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THE WELSH, ANGLIAN AND BELGIAN CALEDONIDES COMPARED

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(4 figures)

ABSTRACT.- Unconformities below the Cambrian, Arenig, Ashgill and Upper Devonian can be traced from the Welsh Basin across the Midland Platform to the buried Anglian Basin and on into the Brabant area of Belgium. The widespread correlation of the resulting tripartite sequence stratigraphy in the Welsh Basin (Dyfed, Gwynedd and Powys Supergroups) reflects shared eustatic and tectonic controls. The Condroz and Ardennes areas of Belgium were dominated by earlier Caledonian events, and a pre-Caledonian depositional history that does not match the other areas.

Published borehole data are used to compare the Welsh and Anglian Caledonides on a number of criteria. In both areas the cleavage and folding front is roughly coincident with the former platform/basin facies transition, but metamorphic isograds show some departures from it. In strong contrast with Wales, Pridoli and Devonian deposition in the central part of the Anglian belt was more persistent both before and after the Acadian orogenic climax. This Devonian basin was partly controlled by a NE-trending basement structure, named the Cambridge Line, which had probably also influenced Lower Paleozoic deposition.

1. GEOLOGICAL SETTING

The Caledonide belts of southern Britain and Belgium form a triangular pattern around the stable Midland Platform (fig. 1). Caledonian relationships to the south of this craton are largely obscured by the later east-west Variscan Belt. The Irish, Welsh, Lakes and Belgian Caledonides are partly exposed and relatively well studied, but the Caledonides of eastern England are concealed beneath Upper Paleozoic and later cover. Renewed investigation of these 'Anglian Caledonides', (Pharaoh et al., 1987 and references therein) is constrained by the lack of surface exposure and limitations of borehole data. The purpose of this paper is to supplement the new data on the Anglian Caledonides by cautious comparisons with the adjacent Caledonian areas of Belgium and particularly of Wales, with reference to the Lakes where appropriate.

The Caledonide belts rimming the Midland Platform share a history of Early Paleozoic sedimentary and volcanic deposition, progessive basin inversion, pervasive Caledonian deformation and low-grade metamorphism, followed by post-orogenic Late Paleozoic sedimentation. Within this framework there are significant differences in timing and nature of events between areas. This paper will first contrast the reference areas of Wales and Belgium (section 2). Comparison of the intervening Anglian Caledonides will demonstrate a closer affinity with Wales than with Belgium. The Welsh/Anglian analogy will then be explored in more detail (section 3).

The term Caledonian is used in a general sense throughout to refer to any late Ordovician to Mid-Devonian orogeny. The term late Caledonian implies a later Silurian to mid-Devonian age, rather than the more restricted Pridoli to Lochkovian usage of, for instance, Ziegler (1988). The term Acadian is used for a late Early Devonian phase (McKerrow, 1988; Soper et al., 1987) temporally, though not necessarily spatially, continuous with the Acadian phase of the Canadian Appalachians.

No attempt is made here to review each area comprehensively. Recent reviews of relevant Welsh geology are given by Woodcock (1984, 1990), Woodcock & Gibbons (1988) and Kokelaar (1988), of the Belgian Caledonides by Michot (1980), Robaszynski & Dupuis (1983) and Verniers & Van Grootel (this volume) and of the buried Anglian

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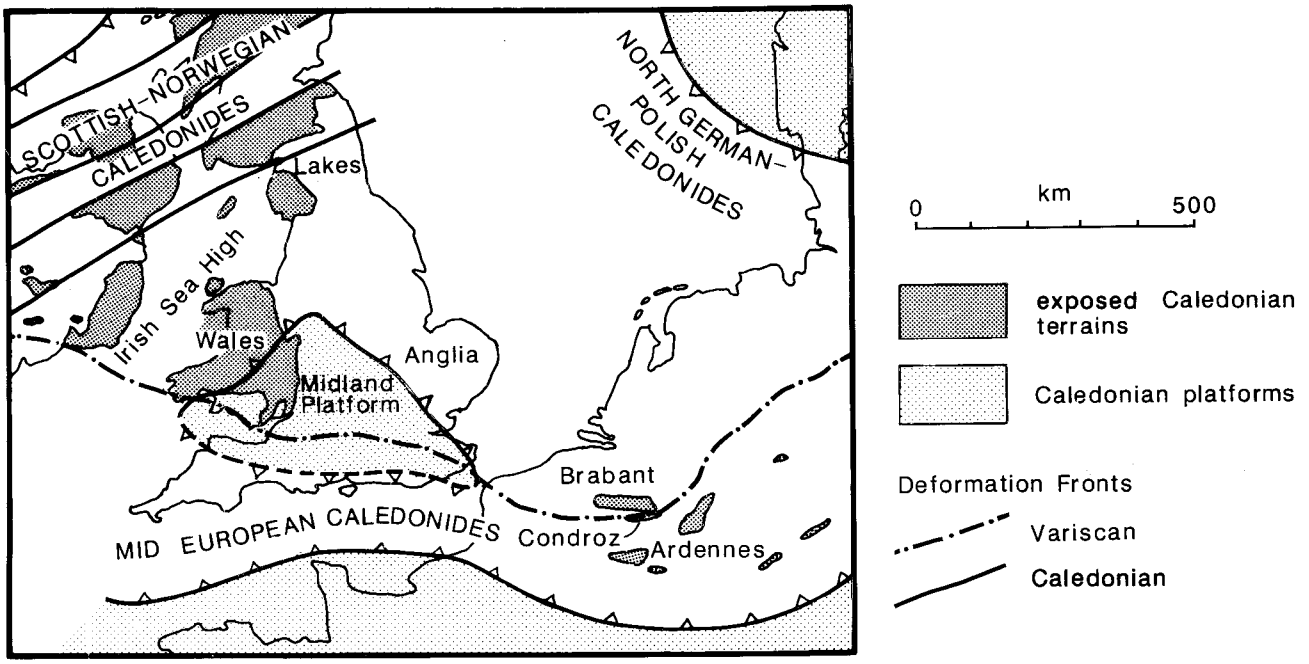


Figure 1.- Location map for Caledonide areas discussed in the text.

