Mercia Mudstone as a Triassic aeolian desert sediment

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Abstract. It has been suggested that at least parts of the Mercia Mudstone in the English Midlands are closely related to loess, or loess-like sediments. It seems likely that the Mercia Mudstone is an ancient form of parna, the aeolian desert sediment formed in the Australian Quaternary. This is essentially a form of loess having silt-sized particles and an open depositional packing. Loess-like systems tend to collapse when loaded and wetted, and this appears to have occurred in the mudstone. The collapse behaviour of the Mercia Mudstone is probably the strongest indication of a loessic origin. Study of the Mercia may throw some light on the nature of parna - the most characteristic of the Australian loesses.

The original idea appears to be due to Bosworth (1913), that the Mercia Mudstone Group (which he of course knew as the Keuper Marl) was possibly in part a loessic or loess-like deposit that had been formed by arid desert processes. In the recent report on the Mercia Mudstone prepared by the British Geological Survey (Hobbs et al, 1998) this idea is still given some credence, as one of the ways in which the Mercia Mudstone was formed. The idea deserves more discussion, from two points of view, as part of a further consideration on the mode of formation of the Mercian, and as a means of providing more data on loessic processes associated with hot deserts. The desert loess problem has been discussed for many years, in particular since the Smalley & Vita-Finzi paper of 1968. They claimed that there were no specifically desert processes which could produce the fine material needed for loess deposits - and this claim is still being discussed (Sun, 2002). Bosworth saw loess as a desert sediment. Today, loess is seen more as a glacial phenomenon, related to cold phases of the Quaternary, rather than as a desert material. The nature of 'desert' loess and the nature of desert-related loessic processes is still being questioned (Wright, 2001) and the nature of the Mercia Mudstone may throw some light on nearly contemporary processes.

Mercia Mudstone

The Mercia Mudstone Group is a sequence of predominantly mudrock strata that underlies much of southwestern, central and northern England and on which many urban areas and their attendant infrastructure are built. Although it causes few serious geotechnical problems, some difficulties do arise as a result of volume change (Popescu et al, 1998). It is significant to the construction industry because it is frequently encountered in civil engineering activities involving foundations, excavations and earthworks (Nathanial & Rosenbaum, 2000). Its nature is such that its properties may vary between a soil and a rock depending on its detailed lithology and its state of weathering. These descriptive statements are supported by the recent report by the British Geological Survey (Hobbs et al, 1998) on the Mercia Mudstone in the context of a series of monographs on the Engineering Geology of British Rocks and Soils; another excellent source of practical data is Chandler and Forster (2001).

It appears that the Mercia Mudstone was deposited in a mudflat environment in three main ways:

- settling out of mud and silt within temporary lakes,
- rapid deposition of sheets of silt and fine sand by flash floods,
- accumulation of wind-blown dust on wet mudflat surfaces.

This last depositional mode has allowed a comparison between the Triassic sediment and Quaternary loess. In fact it seems likely that parts of the mudstone, notably the outliers in Nottingham and Leicester, are like the parna deposits which are observed in south-eastern Australia (defined and named by Butler, 1956).

The overall disposition of the Mercia Mudstone across the country is controlled by the long-term tectonic trends (Smalley, 1967), and lies parallel to, and probably just to the south of, the major tilt axis. Land to the south and east of the Mercian outcrop is subsiding, largely as a result of long-term tectonic trends, but possibly with a contribution from isostatic recovery following the last glacial retreat.

Structure and nature

The Mercia Mudstone has been reported (Hobbs et al, 1998) as having a two-stage structure, formed first by the aggregation of clay-sized particles into silt-sized units, and then by the agglomeration of these when weakly bonded by various cements. The primary 'intra-ped' structure is stronger than the secondary 'inter-ped' structure. This is very like the situation in southeatern Australia where the parna consists of a silt-sized material, often found in dune structures. The silt-sized particles are aggregates of clay units. The Triassic deserts could have provided a depositional environment very similar to that in Pleistocene Australia. Parna behaves in many ways like loess, has the classic, open, airfall structure, and also mantles the landscape.

The Mercia Mudstone is a heavily over-consolidated and partially indurated clay/mudrock. It has been credited with 'anomalous engineering behaviour' and 'unusual clay mineralogy' throughout. The former is usually attributed to aggregation of clay particles into silt-sized peds or clusters. The clay mineral composition is dominated by illite (typically 40-60%) with additional mica, chlorite, and corrensite (swelling, mixed layer, chlorite-smectite), with minor smectite, palygorskite and sepiolite.

