The Cwmystwyth Mines, Ceredigion, Wales, UK: a revision of lode geometry from new surface geological mapping

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Summary

The area around the mines has been remapped and several significant revisions made to the conclusions of previous work by O.T. Jones (1922) and the British Geological Survey (1993, 1994). The resulting map is now consistent with available mine plans. The larger lodes are multi-layered dextral-oblique dip-slip shear zones within which Reidel shears may dip in opposite sense to the system as a whole. The Comet Lode is newly considered to be repeated as the Penparc Lode in the footwall of the Ystwyth Fault and to correlate with the Hen Barc Lode there; furthermore the Kingside Lode is newly correlated with the North Lode in the footwall of the Ystwyth Fault. These identifications allow a new estimate of ca 470 metres of dip-slip and ca 170 metres of dextral strike-slip on the Ystwyth Fault. The latter estimate is unexpected in regional context and possible reasons for this are discussed.

1. Introduction

The Cwmystwyth Mines lie in the SE portion of the Central Wales Orefield (Figure 1) and represent one of the finest areas for geological study of metallic mineralisation therein. This results from a combination of excellent surface exposure, an abundance of variably accessible subsurface exposure and the availability of contemporaneous mine plans locally supplemented above flooded levels by modern resurvey. There is thus the opportunity to assess lode geometry and host rock structure in three dimensions to unusual degree. Moreover, the newly-detailed repetition of parts of the lode system by the Ystwyth Fault, in combination with the steep sides of the valley, sections these lodes over a vertical elevation of ca 800 metres; over twice the extent seen anywhere else in the orefield. As noted by Hall (1989, p 120) “unusually for Central Wales, where any one mine almost always depends on one lode, there are a great number of lodes”. The mine area is also notable for the presence of several unusually lengthy crosscut adits, most of which have long been inaccessible. These latter, if responsibly reopened, would add considerably to knowledge. One such, Taylor’s (Glynderi), has become accessible during this study. The Copper Hill portion of the Mines is of great antiquity and of particular archaeological value (Timberlake, 2003 and references therein). The Mines were worked primarily for lead and large reserves of zinc remain.
The objectives of this paper are to present the results from new surface geological mapping of ca 7 square kilometres around the mines made on 1:10,000 or larger (locally 1:2500) scale using GPS as an aid to positioning. This is integrated with some important recent fieldwork underground together with a re-evaluation of published literature and calibration with the mine plans to assess the extent and identity of the principal lode systems and the geometry of their intersection with the major Ystwyth Fault. No detailed study of the mine plans is attempted.

2. Host strata

The mines are unusual for Central Wales in that the lodes are almost exclusively developed in the basal Rhuddnant Grits of Upper Llandovery age rather than stratigraphically slightly lower in the Devil's Bridge Formation or much lower in the late Ordovician Bryn Glas Formation from which two horizons the great majority of production was derived; see Figure 2 and the regional distribution of mines shown in the compilation by the Institute of Geological Sciences (IGS,1974).

The Rhuddnant Grits comprise a succession of mudstones and fine-grained turbidite sandstones with intercalations of coarser muddy sandstones that are commonly up to about one metre thick (Clayton,1994; Davies et al, 1997). Assuming that the sandstones are relatively brittle in comparison to the mudrock intercalations, there is likely to be considerably greater ductility contrast within the Grits than in the underlying Blaen Myherin Mudstones and it can be argued that this favours development of fracture poro-perm during faulting. It would also induce a degree of decollement above these mudstones during folding and this is observed. The host strata were folded and cleaved

Figure 1. The location of the Cwmystwyth mines within the northern Central Wales Orefield

Main map shows the Cwmystwyth mines within the orefield (shaded) in relation to other important mines and the areas of outcrop of major stratigraphic units. Inset map shows the location of the orefield (darkest shading) in Wales and the mining areas discussed in the books of Bick (DEB) and Hall (GWH), see reference list.
during the regional Acadian deformation of the Welsh Basin ca 396 million years ago (Sherlock et al., 2003) which preceeded the first phase of mineralisation dated by lead isotope studies at ca 390 million years ago (Fletcher, Swainbank and Colman, 1993) and which seems likely to correlate with the "early complex" mineralisation of Mason (1997) who recognised two principal episodes of mineralisation from paragenetic studies. The later episode, "late simple", seems likely to correlate with that indicated by the lead isotopes at ca 360 – 330 million years ago and is broadly of Variscan age. Fold axes around Cwmystwyth trend ca 007° - 015° with gentle plunges to both north and south: they are transected clockwise at about 8° by the steeply dipping regional cleavage (Davies et al, 1997, fig 43).

Figure 2. Host stratigraphy and relative ore-tonnage outputs (post-1845) in Cardiganshire, modified after Foster-Smith (1979).

Foster-Smith (1979) wrongly equated the Cwmystwyth 'Formation' of O.T. Jones (1922) with the Moelfre Group of W.D.V. Jones (1945) which is of griesoniensis Biozone age. The host strata at the Cwmystwyth mine (which are of turriculatus Biozone age) were thus too widely separated from the principal ore occurrences in the Frongoch 'Group'. This created an entirely separate, and unreal, concentration of production within the Pysgotwr Grits rather than a locally increased concentration just above the Frongoch Group, ie at the base of the Rhuddnant Grits at Cwmystwyth (star symbol). Very few lodes in the Drosogol Formation and below were ever explored. Note the relationship between potential hydraulic seals (thick ductile mudstones) with zones that are largely barren and that between hydraulic stores (multilayered sequences prone to more brittle deformation, small-scale folding and permeability connectivity) with zones that are highly productive.

3. Lode morphology and genesis

The lodes map as mineralised dextral-oblique dip-slip faults, commonly with dips of 55° - 70° but locally approaching the vertical on Copper Hill. Fault zone width is variable, from centimetre-scale planar fracture to over ten metres of multiple lode-quality shear zones and cemented breccias interspersed with internal barely mineralised screens that are locally seen in the Comet Lode. The
lode breccias display many textural features suggestive of fracture propagation through strata with unusually high pore fluid pressure (Phillips, 1972, 1986) and their variable width and barren/mineralised zonation is a consequence of processes of asperity bifurcation and tip-line bifurcation set out by Childs, Watterson and Walsh (1996). In detail there appear to be numerous minor lodes but many of these are probably offshoots or associates of the major lode systems (Hughes, 1981). There are four principal systems; the Comet and the Kingside (both S-hading), Michell’s (N-hading) and the Pengeulan complex (both N-hading and S-hading) which appears to be confined to the hanging walls of the Comet and the Kingside systems. The subsidiary dextral movement on many of the faults that is suggested by offset of fold axes is also consistent with the rake of slickensides in the fault planes. The lode systems are offset by the major Ystwyth Fault which is apparently non-mineralised; minor ‘stones’ of ore therein having probably originated as rip-outs from lodes truncated or followed by the fault.

The mineral species present within the Cwmystwyth lodes are discussed in the regional treatment of mineral paragenesis by Mason (1997) which considerably extends and revises work by Raybold (1974). Geochemical studies by Kakar (1971) are also pertinent and support the concept of two principal episodes of mineralisation.