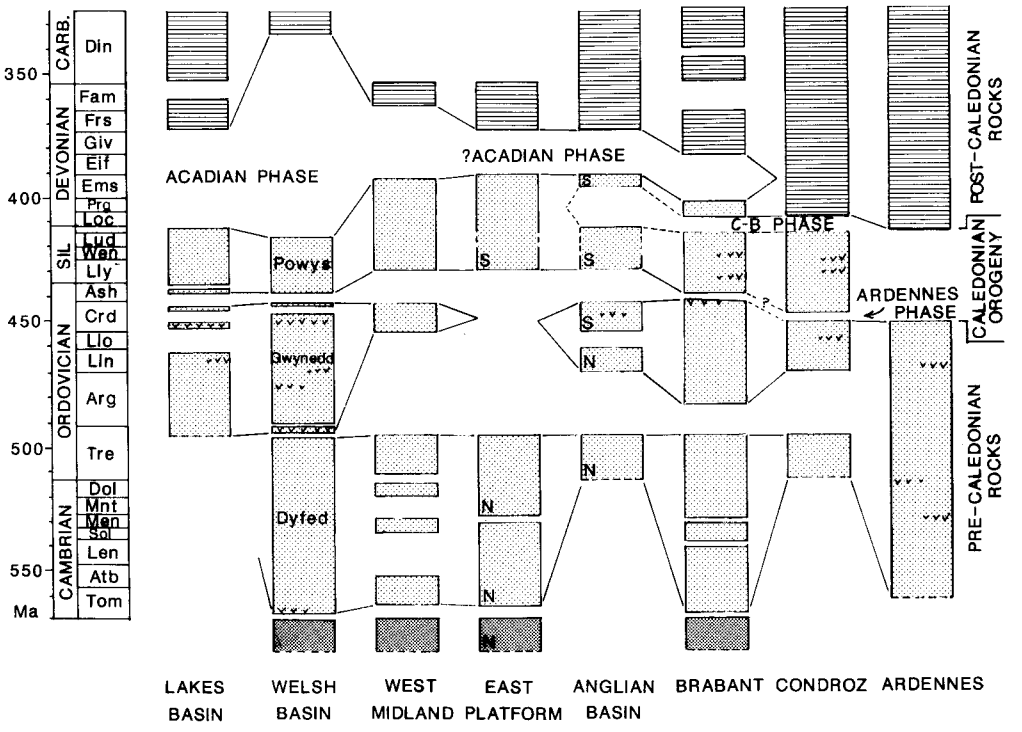


Figure 2.- Comparative time stratigraphy of Caledonide areas located in fig. 1. C-B = Condruso-Brabantian; v = volcanics or volcaniclastics; N = proved north and S = proved south of Cambridge Line (fig. 3). Precambrian rocks (close stipple) and post-Caledonian rocks (horizontal lines) are ornamented distinctively. Time scale after McKerrow et al. (1985) for Ordovician through Devonian, and Harland et al. (1982) for Cambrian scaled to base at 570Ma rather than 590Ma.

belt by Pharaoh et al. (1987), Allsop & Smith (1988) and Molyneux (this volume). The database for the Anglian Caledonides is summarised on fig. 3 and in section 3.1.

2. TIME STRATIGRAPHY

A time stratigraphic diagram (fig. 2) gives a one-dimensional comparison between the Welsh, Anglian and Belgian areas, highlighting major similarities and differences. Each column shows the time-extent of preserved rock, separated by unconformities representing non- deposition or erosion. The lithologies are sedimentary, except where volcanics or intrusives are specifically indicated.

2.1. WELSH CALEDONIDES AND ADJACENT PLATFORMS

Wales is considered first, because it alone exposes an intact transition from the basin to the Midland Platform.

In the Welsh Basin four basin-wide unconformities bound three major sequences, the Dyfed, Gwynedd and Powys Supergroups (Fig. 2; Woodcock, 1989). The unconformities record discrete tectonic events, each of which changed the character of the basin. The sub-Dyfed unconformity spans the Cadomian deformation of the Precambrian basement and the onset of crustal extension to produce the mainly non-volcanic rift basins hosting the Dyfed Supergroup. The sub-Gwynedd unconformity records deformation associated with the onset of a phase of major volcanism in the basin, of first arc then back-arc character, which climaxed in the upper part of the Gwynedd Supergroup. The late Ordovician shut-down of most volcanism coincides with a tectonic event recorded in the sub-Powys unconformity. The Powys Supergroup is dominantly non-volcanic. Its deposition was terminated by basin inversion and the pervasive Acadian (late Caledonian) deformation, recorded by the major unconformity below Carboniferous rocks.

The sequence stratigraphy of the Welsh Basin can be followed reliably onto the Midland Platform to the SE (fig. 2). The sub-Gwynedd and sub-Powys unconformities expand towards the platform and major intervening unconformities appear. The Gwynedd Supergroup becomes largely non-volcanic. The Acadian unconformity is shorter on the platform, due both to the earlier onset of post-Acadian deposition and to less erosion of pre-Acadian rocks.

2.2. BELGIAN CALEDONIDES

2.2.1. Brabant Massif

The Brabant is the northernmost of three Belgian Caledonide areas represented by the time-stratigraphic columns (figs 1,2). Brabant stratigraphy shows the following similarities to the Welsh Caledonides:-

1) The presumed presence of a Cadomian basement and sub-Cambrian unconformity.

2) A probable correlative of the sub-Gwynedd unconformity, in an Upper Tremadoc to Lower Arenig stratigraphic gap (Vanguestaine, 1989).

3) A probable correlative of the sub-Ashgill unconformity, evidenced by contrasts in deformation intensity between Caradoc and Ashgill rocks (Verniers and Van Grootel, this volume) and in map-scale angular discordance (Legrand, 1968).

4) A possible correlative of the Acadian unconformity in the sub- Givetian angular unconformity. In most places in the Brabant the sub- unconformity rocks are Pridoli or older (Verniers & Van Grootel, this volume), but in the Bolland borehole they are folded Lochkovian sediments. The implied Pragian, Emsian or Eifelian deformation, the Bollandian event of Michot (1980), is the best match with the Acadian in Wales. However, the main Caledonian phase in Brabant is more usually taken in the stratigraphic gap between the Lochkovian and underlying Ordovician rocks in the Bolland borehole. This phase is often assumed to be of late Silurian or earliest Devonian age, the Condruso-Brabantian phase of Michot (1980), but could equally well be as early as late Ordovicain (Verniers & Van Grootel, this volume). The preferred correlation of the Bollandian phase with the Acadian is supported by the conformable Ludlow to Lower Devonian sequence in the Liévin borehole on the SW edge of the Brabant Massif.
Brabant stratigraphy differs from that in Wales mainly in that the major magmatic activity spans Caradoc to Llandovery time, as compared with the Arenig to Caradoc maximum in Wales.

