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Discussion on dating the transition of smectite to illite in Palaeozoic mudrocks using the Rb–Sr whole-rock technique

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D. M. D. James writes: It is exciting and important that the variable time intervals between burial, the smectite-illite transition in mudrocks and cleavage formation/uplift which might be expected in the tectonically active Welsh Basin can now be quantified. This will allow estimation of syn-depositional tectonic tilts between different elements of the basin, subject to tilt corrections for the dip of the seabed and for any non-vertical heatflow, i.e. factors jointly determining the dip and depth of the 90°C isotherm. Such corrections are likely to be extremely small in the samples studied, particularly for the 'basin-floor' samples 1 and 2 of the paper which probably had low depositional dip and lie at adequate elevation above the relief of top crystalline basement to suggest that lateral heat-flow complications are minor.

The very sparse and, as yet, statistically inconclusive tilt geometries suggested by the smectite–illite dates can, however, be readily confirmed by the abundance of statistically conclusive data available for the degree of illite diagenesis/metamorphism; i.e. illite crystallinity. Not only is the smectite–illite transition pre-cleavage/uplift (and by implication pre-folding, assuming this to be syn-cleavage) but so also are the higher metamorphic grades, to low epizone. Across central Wales, where no anomalously high-strain zones are reported and where equal values of illite crystallinity (isocrysts) may thus reasonably relate directly to isotherms, the distribution of isocryst values displayed on BGS sheets 178 and 179 (1994, 1993) bears no obvious relation to folding. The map pattern is thus not the result of folding of isotherms that were sub-parallel to bedding at the metamorphic maximum. However, plotting illite crystallinity values along stratigraphic horizons, neglecting folding but accepting discontinuities across tectonic lineaments ('basement faults'), shows an orderly increase in grade with stratigraphic depth, albeit that isocrysts, i.e. isograds, cross cut the stratigraphy at low angles; exactly as reported by Evans (1996) for the smectite–illite transition. A similar analysis of the isocryst data reported by Roberts *et al.* (1991) in the Corris–Cadair Idris district reveals a comparable pre-folding geometry, namely subhorizontal isocrysts cross cutting a tilted stratigraphy, in this case dipping SE off the Derwen Horst. In this area the analysis is complicated by premetamorphic Palaeozoic downthrow on the Bala Lineament which was largely reversed out by an opposite Mesozoic–Tertiary downthrow, possibly with associated local folding of isocrysts. This orderly arrangement in both central and north-central Wales suggests that complications due to lateral heatflow are minor (save possibly adjacent to major syn-depositional faults) and that there is no great or rapid variation in the thickness of the missing Wenlock–early Devonian cover. The data from the areas of sheets 178 and 179 indicate that the principal controls on tilting of stratigraphy relative to isotherms were the Llangranog Lineament (the Bronnant Fault) in the west and the Tywi Lineament in the east, the intervening Central Wales Lineament playing a relatively minor role. Sample 2 of Evans (1996) lies within about 5 km ESE downdip of the footwall crest of the Llangranog Lineament in its northerly (Glandyfi) extension whereas sample 1 lies about 20 km ESE downdip of this crest and near the axis of the synclinal hanging wall 'sag' approaching the Tywi Lineament (the sample appears to be wrongly plotted as within the outcrop of the Rhuddnant Grits on Evans' fig. 2). The age relations for the smectite-illite transition for these two samples, as for sample 3, are thus exactly what would be predicted from the regional tectonic style; low sedimentation rates ('young ages') near footwall highs and high sedimentation rates ('old' ages) near hanging wall lows. Assuming temperature calibration of isocrysts following Roberts *et al.* (1991, p. 643), and assuming the geothermal gradient of 36°C km^{-1} used by Evans (1996) is appropriate in the late Silurian, it can be calculated that the then dip slope of early Silurian sediments within the tilted fault blocks east of the Bronnant Fault and the Central Wales Lineament was about 7°, neglecting the mutually conflicting effects of compaction and tectonic strain. This translates to a beta factor of 1.06 for the Llandovery if fault planes dip at 60° and sea-floor is horizontal.

Since the above was written, Roberts *et al.* (1996) have concluded that maximum illite crystallinity was of an early contractional timing in apparent contrast to my conclusion of a late extensional timing. If Roberts *et al.* are correct, the analogy drawn above between the attitudes of the early smectite–illite transition and those of peak crystallinities with respect to bedding may be somewhat reduced. However, Roberts *et al.* (1996, p. 281) state that peak metamorphism was 'mostly' imposed before the development of the major folds. In practice, the difference in timing between late extension and early contraction may be very small and within the tolerance of both my analysis and that of Roberts *et al.* In addition to analytical and contouring noise this variance includes the following.

(i) The probability of local changes in temperature gradient across lineaments bounding thick sand depocentres.

(ii) The need to construct cross sections far above/below the present day erosion surface, often in areas with variable sedimentary thickness and tectonic strain. This is well exemplified by the Mynydd Bach Fault which, in contrast to the interpretation of Roberts *et al.* might be argued to have formed a graben with the Bronnant Fault during Aberystwyth Grit deposition; the graben serving later as locus for the fold vergence divide. If so, a late extensional timing for peak metamorphism can be plausibly reconstructed.

(iii) The influence of detrital illite of high crystallinity as a function of hinterland tectonism (e.g. the anomalous Wenlock Grit crystallinities reported in Roberts *et al.* (1991), which may reflect uplift of the Iapetus suture). In this connection, it is noteworthy that such complication is unlikely in the samples used for dating by Evans (1996).

In short, the work of both Evans (1996) and Roberts *et al.* (1996) is consistent with the diastathermal metamorphism advanced by Bevins & Robinson (1988).

I venture to suggest that what is now needed is an adequately sampled traverse at about the level of the Ordovician–Silurian boundary, i.e. below the migrating depocentres of the Aberystwyth Grits and later major grits, from the coast near Llangranog in the basin through the Pumpsaint area to the shelf near Llandovery, crossing the Llangranog, Central Wales and Tywi Lineaments. The traverse should determine K–Ar and Rb–Sr ages following Evans together with illite crystallinity values *for the same samples*. Such data could refine considerably our appreciation of Silurian syn-burial tectonism in the Welsh Basin.

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