PERIODS OF VENTIFACT FORMATION IN THE PERMO-TRIASSIC AND QUATERNARY OF THE NORTH EAST CHESHIRE BASIN

by

David B. Thompson and Peter Worsley

Summary

New discoveries of ventifacts are described and related to the local stratigraphy. Their genesis is considered in terms of evidence from modern examples, the facies in which they occur and provenance in relation to likely palaeogeographies. It is concluded that conditions favourable for wind faceting occurred at eight horizons within the sedimentary sequence and that ventifacts may well be forming in the area today.

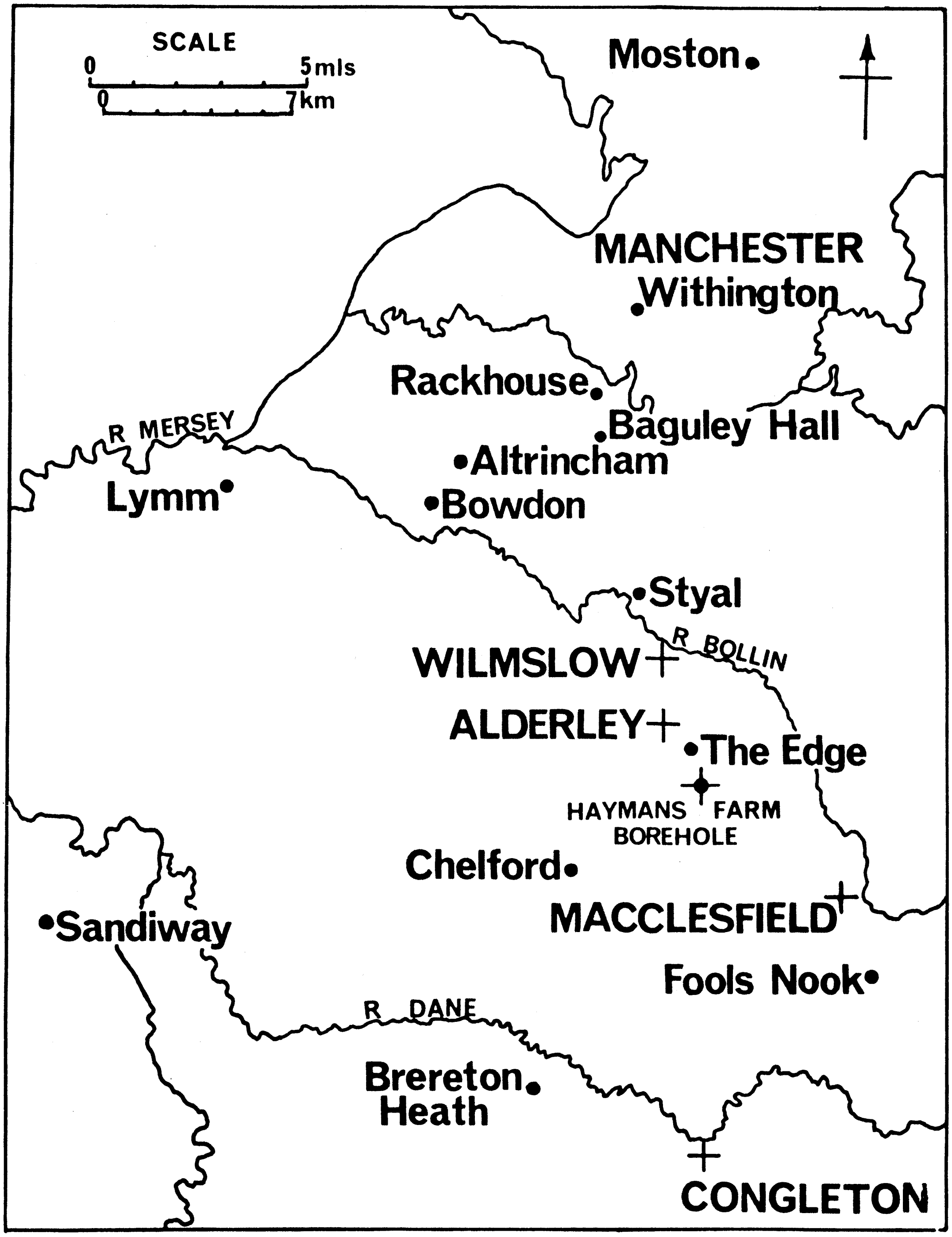
Introduction

In this paper the term ventifact will be used to describe any rock fragment of granule size or greater which shows signs of having been subject to wind erosion.

The first record of ventifacts in Britain appears to date from Bather's (1900) classic paper on "Wind worn pebbles from the British Isles". In an introduction he discussed a dreikanter which was found by workmen at Bowden near Altrincham. This was a liver-coloured quartzite, which probably originated in the Bunter Pebble Beds and was later re-deposited in glacial sands. During recent work on the Permo-Triassic and Quaternary rocks, many ventifacts have been discovered at eight geological horizons in the north-east Cheshire sequence. Those of the Permo-Triassic were found in the Lymm-Styal-Alderley-Mottram-Macclesfield (Fools Nook) areas, whereas those in the Quaternary are spread between north Manchester, Congleton, Delamere and Macclesfield (for the localities see Text-fig. 1). The ventifacts will be described and the palaeo-physical environment discussed in terms of the facies in which they occur.

No ventifacts have been reported previously from the Permo-Triassic of the area under consideration. In the Cheshire Basin as a whole, Pocock and Wray (1925, p. 23) found wind-etched stones in the south of the basin at Lee Brockhurst in the basal pebbly sandstones of the Bunter Pebble Beds; and Lomas (1906, p. 575) noted dreikanter in the Lower Keuper Sandstone without specifying where or at what horizon they occurred.

Elsewhere New Red Sandstone records are more common. Finds in the lower parts include: large types in the Teignmouth Breccias and miniature types in the Dawlish Sandstone of the Devon Basin



Text-Fig. 1. Location map of the major ventifact localities.

(Laming 1954): occurrence of large types in the St. Cyres Bed of the Crediton Valley (Hutchins 1963, p. 119), in Argyllshire (Pringle 1952) and in the Brodick Breccias of the Isle of Arran (? Upper Carboniferous to Permian: Gregory 1915, Tyrrell 1928). Occurrences in the silica pits of the Brassington area in the southern Peak District (Hughes 1952, Yorke 1961) were regarded as Triassic, and Kent (1957) suggested that some of the pebble beds are Bunter in age. Swinnerton (1914) and Elliott (1961, p. 214) mention the occurrence of ventifacts in the Nottingham and Dale Abbey areas at three horizons: (i) on top of the Bunter Pebble Beds, (ii) in the Lower Keuper Sandstone and (iii) in the Keuper Waterstones 'conglomerate'. Watts (1947, p. 111) records polished, glazed, ribbed and corded granite blocks at Nunkley, Charnwood. He regarded most as Keuper Marl in age, but Raw (1934) believed most, if not all, to be Pleistocene. Bosworth (1912, p. 45) found worn grooved pebbles in situ in the Keuper Marl at Croft and Mount Sorrel in Charnwood. (For a recent review of these localities see Ford 1967). L. J. Wills, (personal communication, 1966) reveals that the Lower Keuper Sandstone pebbles of the Midlands are frequently polished, a feature which he attributes to wind erosion, but he does not recall seeing a dreikanter.

Bather (1900), as previously noted, recorded the presence of a ventifact in the Quaternary sequence of the area. More prolific discoveries were reported by Jackson (1918) from the Pendleton area in north-west Manchester, where he found faceted erratic pebbles in the surficial layers of hummocky fluvio-glacial sands. Jackson concluded that the faceting was associated with the deposition of the Shirdley Hill sands in post-glacial times. Other localities yielding ventifacts were recorded from the same area and from the Wirral. Further material was described by Jackson and Jones (1926) in the south Manchester District, occurring as cobble pavements on till outcrops; on fluvio-glacial sands where they form the present day land surface; on the High or Didsbury Terrace of the River Mersey; and finally at the base of the Shirdley Hill sands. At Hale Head (SJ 472809) on the north bank of the Mersey Estuary, Owen (1948) noted the occurrence of ventifacts within a layer up to 0.3 m thick between sands and till. He concluded that the ventifacts formed a blasted pavement and attributed the super-position of the sands to aeolian deposition. The most recent finds are described in the Stockport and Knutsford district where Taylor et al. (1963) record faceted pebbles and wind etched stones which are widely spread over the low ground. In the British Isles generally, ventifacts of Quaternary age are known from several areas and the major accounts include those of Edwards (1936), Raw (1934), Swinnerton (1914), and Wills (1910).