2.2.2. Condroz Ridge and Ardennes

Condroz and the Ardennes show only two main similarities with Wales:-

1) A possible correlative of the sub-Gwynedd unconformity is found in Condroz where it spans

late Tremadoc and the whole of Arenig time. The hiatus is not recognised in the NE Ardennes.

2) A possible correlative of the sub-Powys unconformity is the post-Early Caradoc hiatus in the Ardennes. This gap represents the Ardennian deformation phase (Michot, 1980). Along the Condroz Ridge the corresponding hiatus is clearly intra-Caradoc, as compared with earliest Ashgill extent of the sub-Powys unconformity in Wales.

Non- correspondence or at least diachroneity of controlling tectonics is implied.

Major contrasts with Wales are:-

1) Volcanism is not restricted to the Late Tremadoc to Caradoc range of the Gwynedd Supergroup. Phases occur also in the Cambrian in the Ardennes, and in Ashgill through Wenlock time in Condroz.

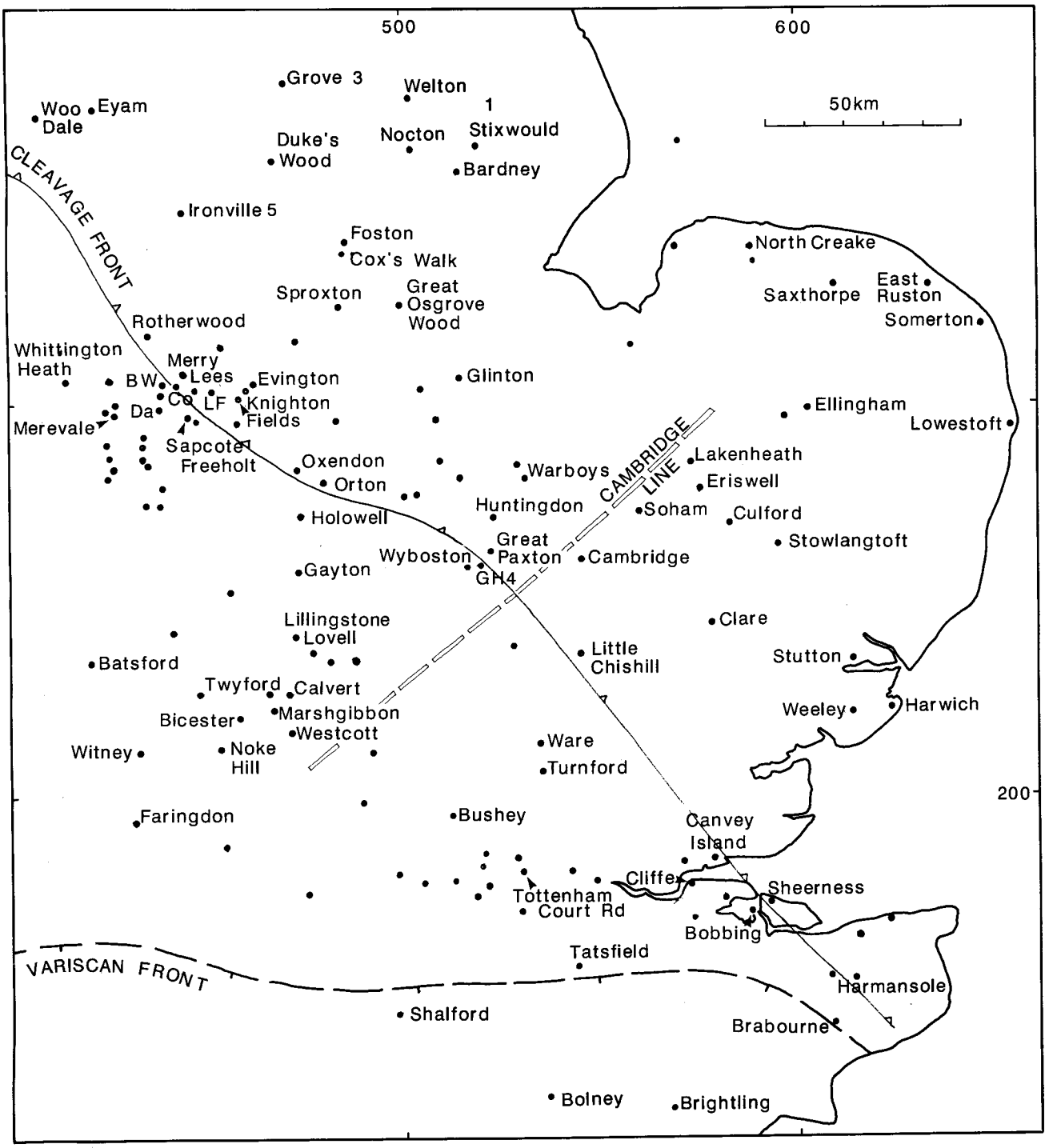


Figure 3.- Map of Anglian Caledonides and eastern Midland Platform with relevant borehole locations. Boreholes are named if referred to in text. BW = Bosworth Wharf; Co = Cowpastures; Da = Dadlington; LF = Leicester Forest.

2) The Acadian, or Bollandian, phase of the Caledonian orogeny only weakly affected the Condroz Ridge and apparently did not affect the Ardennes. The Condruso-Brabantian phase (probably early Lochkovian) is recognised in Condroz, but did not affect the Ardennes.

3) The post-Caledonian transgressive sequence is older and more systematically diachronous than in Wales: Pridoli in the Ardennes and Lochkovian or later in Condroz.

Of the three stratigraphic templates provided by the Belgian Caledonides, that in Brabant shows the closest correlation with the Welsh area and offers the most profitable comparison with the Anglian Caledonides.