4. Previous work

The pioneering study by Smyth (1848) provides a useful contemporary snapshot of development work on the lodes, and trials on barren fractures, but did not recognise the existence of the Ystwyth Fault. Smyth also terminated the Comet Lode near the Kingside shaft, thus making it separate from the Belshazzar Lode on Copper Hill.

The economic memoir by O.T. Jones (1922) remains the one indispensable geological guide to both Cwmystwyth and the Central Wales Orefield in general. Its value rests on the combined usage of detailed mine plans and surface fieldwork, in particular at Cwmystwyth the control afforded by the Nant-y-Graig section and the nearby workings in Level Fawr. Jones recognised the powerful effects of the Ystwyth Fault which he thought (op cit, p 114) to be of simple N-hading dip-slip nature with an offset of ca 820 metres. However his work was required to concentrate on areas with major proven mineralisation and is inevitably locally incomplete. Recent work has indicated that some revisions are also necessary.

- The course of the Ystwyth Fault east of the mine was stated without supporting evidence to turn eastwards under Dol-y-twch (SN 8095 7453) rather than lie within the Ystwyth valley towards Tymawr (SN 815 747). This seems unlikely from the work of the British Geological Survey (BGS, 1993, 1994a) although the BGS bilingual map (1994b) agrees with neither of these courses and shows the fault dying out upvalley near Tylwyd (SN 822 753).
- The South Cwmystwyth workings were considered to lie upon a repetition of the Comet Lode, upfaulted by the Ystwyth Fault. This is confirmed by my work but the associated identification of the Comet Lode as an extension of the Logaulas Lode has been disproven by BGS mapping (1994a) between SN 760 725 and 730 705.
- The East Hafod workings were not discussed, neither were those around Taylor's level (Glynderi); also virtually nothing is given for the Pengeulan lode system.
- The West Cwmystwyth workings are mentioned only briefly in connection with a claim (p 32) that the Comet Lode here offsets the base of the Cwmystwyth Formation by 640 m, implying a throw of 180 - 230 m. These figures are based on mapping now known to require revision.
- The analysis of the area between Mitchell’s (should be Michell’s) adit and Nant y Graig is incomplete (pl XVII) in that continuity of Michells Lode is very difficult to accept unless the two areas are connected by some form of northwest-trending relay.
- The courses of the Comet and the Kingside Lodes to the northeast of Copper Hill towards Ffrwd yr Ydfran (SN 823 763) as shown on pl VII of the memoir are difficult to substantiate and mechanically difficult to envisage if only two major faults are present.
- The Penparc Lode was stated to be north-dipping (p 136): this is now disproven.
- The Hen Barc Lode was thought equivalent to that worked in the Graig Goch opencast: this now seems incorrect.

Although primarily concerned with industrial archaeology and social history, the memoir by Hughes (1981) includes five large scale cross-sections (op cit, figs 3-7) through the workings and much new data on lode distribution and geometry. This work is an essential bridge to modern geological study which should be seeking to reconcile archival data with a new generation of surface and subsurface mapping. It is also the current authority for lode/adit nomenclature where this is not evident on the plans. The throw on the Ystwyth Fault is given as ca 960 metres of sinistral strike slip together with ca 820 metres of dip slip, but without reference: the relevant cross-section (op cit, fig 2) is, however, schematic and wisely without precise location.

The regional mapping by BGS is primarily concerned with stratigraphy and structure and has greatly clarified the regional setting of the Cwmystwyth Mines. Their stratigraphy, adopted herein, not only updates and formalises that of O.T.Jones (1909) but provides detailed description of sedimentary facies. Inevitably, much structural detail cannot be shown on their maps (BGS, 1993, 1994) at 1:50,000 scale. Despite the advances from their work, which is the first to produce a complete geological map of the mine area, several of their conclusions remain open to revision.

- The throw on the Ystwyth Fault at the Mines is likely to be considerably different from that suggested, which assumes no change from an estimate of 1300 metres of sinistral strike-slip together with 300 metres of dip-slip around SN 715 721 ca 9 km to the WSW (Davies et al, 1997, p 195). Even if this figure is correct where estimated, the throw is known to be negligible around SN 849 757, ca 4 km to the ENE of the Mines.

- BGS (1993) show an apparent northerly downthrow of the top of the Llyn Teifi Member across the Comet and the Kingside systems in the area NE of Copper Hill. This would be consistent with the proven southeasterly downthrow on these lodes only in the cases of appreciable sinistral oblique slip; contrary to the sense of movement suggested by slickensides in the mine area.

- No Comet Lode or fault offset is shown in the West Cwmystwyth area, in conflict with outcrop and mine working evidence by Tyn y llechwedd (SN 789 746) where the Penshaft workings drove ca 165 metres east along this lode. Moreover the Comet is not shown at East Hafod where it was most probably encountered after drivage of ca 366 metres: the fault shown on the BGS map here is not supported by either surface or mine evidence.

- The area north of Michell’s adit is extensively reinterpreted, compare Davies et al (1997, fig 62) with O.T.Jones (1922, plate XVII) but the results are in conflict with the data presented by Hughes (1981, fig 3) which is not discussed.

- The N-hading lode shown at Graig Goch (SN 804 743) is contrary to evidence from the Hen Barc adit which found a S-hading lode at ca 45 m drivage; also the S-hading fault shown ca 200 metres to the NW of this lode is at odds with field evidence.

General conclusions that can be drawn from previous work are that interpretation of lode geometry is quite well constrained for the Comet/Kingside systems around Pugh's shaft and from the Kingside shaft to the western slopes of Copper Hill. The intervening ground around Michell’s adit is much less clear, as is the Penguelan system around Taylor's shaft. The outlying areas of East Hafod, West Cwmystwyth, the northern and eastern parts of Copper Hill and, to less extent, South Cwmystwyth remain very poorly known.
Figure 3. A geological map of the Cwmystwyth mines

Legend: Major adits; E, Evans'; EH, East Hafod; G, Gallois; HB, Hen Barc; K, Kings; LF, Level Fawr; M, Michell's; PE, Penguelan East; R, Raw's; T(G), Taylor's (Glynderi); WC, West Cwmystwyth (From). Shafts; K, Kingside; P, Pugh's; Pg, Pengeulan; SCE, South Cwmystwyth Engine; T, Taylor's Streams; NB, Nant Byr; NCd, Nant Cwm-du; NCg, Nant Cae-glas; NGg, Nant Gwndwn-gwyn; NyG, Nant y Graig; NM, Nant Milwyn; NT, Nant Trefach; NyO, Nant yr Onnen; NW, Nant Watcyn. National grid markings at 1 kilometre intervals; sheets SN 77 and 87.

5. Remarks on the mapping

Much of the Ystwyth valley in the vicinity of the mine workings is well exposed. The location precision of the GPS used for positioning is in most cases within 5 metres and grid references may safely be rounded to eight figures.