Occurrences

Permo-Triassic

Trotter (in Taylor et al. 1963) showed that the succession in the Alderley area revealed a three-fold development of a coarse pebbly sandstone or conglomeratic facies; this has been confirmed by recent mapping and by the logging of the Hayman's Farm Borehole (SJ 857763). This tripartite succession can now be recognized in the adjacent Kirkleyditch area 2 km to the east and in the isolated Styal area 7 km to the north west (Thompson 1966). Between the three conglomerates are sandstones, similar to the underlying Bunter Upper Mottled Sandstone, which lack mica and often bear millet seed grains in lenses, as single grains in finer sandstone, or, in the case of sandstones within the Lower Keuper Sandstone at West Mine, Alderley, as whole sets or co-sets of cross strata.

The ventifacts occur at 2 major horizons:

(i) In the Bunter Upper Mottled Sandstone. Faceted sand grains and granules were found in a 10 cm. band of red brown, very argillaceous sand and grit, interbedded with finer sediments, at the base of the eastern side of the central ridge in the Alderley Red Moulding Sand Quarry (SJ 862783), possibly 70-100 m below the top of the formation.

(ii) In the Lower Keuper Sandstone. The ventifacts formed a small proportion of the pebble content of each conglomerate or pebbly sandstone horizon. They were recorded at the following places in the Mottram-Alderley-Styal area:

a) Top Conglomerate. Pottbrook (SJ 874775): Brynlow (SJ 855772): to the east of Mottram House (SJ 860767): Quarrybank House Quarry (SJ 835831): behind and within Quarrybank Engineering Works (SJ 834829).

b) Middle Conglomerate. Church Quarry (SJ 858773): in the plantation of Finlow Hill (SJ 862768): in Worms Hill Quarry (SJ 833825).

c) Basal Conglomerate. Kirkleyditch Quarry (SJ 874784): Clockhouse Wood (SJ 866780): Engine Vein (SJ 861774): Doc Mine (SJ 861778): Stormy Point (SJ 861778): Holy Well (SJ 868778): Glaze Hill (SJ 860779): Saddlebole (SJ 860781): Castle Rocks (SJ 856779): Wizards Well (SJ 854780): Swiss Cottage (SJ 850782): Willow Ground Wood (SJ 836824).

They have also been found in rock forming the face of the waterfall alongside Sow Brook, north of the Bridgewater Canal, Lymm (SJ 682874) and in the sandstones by the Red Rock Fault at Fools Nook, south of Macclesfield (SJ 921694).

The ventifacts of the Lower Keuper Sandstones occur in the following facies or sub-facies:

a) Mostly in the pebbly sandstones which occur in large-scale, cyclically grouped co-sets of lenticular planar and, rarely, trough cross-strata which are well displayed at Stormy Point, Alderley, or Worms Hill, Styal.

b) In the coarse, unbedded conglomerates which are occasionally found at the base of some cycles e.g. in Kirkleyditch Quarry (SJ 874784) and immediately to the north of Pillar Mine (SJ 861778).

c) Below Castle Rocks, Alderley (SJ 856779), a few specimens were found in the top of a rubbly 'marl' band.

d) At Lymm the pebbles were all found lying on and within the top 2.5 cm of a large set of cross strata; they seemed to be associated with the erosion surface at the top of this set.

Quaternary

Boulton & Worsley (1965) have proposed an interpretation of the Quaternary succession which distinguishes, as its basal unit above bedrock, a sequence of alluvial deposits comprising the Chelford Sands Formation. This formation consists essentially of flat-bedded sands with low angle cross-stratification and the occasional development of large scale trough cross-beds. Natural exposures are rare, but excellent sections are available in the several working quarries (see Text-fig. 1). In one locality, the Farm Wood Quarry (SJ 810730), an intraformational organic horizon outcrops approximately in the middle of the local succession and has yielded pollen and a radiocarbon date of 60,800 ± 1500 yrs. B.P. (GrN - 1480) suggesting a Pleniglacial A age. Lying upon the Chelford Sands with varying degrees of angular unconformity is a complex series of glacial deposits consisting mainly of a shelly red brown till and fluvio-glacial sands. This series exhibits large areas of depositional topography. Partly as a result of a radio carbon assay on derived marine shells yielding an age of 28,000 ± 1800, - 1500 yrs. B.P. (I - 1667) from within the fluvio-glacial sands, the series has been dated as Main Weichselian in age (Pleniglacial B). The name Stockport Formation has been proposed for these deposits (Worsley 1967). Since this Weichselian glacial sub-stage, the major westward-draining streams rising in the western Pennines have cut through the entire Weichselian succesion to become deeply incised into the Permo-Triassic strata. Along these water courses a suite of river terraces is developed, and in the north the highest River Mersey terrace is overlain by Shirdley Hill Sand.

Within the Quaternary succession ventifacts having been found at four distinct horizons:

Plate 8

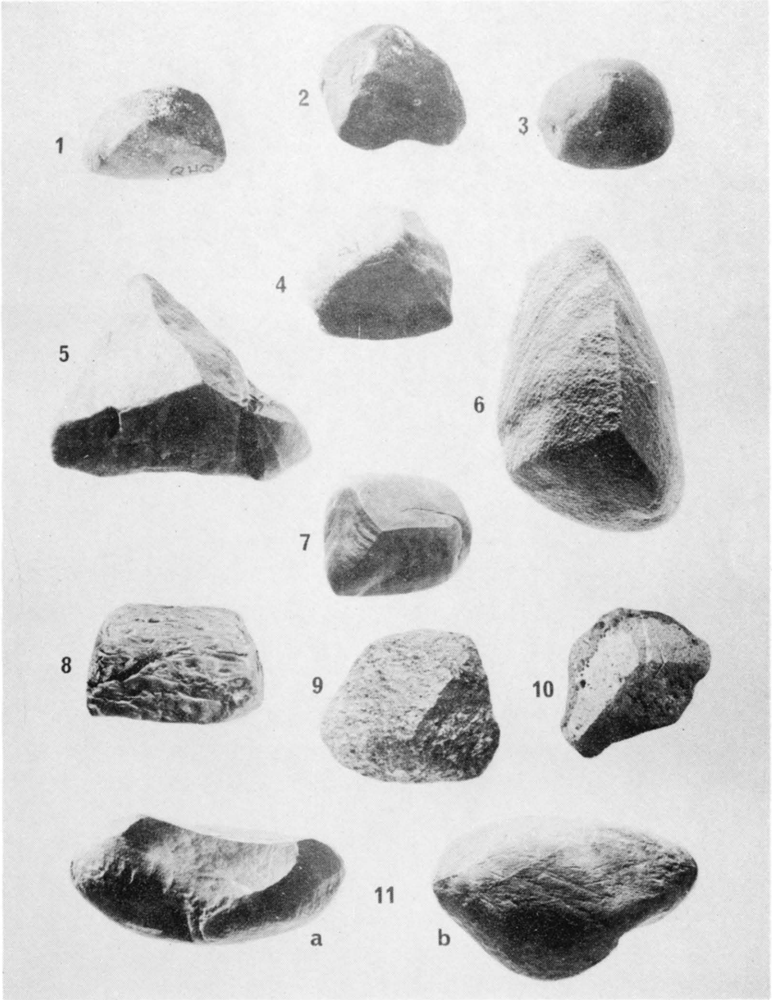


PLATE 8 PERMO-TRIASSIC AND QUATERNARY VENTIFACTS

Fig. 1.	from the Top Conglomerate, in Quarrybank House Quarry, Styal.
Fig. 2.	from the Basal Conglomerate at Styal.
Fig. 3.	from the Basal Conglomerate at Alderley Edge.
Fig. 4.	from the Middle Conglomerates in Church Quarry, Alderley.
Figs. 5, 6, 7 and 8.	from the Chelford Sands Formation, Brereton Heath Quarry. Fig. 5 shows the classical dreikanter form and the specimen in Fig. 8 bears pits of Stigmaria ficoides Brogniart which was probably derived from Namurian or Westphalian localities along the west Pennine Edge. The polished surface is evident from the reflected light.
Figs. 9, 10 and 11.	from the top of the Stockport Formation, Farm Wood Quarry, Chelford. Specimen 11a shows the faceted upper surfaces whilst 11b shows the glacially striated underside.