Collapse and subsidence

L. J. Wills, who devoted much time to the study of the Triassic in England, appeared to suggest that mudrocks in the Nottingham-Leicester area were perhaps the most likely to be of a loessic nature (Wills, 1970). He pointed out that the 'loess' school of thought was initiated by Bosworth in his famous monograph for the Leicester Literary and Philosophical Society in 1913, although Bosworth does not actually say much about this idea.

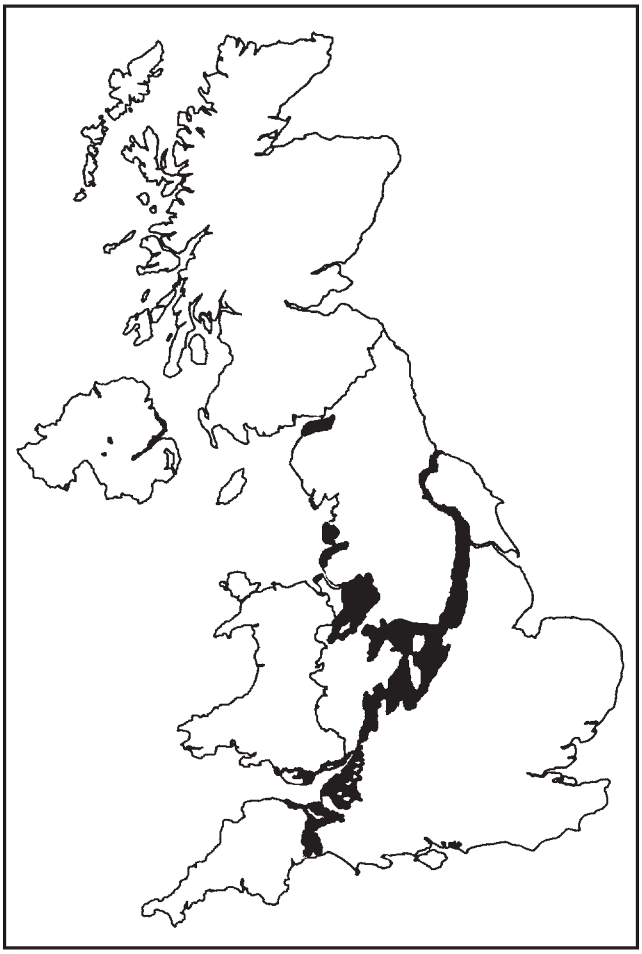


Figure 1. Outcrop of the Mercia Mudstone Group (after Hobbs et al, 1998).