2.3. ANGLIAN CALEDONIDES

Two simplified time-stratigraphic columns (fig. 2) for the Anglian Basin and for the mainly buried eastern part of the Midland Platform rely on the published records of boreholes plotted on fig. 3. Each column is a composite of proven ranges of encountered rocks; the complete sequence is seen in no one borehole. New boreholes may expand the currently proved ranges. There are significant differences between the northwest and southeast segments of both the basin and the platform (across the 'Cambridge Line' of fig. 3). These differences are indicated on the columns, and are discussed more fully later.

The known stratigraphy in the Anglian Basin and its southeast platform permit a simple correlation with the Welsh Basin and its margins. The matching Anglian features can be summarised as:-

1) A Precambrian basement deformed by the Cadomian event. Note that some of the supposed Precambrian beneath the basin may in fact be of Ordovician age (Pharaoh et al., 1987), and some of the deformation in proved Precambrian may in fact be post-Cadomian (Le Bas, 1972; Evans, 1979).

2) A sub-Cambrian lacuna, at least on the platform, correlating with the sub-Dyfed unconformity.

3) A non-volcanic Cambrian and Tremadoc sequence correlating with the Dyfed Supergroup, but only proved in the northwest part of the basin and adjacent platform. This sequence is fuller on the eastern Midland Platform than on its western part.

4) An Arenig lacuna correlating with the sub-Gwynedd unconformity.

5) An Ordovician sequence with a volcanic component, correlating with the volcanically-influenced Gwynedd Supergroup. This sequence is absent on the platform but in the basin is represented by Llanvirn and Caradoc sediments, and two volcanic units giving Rb-Sr ages of 448+32 (Caradoc) and 466+11 Ma (Llanvirn) respectively (Pharaoh et al., 1987, this volume). Other volcanic rocks in the northwest part of the basin, previously assumed to be Precambrian, have arc and within-plate geochemistry distinct from the known Precambrian suite of Charnwood Forest, and closer to that of the dated volcanics and to Welsh Basin Ordovician rocks.

6) An Ashgill through Mid-Llandovery lacuna correlating with the sub-Powys unconformity.

7) A non-volcanic Upper Llandovery through Emsian sequence in the southeast basin and platform, correlating with the Powys Supergroup. However, Lochkovian and Pragian have not been proved in the basin, and the relationship of the Emsian here to the underlying Silurian is ambiguous.

8) An unconformity spanning most of the Mid-Devonian, correlating with the Acadian unconformity.

9) A diachronous post-Acadian overstep sequence, typically beginning in latest Givetian or Frasnian time. As on the western platform, its base tends to be younger in the north, as late as Dinantian. Southwards, the Acadian unconformity narrows and pinches out near the position of the Variscan Front (Allen, 1979). However, Devonian relationships in the Anglian Caledonides are open to several interpretations, to be discussed later.

There are, however, several components of the Anglian Caledonides which do not match with Wales, and which may have other affinities:-

1) The lack of Lochkovian and Pragian in the basin is partially analogous to Brabant and Condroz, with their possible Pridoli to lower Lochkovian unconformity. This might indicate a component of early Devonian deformation in the Anglian Basin, similar to the Condruso- Brabantian phase in Belgium. This possibility is discussed later.

2) The geophysically indicated granites in the northwest basin and platform have a probable Devonian component which is best correlated with the Shap/Skiddaw granites in the Lake District (Allsop, 1987). The Lakes and Anglian granites may be part of a NW trending belt including the

Southern Uplands granites and other buried plutons beneath eastern England

3) The presence of post-Caledonian Devonian rocks above strongly folded and cleaved parts of the Anglian Basin sequence contrasts with the Welsh Basin, similarly deformed, where overstep only began in the Dinantian. In this respect the basin matches the Midland Platform and the Brabant.

The conclusion from the time-stratigraphic analysis is that the Anglian Caledonides invite close comparison with the Welsh Caledonides, but that several components may have affinities with Belgium or the Lake District. Further assessment of the Anglian Caledonides requires its more detailed specification, in particular involving areal relationships rather than simply vertical time- stratigraphy.

3. 3D STRATIGRAPHIC RELATIONS IN THE ANGLIAN CALEDONIDES

3.1. THE DATABASE

Locations of boreholes in the Anglian Caledonides which have been used in this study are plotted on fig. 3. The positions of the Acadian Front, and a NE-SW subdivision termed the Cambridge Line are plotted for spatial reference and are justified later. Each borehole is named if it is referred to in the text or plotted on figs 4b or 4c. The sources of specific data or interpretation relating to each borehole are cited in the text. The following reviews have been used for more general information: Bullard et al. (1940) for early boreholes, mostly southeast of the Cambridge Line; Harris et al. (1975) for the Precambrian; Le Bas (1968, 1972), Cowie et al. (1972) and Evans (1979) for the Cambrian and Tremadoc; Williams et al. (1972) for the Ordovician; Cocks et al. (1971) and Ziegler et al. (1974) for the Silurian; House et al. (1977) and Allen (1979) for the Devonian; and Wills (1978), Allsop (1985, 1987), Pharaoh et al. (1987) and Molyneux (this volume) for more recent data.

Specific components of the Anglian Caledonides are reviewed below and illustrated on fig. 4. The Welsh Caledonides are used as the main analogue because of a) stratigraphic similarities outlined previously, b) their well defined basin to platform facies transition and Acadian deformation front, and c) their position on the northwest side of the microcraton mirroring that of the Anglian belt on the northeast.

3.2 THE CAMBRIDGE LINE

The existence of a NE-SW subdivision of the Anglian Basin and adjacent platform are apparent from the discussion of time stratigraphy (section 2.3). This 'Cambridge Line' (named after its central point) is plotted on figs 3 and 4, mainly to aid description of stratigraphic variations. However it is thought to mark a major basement fault/fold belt that influenced at least Palaeozoic and Mesozoic sedimentation and tectonics. This interpretation will be justified elsewhere. For the present descriptive purpose, the contrasts across this boundary can be summarised as follows:-

1) Precambrian, Cambrian and lower Ordovician rocks are only proved northwest of the line, and upper Ordovician, Silurian and Lower Devonian sediments mainly to the southeast.

2) Pre- or syn-Caledonian igneous rocks are only proved northwest of the line.

3) The post-Caledonian cover only has a substantial Upper Devonian component to the southeast of the line. To the northwest its base is usually Dinantian or later.