Specimens lodged in the collections at the Quaternary Research Unit, University of Reading.

(i) In the Chelford Sands Formation the ventifacts were found amongst the pebble and cobble-size material which generally occurs scattered randomly in predominantly flat-bedded sands and rarely as stringers or pockets. As far as could be determined the ventifacts were not restricted to any one horizon. Generally speaking, material greater than coarse sand size is uncommon in the Chelford Sands; in some localities it is difficult to gather enough of this grade of material to make a meaningful analysis of the macrolithological types. The most prolific locality is Brereton Heath (SJ 797652). In comparison with the other localities, ventifacts are relatively common at this site and occasionally concentrations of pebble size material may be seen at outcrop. The samples illustrated were collected by sieving sand through a No. 7 mesh sieve and by selecting specimens from the grading screens used in the commercial exploitation of the deposit. On average, a reasonably well developed ventifact would be discovered in every 300 pebbles examined, but true dreikanter are decidedly rare. Most of the larger material, however, showed one or more of the chacteristics of wind erosion, the most common being differential etching of the more, or less, resistant minerals. Because of a high groundwater table, no more than 3 m. of the formation may be examined at Brereton Heath. At the other three localities yielding ventifact material from the Chelford Sands, Sandy Lane Quarry, Hulme Walfield (SJ 855643), Taxmere Quarry, Arclid (SJ 778622), and Farm Wood Quarry, Chelford (SJ 810730), many hours search is necessary to produce a representative sample of the various types.

(ii) At the base of the Stockport Formation where the Chelford Sands are para-unconformably overlain by the till and fluvio-glacial sand members in the east face of the Farm Wood Quarry, Chelford, it appears likely that the interface is, or is near to, the original upper surface of the alluvial fan deposits. Along this surface occasional ventifacts may be found.

(iii) Within the basal poorly sorted outwash of the Stockport Formation, which exhibits a range of cross-stratification types including large scale trough and lenticular planar varieties. Very rarely ventifacts have been found within the basal metre of sediment.

(iv) On or just below the present day land surface. These ventifacts may be subdivided into 4 groups:-

(a) Those found on the upper surface of the Stockport Formation. Localities include Farm Wood Quarry, Chelford (SJ 810730); Sandiway Quarry, Cuddington near Northwich (SJ 615712); Moston Sand Quarry (SJ 878028); Alderley Edge east of Edge House (SJ 866775) and (SJ 878028); at the top of the river cliff north of Giants Castle Rocks, Styal (SJ 828835 and SJ 826836); Davenport Green (SJ 802868); and John Leigh Park, Altrincham (SJ 765883).

(b) Those within late and post glacial alluvial sands and gravels. These are found within the upper 1.5 m of pebbly sands comprising the Mersey High Terrace at Rachhouse, Wythenshawe (SJ 819906), at Withington Hospital (SJ 834925), and at Withington (SJ 842939); within pebbly sand mantling restricted areas of the north western flanks of Alderley Edge at (SJ 848779); in the lowest terrace of the River Dean near Wilmslow (SJ 843823); and on the present floodplain of Baguley Brook (e.g. at SJ 795904).

(c) Those on the Permo-Triassic where it breaks through the drift at Alderley Edge (SJ 855779).

(d) Those associated with a patch of blown sand at Baguley Hall, Wythenshawe (SJ 814888), thought to be correlative with the main Shirdley Hill Sand outcrop.

Description

Where faceted stones are found in present day lag gravels, it is possible to recognise a sequential development from incipient forms to fully faceted types. Distinguishing these types of pebble was difficult because in the Permo-Triassic, and to a much lesser extent in the Quaternary, they have suffered subsequent abrasion and attrition during fluvial transport and become mixed with river gravels. In addition a further complication arises from the fact that under sand blast action the cavity-bearing vein quartzes have their cavities extended rather than their faces developed, and a long abraded vein quartz pebble of this type tends to become more knobbly than faceted (cf. Swinnerton, 1914).

Our findings are in accord with the conclusions of other workers (cf. Sugden, 1964) who state that the classical dreikanter forms are relatively rare in a whole ventifact assemblage. For general descriptive purposes the ventifacts may be classified morphologically into six groups:-

(i) Einkanter - single smooth facets cut across sub-angular and rounded pebbles.

(ii) Zweikanter - generally ridge shaped stones with two opposing facets meeting along a sharp edge.

(iii) Dreikanter - stones with three facets meeting in a common angular apex.

(iv) Pyramidal - in cases showing more than three facets. On occasion a pebble appears to be a normal dreikanter but upon inspection of the under surface another set of three facets meeting in a point may be found. These are the "doppel dreikanter" of German authors.

(v) Triquetrous - brazil nut shaped with three facets meeting longitudinally at about 60°.

(vi) Irregular - incipient forms only slightly modified by wind action. This class probably embraces the 'eoliths' of Raw (1934).

Criteria by which the former action of wind erosion on a given specimen may be deduced fall into two categories. Firstly, where the wind has sand blasted essentially homogeneous lithological material such as orthoquartzites, it is usual to find one or more of the following:- (a) polish, (b) smooth surfaces with a greasy or waxy feel and (c) concave upwards facets. Secondly, with inhomogeneous material the differing resistance to blast action of the constituent minerals produces differential etching, fluted surfaces, grooves, pits and cuspate hollows. These two sub-groups are not, however, mutually exclusive, and many of the orthoquartzites, for instance, are differentially eroded along the bedding.

To describe all the material found which is considered to bear evidence of sand blast would naturally be impractical. Basically the ventifact assemblages under discussion fall into three stratigraphic groups:- (i) the Permo-Triassic, (ii) the Quaternary Chelford Sands and (iii) post-Chelford Sands. Whilst it is considered that all the ventifacts were essentially produced by the same processes, their present morphological differences must reflect, in part at least, differing post-formational histories and constituent lithological types.

1. Permo-Triassic

Bunter Upper Mottled Sandstone. The grains and granules, generally 1.5 - 3 mm in size, are well polished, exceedingly smooth and possess distinct but rounded edges. They are set amidst grains of similar size which have a high degree of roundness and sphericity and are equally smooth and polished. The horizon is interbedded with strata which show small-scale cross-bedding, rhythmically interbedded fine sandstone and mudstone laminae, asymmetric ripple marks and repeated wavy bedding.

Lower Keuper Sandstone. The identification of certain, probable and possible types was made whilst pebble counts were being made upon 6,000 pebbles. Since normal well-rounded pebbles were the rule, abnormal types were easier to pick out by comparison at that time (see Table 1 for average figures for roundness and sphericity of random pebble samples, which on occasion included ventifacts).

The ventifacts are all rolled; their edges are rounded, their surfaces probably less smooth than originally. Weakness inherent in the structure of the pebbles, for example along former bedding, is sometimes picked out. Allowing for uncertainties in the identification of rolled specimens, Table 1 sets out some of their characteristics and gives a rough idea of the occurrence of various types.

The suggested percentage of faceted types within the ventifact assemblage is undoubtedly high when compared with present day analogues (cf. Sugden, 1964), but this is not unreasonable since irregular types of ventifacts would be less easily identified in a well-rolled assemblage. Most frequent types are of two or three facets: four facets are less common, more than four very rare. Few specimens show any perfection of faceting which would indicate long periods of abrasion; most show an uneven, subdued but knobbly surface, which is an indication of the onset of abrasion rather than its prolonged effect.

The vein quartz pebbles are all very knobbly, with extended former drusy cavities whose interiors are often as smooth as their exteriors. The quartz-feldspar and feldspar porphyries bear cavities where decomposed feldspar phenocrysts have been most readily attacked. Quartzites possess the best facets. One quartzite specimen (Plate 8 No. 3) was almost conical, and this may be the result of rotation of the specimen at the site of abrasion. Upon analysis there was little detectable difference between the proportions of ventifacts developed amongst the vein quartz, quartzite, and other groups.