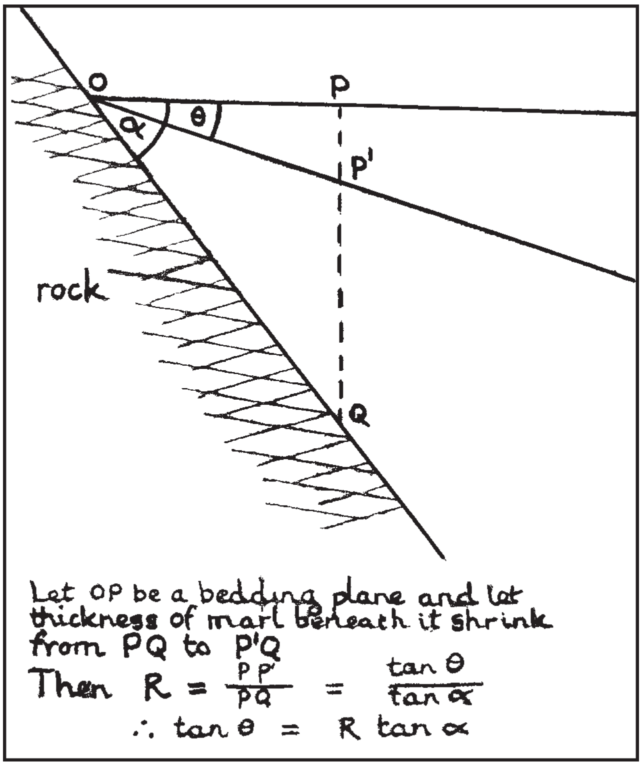


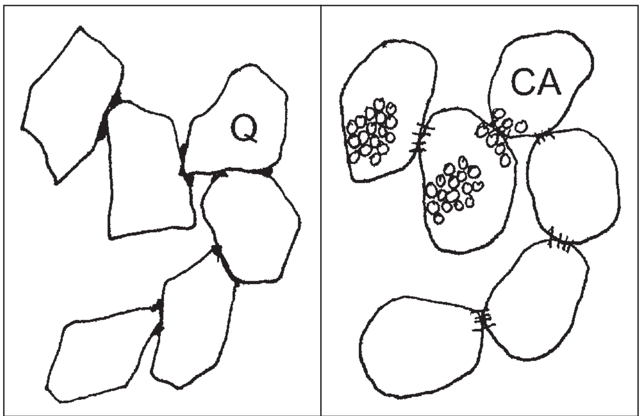
Figure 2. The original Figure 33 from Bosworth (1913) showing subsidence in the Mercia Mudstone; a rough diagram, but possibly one of key significance. Citing Bosworth - "thus taking $\alpha = 35^o$ and $\theta = 10^o$, values observed in several cases, we obtain R = 0.25".

In most parts of England and Wales the Mercia Mudstone has been subjected to only mild tectonic deformation. Dips are generally $<5^o$, except in the vicinity of faults, though steeper radial dips occur locally around the flanks of contemporaneous landmasses such as the Mendips. Examining this aspect, Bosworth showed how the mudstone subsided after deposition (Fig. 2). The Bosworth calculation showed a structural rearrangement followed by a collapse of about 25% - which compares reasonably well with the 15% subsidence observed when classic loess suffers from hydrocompaction.

The study of the mudstone collapse may throw some light on to the nature of the collapse mechanics in loess and loess-like materials. There is still a large amount of interest in the problem of hydrocollapse and subsidence in loess soils - in particular in the Russian language literature (Trofimov, 2001). The Russian investigators see the 'development of collapsibility' as a critical problem in the study of collapsing loess, and it is possible that collapse of parna and Mercia Mudstone may provide useful additional information for this debate. Loess collapse is influenced by the clay in the system (Rogers et al, 1994). In the parna/mudstone system, where the particles are all clay mineral material (despite their aggregated silt size), the particle contacts should all be mobilizable.

The 25% collapse may be an example of the ideal collapse in aeolian silty sediments. This is a significant observation and could prove to be the critical link between the two systems (Fig. 3). The all-clay particles may behave in an interestingly different manner from the quartz silt particles; they should certainly have different shapes. The quartz silt particles are remarkably flat (Assallay et al, 1998) but the parna/mudstone particles could be much rounder - as they accumulate, no breakage is involved. These could form more collapsible structures, giving >20% collapse, rather than the normal 15% in classic loess deposits.

The Mercia Mudstone is found to be 'water-softened' where its upper boundary acts as an aquiclude below sandstone or permeable fill. Here it can be expected to have a low strength and high deformability. The factors that cause water-softening in the lithified deposit could be similar to those that cause hydro-compaction in a recent loess deposit. In each case the effect of water at the particle contacts allows strains to develop; in the Mercia Mudstone this is seen as high deformability. In the loess there is also high deformability - which takes the form of structural collapse or hydro-compaction.



loess	parna Mercia Mudstone
open airfall structure e = 1; PD = 0.5 Q = angular comminuted quartz particles ~30 μm some clay #10%	open airfall structure e = 1; PD = 0.5 CA = clay aggregate particles ~30 μm
short range bonds modified by clay at contacts linear collapse 15%	initial short-range bonds transform quickly when wet linear collapse 25%
cold formation environment periglacial, glacial source	hot formation environment desert fringe, dry lakes salt lakes, clay dunes
Quaternary - loess	Quaternary - parna Triassic - Mercia Mudstone

Figure 3. Collapsing systems in metastable airfall structures compared - loess versus parna (and possibly Mercia Mudstone).

Loess and deserts

If loess is a deposit of wind-blown dust (silt), and if deserts are places where dust-storms are observed, it seems intuitive that deserts and loess go together. But the relationship is not as close as it may appear. Since Smalley & Vita-Finzi (1968) raised the issue, there has been the large problem of 'making the material'. There are no obvious sources, in dry sandy desert regions, of the silt-sized quartz particles that constitute most of the world's loess deposits. Sun (2002) is close to solving the 'desert loess' problem by showing that the great deserts to the north and west of the Chinese loess deposits act as 'holding-areas' or large silt reservoirs. These supply silt for the thick loess deposits, but are themselves supplied with silt material from the mountains of High Asia.