4) Magnetic basement is shallow to the northwest of the line (generally <3.5km) and deeper to the southeast (Allsop, 1985).

A unique NE-SW line can be drawn (figs 3,4) across which all the above contrasts occur, except the overstep of thin Upper Devonian on the platform. Elements of the line can be seen on previous maps by Wills (1978), as the 'putative limits of transgressive Silurian and of Middle and Lower Devonian', and by Allsop (1985) as the northwestern edge of the Luton-Cambridge Devonian basin (fig. 4e).

3.3. BASEMENT AND IGNEOUS CONTRASTS

By analogy with Wales (fig. 4a) the boundary between the Early Paleozoic Midland Platform and the Anglian Basin might be defined on the following criteria:-

1) Restriction of contemporaneous volcanic and intrusive rocks to the basin or its immediate edge.

2) Predominance of Precambrian basement inliers on the platform.

These two criteria give conflicting results in the Anglian area (fig. 4a):-

1) On the igneous criterion the basin edge runs to the southwest of the South Leicestershire diorites, of possible Cambrian age (Allsop, 1987, Le Bas, 1968, 1972), and of the volcanics in the Orton and Oxendon boreholes, geochemically similar to the basinal Ordovician volcanics (Pharaoh et al., this

volume). This line leaves the supposed Precambrian tuffs in the Holowell borehole (Allsop et al., 1987) on the platform, but isolates the exposed Precambrian of Charnwood Forest in the basin.

2) On the Precambrian criterion, the basin edge could run just northeast of the Charnwood Forest Precambrian. Such a line leaves in the basin the dated (Rb-Sr) Ordovician volcanics at Glinton and Cox's Walk, the geochemically similar volcanics at Great Osgrove Wood and Woo Dale (Pharaoh et al., 1987, this volume), and the Ordovician intrusives at Mountsorrel and Warboys. However, it confines to the platform the South Leicestershire diorites and the volcanics at Orton and Oxendon.

The first of these two alternatives is preferred here, partly because a tectonically controlled Precambrian inlier in the basin is considered more likely than Ordovician magmatism within the platform. The resulting boundary is also coincident with the Acadian cleavage front (fig. 4c). presumably marking the limit of the thinned continental crust of the basin. However the possibility that the basin margin shows a more complex tectonic interleaving of former platform and basin crust cannot be discounted.

3.4. PLATFORM-BASIN FACIES TRANSITION

In Wales, the Early Paleozoic platform/basin boundary can be defined on the following sedimentary criteria:-

1) A facies transition from shallow marine quartzites, carbonates, sandstones and mostly bioturbated mudstones on the platform to turbidite sands, turbidite mudstones and often-laminated hemipelagic mudstones in the basin.

2) A transition from more shelly to more graptolitic faunas.

3) A marked basinward increase in accumulation rate and resulting stratigraphic thickness.

4) A basinward decrease in the duration of unconformities, with resulting increase in stratigraphic completeness of preserved sections.

The last two criteria are difficult to use in the Anglian region because of the fragmentary nature of the database.

The first two criteria can be used southeast of the Cambridge Line to define a NW-trending Silurian shelf-basin transition (fig. 4b). A key constraint is the shelly/graptolitic transition between Brabourne and Chilham (Cocks et al., 1971). The boundary must then pass northeast of the shelly facies at Cliffe and Ware and southwest of the probable basinal mudstones at Sheerness (Lamplugh et al., 1923), Bobbing (Lister et al., 1970) and Culford (Ziegler et al., 1974). Silurian sediments further east are basinal mudstones and greywackes, sometimes graded or slumped. Mudstones at Lowestoft formerly thought to be non-marine (Cocks et al., 1971) are now known to contain chitinozoa (Molyneux, this volume) and are presumably marine.

Silurian rocks are absent northwest of the Cambridge Line (fig. 4b). In Tremadoc time the basin margin presumably lay northeast of the widespread shallow marine shelly mudstones on the eastern Midland Platform, that is northeast of a line from Wyboston to Evington. However, the quartzites and sandstones at Duke's Wood, Nocton, Stixwould and Bardney may be ?Cambrian shelf facies (Cowie et al., 1972), in which case part of the Cambrian shelf must have extended well to the northeast. This might be a separate platform fragment to the north of the Anglian Basin, analogous to the Irish Sea Platform north of the Welsh Basin. Evidence for Llanvirn time is provided by the mixed graptolitic/shelly faunas at Great Paxton and Huntingdon (Williams et al., 1972). These are faunally similar to the Shelve Inlier (Stubblefield, 1967) just within the Ordovician Welsh Basin.

Whereas the Silurian platform edge southeast of the Cambridge Line almost coincides with the Acadian cleavage front (fig. 4b), the Cambro-Ordovician platform edge further northwest shows no such coincidence. This implies that a large volume of 'platform' sediments were nevertheless strongly deformed by subsequent 'basinal' shortening. This paradox requires further investigation.

The platform edge is marked on fig. 4b as colinear across the Cambridge Line , even though constrained by data of differing age. This colinearity is of arguable significance if the basin edge shifted position through time, as it did in Wales between deposition of the Gwynedd and Powys Supergroups.

Marine Silurian rocks occur south of the Variscan Front at Shalford and, more dubiously, in Cornwall (Cocks et al., 1971). These fragments, together with the marine Devonian and Carboniferous of the Cornwall Basin suggest the possibility of an Early Paleozoic basin south of the Midland Platform. This provides a southern link between the Welsh and Anglian Basins, and on into Belgium.