Comparison of the lithology of the Keuper quartzite pebbles with those of the Wills' Collection of Bunter Pebble Bed pebbles held at Birmingham University (cf. Thomson, 1953) reveals close similarities (Thompson, 1966); and it is likely that the pebbles of the Lower Keuper Sandstone were either derived from similar sources or were reworked from the Bunter Pebble Bed Formation, probably the latter, as first suggested by Hull (1864, p. 67).

II. Chelford Sands

These ventifacts are almost wholly developed from fine and medium grained sandstones and orthoquartzites, and all save the very rare coarse grained igneous erratics display polished surfaces to varying degrees of perfection. Naturally the fine grained lithologies are more susceptible to this action; it is particularly well developed on the orthoquartzites, flints and cherts. Most ventifacts show the effects of sand abrasion on all faces. The pebbles generally appear to have been originally rounded and in some instances part of the original curvature may be retained between the facets fashioned by sand blast. In these instances the ventifacts usually have an overall tabular shape. Bedding planes which would otherwise be indistinct are etched out and often show convincingly the discordance of the facets and the stratification. Upon close inspection many of the cobbles reveal incipient fractures; and these are no doubt related to the occasional occurrence of pebble faces which have fresh fracture surfaces. In one instance the matrix of a conglomeratic cobble was seen to be more resistant than the entombed pebbles.

III. Post-Chelford Sands

These ventifacts are fashioned from a wide range of erratic lithological types, as might be expected of material derived from a glacial deposit. Representatives of all the morphological classes have been found but the irregular types are overwhelmingly predominant; most appear to be incipient forms without facets, displaying differential etching of the constituent minerals and bedding surfaces. Occasional true dreikanter are found, together with polyfaceted types. One large cobble showed concave facets, the only example in the entire ventifact assemblage examined. Sometimes, on material collected from the surface of the till or fluvio-glacial outwash, striations may be detected on the underside. Generally ventifacts found on the surface of these latter two lithologies have the best developed facets. Where vein quartz pebbles occur, they invariably have a knobbly shape with extended cavities.

INTERPRETATION AND DISCUSSION

A. Environmental interpretation of the facies in which the ventifacts occur

The origin of the Permo-Triassic ventifacts is clearly predepositional, since in every case they are scattered in the mass of the pebbly sandstone and do not occur in lenses or pockets such as are normally associated with lag or reg gravels of a subaerial surface. Where they do occur in the lag or race facies, the pebbles are found scatterd or overturned and their edges rounded. The environmental interpretation of these facies and sub-facies can only be given here in summary form.

Bunter Upper Mottled Sandstone. The association of the miniature ventifacts with asymmetric ripple marks, repeated wavy bedding and mudstone laminae suggests that these strata are waterlaid, but it is not yet clear whether the associated large scale cross-bedded strata of this formation are aqueous or aeolian. The angular nature of the grains suggests that they were subject to physical fracture, probably by insolation changes. Normally faceting does not occur where the size grade is less than 9 mm, but some observers e.g. Laming (1954, pp. 61, 114) and Higgins (1956, pp. 508, 518) note small wind faceted and polished granules down to 2 mm. The present finds are similar to these. Higgins gives cogent reasons for believing that such quartz fragments, little larger than sand grains but possessing sharp edges, could not be formed by the uniform undeviating attack of saltating sand grains and hence could only be abraded by the smaller tools carried in suspension. It is therefore considered that these grains lay upon a bare subaerial surface, that they were etched and polished by fine sediment carried in suspension, picked up by a floodwater current, carried as bed load and deposited in local basins. The deposits probably represent a marginal floodbasin or swale fill environment, or if a dominantly aeolian environment is eventually demonstrated, a local but restricted shallow lake in a desert area such as those described by Sugden (1964, p. 67).

Lower Keuper Sandstone. All four facies are associated with red bed cycles which Allen (1965 a) has shown to be typical of alluvial sedimentation. Further details are to be found in Thompson (1966). The strata of facies (a) (see page 282) may be referred to former migrating megaripples, channel bars and point bars of low sinuosity streams; those of facies (b) to traction clog, race or channel lag facies. Facies (c) is more difficult to interpret, but it is believed to develop where the laminated argillites of an upstream or downstream cut-off channel (Doeglas, 1962) represented by the underlying and adjacent marl are channeled by floodwater, and channel edge gravels intermingle with clay galls, mudballs and armoured mudballs.
The deposit at Lymm, facies (d), would develop where a scouring current was able to erode the top of a cross-bedded set, but was of insufficient strength to carry off included pebbles which therefore accumulated as a weakly developed lag deposit.

The presence of ventifacts in all three conglomerate horizons implies that their source of production and/or supply remained open for a period during which 120 m. of strata were deposited.

The ventifacts from the Quaternary sequence may be assigned to both pre-depositional and syndepositional wind erosion régimes according to the horizon at which they occur. Usually, in the instances where ventifacts have been recovered from the present day land-surface, they have been disturbed by constructional or quarrying activity. Hence it is unlikely that these and the intraformational finds within fluvial facies are in situ. Unfortunately this fact makes a consideration of wind direction data derived from facet orientation invalid.

The Chelford Sands facies is interpreted as being basically a flash-flood deposit with attendant brief intervals of fluvial transport in the higher flow régime, periodically reworking surficial clastic debris and incorporating this material with newly supplied detritus. It is possible that the sedimentation was on a gently sloping sub-aerial fan surface. Between the flood episodes, the fan surface may have been scantily vegetated, and the presence of abundant intraformational ice wedge pseudomorphs within the alluvial sediments would support the inference that the climatic environment was cold and semi-arid (Worsley, 1966). It is hoped to discuss the geology of the formation more fully on another occasion and this must necessarily be a summary statement.

The relatively poorly sorted fluvio-glacial outwash sands are of two facies. The first is likely to have been deposited in a sandur environment consisting of braided stream systems. A facies model for this type of fluvial environment has recently been devised by Allen (1965 b), in which bed load deposition is dominant because the streams constantly migrate laterally. Large scale cross-bedding and plane beds predominate, though small scale types are not excluded since low stage channel infills may be preserved. The model accords with the sedimentary data found in the outwash sands. The second facies consists of sands deposited in intimate association with the ice, mainly in a sub-marginal environment. Significantly this facies has not yet yielded any ventifacts; this is to be expected, since they are unlikely to form in sub-glacial conditions.

The sediments comprising the High Terrace are mainly sands with gravel stringers. Like the outwash, it is considered that the fluvial environment was of a braided pattern, but in this instance it was probably confined to a definite floodplain. In such conditions pebbly material could be stranded on alluvial islands or channel bars for a period long enough for it to be modified by sand blast.

B. Origin of facets

Unpolished faceted boulders can be formed by abrasion of pebbles by water transported sand (Kuenen 1947), whereas most polished types are thought to be the result of pebbles being cut by the action of wind-powered sand grain abrasion tools. Heim (1888) suggested that the dominant wind direction controlled the nature and number of facets that developed and that each facet was cut perpendicular to the wind, whilst Kuenen (1928) showed that the final shape depended on the form of the face on which the pebble lay. Shoewe (1932) indicated that facets could form by regular as well as irregular blast.

Many opinions have been expressed concerning the rate of production of facets. Much depends on the size and lithological organisation of the stones, the extent to which they are fractures, the strength and direction of the wind and the availability of coarse, abrasive sand. Kuenen (1960) showed experimentally that with a constant velocity wind, increase of the sand size reduced the period necessary to produce any surface. He deduced that any given abrasive sand size would produce facets more slowly inland than at coastal sites, since frequency of storm winds was lower there. He concluded that where dry coarse or very coarse sand was available, faceted stones could be produced in a few weeks provided that storm wind were developed in dry periods. It has been argued elsewhere (cf. Wills 1950) that considerable dry periods are likely to have prevailed in the area in the two periods under discussion. It is likely on general environmental grounds that during the Permo-Triassic there were periods of severe atmospheric convection in which violent dust storms would be expected.

On the other hand, it is perhaps pertinent to note that Hobbs (1918) and Sugden (1964), both deriving their evidence from the Middle East, concluded that fracturing is the dominant process in facet formation. Hobbs maintained that the fractures are entirely thermally induced. Sugden did not deny the validity of this process, but considered that the diurnal effect of expansion and contraction exploited previously existing planes of weakness such as bedding and cleavage planes in the pebble material. The major source of fracture, however, was thought to be associated with cracks inherited from collision impact at some stage in the previous history of the pebbles. The thermal agency than caused the fracture and splitting; the new surfaces so produced were then trimmed by sand scour into facets analgous morphologically with those formed solely by attrition. Such a mode of origin for the Cheshire examples must obviously be considered. Indeed

Jackson, writing as early as 1918 (p. 28), concluded that although the Pendleton and other local ventifacts exhibit evidence of sand blast either in the form of polish or erosion, there was little evidence that any large face had been produced solely by wind and sand erosion.