The new map, Figure 3, differs from the BGS maps (1993, 1994) in the following key areas:
- in the lower part of Nant Cae-glas around SN 786 742 there are sandstones which seem to represent the Rhuddnant Grits Formation. This opinion is supported by O.T. Jones (1922, p 34). Nowhere around Cwmystwyth do such sands form an intercalation within the Blaen Myherin Mudstones. The boundaries of the sandstones are very poorly constrained and it may be that this outlier is in part fault-bounded. The new map shows the simplest interpretation.
- immediately N and NNW of Pentre Farm around SN 789 741 large areas of Blaen Myherin Mudstones are present where BGS show Rhuddnant Grits Formation. The section along the ‘M1’ road here is quite unequivocal and the base of the Rhuddnant Grits Formation can be followed without much difficulty along the flanks of Glog Hill to the E.
- the road section by Penparc at SN 7965 7403 and the riverbed of Afon Ystwyth immediately to the SE are now considered to lie within Blaen Myherin Mudstones rather than Devil's Bridge Formation. Where the mudstones cross the river there is an almost complete lack of exposure in marked contrast to the abundant riverbed exposures of the Devil's Bridge Formation. This is critical evidence regarding the sense of slip on the Penparc Lode.
- no Devil's Bridge Formation is confirmed around SN 808 746 and it is assumed that BGS have constructed its position here. This is important for the sense of throw on the Hen Barc Lode which I consider to throw down to the SE rather than the NW as shown by BGS.

Results of the new mapping are given in Figure 3 which is deliberately only descriptive; Figure 4 is interpretive and shows the nomenclature and identification of the main lode systems: a ‘system’ being a major shear zone of genetically related fractures. This usage wherever possible follows that of O.T.Jones; the major difference being my more restricted usage for the Kingside Lode which is discussed below.

![Figure 4. The major lode systems at the Cwmystwyth mines](image)

The main figure shows the interpreted identification of the systems and the location of the various cross-sections. The smaller figure illustrates the repetition of the Comet / Kingside relationships across the Ystwyth Fault. National grid markings at 1 kilometre intervals; sheets SN 77 and 87.

6. The Comet system north of the Ystwyth Fault

Before attempting any analysis of the structure at the mines, some assessment must be made of the likely along-strike continuity and the variability of orientation ( and dip ) shown by the major lode systems. This is a particularly acute problem for the Comet system which is believed to extend over a distance of at least ca 6 km from East Hafod to Copper Hill.

My usage of the Comet ‘system’ includes the ‘Main’ Lode that lies ca 8-16 metres S of the Comet Lode over large areas in the W of the mine ( 1922, p 30 ) and which warranted separate working. O.T.Jones considered this to represent the Kingside Lode but this requires a mechanically unrealistic stress field to explain the difference in strike between the ‘Kingside’ here ( ca 080° - 100°) and the Kingside east of Nant y Graig ( ca 035° - 050°); lodes which are required to be contemporary. The scale of the Kingside does not support the idea that it is merely a contemporaneous split of the Comet, rather the mapping suggests the Comet to be later than the Kingside and to displace it. It seems that the Comet system ‘bellies out’ to a width of ca 10 - 20 metres in the productive workings.
off Pugh’s Shaft / Raw’s adit, Level Fawr (below Graig Fawr) and Kings adit (on Copper Hill) but is commonly less than five metres thick, and sub-economic, between these areas; see Figure 5. One may speculate that the first phase of mineralisation of the Comet was contemporaneous with, and mineralogically similar to, that of the Kingside and dominantly followed the ‘Main’ branch; later fluids found this largely impermeable and followed the northern branch, ie the Comet as indicated on the mine plans.

**West of Nant Trefach**

The East Hafod adit lies at SN 7828 7408 and was driven broadly northerly. According to Spargo’s account (1870) it hit a lode at a drivage of 366 - 549 m giving a back of 128 m at this point. If the Comet strike W of Nant Cae-glas is ca 080° a back very close to this estimate would be expected at ca 366 m if lode dip was 65°. There is thus a strong suggestion that Spargo’s account can be reconciled fairly easily with the surface mapping although to what his higher distance estimate might refer is uncertain (was there a drift of 183 metres along the lode?). The Mining Journal (MJ, 1871, p 697) gives a drivage of 340 fathoms that encountered “several” lodes of which two were tried for short distances.

The Comet system is well constrained in location by surface workings and by a now collapsed adit where it crosses Nant Cae-glas at SN 7872 7452 and at the surface cross-cut trials centred at SN 7893 7458 (these are the Tyn-y-glog workings, later known as the Penshaft workings) worked from the West Cwmystwyth adit. These constraints indicate a strike of ca 082° here. Projection of this strike to the west places the outcrop plausibly in the marshy depression around SN 779 743 by Brynawelon.

What seems to be the Comet Lode in the hanging wall of the Yswyth Fault was found after a drivage of ca 650 metres from the portal of Taylor’s adit (Glynderi): it was very poor (O.T. Jones, 1922, p 136). At a dip of ca 65°, this fits well with the surface mapping assuming a local strike of ca 080° hereabouts. The lode was also very poor in the Tai Newyddion adit (SN 7912 7473) and there was little encouragement in the extensive trial pits around SN 7893 7458.

In the workings off Pugh’s Shaft there is abundant evidence from the mine plans that the lode strike swings locally to ca 100°- 105°, particularly in the area of Raw’s adit (SN 8002 7459). This swing is unlikely to result from any disturbance adjacent to the Ystwyth Fault. It is this local orientation that allows the outcrop of the lode to closely parallel the line of Nant Trefach from SN 8000 7479 to 8012 7473. Consideration of hillside dip and a 100 - 105° strike requires a lode dip of ca 45 - 50° for this continuity and dip segments of this value are proven by the mine plans NW of Raw's adit nearby. Modern resurvey of the Nant Trefach workings by R. Protheroe-Jones (in Bick, 2004, p 50) confirms this geometry. Below SN 8012 7473 the Comet lies in the footwall of the West Joint and its strike must swing towards that seen in Michell’s adit. Accordingly its outcrop must lie W of the stream. Mine plans suggest that the dip of the Comet decreases from ca 57° in the hanging wall of the West Joint to ca 45° in its footwall, suggestive of an increased throw on the West Joint to the SW. Neither the West Joint nor the East Joint (not mentioned by O.T.Jones) has been identified at surface and the position of the former on Figures 3 and 4 is constructed. The ‘Main’ Lode and the closely adjacent, probably genetically associated, North Lode are similarly not evidenced at surface.

**Nant Trefach to Nant y Graig**

The BGS mapping between these streams (Davies et al, 1997, fig 62) shows a continuous outcrop of the Comet at ca 370 metres elevation, ie above the Rosa adit, which is not clear in well exposed ground and would imply an implausible failure of generations of miners to find it where shown. My map does not support this, see also Figure 5.
Lode rock outcrops at SN 8012 7469 immediately E of the Nant Trefach gully; strike is here ca 083°, suggesting that the more easterly strikes immediately to the west have begun to revert to a more usual Comet orientation. Between Michell's adit and Nant y Graig there is extensive exposure of fault damaged rock, locally forming a poor lode as at SN 8021 7473 southeast of the Rosa portal, but scarcely any mineralisation. These outcrops display rather more northeasterly fabric strike than suggested by the map of O.T.Jones (1922, plate XVII): many of the fractures hereabouts strike ca 030° – 050° and the ‘Comet’ strike in Michell’s level is also ca 050° according to the mine plans. Exposure is not conclusive as to how the ‘Comet’ in this area links up with the good exposure in Nant y Graig at SN 8037 7484, probably crossing the topographic shoulder at ca SN 8033 7480, but the solution shown in Figure 3 and Figure 5 must be fairly close to reality. It is remarkable how rapidly this and other lodes become of major economic value to the E of the stream here.