If there were an alternative method of forming silt-sized particles then desert sources might look more promising; the alternative would have to provide a way of avoiding the need for large geo-energies to fracture quartz particles to provide silt. A non-comminutive method of making silt might be to agglomerate clay-sized particles; these could then be moved by the wind and deposited as loess-like sediments. It appears that this is what happens in parna deposits (the study of which is rapidly developing) and it may have occurred in at least parts of the Mercia Mudstone. The Mercian occurrence is interesting and important because it offers an extra window on to a currently important problem in loess sedimentology.

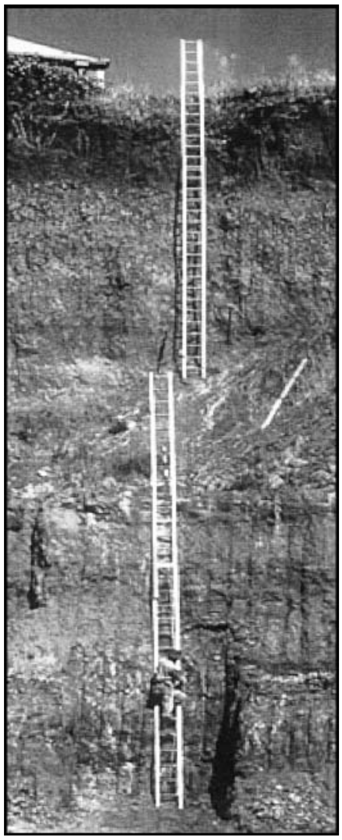


Figure 4. A classic exposure (now flooded) of parna in the Pioneer Pit in the Murrumbidgee floodplain 340 km east of Balranald. The 2 m of pale soil with blocky jointing just below the dark top layer is the Wills Parna.

Parna

We know relatively little about parna (Fig.4) - it is a late-comer among the loess-like materials. It is an aeolian loessic clay, named by Butler (1956) in Australia, and it has little local geotechnical significance. A recent study (Chen, 1997) of parna near Wagga Wagga (in S.E. New South Wales) has described the Quaternary sedimentation, landforms and soils of the region, and a large step forward has been made by the publication of a superb and timely review (which provoked this Mercian correlation) by McTainsh and Hesse (2001). These authors want to call their material 'loess', claiming that confusions over terminology have prevented Australian investigators from playing a significant role in international loess science, and the desert loess debate.

The sedimentary environment in southeastern Australia over a period of around 17000-15000 BP could have been very similar to that in parts of England during the Triassic. The Wills map (1970) of the dried-out phases of the German and English Neotrias shows salt lakes and 'loessic' regions (Fig. 5). The Bowler map (1975) shows the parna environment in part of Australia, with salt lakes and parna dunes (Fig. 6). The unconsolidated sediments of the Riverina Plain of New South Wales and northern Victoria are dominated by fluvial deposits, but interspersed through the materials, and spread extensively across the plain, Butler recognized an aeolian clay - parna. These parna deposits occur either as discrete dunes (dune parna) or as thin, discontinuous but widespread sheets (sheet parna). The principal feature of both forms is their origin as aeolian clays transported not as separate clay-sized particles but as stable clay aggregates or pellets. Dare-Edwards (1983) proposed three mechanisms for the production of clay pellets:

- deflation of the aerated clay surface of a lake floor, swamp or dune corridor, following the evaporation and efflorescence of saline water,
- aeolian erosion of pre-existing soil surfaces,
- stripping of alluvial clays.

The production of aeolian clay dunes requires the seasonal filling of lakes and swamps by saline water followed by the evaporative drying of these water bodies. The Australians would like to call parna loess, and there is no doubt that there are striking similarities (Fig. 3).