C. Environments of modern ventifact formation

In general, faceted stones suggest considerable periods when pebbly deposits were exposed to abrasion by sand tools. Many writers seem to have accepted that wind-worn pebbles imply desert or at least steppe conditions and they proceed to draw palaeo-climatic and geological inferences.

As long ago as 1900, however, Bather was able to state (p. 411), "Faceted and wind-polished pebbles have been found over almost all parts of the present surface of the earth, under tropical, temperate and Arctic climates, on plains, on hills, or in valleys, scattered over steppes and deserts, or confined to small clearings in the midst of fertile fields and evergreen forests".

Quite recently for example Hickox (1959) has shown how faceted ventifacts have been cut in less than 10 years on quartzites, vein quartz pebbles and indurated sandstones in the moist temperate climate of Maine in the north eastern United States, where the average rainfall is 104 cm per annum. It is apparent, therefore, that the palaeo-climatic inference from ventifact occurrences must be treated cautiously, and need not necessarily imply arid or proglacial environments as has generally been thought. Hence it can be said that wind eroded stones merely denote:-

(a) an unvegetated land exposed to winds of moderate strength.

(b) a surface strewn with boulders and pebbles.

(c) associated dry transportable sand.

(d) (probably) a mechanism which provides for fracturing of pebbles e.g. riving or rapid insolation changes.

D. The provenance of the ventifacts

Bunter Upper Mottled Sandstone. A local origin has been argued previously.

Lower Keuper Sandstone. Four hypotheses of the provenance and origin of the ventifacts seem possible:

1. A reworking of ventifacts of previous age or origin e.g. from the Bunter Pebble Beds or earlier formations.
2. A reworking into the Keuper of Bunter pebbles faceted in suitable areas in immediately post-Bunter Pebble Bed times i.e. possibly in the period represented elsewhere by the Upper Mottled Sandstone.
3. The formation of the ventifacts during Keuper times in far off regions where suitable Bunter Pebble Bed outcrops were exposed and the transport of these pebbles northwards.
4. The formation of faceted pebbles in depositional environments not far from the place of deposition in Keuper times.

Hypothesis 1. Assiduous search amongst the Bunter Pebble Bed outcrops has revealed only one instance of the presence of non-faceted ventifacts (Pocock & Wray 1925, p. 23). This is surprising in view of the environmental origin proposed by Wills (1950, 1956) and Thomson (1953). We exclude here the occurrences in the Silica Pits of Derbyshire (Hughes, 1952; Yorke, 1961) whose ages are highly debatable. Kirkaldy (personal communication, 1966) is not sure of the authenticity of the dreikanter in the Bunter Pebble Beds which he notes in his joint textbook (Wells and Kirkaldy 1959, p. 224-5). We are left, therefore, with dreikanter, the few ventifacts of Pocock and Wray, and Beasley's belief (1905, p. 87) that the extremely fine polish of the pebbles of the Bunter Pebble Beds of Cannock Chase was due to erosion by sand laden wind after the pebbles had been rolled along stream beds. The Keuper ventifacts are not likely to be explained by this hypothesis.

Hypothesis 2. Production of faceted pebbles from previously deposited beds undergoing erosion is not uncommon (Heim 1888, Bather 1900, Hickox 1959, Sugden 1964). Dreikanter up to 20 cm across have been found in pockets and lenses (80 cm. thick) at the top of the Bunter Pebble Beds of Nottinghamshire and Dale Abbey (Swinnerton, 1914, p. 209). The beds were sand free and were interpreted by Swinnerton as lag gravels lying on a bare surface swept by winds. Unfortunately the true age of the Nottinghamshire Bunter Pebble Bed is in doubt (Wills, 1950); and Elliott (1961, p. 212) believes that the faceting in the Nottingha area is at least Keuper in age.

Wills (1950, p. 80-1) notes that the Upper Mottled Sandstone is not present above the Bunter Pebble Beds in the country between Stafford and Lichfield. He is not sure "whether this apparent absence is due to the two rocks becoming indistinguishable or to non-depostion or to deposition followed by uplift and erosion... ... If this last is the case the upward movement must have been very uniform since there is no appreciable difference in dip between the Keuper Sandstone and the Pebble Beds" (p. 81). Powell (1956, p. 27) argues that the Upper Mottled Sandstone was not widely deposited between Burton and Birmingham and that the Bunter Pebble Beds and the Lower Mottled Sandstone had undergone uplift and were being reworked by both rivers and an easterly wind. The eroded products were said to be carried into the water of a cuvette to give the Upper Mottled Sandstone of the present outcrops. Here is at least one time, place and opportunity for the faceted pebbles of Nottinghamshire and Cheshire to form. Since no faceted pebbles have been reported at the top of the Bunter Pebble Beds in this Midlands area, they would have to be totally borne away before the onset of the Keuper period.

It is possible that Bunter Pebble Beds laid down on the southern fringes of the Pennines (of Kent 1957, p. 6) would be reworked at this post-Bunter Pebble Bed, pre-Keuper Sandstone time, and indeed Hughes (1952) has recorded dreikanter from sands in the silica pits of the Brassington area whose surrounding heavy mineral grains were said to be Bunter type. The age of these latter deposits is controversial, but some of them at least have been claimed as true Permo-Triassic (e.g. Fearnsides, 1932; Hughes, 1952; and Kent 1957). Others regard them as Tertiary or Pleistocene (e.g. Clayton, 1953); and Shotton has reported that there are Plio-Pleistocene spores and pollen grains in their upper part. Even if the latter were the age of the deposit, the Permo-Triassic would have had to lie near or over the area if undoubted Bunter pebbles were to be brought to that area and incorporated in the deposits.

Hypothesis 3. It is argued by Wills (1950, 1956) that the origin of the Keuper conglomerate implies uplift in the Midlands and south; and that this would allow parts of the Bunter Pebble Beds to be exposed and available for erosion. Some of the places mentioned previously are, however, ruled out as possible source areas because they are covered by early transgressive pebbly Keuper Sandstone in which ventifacts have not been recorded. Marginal areas with exposed Bunter Pebble Bed outcrops, such as the southern Pennines, could have remained above the encroaching transgressive sedimentation for long enough to have contributed to these beds.

Elliott (1961, p. 212) believes that faceting in Nottinghamshire took place during the formation of the early Keuper beds. He argues that the Bunter Pebble Beds were first winnowed by shore currents, then subjected to faceting while they lay upon the planated beach surface before being finally submerged. He also records dreikanter in the base of the Waterstones Conglomerate some 5-13 m. above the former occurrence. This, too, implies that a source of dreikanter supply and/or production remained open through the period of the early Keuper. Elliott does not describe the dreikanter, but it is well to bear in mind that zweikanter can be produced by wet-blast in the type of beach environment which he envisages.

TABLE I

Data concerning ventifacts in the Permo-Trias of N.E. Cheshire.