A possible explanation for the curious strike of the Comet around Michell’s level is that some of its displacement is partitioned into the Kingside system and other sub-parallel fractures in the Kingside footwall; this may explain the apparent rapid westerly decrease in throw on the Comet in this area. Similarly, in Pugh’s Mine, growth of the Comet may have been influenced by pre-existing fractures oriented ca 100°-105°, possibly a-c joints related to the regional folding. This may have created a small right-stepping jog in the area of the 105° strikes; a similar feature is exposed around SN 795 741 on the hillside above Taylor’s adit (Glynderi) in the footwall of the Ystwyth Fault and may correlate with this jog.

**Figure 5. Strike geometry of the Comet lode system**

The figure is constructed for a datum equivalent to Level Fawr and thus the positions of the lode system do not match outcrop positions. The flats do not connect with the mapped position of the Comet for the same reason. The ‘generalised strike of master fracture’ may be thought of as the likely strike should the growing fault not have encountered structural complications leading to partitioning in the damage zone of the Kingside Lode (KL) system. The three principal productive areas off Raw’s, Level Fawr and King’s are shown schematically as ‘bellying out’. Note the changes in dip (grey arrows) proceeding east.

Legend: Major adits; E, Evans’; K, King’s; LF, Level Fawr; M, Michell’s; R, Raw’s; Shafts; KS, Kingside; PS, Pugh’s; Streams; NyG, Nant y Graig; NT, Nant Trefach; NyO, Nant yr Onnen; NW, Nant Watcyn.
Figure 6. Fabric elements within a complex fracture zone.

Internal shears (a) comprise synthetic (R) and antithetic (R') Riedel fractures, tension fractures (T), zone parallel shears (Y) and reverse fractures (P), after Christie-Blick and Biddle (1985). R fractures are very common in mid-Wales and where the dip of the main fracture zone is very steep they may dip in an opposed direction to the dip of this zone. Sense of movement is shown by arrows. The figure is two dimensional, where a strike-slip component of deformation is present an added complexity will be present as the strike of the internal fractures may not parallel that of the zone as a whole.

Clearly the overall dip averaged over large distances may differ appreciably from that estimated from measurements taken at outcrop scale. Panels (b) and (c) illustrate two possible internal configurations within shear zones of the same dip that result from differing scale and dominance of various internal shears: (b) may typify the Comet Lode in the west of the mines and (c) in the east.

East of Nant y Graig

Extensive outcrop and the open-cast workings on Graig Fawr give excellent control in this sector and the link to mine plans for Level Fawr and Evans’ adit is simple. Hughes (1981, fig 4) gives a very useful cross section for Level Fawr. From Nant y Graig to Nant yr Onnen and again on Copper Hill strike is regular and well constrained at ca 070 - 75°.

East of Nant Watcyn the Comet Lode is exposed in the Day adit (SN 8073 7505) where it dips at ca 65° to SE but is poor and barely 3 metres wide, as it is where crossing Nant yr Onnen at SN 8085 7510. On Copper Hill it widens to ca 16 m near King’s adit and at SN 8105 7518 what I interpret as Reidel shears (Figure 6) filled with iron carbonate dip NNW at 70-80° within a larger shear dipping 85° SSE. At the portal of the “ancient 53” adit (SN 8086 7508) a fracture striking parallel to the Comet dips NNW at 73°, ie antithetic to it.

It is well known that the Comet Lode steepens to near vertical on Copper Hill. Its position, non-economic, in the Pengeulan East adit proves this to occur over a vertical interval of at least 90 metres: only 550 metres to the WSW however the mine plans prove a very planar dip of ca 63° over a vertical interval of at least 200 metres between Evans’ adit and the workings off Taylor’s Shaft. Surface mapping and subsurface control in Taylor’s adit (Nant yr Onnen) prove that this variation occurs within one fault only (Figure 5). If so, then the junction between steep and gentle dip segments must plunge to ENE at least at 13°, possibly a little more steeply: it does not seem that the segments lie on
one gradually curving plane. The origin of such a rapid change in dip is uncertain. Rapid lateral variation of pore-fluid pressure at time of fracture has been suggested (Phillips, 1972). It is also geometrically possible that an inhomogeneous host stratigraphy has induced variable segmentation and relay jogs within a single shear system with overall dip of ca 65°, see Figure 6, but the requisite scale of such jogs would seem likely to induce a greater width of damage than is observed. Possibly both factors have operated. Whatever its origin such a system would contain both releasing and restraining bends in cross-section, cf the geometry shown in plan for strike-slip faults by Woodock and Fischer (1989), and these may influence adjacent deformation in the hanging wall. In particular it can be argued that this mechanism provides an explanation for the development and location of the Pengeulan lode system, see below, and of local ‘flats’, which are conveniently discussed here.

‘Flats’ at Cwmystwyth

The formation of flats (mineralisation along bedding planes) in mid-Wales is not well understood, largely because the best examples are no longer accessible. There is no surface evidence bearing on this subject at Cwmystwyth but a synopsis of the subsurface data is included here for completeness.

The ‘Great Flat’ off the Comet Lode that was worked in the 1840’s at Cwmystwyth was described by Smyth (1848, p 665) as dipping at 8-10°, presumably to the S. It lies at or a little under the 15 fathom level below Pugh’s adit and mine plans indicate a length of ca 40 metres and a width, to truncation by the Ystwyth Fault, of ca 17 metres, ie an extent of ca 680 square metres. Data from the Mining Journal (1847, p 557 and 566) indicate a much steeper dip of 32-34°, interpreted as a possible thrust cutting out the master fault, i.e the Comet in the terminology of this paper. The thrust hypothesis was disproven when the Comet was found undisplaced in the 30 fathom level. O.T. Jones states the ‘flat’ to have been “almost horizontal”; possibly the reported ‘thrust’ dips relate to the zone in which the ‘flat’ and the Comet join. The ‘flat’ reached a maximum thickness of 1.88 metres over an area of ca 125 square metres according to Jones. Control on bedding attitude at depth is unavailable but fold style as observed at outcrop nearby makes it most improbable that the ‘flat’ lies parallel to bedding.

My preferred explanation for the ‘Great Flat’ is that it relates to differential rotation within the hanging wall caused by a steepening of the fault plane such that the deeper portion of the hanging wall would seek to move faster than the shallower portion. This would be liable to induce a sub-horizontal fracture to splay off the master fault, see Figure 7. Should such a fracture be able to utilise bedding fabric to propagate it would form a classic flat, however should strain rate be high enough a similar geometry would be propagated irrespective of bedding plane attitude. An origin as ‘P’ shears (Figure 6) if oriented sub-parallel to bedding planes is geometrically possible but kinematically improbable as it requires the flat to lie at a restraining jog in the shear zone; the requisite extension to create space for mineralisation would thus need to result from hydraulic jacking up of the entire hanging wall.

