Series, Vieweg, Braunschweig.

GAYER, R. AND JONES, J. 1989. The Variscan foreland in South Wales. *Proceedings of the Ussher Society,* **5.**

GAYER, R.A., COLE, J., FRODSHAM, K., HARTLEY, B., HILLIER, B., MIUORIZOS, M. AND WHITE, S.C. 1991. The role of fluids in the evolution of the South Wales Coalfield foreland basin. *Proceedings of the Ussher Society,* **7,** 380-384.

GAYER, R.A. AND NEMCOK, M. 1994. Divergent tectonic transport in external orogenic zones: The result of transpressionally driven rotation. *Proceedings of the Ussher Society,* **8,** 317-320.

GILLESPIE, P.A. 1991. A study of folding and faulting in the South Wales and Ruhr coalfield. *Unpublished PhD Thesis, University of Wales*.

JONES, J.A. 1989b. Sedimentation and tectonics in the eastern part of the South Wales Coalfield. *Unpuhlished PhD Thesis, University of Wales.*

JONES, J.A. 1991. A mountain front model for the Variscan deformation of the South Wales Coalfield. *Journal of the Geological Society,* **148,** 881-892.

OWEN, T.R. AND WEAVER, J.D. 1983. The structure of the Main South Wales Coalfield and its Margins. In: *The Variscan Fold Belt in the British Isles.* Ed: P. L. Hancock. Hilgar, 74-87.

VANN, I.R., GRAHAM, R.H AND HAYWARD, A.B. 1986. The structure of mountain fronts. *Journal of Structural Geology,* **8,** 215-227.