STRATIGRAPHIC HORIZON AND LOCALITY	VENTIFACTS							Random sample of all pebbles n = 50 except where stated FIGURES ARE FOR THE 16-32 mm. STANDARD SIZE SAMPLE OF KRUMBEIN		Size of pebble sample
	Percentage of all pebbles		Percentage of all ventifacts							
	certain + probable	certain + probable + possible	faceted	no.of facets 2	3	4	4+	Sphericity	Roundness	
TOP CONGLOMERATE										
Alderley - Mottram House	0.0	1.0	33.0	0	100	0	0	.69	.56	300
Brynlow, Artists Lane	0.5	3.6	14.3	0	0	0	0	.69	.52	196
Styal - Quarrybank House Quarry	12.1	23.2	50.0	57	38	5	0	.73	.59	190
Quarrybank Mill Quarry	11.3	20.8	53.0	75	25	0	0	.70	(n=40) .56	53
MIDDLE CONGLOMERATE										
Finlows Wood Plantation (felled 1966)	0.25	1.45	0	0	0	0	0	.67	.61	409
BASAL CONGLOMERATE										
Alderley - Kirkleyditch	1.0	3.6	28.9	15	70	15	0	(a) .74 (b) .73	.68 .70	1245
Clockhouse Wood	7.0	14.3	41.5	18	76	6	0	.74	.66	286
Engine Vein Mine	3.2	6.1	36.0	33	56	11	0	.73	.68	413
Stormy Point	1.7	6.6	38.5	20	60	20	0	.75	.67	588
Castle Rocks	3.6	8.5	55.6	44	40	13	3	.74	.66	634
Styal - Willow Ground Wood	3.7	8.7	57.6	26	58	16	0	.73	.64	381
Lymm - Sow Brook	2.6	5.1	0	0	0	0	0	.64	(n=24) .56	39
Maer Hills Berry Hill (Staffs.)	0	1.9	0	0	0	0	0	.68	.61	161
HORIZON NOT IDENTIFIED										
Macclesfield Fools Nook	0.8	3.1	0	0	0	0	0	.63	(n=29) .46	131

Adherence to the second and third hypotheses would imply currents from the East Midlands and what is now the Southern Pennines, a suggestion not ruled out by the evidence of cross-stratification palaeocurrent data collected in Cheshire (Thompson, 1966), which accords with Wills general hypotheses (1950, 1956) and the evidence of the isotopic age dating of detrital micas (Fitch et al., 1967). The Rudyard Valley, first postulated for Bunter Pebble Bed times (Wills, 1956) could, if reactivated, possibly provide a through route for some of the material. A route which is more directly southerly seems unlikely, for the Geological Survey (1965) note that the Keuper Sandstone in the Stoke area lacks any pebbly devlopments which might be indicative of a major channel. Reconnaissance work by the writers at Berry Hill in the Maer Hills (SJ 790395) has revealed poorly bedded pebbly sandstones with huge intraformational blocks of Bunter Upper Mottled Sandstone and deep fluvial erosion channels which would seem to indicate the presence of strong fluvial agencies. This route is, however, rather far to the west to be of use in the present instance. A pebble sample yielded no certain or probable ventifacts.

Hypotheses two and three are particularly suited to the explanation of faceted stones at the base of the Keuper; they will also account for a continuance or increase in production and supply. In addition they support the view that the faceted stones of the Keuper Basal Conglomerate were formed under aeolian conditions represented by the uppermost relatively mica-free conditions of the Bunter Upper Mottled Sandstone, when aeolian influence is marked by abundant millet seed grains and the odd very large cross-bedded set which is probably part of a fossil dunefield (for example in Waterfall Wood, Alderley). On these hypotheses, the ventifacts in the Keuper Middle Conglomerates could be produced during Mottled Sandstone conditions in the general period represented by strata between Basal and Middle Conglomerates and seen at Beacon Lodge Alderley: those in the Keuper Top Conglomerates by the probably more severe aeolian influences in the period represented by the Mottled Sandstone strata between Middle and Top Conglomerates and seen at West Mine, Alderley. It seems no coincidence that the greater incidence of aeolian influence in these latter beds, typified by the greater abundance of millet seed grains, immediately precedes the period when the pebbles are least rounded and the greatest number of ventifacts is developed at Styal (see Table 1).

Hypothesis 4. This hypothesis envisages sand-laden wind acting upon pebbles lying on the surface of river beds during periods of aridity. These periods would presumably have to be quite short, since drifting sand could quickly cover a low-lying river bed.

The fairly high percentages of ventifacts in the Top Conglomerate at Styal might indeed suggest that the ventifacts were developed along a river course, presumably an abandoned channel, during an arid period. Allen (1965 b, pp. 161-3) has drawn attention to the great amount of aeolian redistribution of material which goes on along river courses after flood. If the period of aridity or abandonment was long and vegetation absent, any weaknesses in the pebbles could be opened by insolation changes (Jackson, 1918; Sugden, 1964) and blasted by wind armed with grit and sand from the bed of the channel. The signs of secondary breakage of clasts, together with the poor degree of rounding in the Top Conglomerate at Alderley and Styal (see Table 1), supports this view. The fact that there are few ventifacts developed in this material at Alderley but many at Styal could be explained by suitable raw material being quickly incorporated in a bed load in the first case, but being long exposed to abrasion and attrition to give ventifacts in the second.

Against such a theory of very local origin is the fact that all the edges of these ventifacts are much abraded by fluvial traction and their surfaces, though smooth, lack any sign of polish. This suggests that even if the ventifacts did originate within the stream channel in the manner described, they have travelled a considerable distance since that time.

In conclusion, the present writers believe that any conbination of the last three hypotheses would permit the necessary production and supply of ventifacts.

Chelford Sands Formation

These ventifacts are considered to be pre-depositional in origin. An analysis of percentage lithological composition, as revealed by random sampling of the particles greater than granule size taken from all available outcrops, demonstrates that two major local sources are possible for this material, namely the Carboniferous and the Permo-Triassic rocks, both of which outcrop to the east.

For examples at Brereton Heath the sample analysed (478 counts) gave :-

Carboniferous types	68.8 %
Permo-Triassic types	29.5 %
Others	1.7 %

The sum total of evidence, as stated previously, strongly supports the contention that the palaeo-environment of the Chelford Sands was one of low angle alluvial fans building out from the western flanks of the Pennines and coalescing into aprons. The greatest known thickness of these alluvial deposits is some 47 m. at Congleton and the likely duration of deposition is estimated as ranging from the end of the last or Eemian interglacial, circa 70,000 years B.P., to the arrival of the Main Weichselian ice circa 20,000 years B.P. Even allowing for periods of non-deposition when the supply of clastic material ceased and the organic Chelford Interstadial beds were accumulating, net fan accretion must have been slow, for no buried soils or major unconformities other than at Chelford have yet been detected with in the alluvial sequence. The physical conditions inferred from the facies interpretation are analogous with present day semi-arctic areas in which wind erosion is important where the vegetation is scarce. Thus the ventifacts are likely to have been fashioned during the considerable periods between the flooding; and the mechanism of pebble rotation could be sought in the floodwater medium. One might expect to find some true aeolian deposits within the sequence, but none has been recognised so far, perhaps because the periodic flooding and reworking destroyed any dunes which may have formed.

A possibility to be considered is that the Carboniferous and Perm-Triassic rocks may have supplied ready-fashioned ventifacts. A search of the literature and field experience has not produced any evidence of Carboniferous ventifact material in the west Pennine sequence. On the other hand, as has been demonstrated above, ventifacts do occur within the Permo-Triassic succession. In comparision with the Late Pleistocene material, it is readily seen that Permo-Triassic ventifacts are unlikely to have contributed to the former, for the Permo-Triassic ventifacts are invariably abraded, whilst those of Late Pleistocene age show much less evidence of fluvial abrasion subsequent to faceting, and hence are short travelled. In addition the ventifact material itself provides further confirmation of this argument, for the two ages of ventifacts have their own distinctive lithological compositions.

As noted previously, the relationship between the Chelford Sands Formation and Stockport Formation is one of unconformity. Occasionally, for instance at the Farm Wood Quarry, Chelford, ventifacts are found just above the actual line of contact between the formations. Chronologically the unconformity represents the time span of the Paudorf Interstadial dividing the Pleniglacial A cold arid period from the Pleniglacial B glacier advance into Cheshire. The ventifacts are most likely to have been formed at the onset or deterioration of the interstadial climatic amelioration. Rare ventifacts incorporated within the basal cross-stratified outwash are probably reworked, having been picked up from the surface of the unconformity.

Because the present day landsurface is a polygenetic feature composed of various ages of strata, it is not easy to date ventifacts lying on or within the soil profile immediately below it. The most prolific new source at this horizon occurs at the Farm Wood Quarry on the landsurface underlain by the Stockport Formation. These finds have been revealed by the removal of the soil horizons before excavation of the predominantly fluvio-glacial overburden. Their age cannot be precisely determined, but they are obviously of late-glacial or post-glacial origin.