A possible true flat was found in the Nant y Graig workings in the immediate hanging wall of the Kingside Lode, possibly on the extension of a vein sub-parallel to this lode that was tried at surface at SN 8034 7470. The stoped area lies parallel to bedding over an extent of ca 35 metres by ca 15 metres containing the axis and two flanks of a syncline striking ca 015°: it is elongated parallel to this fold axis. The stoped area lies in relatively muddy strata below an intensely hard massive sandstone, itself cut by closely spaced (1-2 metres) fractures striking ca 020° and dipping ca 60–75° to SE. It is not clear if the main economic interest was in the latter fractures or along bedding, ie a true flat; the sandstone seems to have formed a relatively impermeable roof hereabouts. As the bedding here strikes sub-parallel to the Kingside Lode its attitude would favour bed-parallel slip on the western limb of the syncline; see Peacock and Sanderson (1992) for discussion of these mechanical principles.
Figure 7. Schematic illustration of the geometry and genesis of the ‘Great Flat’ at Cwmystwyth

Schematic sections (a) and (b) illustrate respectively the controlling role of friction around a releasing bend in the fault cross section and how this may lead either to a steep cut-off fault or a low angle ‘flat’. Note the analogy of (a) with the postulated genesis of the Penguelan lodes; Figure 10.

Synthesis

It is difficult not to accept the consensus of O.T. Jones and the old miners that the Comet is one system throughout the mines despite the apparent disconnection between Nant Trefach and Nant y Graig. Pending further work it is probably premature to use different names for a ‘Comet West’ and a ‘Comet East’; I provisionally relate both to inhomogeneous growth within one major system.

An interesting feature of the local strike swing to ca 100° near Nant Trefach is that the Comet is known to have some dextral strike-slip and this would result in transtensional jog hereabouts which would favour mineralisation relative to the very poorly mineralised area around Michell's adit.

The Comet has an apparent normal dip-slip of ca 100 metres where it displaces the base of the Rhuddnant Grits. It displays slickensides indicative of dextral-normal movement although these cannot be presumed to quantify the movement vector applicable for the entire duration of slip.

7. The Michell’s Lode / New Lode system

O.T.Jones (1922, plate XVII) does not comment on the apparent disconnection between Michell's Lode in Michell's adit (here closely associated with the New Lode), and its extension SW of Nant Trefach towards the West Joint, with his lode of the same name in Nant y Graig. BGS (Davies et al, 1997, fig 62) recognised this problem but their single lode solution implies an improbable lode dip of only ca 43° and shows the outcrop of Michell’s to lie below the Rosa adit which is impossible as mine plans prove that the major north-hading lode was cut therein. Figure 8 a and b illustrate the alternative structural concepts in cross section, that preferred being similar to that shown by Hughes (1981, fig 3). The mine plans show the New Lode to dip ca 71° to the NNW over a vertical interval of ca 120 metres but outcrop control shows that its upper tip barely if at all reaches surface. The New Lode appears to abut the West Joint, rather than be offset across it; if so this suggests the latter may be earlier.

Important control in the poorly exposed area between here and Nant y Graig, where the Michell’s system is non-commercial and splits into several local splay's, should be given by Dick’s adit, driven 105 metres towards 280°, which shows no lode of size or value beyond what appears to be a poor portion of the Kingside Lode a short distance beyond portal. The mine plans suggest that the adit portal should lie at SN 8035 7474 but it has yet to be proven here below scree. The difficulty of
simple along-strike correlation towards Nant y Graig strongly suggests ‘jogs’ or relay connections. Figure 9 shows my preferred correlations in plan.

I consider that Michell's Lode in Level Fawr is the probable strike equivalent of the Steel Ore Lode seen in Nant Watcyn to the E, a conclusion also reached by Hughes (1981, pp. 47). The lode has an apparent dip-slip of ca 37 metres in Level Fawr (Hughes, 1981, figure 4). At the portal of Steel Ore adit its strike is 058° and dip is 76° to NW with slickensides indicating a component of dextral strike-slip. It may link with the N-hading lode striking ca 073° exposed a few metres N of Taylor’s Shaft (see Figure 9) but the latter lode could have originated earlier within the Pengeulan system.

**Figure 8. Alternative reconstructions of lode geometry along Michell’s adit**

(a) based on current mapping, data from Hughes (1981) and the evidence of the mine plans.; (b) after BGS. (1997, fig 62). Both sections are at natural scale. Comet footwall below land surface is shaded. Location of section shown in Figure 4. Key to lodes: C, Comet; HT, Henry Taylor’s; ‘M’, Michell’s; N, New; ‘S’, South. ‘Michells’ as found in Nant y Graig is arguably the New Lode and ‘South’ is arguably the North Lode portion of the Comet system off Pugh’s shaft. GL denotes Gill’s Lower Level and 15 fa the 15 Fathom Level below Pugh’s Adit.
Figure 9. Strike Geometry of Michell’s lode system and the West Joint

The figure is constructed for a datum equivalent to Level Fawr and thus the positions of the lode system do not match outcrop positions. West of Nant y Graig the construction is based solely on mine plans as the West Joint (WJ), East Joint (EJ) and Henry Taylor’s Lode (HT) are known only from the subsurface. Note the parallelism of the West Joint with the Kingside Lode and the right-stepping jogs in the Michell’s system (M) with fractures offsetting the Kingside Lode (shaded), suggesting control by a pre-existing fabric. The geometry of the East Joint is not well constrained. Lode dips are shown as grey arrows.

Legend: Major adits: E, Evans’; LF, Level Fawr; M, Michell’s; R, Raw’s; S, Steel Ore; T, Top. Shafts: KS, Kingside; PS, Pugh’s; TS, Taylor’s. Streams: NyG, Nant y Graig; NT, Nant Trefach; NW, Nant Watcyn.

8. The Pengeulan system

North and west of the Pengeulan Shaft there is a modicum of subsurface control from the mine plans but very little useful control from surface mapping. It seems likely that the complex of Pengeulan lodes does not extend into the footwall of the Kingside system (Figure 3). The Pengeulan lodes die out at surface to ENE before reaching the Pengeulan East adit. They thus appear to be confined to the structurally highest portion of the hanging wall of the Comet Lode in the area where this has relatively gentle dip of ca 65°, eg around Evans’ adit (SN 8061 7492) and few extend east of Nant yr Onnen where the Comet dip steepens to an average approaching 80° on Copper Hill. This suggests a genetic relationship (Figure 10) in which the Pengeulan lodes develop in a region of localised extension above a ‘releasing bend’ caused by steepening of the Comet. Lodes within the Pengeulan system downthrow both to northwest and to southeast. Some strike sub-parallel to the Comet but there are several linking relays at high angle to this strike, some of which probably follow fractures with a ‘Kingside’ orientation (047°). Mine plans show that Burrell’s Lode dips at ca 82° to NW; and the complex of lodes encountered in the workings off Cross Roads adit includes the preserved intersection of the Pengeulan ‘North underlier’ and the Pengeulan ‘South underlier’ forming an inverted ‘V’ in the stopes.
Figure 10  Possible control on the development of the Pengeulan lodes

Two alternative geometries above a releasing bend on a fault surface are shown in (a) and (b). In (a) the strain rate is high enough to make a pull-apart structure (a good potential site for ore precipitation); in (b) the hanging wall strain rate is low enough for zones of ductile extension and compression to develop as the hanging wall tries to adjust to the change of fault dip as movement proceeds. The case of the Comet / Pengeulan relationship is illustrated in cartoon fashion in (c); it is thought that the releasing bend favours development of brecciation and that extensional collapse of the hanging wall into this zone has occurred, possibly utilising short-cut faults.