3.5. CALEDONIAN CLEAVAGE FRONT

The southeast limit of Acadian (late Caledonian)

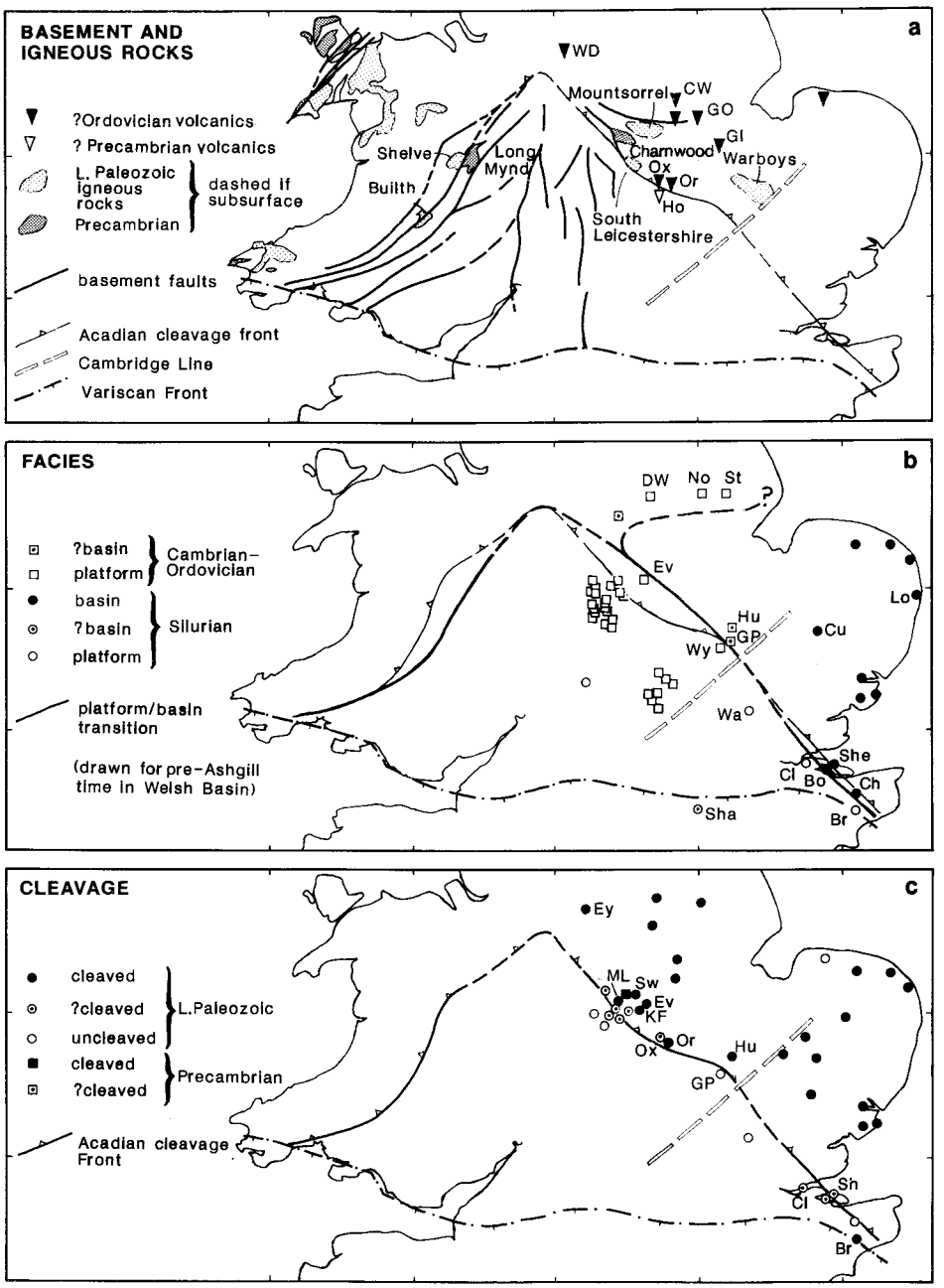
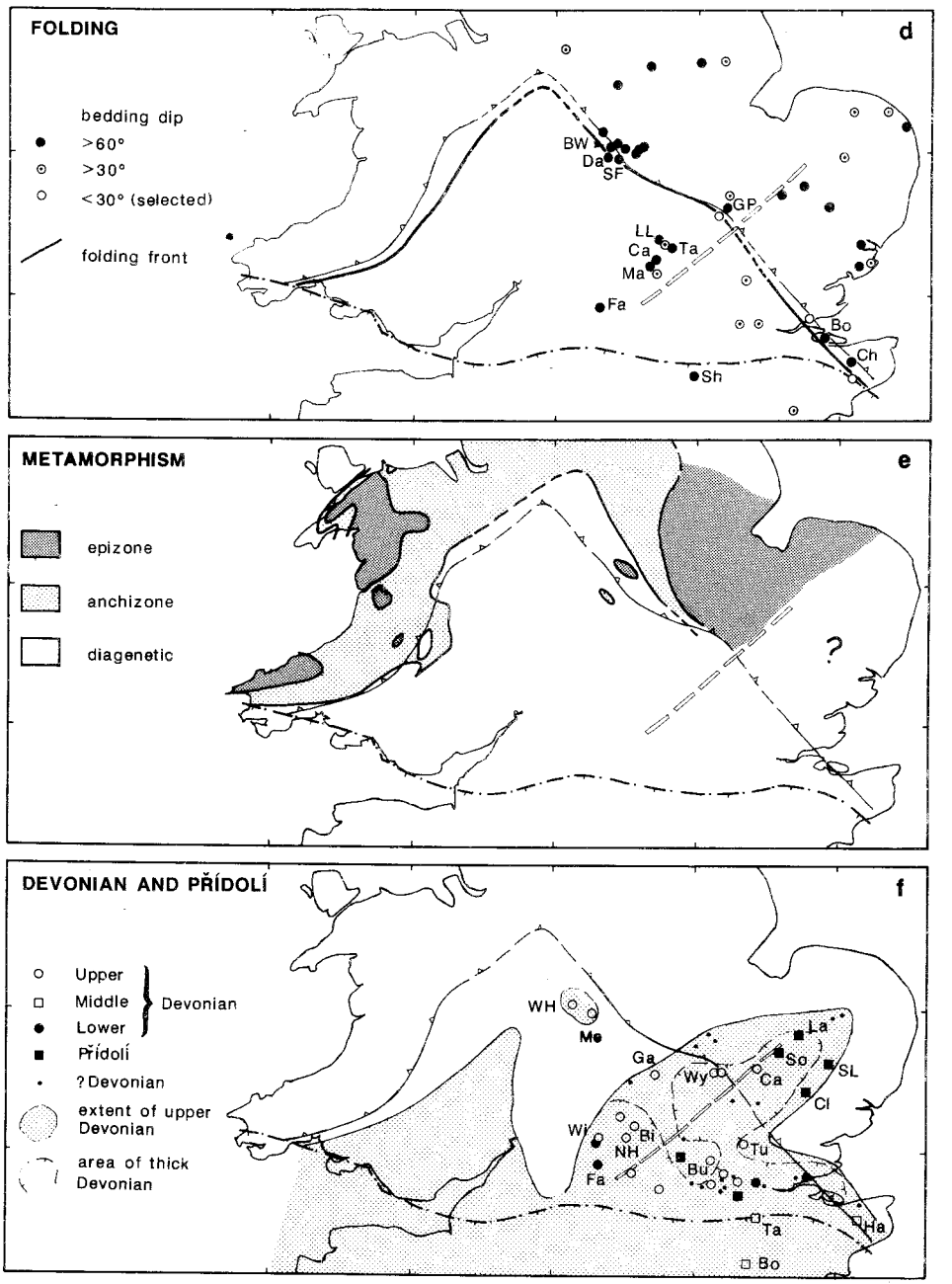