One of the most interesting ventifact types (Plate 8 Fig. 11) was found after the above mentioned overburden removal process. This particular ventifact consists of a cobble of medium-grained orthoquartzite penetrated by thin quartz veins. As can be seen the upper and lower surfaces present contrasting forms. The lower or underside bears abundant evidence of striations suggesting that the cobble has been subject to a period of transport in an ice medium for the generally flat base and intersecting striations are diagnostic of glacier abrasion. There appears to be little doubt that the cobble was derived from the Stockport Formation, and it was then subjected to a period of sand blasting without overturning as this process has only affected the upper surface. A similar history could be deduced for a similar but smaller cobble found at Moston.

This was the only example found which displays such prominent concave facets. It is generally believed that facets are cut normal to the direction of wind transport and hence the wind (Heim 1888). As the cobble has two major facets, either it was subject to two major directions of sand supply or it was gently rotated by some agent around a vertical axis during the period of blasting without being rolled over. The restriction of faceting to the upper dome probably signifies that the lower half was buried in the sand to a depth of 3-4 cm. and thus protected. Sharp (1949) has stated that a stone wholly in the basal layer of saltating sand grains will be uniformly cut. Concave facets develop where the stone projects above this basal saltating sand traction carpet, but the reduced number of impacts by grains is supposed to be compensated by the higher velocity of bombardment. In the instance under consideration it is possible to estimate the original cobble surface shape with some degree of confidence and this leads to the inference that the original surface gradient cannot have been greatly in excess of 30 degrees. Since the experience of workers in desert environments is that the reduction of facets below 30 degrees is extremely slow, it is concluded that the cobble is likely to have been subject to blast for a very considerable period.

The new finds on the Mersey High Terrace substantiate the discoveries of Jackson and Jones (1926). It is likely that some of this material has been reworked. The High Terrace has been described as a fluvio-glacial gravel deposit by the Geological Survey (Taylor et al., 1963), and they have interpreted it as an aggradation deposit formed when the proto-Mersey flowed into glacially ponded water occupying the present Lower Mersey estuary. This glacial lake was considered by J.R. Earp to overflow through the Deva Spillway, a channel sited north west of Chester. Full details of this hypothesis are promised in the forthcoming Chester Memoir. O.T. Jones (1924) thought that the aggradation was largely climatically-controlled and associated with a pluvial period. This is not, however, the place to enter into a discussion of the High Terrace genesis.

It should be noted that the finds of Jackson and Jones (1926) are restricted to the upper parts of the High Terrace and none were found on the Middle or Lower Terraces. The occurrence at Wilmslow in the Dean Valley may, however, be interpreted stratigraphically as coming from the lowest or floodplain terrace deposit.

The Shirdley Hill Sand depositional episode would appear to post-date the Flandrian transgression. The perfection of the ventifacts found associated with the sands would suggest that, for a period, favourable conditions for their formation were maintained. It follows that this was likely to be a period when little vegetation was developed; however, the possibility does remain, as noted by Taylor et al. (1963), that any surface ventifacts could have been in the process of fromation in any period of post-glacial time up to and including the present day. F. M. Trotter (personal communication, 1965) has claimed that ventifacts are being formed at the present day on the surface of working sand quarries, and the evidence deduced by Hickox (1959) certainly supports this contention. L. J. Wills (personal communication, (1966) believes that they may still be forming in the Severn Valley.

Finally, indications of former wind erosion episodes may be derived by examining the morphology of the edges or cuestas which border the north east Cheshire area. Bedding which displays ropy or corded texture has long been noticed in the Pennines, where many of the Namurian grit outcrops have vertical faces of this nature. The same structure is found in the Keuper Basement Beds in rocks of similar grain size, at localities all around the Cheshire Basin. The features have been noted in the following horizons and areas:- Namurian: Kinderscout Grit on the Kinderscout Plateau: Lower Keuper Sandstone: at Alderley, Lymm, and along the westward facing escarpment of the Bickerton-Peckforton Hills. Wright (1964 p. 520) believed that "this irregular bedding can be classed as cross bedding if the term is considered in its broadest sense, but the significance and origin of this type of bedding will remain obscure until our techniques for its examination have improved, or until modern equivalents are described". The writers do not consider that these are sedimentary features, but rather that they are the results of aeolian weathering during late-glacial and possibly post-glacial times, the tools of abrasion being the locally derived grains of the mechanically weathered gritstones or conglomerates. Asymmetry and fluting of the outcrop can on occasions reveal the direction of the wind. One occurrence to the north west of Edale village to the north of Grindslow Knoll seems to indicate a wind from the north. The feature is not restricted to cross-bedding as Wright would seem to imply, but is seen also where flat bedding is involved.

We would stress that we do not envisage wind erosion as being a major agent in the fashioning of the edges and allied tor features, but rather an agency which has slightly modified the micromorphology.

Conclusions

A. Permo-Triassic

1. That aeolian influence was negligible during the deposition of Bunter Pebble Beds, presumably becuase the river courses were continually operative and did not dry out. This suggestion does not accord very well with present hypotheses of the environment of the formation. The single case of ventifacts present at the base of the formation (Pocock and Wray, 1925) must relate to an episode of aeolian influence and ventifact formation immediately after the interval between the Lower Mottled Sandstone and the base of the Pebble Bed formation. The former beds are known to be aeolian (cf. Shotton, 1937).

2. Insolation changes on a bare land surface caused cracking of small pebbles or granules in Upper Bunter Upper Mottled Sandstone times. These fragments were abraded and smoothed by wind, transported by water and deposited locally.

3. During late Upper Mottled Sandstone times, aeolian action was operative in a belt of positive uplift between Nottingham and Burton in the North, bounded by Sandon in the West, through Lichfield to a point just north of Birmingham, in the south, where Bunter Pebble Beds and Lower Mottled Sandstone were exposed. This was possibly the time when ventifacts were forming on the surface of the Bunter Pebble Beds.

4. Ventifacts were fashioned, or continued to be fashioned, in Lower Keuper Sandstone times on the top of Bunter Pebble Beds in Nottinghamshire and probably elsewhere (e.g. in north-east Staffordshire, in the Rudyard Valley); these were carried into north east Cheshire and are represented in the Keuper Basal Conglomerates.

In the same areas wind faceting continued during the two periods represented by the development of the Frodsham (Upper Mottled Sandstone) facies in the Alderley-Styal area, i.e. during the depostion of the sandstones seen at Beacon Lodge and West Mine, Alderley and Worms Hill, Styal. The ventifacts were supplied to the pebbly river sediments of the Middle and Top Conglomerate which immediately overlie these beds. The ventifacts may have developed along the river course in the last case.

B. Quaternary

1. In a predominantly arid cold tundra-type climatic environment during the Weichselian Pleniglacial A,

ventifacts were fashioned on alluvial surfaces between rare fluvial episodes. Some of the ventifacts attained a high degree of perfection.

2. After the cessation of alluvial deposition wind action was again operative. This may have occurred during some part of the Paudorf Interstadial, which preceeded the extension of the Main Weichselian Pleniglacial B outwash sandurs across the area from the north-west. The outwash streams eroded parts of the Chelford Sands and incorporated derived ventifacts.

3. Since the decay of the Weichselian ice, there has been a periodic recurrence of conditions favourable for ventifact cutting, and indeed the present environment may in some instances foster their formation. Only those found in the Shirdley Hill Sand can be dated with any confidence.

Acknowledgements

We wish to record our sincere thanks to the many landowners who permitted access to their property. One of us (P.W.) wishes acknowledge his gratitude to the Science Research Council for a maintenance award during part of the work. We are indebted to Professor T. G. Miller for a critical reading of the manuscript and to Professor L. J. Wills for valuable discussion. Mrs. Monika Wheeler and Mrs. Doreen Thompson kindly typed the manuscript.

Peter Worsley, B.A., F.G.S.,
Quaternary Research Unit,
Department of Geography,
The University,
Whiteknights Park,
Reading.

David B. Thompson, B.A., M.Sc., F.G.S.,
C/o Department of Geology,
The University,
Manchester 13.

References

ALLEN, J.R.L. 1965 a. Fining-upwards cycles in alluvial successions. Geol. J., vol. 4, pp. 229-46.

1965 b. A review of the origin and characteristics of recent alluvial sediments. Sedimentol., vol. 5. pp. 89 - 191.

BATHER, F.A. 1900. Wind worn pebbles in the British Isles. Proc. Geol. Ass. Lond., vol. 16, pp. 396-420.

BEASLEY, H.C. 1905. Some difficulties with regard to the formation of the Keuper Marls. Proc. Lpool. Geol. Soc., vol. 10, pp. 79-97.