9. The Kingside system north of the Ystwyth Fault

The Kingside Lode is doubly exposed in Nant y Graig owing to repetition by several strands of Michell’s system but the map of O.T.Jones (1922, pl XVII) suggests a divergence of strike between the two outcrops, the more northerly tending to swing sub-parallel to the Comet as the two lodes get close to intersection. The more southerly outcrop strikes at 044° and exhibits very well developed slickensides plunging to the SW at 55°, indicative of a component of dextral strike-slip. At SN 8034 7470 a shallow trial gives good exposure of a sub-parallel minor lode in the Kingside hanging wall ca 35 metres east of the major fracture worked off the Kingside shaft.
On a large scale the Kingside strike varies between 025° and 050° but values of 035° - 045° are typical: dip is generally 50 - 60° to SE. Between Nant y Graig and Nant yr Onnen there is good subsurface control in numerous workings, notably at the various levels served by the Kingside Shaft and between Alderson’s adit and Herbert’s stope where dip steepens to the sub-vertical over considerable depth. Further control results from an adit recently discovered by Barry Clarke at SN 8075 7513 where there is a local jog to a strike of ca 065°, possibly related to interference from the Comet system. Despite good map control the Kingside throw has not been estimated with any precision. In the upper reaches of Nant yr Onnen there is clear dextral offset of a major synclinal axis.

10. The Copper Hill 'horse' system

The main problem in the area east of Nant yr Onnen is lack of adequate surface or subsurface control on lode dip and strike, although some help comes from the plans of Taylor's level (Nant yr Onnen) and Bonsall’s level. Surface control (O.T.Jones, 1922, pl VII) seems to define the outcrop traces of the complex of minor lodes lying between the Kingside and the Comet (Belshazzar) lodes, assuming that the various adits, now essentially inaccessible, were driven as drifts. Such minor lodes do not appear to be present in the footwall of the Kingside system, cf the Pengeulan system. Jones (1922, p 31-32 and plate VII) considered the area between the Comet and the Kingside on Copper Hill to be a large 'horse', the bounding faults having rejoined before reaching the Frwd yr Ydfran ravine around SN 823 763. There is no direct proof of this (the higher ground is largely peat covered) and as the Comet is here considered to cut and offset the Kingside (ie is later) any horse geometry would be fortuituous, not genetically related to the simultaneous interaction of the two faults. An alternative interpretation is shown in Figure 11; in which the Comet would simply die out ENE of the Bronze age workings on Copper Hill. Also the Kingside, or a similar lode, would resume an orientation of ca 030° - 035° (or die out) ca 600 metres NE of Bonsall's adit: it was probably just missed by the Gallois adit at SN 8154 7588. This adit drove NW for ca 50 metres just to the NW of where I place the fault.

The minor lodes in the 'horse' are concentrated adjacent to the Kingside hanging wall and are not similarly abundant in the immediate footwall of the Comet. Their southern extent is probably defined by Bonsall's level (SN 8091 7533). This impression from the surface distribution of dumps seems to be confirmed by the results of driving Taylor's level (Nant yr Onnen) which found no lode in the hanging wall of the Kingside, a fact requiring that vein 'A' and probably also vein 'F' dip to the northwest, ie are antithetic to the Kingside. A plausible explanation for the distribution of minor lodes is that the Kingside strike swings very rapidly more easterly hereabouts, possibly at a site of a relay structure (Figure 11 b) and is contiguous with the 'Stamping Mill Vein'. A dextral strike-slip component of movement on the Kingside system would produce a structure geometrically analogous to an extensional duplex (Woodcock and Fischer, 1986) and would be expected to form a favoured area for ore precipitation. Certainly a huge amount of work was done in this small area (Hughes, 1981, p6). The footwall of vein 'A' displays an interesting small scale interference of 030° strikes ('Kingside') and 065° strikes ('Comet'), a phenomenon suspected to occur elsewhere and on larger scale, see above and Figure 5.

At Frwd yr Ydfran (SN 822 764) two lodes lie ca 19 metres apart and the southern strikes 030° and dips 85° SE at its hanging wall margin: certainly not suggesting a correlation with lodes seen in Nant yr Onnen. The gorge section here does not allow good reconstruction of lode geometry as its western bank displays strata overturned by hillcreep and there is no exposure on adjacent hilltops. Both lodes were tried in shallow opencasts but clearly without success.
Figure 11. The geometry of lodes on Copper Hill

Map (a) illustrates the view of O.T. Jones with a mechanically suspicious kink in the strike of the Comet; (b) illustrates the view adopted herein indicating the strikes of the principal lodes; note the very large change in average dip of the Comet going ENE from control by Evans adit.

Legend for workings: E, Evans adit; G, Gallois trial adit; H’s S, Herbert’s Stope; K, King’s adit; o-c, the prehistoric opencast; PE, Pengeulan East adit; Q, Queen’s adit; T(NyO), Taylor’s adit (Nant yr Onnen). For clarity (b) omits some of the adit control in (a). A and F are the veins worked by Waller at the beginning of the eighteenth century, as is SMV, the Stamping Mill Vein.

11. Lode identity south of the Ystwyth Fault

This problem is fundamental to analysis of the large-scale geometry of the mining area and its successful resolution at the same time yields the displacement on the fault. Evidence comes from both the mine plans of the South Cwmystwyth workings and from locally good lode exposure at surface there. It is noted that the Penguelan system is known only in the hanging wall of the Comet N of the Ystwyth Fault and that the N-hading portion of Michells system cannot realistically be
expected to be repeated across the Fault, although repetition is more probable for the NW-dipping West Joint. The essence of this situation was correctly shown by Hughes (1981, fig 2) but any one cross section cannot yield a unique estimate of dip-slip if there is non-parallelism of the various faults and the presence of strike-slip: moreover the figure does not illustrate the Kingside system. As the Comet and Kingside strikes are different it is geometrically possible for their intersection to be repeated across the fault. The BGS work (Davies et al, 1997, p 214) concluded that there was "no evidence" that mineralisation south of the Ystwyth fault represents the continuation of that to the N of the fault. As shown below, and in Figure 4, the remapping does not support this view.

The Penparc (Comet) Lode

The first step in the correlation suggested by the new mapping is the identification of the Penparc Lode with the Comet, contrary to the conclusion of O.T. Jones (1922, p 136) that the Penparc Lode was N-dipping (implying a strike of ca 110° - 120° which is seen nowhere else at Cwmystwyth). I consider there is clear stratigraphic evidence for southerly downthrow along the road and river sections just by Penparc, see map Figure 3. The lode map trace of ca N 95° -100° E to the W of Penparc is deceptive as a guide to strike and results from the intersection of a ca 55° - 65° SE-dipping lode striking ca 085° - 090° (the Comet strike N of the Ystwyth Fault in this area) with a steep hillside dipping ca 30° to the SE. Construction with this geometry allows the Comet/Penparc system to correlate directly with that intersected at ca 45 metres drivage in the Hen Barc adit (portal at SN 7996 7414). Mine plans show that the lode in the intervening ground was followed in a drivage of ca 120 metres to the ENE from the now-collapsed riverbank adit at SN 7982 7404.