Figure 4.- Maps of selected geological components of the Anglian and Welsh Caledonides. The Variscan Front, Acadian cleavage front, and Cambridge Line (fig. 4a) appear for reference on each map. Boreholes referred to in text are marked with abbreviated name; see fig. 3 for full name.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deformation in Wales (fig. 4c,d) can be defined by three interrelated but not spatially coincident features:-

1) The rapid platformwards transition from cleaved to uncleaved Lower Paleozoic rocks.

2) The more gradual waning in frequency and tightness of folds. Folds with steep limbs may persist platformwards of the cleavage front, especially near major faults in the Midland Platform.

3) The increasing platformwards dominance of large faults rather than folds in the structural style.

The last criterion cannot be used in the Anglian Caledonides, because the later cover precludes reliable assessment of fault frequency and size. The first two can be applied more successfully (fig. 4c,d).

The cleavage front (fig. 4c) is taken as a line bounding records of tectonic cleavage in Anglian boreholes. It trends NW-SE, roughly coincident with the platform-basin transition defined by the presence of igneous rocks and Silurian facies. However, there are ambiguities associated with some records near the cleavage front.

Southeast of the Cambridge Line, the shelly facies at Brabourne has a weak but definite cleavage (Lamplugh & Kitchin, 1911), but is far enough south for the cleavage to be Variscan rather than Caledonian. The Wenlock lithology at Cliffe is described as 'slaty' by Lamplugh et al. (1923), but only as 'clayey' in the original description by Whitaker (1908a,b). and that at Sheerness is variously described by Lamplugh et al. (1923) as slaty or shaly. A compromise line has been drawn between these two (fig. 4c). Because the cleaved rocks are dominantly Silurian, the line is the late Caledonian (probably Acadian) cleavage front analogous to that in Wales.

Northwest of the Cambridge Line, the cleavage front is constrained by four pieces of evidence:-

1) The contrast between the cleaved Llanvirn rocks at Huntingdon (IGS, 1966) and uncleaved Llanvirn at Great Paxton (Stubblefield, 1967).

2) Cleaved volcanics in the Orton and Oxendon boreholes, of Ordovician geochemical character (Pharaoh et al., this volume).

3) Cleaved mudstones exposed just east of Charnwood Forest (Swithland Reservoir, Le Bas 1968) and in the subsurface at Merry Lees, Evington and Knighton Fields of supposed, but not always proven, Tremadoc or Upper Cambrian age. An alternative is that these mudstones are Precambrian. Evans (1979) reviews the evidence, and his conclusion that the cleavage is post-Tremadoc is accepted here. Less well attested records in this area (fig. 4c) would shift the cleavage front even further southwest.

4) Cleaved Precambrian volcanoclastics in the Charnwood Forest inlier. The cleavage here could be of Precambrian age, but Evans (1979) makes a structural case for correlating it with the post-Tremadoc cleavage.

The resulting cleavage front is roughly coincident with the edge of the Midland Platform as defined by Ordovician volcanics (fig. 4a) and as drawn by Smith (1987) and Pharaoh et al. (this volume), but is inboard of that drawn by Pharaoh et al. (1987).

The possibility cannot be ruled out that the cleavages northwest of the Cambridge Line are of more than one age. Although an 'Acadian' (Early/Mid Devonian) age is favoured here, the cleavage could be earlier, given that the latest proven rocks to be affected are Llanvirn (Huntingdon). The sequence stratigraphy and correlation with Wales allow for a late Ordovician deformation episode, matching the sub-Powys deformation in Wales, and an early Ordovician phase matching the sub-Gwynedd deformation. Neither of these phases resulted in a cleavage in Wales.

3.6. CALEDONIAN FOLDING FRONT

A line bounding the strong folding in the Welsh Caledonides runs roughly parallel to, but just inboard of the cleavage front (fig. 4d). This line excludes localized steep dips near major faults in the platform, notably the Malvern Line. A line bounding records of high dips (>60° or 'steep') in the Anglian Caledonides also runs just inboard of or coincident with the cleavage front of fig. 4c. Key constraints are the steep dips at Chilham and Bobbing in the southeast, and in Great Paxton, Sapcote Freeholt, Dadlington and Bosworth Wharf further northwest.

Several anomalously steep dips occur platformwards of the chosen folding front (fig. 4d). That at Shalford is far enough south to be of Variscan age. That further north at Faringdon has been attributed to the same event (Falcon & Kent, 1960), but may instead belong to the other group of anomalously steep dips further northwest at Marshgibbon, Calvert, Tattenhoe and Lillingstone Lovell. These could be adjacent to roughly N-S fault belts in the platform, or might be related to the NE-SW trending Cambridge Line.

3.7. CALEDONIAN METAMORPHIC FRONT

The metamorphic grade in the Welsh Caledonides reaches greenschist facies in metabasites, and the epizone in pelites (Robinson & Bevins, 1986). The highest grades occur within the central and northwestern parts of the Welsh Basin and decrease progressively towards the Midland Platform (fig. 4e). Higher grades may in part correlate with high strain (Roberts and Merriman, 1985, Roberts et al., 1989), but a component of pre-deformation burial metamorphism may be present (Robinson & Bevins, 1986; Bevins & Robinson, 1988). The anchizone-diagenetic zone boundary occurs close to the Acadian cleavage front, transgressing it only in its central segment.