BOSWORTH, T.O. 1912. The Keuper Marls around Charnwood Forest Leicester: W. Thornley & Son (For Leicester Lit. & Phil. Soc.) 127 pp.

BOULTON, G.S. and WORSLEY, P. 1965. Late Weichselian glaciation in the Cheshire-Shropshire Basin. Nature. Lond., vol. 207, pp. 704-6.

CLAYTON, K.M. 1954. The denudation chronology of part of the Middle Trent Basin. Trans. Inst. Brit. Geogr., vol. 19 (for 1953), pp. 25-36.

DOEGLAS, D.J. 1962. The structure of sedimentary deposits of braided rivers. Sedimentol., vol. 1, pp. 167-90.

EDWARDS, W. 1936. Pleistocene dreikanter in the Vale of York. Mem. Geol. Surv. Summ. Prog. for 1934. pt. 2, pp. 8-19.

ELLIOTT, R.E. 1961. The stratigraphy of the Keuper Series in southern Nottinghamshire. Proc. Yorks. Geol. Soc., vol. 33, pp. 197-234.

FEARNSIDES, W.G. 1932. The geology of the eastern part of the Peak District. Proc. Geol. Ass. Lond., vol. 43, pp. 152-91.

FITCH, F.J., MILLER, J.A. and THOMPSON, D.B. 1967. The palaeogeographic significance of isotopic age determinations on detrital micas from the Triassic of the Stockport-Macclesfield district, Cheshire. Palaeogeography, Palaeoclimatol., Palaeoecol., vol. 2, pp. 281-312.

FORD, T.D. 1967. Deep weathering, glaciation and tor formation in Charnwood Forest, Leicestershire. Mercian Geol., vol. 2, pp. 3-14.

GEOLOGICAL SURVEY. 1965. North-western district. Mem. Geol. Surv. Summ. Prog. (for 1964), p. 55.

GREGORY, J.W. 1915. The Permian and Triassic rocks of Arran. Trans. Geol. Soc. Glasg., vol. 15, pp. 174-87.

HEIM, A. 1888. Uber Kantergeschiebe aus dem norddeutschen Diluvium. Vierteljahresschr. Naturforsch. Zurich Ges., vol. 32. pp. 383-5.

HICKOX, C.F. 1959. Formation of ventifacts in a moist temperate climate. Bull. geol. Soc. Amer., vol. 70, pp. 1489-90.

HIGGINS, C.G. 1956. Formation of small ventifacts. J. Geol., vol. 64, pp. 506-16.

HOBBS, W.H. 1918. The peculiar weathering processes of desert regions with illustrations from Egypt and the Sudan. Rept. Mich. Acad. Sci., vol. 20, pp. 93-9.

HUGHES, E.M. 1952. The geology of an area north of Brassington. Unpublished M.Sc. thesis, University of Nottingham.

HULL, E. 1864. On the copper-bearing rocks of Alderley Edge. Geol. Mag., vol. 1, pp. 65-9.

HUTCHINS, P.F. 1963. The Lower New Red Sandstone of the Crediton Valley. Geol. Mag., vol. 100, pp. 107-28.

JACKSON, J.W. 1918. The association of facetted pebbles with glacial deposits. Mem. Proc. Manchr. Lit. Phil. Soc., vol. 62, No. 9, 15 p.

JACKSON, J.W. and JONES, O.T.
1926. Facetted pebbles in the south Manchester district. Mem. Proc. Manchr. Lit. & Phil. Soc., vol. 70, pp. 125-32.

JONES, O.T.
1924. The origin of the Manchester Plain. J. Manchr. Geogr. Soc., vol 39-40, pp. 89-123.

KENT, P.E.
1957. Triassic relics and the 1000 foot surface in the southern Pennines. East Midl. Geogr., vol 8, pp. 3-10.

KUENEN, Ph. H.
1928. Experiments on the formation of wind worn pebbles. Leid. Geol. Med., vol 3, pp. 17-38.

1947. Water-faceted boulders. Am. J. Sci., vol. 245, pp. 779-83.

1960. Experimental abrasion: 4. Eolian action. J. Geol., vol. 68, pp. 427-44.

LAMING, D.J.C.
1954. Sedimentary processes in the formation of the New Red Sandstone of south Devonshire. Unpublished Ph. D. thesis. University of London. 260 pp.

LOMAS, J.
1906. Discussion on the origin of the Trias (with T.G. Bonney, T.H. Holland and Grenville Cole). Rept. Brit. Ass. for 1906, pp. 574-6.

MANTLE, H.G.
1927. On a faceted quartzite pebble from a coal seam at Ashby-de-la-Zouch. Geol. Mag., vol. 64, pp. 123-4.

OWEN, D.E.
1948. Recent Merseyside sections; parts 4-8. Proc. Lpool. Geol. Soc., vol. 20, pp. 40-7.

PRINGLE, J.
1952. On the occurrence of Permian rocks in Islay and North Kintyre. Trans. Edin. Geol. Soc., vol. 14, pp. 297-301.

POCOCK, R.W. and WRAY, D.A.
1925. Geology of Wem. Mem. Geol. Surv. U.K. 125 p.

POWELL, K.
1956. The petrography of the Upper Bunter Sandstone of the English West Midlands. Unpublished M.Sc. thesis, University of Birmingham. 35 pp. and 14 pp. of appendices.

RAW, F.
1934. Triassic and Pleistocene surfaces on some Leicestershire igneous rocks. Geol. Mag. vol. 71, pp. 23-31.

SHARP, R.P.
1949. Pleistocene ventifacts east of the Big Horn Mountains, Wyoming. J. Geol., vol. 57, pp. 175-95.

SHOEWE, W. H.
1932. Experiments on the formation of wind-faceted pebbles. Am. J. Sci., vol. 24, pp. 111-34.

SHOTTON, F.W.
1937. The Lower Bunter Sandstone of North Worcestershire and East Salop. Geol. Mag., vol. 74, pp. 534-553.

SUGDEN, W.
1964. Origin of faceted pebbles in some recent desert sediments of southern Iraq. Sedimentol., vol. 3, pp. 65-74.

SWINNERTON, H.H. 1914. *Periods of dreikanter formation in south Notts.* Geol. Mag., Dec 6, vol. 1, pp. 208-11.

TAYLOR, B.J., PRICE, R.H. and TROTTER, F.M. 1963. *Geology of the country around Stockport and Knutsford.* Mem. geol. Surv. U.K. 183 p.

THOMPSON, D.B. 1966. *Some aspects of the stratigraphy and sedimentology of the New Red Sandstone of the N.E. of the Cheshire Basin, with special reference to the nature and origin of the Lower Keuper Sandstone Formation.* Unpublished M.Sc. thesis, University of Manchester. 350 pp.

THOMSON, W.M. 1953. *The origin of the Bunter Pebble Beds of the Midlands.* Unpublished M.Sc. thesis, University of Birmingham. 128 pp.

TYRELL, G.W. 1928. *The geology of Arran.* Mem. geol. Surv. U.K. 292 p.

WATTS, W.W. 1947. *Geology of the ancient rocks of Charnwood Forest, Leicestershire.* Leicester: Leicester lit. phil. Soc. 160 pp.

WELLS, A.K. and KIRKALDY, J.F. 1959. *An outline of historical geology.* (4th edn). London: Murby 398 pp.

WILLS, L.J. 1910. *On the occurrence of wind-worn pebbles in high level gravels in Worcestershire.* Geol. Mag. Dec. 5, vol 7, pp. 299-302.

1950. *The palaeogeography of the Midlands.* (2nd edn) Liverpool: University Press. 147 p.

1956. *Concealed Coalfields.* London: (Blackie) 208 pp.

WORSLEY, P. 1966. *Some Weichselain fossil frost wedges from East Cheshire.* Mercian Geol., vol 1, pp. 357-65.

1967. *Problems in naming the Pleistocene deposts of the north-east Cheshire Plain.* Mercian Geol., vol 2, pp. 51-5.

WRIGHT, M.D. 1964. *Cross-bedding in the Millstone Grit of the central Pennines and its significance.* Geol. Mag., vol 101, pp. 520-30.

YORKE, C. 1961. *The Pocket deposts of Derbyshire.* Birkenhead: privately published. 64 pp.

Manuscript received 5th December, 1966.