Taylor’s adit (Glynderi) became accessible for the first time for many years on 21/9/04 following a water burstout on 27/8/04 after heavy rain and rapid action by a working group of the Welsh Mines Preservation Trust to install a plastic pipe giving temporary safe access to the bedrock tunnel to allow survey. Results are shown in Figure 12. The adit now provides geological control only as far as the Ystwyth Fault and is consistent with the surface mapping assuming the collapse at ca 260 metres drivage represents the ‘soft ground’ that typifies this fault in several workings to the east. Until very recently the only subsurface evidence for the geometry of the Penparc Lode was the section along the line of this adit shown by O.T. Jones based on the 1873 mine plans. The section actually shows a southward dip component for two of the shoots (termed lodes “No.1” and “No. 2”) worked here. It is now clear that lode “No. 2” is the Comet and the adit confirms its southerly dip deduced from surface mapping. Strike is ca 085-095° and dip ca 57°: an oblique forward split striking ca 072° and similarly dipping at 57° to SE is equally clearly the “No.1” lode.
The adit originally extended far beyond the current collapse on the Ystwyth Fault, see Figure 13a and text for discussion.

The conclusion that the Hen Barc Lode correlates with the Penparc Lode means that it cannot be the simple extension of the Logaulas Lode as thought by O.T.Jones. The lode dip seems to steepen to the east (as does the Comet north of the Ystwyth Fault) and locally reaches ca 75° in the 200 metre eastward drift off the Hen Barc level (Jones, 1922, p 135).

The West Joint

Identification of this fracture S of the Ystwyth Fault is speculative but the ‘top wood’ adit at SN 7967 7421, driven towards 314° and still open, encountered a 10 m ‘clay joint’ trending ca 050° after ca 70 m. This might be an irregularly trending margin of the Ystwyth Fault, which hereabouts strikes ca 065°, but the distance seems about 20 - 30 metres too short. Unfortunately, the precision of the mapping of the fault outcrop nearby is not high and this identification of the joint may not be definitive. In the river bed at SN 7936 7382 near Glynderi there is a complex of massive quartz veins, either internally faulted or filling pre-existing rhomb-shaped fractures in very steeply dipping Devil's
Bridge Formation. The thickest vein is ca 2.3 m thick, 3m upstream another vein is ca 0.6 m. Somewhat speculatively this could represent a much weakened extension of the joint.

The North (Kingside) and South Lodes on Graig Goch

The narrow SE-dipping lode in the opencast at SN 8038 7631 on Graig Goch to the NE of Hen Barc has a local strike at surface of ca 052°, but on much larger scale in the adjacent stopes is ca. 041°, reminiscent of that of much of the Kingside system with which it is identified. Any other identification improbably requires that the only major and productive lodes with this strike N and S of the Ystwyth Fault are different and that neither is repeated across the fault. The lode at the opencast is correlated with the similarly striking North Lode seen in the South Cwmystwyth eastern crosscut, driven SSE from SN 8055 7447 near the South Cwmystwyth Engine Shaft, an identification supported by the mine plans, although these two areas of working were not connected. My map does not support the identification of this lode with the Penparc Lode (ie Hen Barc / Comet Lode) that is made on these plans. In the workings at top adit level off the opencast the lode dip varies between 65° and 77° to the SE, slickensides indicate a dextral-oblique movement.

The South Lode in the eastern crosscut adit is a poor stringer at ca 125 metres drivage explored by a drift for ca 35 metres to the SW. Its dip is unknown but it has a strike typical for the Comet system according to the plan. It is not easily correlated with the Hen Barc Lode as the surface position of the latter would require the South Lode to have a northerly dip. The most likely fracture correlative of the Hen Barc Lode would pass through the gully in the grit ridge at SN 8097 7444 and, if dipping SE at ca 70°, would probably not quite have been reached by the drivage of 173 m (O.T.Jones, 1922, p 135-6) in the eastern crosscut which found no lode around this distance. If an equivalent of the South Lode exists in the hanging wall of the Ystwyth Fault it could be either the Furzy Lode which lies ca 30-50 metres north of the Comet in Nant yr Onnen or the near-vertical lode lying ca 65 metres NW of the opencast on Copper Hill.

The deceptively similar outcrop orientations of the lode at the opencast and the Hen Barc Lode near Hen Barc result from steep NNW-facing topographic contours around the former lode lying clockwise of true strike but steep WNW-facing topographic contours around the latter lode lying anticlockwise. Mine plans confirm that the true strike difference is ca 34°. Near the junction with the North Lode the Hen Barc / Comet Lode suffers a ‘jog’ of ca 50 metres southeast and is elevated 25 metres relative to its position to the west.

As the Comet is a later fracture than the Kingside it is possible that on Graig Goch much of its displacement could have been partitioned into the Kingside and that any prolongation to the E would be very weak.

The southerly extent of the North (Kingside) Lode

If the North Lode at South Cwmystwyth is indeed the Kingside and the Hen Barc Lode is the Comet then the Graig Goch area exposes the former in the footwall of the latter in a simple repetition by the Ystwyth Fault. Both lodes appear to be weak S of this fault and may lie near the structurally lowest SE tip lines for their systems. The correlation requires the Kingside to repeat in the hanging wall of the Comet on Graig Goch: it has not yet been found but would be expected to be very weak. A possible location would lie in the NNE-trending depression between the main cliff of Graig Goch and the small crags at SN 7995 7395. The nearby 'foxhole' adit at SN 7998 7388 may have narrowly missed it; this drove ca 27 m southeast and then ca 37 m ENE, without success, on a north-hading fracture underlying the gully towards Nant Byr: at a dip of ca 65° this appears to correlate with the fracture seen at ca 220 m drivage in the Hen Barc adit which was recorded by O.T.Jones (1922, p 135) and is marked on the mine plans. Speculatively, the Kingside fracture could extend SSW to the 1.2 metre quartz body exposed in Nant Byr at SN 7984 7350 which has a strike of 026° very similar to the Kingside strike locally seen in the Comet hanging wall north of the Ystwyth Fault. This
possible course for a very weak Kingside is in apparent conflict with the evidence of the Hen Barc workings in which there is no record of a significant southeast-facing fault / lode of correct strike where it might be predicted on the above reasoning. Perhaps the surface mapping may bear revision, alternatively the lode may here be expressed as a weak bed-parallel ‘flat’ which would be favoured by the mapped southeasterly bedding dips of 30°-45° above the Hen Barc adit. A weak ‘flat’ could easily have been ignored; without further subsurface data this problem is unlikely to be solved.

Craig Ddu

There is a fault system exposed in the Craig Ddu cirque although unfortunately its extension into the ground N of there in Nant Cwm-du is covered with glacial debris. The fault in the ravine bed in the cliffs at SN 8102 7380 strikes ca 025°-030° and dips SE at ca 50°; it displays two metre-scale vein quartz ‘horses’ in its footwall. A nearby fracture system at SN 8112 7378 strikes irregularly towards ca 360° and displays major quartz bodies up to 2.6 metres thick which are variably sub-parallel and transgressive to the bedding which here dips steeply SE. The quartz veins do not show any obvious metal mineralisation and are not considered related to any of the lodes at the Mines. Geometrical relationships between some of the veins at Craig Ddu are shown by Davies et al. (1997, fig. 51).