A mica crystallinity study of the northern Anglian Caledonides (Pharaoh et al., 1987) shows a broadly analogous pattern (fig. 4e). Epizone grades in the basin decrease to diagenetic zone on the platform. Higher grades in Precambrian inliers disrupt the pattern near the basin edge. These can be explained by a separate Precambrian metamorphic event (Pharaoh et al., 1987) or by greater burial of Precambrian rocks during basin accumulation or deformation. They have no analogue across the Welsh metamorphic front, where the Precambrian shares the low grades of surrounding Paleozoic cover.

3.8. AGE AND EXTENT OF DEVONIAN ROCKS

In the Welsh Basin and on its southeast margin, Devonian rocks are involved as follows:-

1) The pre-Acadian sequence comprises non-marine Lower Devonian (Lochkovian through Emsian) rocks conformably overlying marginal and non-marine Pridoli and marine earlier Silurian rocks.

2) The Lower Devonian component of this sequence is now only preserved on the Midland Platform, but its lower parts were deposited in the basin, and later eroded and recycled southeastward into its upper parts (Allen, 1962, 1979).

3) Middle Devonian rocks are missing, even on the platform, due to non-deposition and erosion during the peak uplift during or after Acadian deformation.

4) The post-Acadian sequence comprises a Famennian to Dinantian transgressive unit, disconformably underlain in places by a Frasnian unit.

5) The Upper Devonian (Frasnian and Famennian) component of this sequence did not overstep northwest of the Acadian front, and even the Dinantian only transgressed the northeastern extremes of the Welsh Basin.

6) The Devonian sequence increases in its completeness and extent of marine influence southwards, towards and across the Variscan Front.

The Welsh Basin therefore displays a direct control on the distribution of syn- and post-inversion sediments by the position of the inverted basin margin with the Midland Platform (fig. 4f). The Anglian Basin shows no such simple control.

The only close analogy with Wales is on point (6) above (Allen, 1962), suggesting a continuous Devonian marine basin across southern England; the Cornwall Basin (Ziegler, 1982, 1988) or South England Basin (Allen, 1962). Proximity to this basin explains the presence of Middle Devonian rocks at Bolney, Tatsfield and Harmansole, and a slightly earlier onset of the post-Caledonian transgression marked by the late Givetian rocks at Turnford, Bushey and Noke Hill. Middle Devonian rocks are unproven further north, consistent with a Mid- Devonian uplift as in Wales.

The main contrast with Wales is the lack of control on Devonian sedimentation by the NW-SE Anglian Basin margin and deformation front. A more important control is the NE-SW Cambridge Line (fig. 3, 4f), though this control weakens southwestward. Devonian rocks are thin or absent to the northwest of the line in the basin (fig. 4f). Thin Upper Devonian sediments overstep it on the platform (e.g. at Wyboston, Gayton and Witney) and Lower Devonian and probably Silurian units are continuous across it in the Oxford-Reading Basin (e.g. at Bicester, Witney and Faringdon). The Upper Devonian on the northern platform at Whittington Heath and Merevale is probably either an isolated basin or depositionally connected with the northern end of the Welsh Borderland system.

Devonian rocks are present southeast of the Cambridge Line in a NE-SW trending area completely spanning the Anglian Basin margin (fig. 4f). Gravity modelling suggests up to 900m of Devonian and Pridoli sediments in this 'Luton/Cambridge Basin' (Allsop, 1985), probably bordered to the south by the fault-bounded 'Ware High'. The age of the basin fill is less certain, though critical to interpretation of this anomalous area. Allsop (1985) suggests a mainly Upper Devonian age, based on Frasnian rocks at Cambridge, Wyboston, GH4 and less certainly Little Chishill. This would imply only a post-Acadian age for the Luton-Cambridge Basin. However records of probable Pridoli rocks at Soham, Lakenheath, Stowlangtoft and Clare (Bassett et al., 1981, Pharaoh

et al., 1987) suggest that pre-Acadian sedimentation was also more persistent here, and, or that syn-Acadian erosion was less extreme.

A probable history for the Cambridge-Luton basin therefore involves:-

1) Pre-Acadian subsidence, bounded by faults against the Ware High to the southeast and along the Cambridge Line to the northwest. Subsidence continued in the basin at least into the Pridoli at a time when no deposition is evidenced to the northwest. This subsidence contrast may have persisted at least as far back as Llandovery time (Wills, 1978), but this and its earlier history are obscure.

2) A post-Acadian, pre-Variscan subsidence to give thick Upper Devonian sediments in the basin compared with thin or absent equivalents northwest of the Cambridge Line.

3) Variscan positive inversion of the Luton-Cambridge Basin, and erosion from it of most of the Carboniferous sequence presumed to overlie the preserved Upper Devonian.

It must again be emphasized that the Luton-Cambridge basin has no analogue in the Welsh Caledonides. The persistence of both pre- and post-Acadian sedimentation in this basin is best attributed to structural control by NE-SW trending basement structures at the basin margins, the northeastern one coinciding with the Cambridge Line.

Although a late Emsian to Givetian (Acadian) timing for the main Caledonian deformation and uplift is favoured here, two pieces of evidence raise the possibility of an earlier, perhaps Pridoli to Lochkovian pulse. These are the absence of proven Lochkovian and Pragian rocks in the Anglian Basin and the presence of only gently dipping Emsian rocks at Canvey Island, northeast of the Acadian Front. Neither piece of evidence is conclusive. A latest Silurian or earliest Devonian deformation pulse would correlate with disconformities near the southern margin of the Welsh Basin at this time (Allen, 1979) and with the Condruso-Brabantian phase in Belgium (fig. 2).

4. SUMMARY

The new conclusions of this study are:-

1) The sequence stratigraphy of the Welsh Basin can be reliably traced across the Midland Platform into the Anglian Basin, implying shared eustatic and tectonic controls.

2) The same sequence stratigraphy is mostly matched in the Brabant area of Belgium, but stratigraphic contrasts develop rapidly southwards through the Condroz area into the Ardennes.

3) Whilst the Anglian Caledonides are in some respects a mirror image of the Welsh Caledonides, there are important contrasts:-
   a) a Precambrian inlier in the basin,
   b) several areas of strongly deformed platform facies,
   c) more persistent Early Devonian deposition in one area of the basin and much earlier onset of post Caledonian sedimentation in the same area,

4) The transverse, NE-SW, Cambridge Line separates areas of strongly contrasting Paleozoic geology in the basin and outer Midland Platform.

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