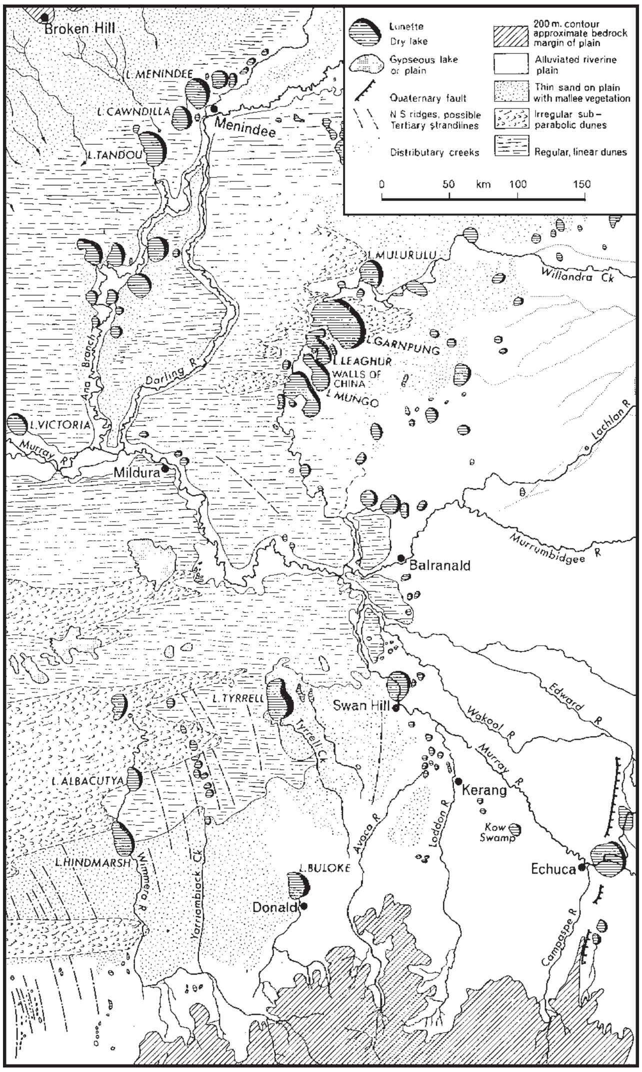


Figure 6. The landscape with aeolian loessic clays in western New South Wales and northern Victoria (from Bowler, 1975) - a possible model for parts of the Triassic in the English Midlands.

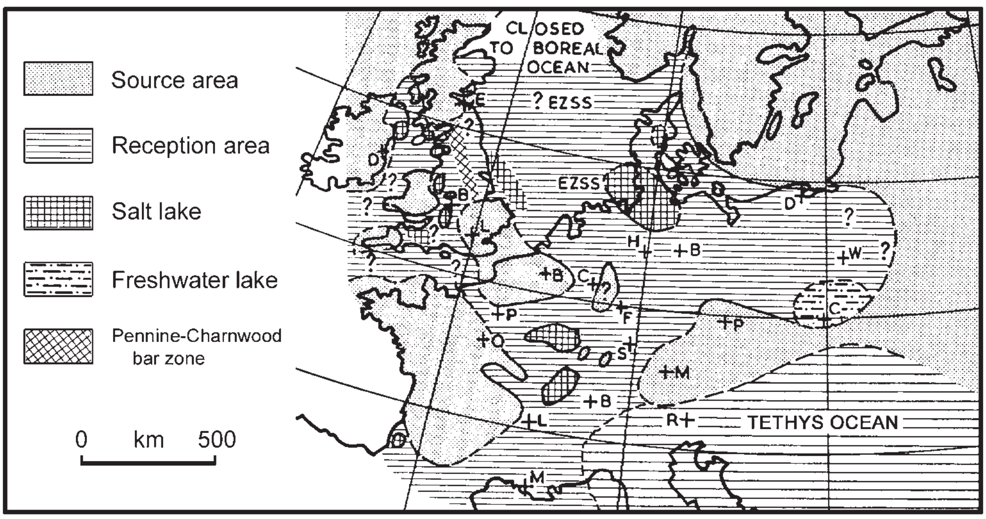


Figure 5. The Neotrias (Mercia/Keuper) in Europe (from Wills, 1970). Reception areas were described by Wills as shallow basins on the peneplain, which was largely dry and loess-covered.

Figure 7. Saltbush plains north of Balranald.

The scenario of a wind-swept, unstable landscape, in which lakes and rivers are drying up, vegetation cover is sparse, saline groundwater tables are high and episodic flash flooding occurs, corresponds with reconstructions of palaeo-environments proposed from the period 18,000 to 15,000 B.P., in southeastern Australia. It might also be viable for the English Midlands in the Triassic, and Figures 7 and 8 may therefore give some indication of the environments around Nottingham in the late Triassic.