12. Throw of the Ystwyth Fault

The estimate of ca 823 metres of, implicitly, down-to-north dip-slip that was made by O.T. Jones (1922, p 35-36) was acknowledged to be possibly somewhat high. It used an average ‘sheet dip’ of ca 20° for the base of the Rhuddnant Grits between Afon Milwyn and Graig Goch. The new mapping suggests that this dip varies between 14° and 18°. Taking account also of the new mapped positions of the base of the Grits, an apparent dip-slip (i.e. neglecting any strike-slip) of ca 450-500 metres is calculable using the method employed by Jones.
Figure 13. Natural scale cross sections across the Ystwyth Fault

Note the very similar apparent offsets on the Ystwyth Fault. Section (a) near Taylor’s adit (Glynderi) illustrates the adit control (projected) on the subsurface location of the Comet (Penparc) Lode and section (b) near the Hen Barc adit that on the subsurface location of the Comet (Hen Barc) Lode. Fault / lode legend as previous figures. Comet footwall below land surface is shaded. Location of sections shown in Figure 4.

As the strikes of the Ystwyth Fault and the Comet Lode are seldom divergent by more than 10°, i.e., the rake of their intersections is almost horizontal, a fairly good estimate of the dip-slip on the former can be made by drawing suitably located cross sections and estimating the offset of the latter. Using default dips for all the faults of 65° but recognising the effect of Michell’s lode on the Comet and that this lode locally flattens to ca 55° or a little less, three cross sections yield very consistent estimates of ca 470 (plus or minus 10%) metres of dip-slip in the plane of the Ystwyth Fault between Taylor's Glynderi level and Level Fawr (Figures 13 a, b and 14 a). The local flattening of the Comet dips might reflect ductile deformation (‘normal drag’) prior to throughgoing brittle fracture on the Ystwyth Fault but is probably more likely to be an original feature.

Drawing strike contours in the Comet footwall on the Kingside Lode (i.e., a plane with appreciably dipping rake at intersection with the Ystwyth Fault), the oblique-slip on the Ystwyth Fault can be resolved into a dip-slip of 470 metres and a dextral strike-slip of ca 170 metres (the latter value being favoured if the Kingside steepens uniformly to ca 72° dip in depth as seen in the upper workings off the South Cwmystwyth opencast and also from Herbert's Stope at SN 8089 7539 which lies in comparable geometrical position N of the Ystwyth Fault). The geometry for this calculation is illustrated in Figure 14 b. The apparent sinistral offset of the top of the Llyn Teifi member around SN 818748 shown on the BGS map cannot be used to calculate displacement as unexposed minor folding on the generally ca 70 -75° E-dipping fold limb cannot be ruled out by analogy with exposure at Nant Stwc nearby.

Correlation of the major fold patterns across the Ystwyth Fault near Ty'n-y-ddol (SN 8086 7470) can be attempted for major folds in the hanging walls of both the Comet and Kingside systems but is not quantitatively conclusive as attitude of fold axial planes is not truly vertical and both fold axis strikes and fold profiles in depth are not truly constant. A ‘best estimate’ does not however conflict with a small dextral strike-slip component.

The conclusion of a dextral component of movement at the mines is apparently at variance with the locally large sinistral component deduced by Davies et al., (1997, p 195) ca 9 km to the WSW. However it is possible that both views are correct. The Ystwyth Fault is clearly a compound structure viewed regionally: in particular it suffers an abrupt strike swing from ca 080-086° to ca 055° around SN 770 731 where it intersects the NW-hading lode system of the Glogfawr and Glogfach mines, see BGS (1994), suggestive of its local capture within this system before re-orienting to ca 080° at Cwmystwyth where it may have likewise followed an earlier fault / lode system with NW hade. By analogy with similarly oriented systems at the mines, e.g. Michell’s, such a system would be expected to have some dextral strike slip. As the offset on the Ystwyth Fault is negligible only ca 4 km to the ENE, any late sinistral strike-slip at the mines may not have been sufficient to reverse an earlier larger dextral strike-slip; net strike-slip would thus now be dextral. Alternatively, the sinistral movement may be Acadian in age, i.e., immediately post-softening, and entirely predate the formation of the lodes and their dextral offset by relatively minor renewed movement of Variscan age. The lack of mineralisation on the fault tends to support the latter explanation.
Cross section (a) shows the difference in offset for the Comet Lode (offset approximately correct) and the the Kingside Lode (an apparent offset only) which is caused by their having different angles of intersection with the Ystwyth Fault. Restoration of the Kingside to a position compatible with the offset of the Comet allows estimation of the strike-slip. The vertical movement (t) for this restoration yields the strike slip component when multiplied by the tangent of the Kingside dip. Fault / lode legend as previous figures. Comet footwall below land surface is shaded. Location of section shown in Figure 4.

Map (b) shows the strike contours in metres O.D. for dip of ca 70° for the Kingside Lode in the footwall of the Comet Lode as these intersect strike contours for the Ystwyth Fault, shaded, for which a dip of 65° is used. The difference between the actual position and that computed for true dip-slip of any one Kingside strike contour in either wall of the Ystwyth Fault yields the strike-slip (ss). The true offset is about 470 metres vertically (plus or minus 10%), corresponding to a heave (h) of ca 210 metres, and about 170 metres horizontally (plus or minus 50%) in a dextral sense.

13. Remaining prospectivity
Around Pugh’s and the Kingside workings there is no scope for future production in new ground as the lodes are cut out in depth by the Ystwyth Fault and their lower portions, upthrown south of the river, are very poor. If the current mapping is correct, the Comet may lie at shallow depth in the footwall of the Ystwyth Fault to the SW of the village where it has never been tested. By analogy with Hen Barc it may however become poorer in depth. In terms of untested volume, the best area for exploration would be below the adit levels on Copper Hill where both Comet and Kingside systems extend to greater depth than to the SW. Moreover, such structural levels on these systems would be higher than any seen S of the Ystwyth Fault and accordingly likely to be more prospective.

14. Research needs

Cwmystwyth would seem a good site to refine appreciation of the different phases of mineralisation. According to Mason (1997, p 137) the mineralisation is "almost exclusively" of his “late simple” A2 type but massive white milky quartz similar to his “early complex” A1 type also appears to be present. The mines are unusual in mid-Wales in displaying at least three episodes of fracture (Michell’s crosscuts the Comet which in turn crosscuts the Kingside) and according to whether or not differing mineral parageneses are present in each it might be possible to clarify to what extent A2 is a reworking of A1 or whether new sources of metallic ions were then contributing. If one allows that a later mineral paragenesis may selectively overprint an earlier, then clearly one fault generation may exhibit multiple parageneses. Moreover, multiple fault generations might carry identical mineral parageneses should their formation entirely predate mineralisation.

As yet there is no quantitative data on the distribution, scale and type of brecciation fabrics within the lodes, using the descriptive criteria of Woodcock, Omma and Dickson (2006). This would seem a promising line of enquiry with implications for preferred pathways of fluid flow but, as with the mineralogical research, would require extensive sampling underground.

There is still much work to be done in disentangling the relationships of minor lodes, particularly within the Pengeulan system. Surface work will not be adequate in isolation to do this; what is urgently needed is publication of a detailed modern underground survey of the accessible workings to assist interpretation of the old plans where these are equivocal. Such study must be integrated with the archival record in the Mining Journal. Only then will a fully consistent 3D evaluation of lode geometry be possible: this paper should be regarded as one step towards that objective.

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Permission for access from landowners Gwyn Morgan, Brynmor Morgan and Mary Raw is greatly appreciated.

16. References


17. Archival sources

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