Discussion

There is a precedent for comparing the Triassic English Midlands with Quaternary Australia. Talbot et al (1994), looking at problems of sedimentation in low-gradient desert-margin systems, compared the Late Triassic of northwest Somerset to the late Quaternary of east-central Australia. This comparison appears to be valid, and it allows examination of a sedimentary system that delivers silt-sized clay agglomerate particles. Bowler (1975) records the first appearance of clay pellets in aeolian sediments on the Walls of China (a lunette - a crescentic ridge of aeolian sediment on the lee-side of a salt lake - located on figure 6) at about 26 000 BP. The appearance of the clay pellets is related to a phase of increasing aridity and the drying out of the salt lakes in the landscape. The link between salt lakes and Mercia Mudstone is also shown on the Wills map (Fig 5).

Comparisons between Mercia Mudstone and parna are made somewhat difficult by the variation in lithology in the former. We can recognise, in the East Midlands, five main lithofacies in the Mercia Mudstone Group:

- Laminated silty mudstone - very finely laminated, with ripple marks, shrinkage cracks and planar lamination. Notably the Radcliffe Formation and parts of the Gunthorpe Formation. Definitely water deposited, possibly lacustrine.
- Deformed mudstone - as above, but with lamination highly disrupted by shrinkage cracks, soft sediment deformation, and growth and dissolution of evaporitic minerals, though traces of lamination remain. Common in the Gunthorpe and Edwalton Formations. Definitely water deposited.

Figure 8. Eroded remnants of a lunette, dated from about 65 000 BP, overlie lacustrine sediments on the margins of the Mungo salt lake.

- Thin beds of dolomitic or siliceous, fine sand or coarse silt, often occurring in units of several beds separated by mudstone partings - giving rise to the so-called 'skerries'. Abundant laminations, with ripples and slumped laminae. Common throughout the Gunthorpe and Edwalton Formations. Definitely water deposited, probably by flash floods.
- Fine sandstone, in beds up to 400mm thick, well laminated, interbedded with mudstone of the first two types, containing common mudstone rip-up clasts. The Sneinton Formation, Cotgrave Sandstone Member and Hollygate Sandstone Member (= Dane Hills Sandstone) fall into this category. Definitely water deposited, probably on distal alluvial plains with periodic floods.
- Structureless mudstone. Most of the upper 40m of the Mercia Mudstone Group (Cropwell Bishop Formation, above the Hollygate Sandstone, below the Blue Anchor Formation) is of this lithofacies, the best examples being associated with the more gypsiferous levels mined at East Leake and Barrow on Soar. There is another 5m of this facies at the top of the Gunthorpe Formation. It occurs in thin beds elsewhere in the Mercia Mudstone Group, but is minor compared to the other types. This seems to be the strongest candidate for a parna-type deposit; if our concept is going to work, this appears to be the material to be compared to the parna.

The original Bosworth proposal still has merit; the only change required is to replace loess with parna - then the fit appears to be reasonable. We need to know more about the lithology of parna before more exact comparisons can be made; the Mercia Mudstone has been studied for generations but the parna is new on the scientific scene.

The most interesting aspect of the Mercian material could be its capacity for subsidence. This is one of the defining parameters for loess and loess-like materials, the one that gives them their major geotechnical interest, and in this sense parna and classic loess behave in similar fashion. Bosworth's rough calculation yields a 25% linear collapse; the usually cited figure for loess collapse is 15%. There is a critical value of clay mineral content that allows a loess to collapse efficiently, and it appears to be about 20%. This 'small clay' system (Rogers et al, 1994) allows deformation at the particle contacts when the system is loaded and wetted, with the initial requirement being an open, metastable structure for the structure-forming primary mineral units. More effective compaction might occur in the Mercia Mudstone due to higher loads over longer times. The observation of structure collapse and subsidence is the best evidence that Mercia Mudstone initially had an open metastable structure, and the parna seems to be a likely analogue.

Acknowledgements

We thank the organisers and leaders of the INQUA Loess Commission Western Pacific Working Group field trip to S.E.Australia for demonstrating the realities of the Australian Quaternary and the possibilities of the English Triassic. We thank in particular Prof Jim Bowler of the University of Melbourne, and Dr David Gillieson for providing photographs. We thank the BGS for bibliographical assistance, and particularly Dr Andy Howard for guidance on the lithologies of the Mercia Mudstone.

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