

NANSEN war eine komplizierte Natur mit sehr widersprechenden Eigenschaften. Aber er beherrschte sie alle mit seinem unbeugsamen Willen, um die Ziele zu erreichen, die sein ebenso großer Ehrgeiz ihm gesteckt hatte. „Ich habe meine Schiffe verbrannt und die Brücken hinter mir abgebrochen. So verschwendet man keine Zeit mit Rückwärtsblicken, denn man hat genug

damit zu tun, nach vorwärts zu schauen.“ Diesem Prinzip folgte er als Forschungsreisender und dieses brachte ihm seinen frühen Ruhm. Später trat mehr und mehr die Pflicht in den Vordergrund, das bestmögliche im Leben für sich selbst und damit für die anderen zu tun. Diese Haltung beherrschte sein von allen bewundertes Rettungswerk.

## PITS AND PONDS IN NORFOLK

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With 7 Tables and 21 Figures

### *Zusammenfassung: Gruben und Teiche in der Grafschaft Norfolk*

Von den in der neuesten Ausgabe der Ordnance Survey Karten eingetragenen 27015 Eintiefungen sind die großen Steinbrüche mit unregelmäßigem Umriss die auffälligsten. Sie kommen in unregelmäßiger Verteilung in der ganzen Grafschaft vor, machen zusammen jedoch nur 1,5 % der Gesamtzahl aus. Zusätzlich zu diesen verdankt eine unbestimmte Zahl anderer, kleinerer Vertiefungen der Gewinnung von Baumaterial und Straßenschotter ihre Entstehung. Weitaus die meisten der Eintiefungen haben jedoch einen regelmäßigen, im allgemeinen runden oder elliptischen Umriss und sind kleiner als ein acre (0,4 ha). Sie entsprechen den „Söllen“ (Sing. „Soll“) der Grundmoränenlandschaften des nördlichen Mitteleuropa. (Vgl. den folgenden Aufsatz von C. TROLL.) Diese Kessel sind oft in der Mitte von Feldern gelegen und dicht mit Eschen, Eichen und Hagedornestrüpp überwachsen. Die örtliche Bevölkerung hält sie für ehemalige Mergelgruben. Flurnamen des 13. und 14. Jahrhunderts machen die Annahme wahrscheinlich, daß damals in vielen Teilen der Grafschaft gemergelt wurde, und eine erhebliche Zahl von Mergelgruben sind auf Karten des 16. und 17. Jahrhunderts eingetragen. Die Buchhaltungen von Gütern beinhalten Eintragungen über das Ausheben und Streuen ungläublicher Mengen von Mergel während des 18. und 19. Jahrhunderts. Landwirtschaftliche Schriftsteller betonen die wichtige Rolle, die er für die Urbarmachung von Schaf-Hutweiden in den Gebieten leichter Böden im westlichen Norfolk spielte. Am Ausgang des 19. Jahrhunderts kam aber diese Methode der Bodenverbesserung zum Erliegen und wird jetzt nirgends mehr angewendet.

Eine gewisse Anzahl der Eintiefungen von Norfolk scheinen jedoch nicht durch Ausheben des Bodens entstanden zu sein. Sie sind entweder so regelmäßig im Umriss, so seicht oder so groß, daß man annehmen möchte, daß sie natürlicher, nicht anthropogener Entstehung sind. Einige davon, wie die Breckland Meere (Weiher) mögen als Erdfälle oder „sink holes“ durch Lösung des Kreide- oder sehr kreidereichen Moränenuntergrundes entstanden sein, andere, besonders im mittleren Norfolk, mögen periglaziale „thaw sinks“ („Pingos“) sein, die durch Auftauen von Bodeneislinsen in feinkörnigem Material zustande kamen. Weitere mögen auf diese Weise entstanden und durch Lösung im Untergrund, unter kälteren und feuchteren Verhältnissen als heute, vergrößert worden sein.

*Acknowledgements:* My thanks are due to University College London for a grant towards field-work expenses and maps, to Mr. A. R. H. BAKER, who provided several photographs, Mr. F. C. GREEN and other members of the

Department of Geography for their valuable assistance in the field work carried out in the summer 1958 and spring 1959. I am indebted to the many landowners who kindly allowed us to inspect their fields, and in particular, to the Earl of Leicester, his Librarian, Dr. W. O. HASSALL, and his Estate Agent, Mr. F. S. TURNER, for permitting me to consult the map collection and other records at Holkham. To Mr. J. BRYANT I owe thanks for drawing the maps.

Among the most widespread minor features of the Norfolk landscape are the small hollows which are to be found in almost every field. Viewed from the road or the edge of a field they may easily be mistaken for ornamental clump plantations, so well are they hidden by trees and shrubs. On closer inspection the dense undergrowth of ash, oak, hawthorn and elder is seen to form a ring surrounding a steep-sided hollow, often occupied by a pool of deep, clear water. Seen from the air or on a map they are sharply defined (Figs. 1 and 2). To describe briefly their form and pattern of distribution is the first object of this paper.

Their mode of origin is not easy to discover. By observing the variety of local topographic conditions, such as slope, geology, soils and the record of human activity within a particular area, alternative explanations for morphologically similar hollows may be suggested. Then, by studying the operation of particular processes, such as mineral working, marling, chemical weathering and periglaciation, an attempt may be made to explain particular hollows in terms of related phenomena. We may note that, apart from recent mineral workings, few bear obvious marks of digging; yet historical records indicate that a large number of pits have been dug in the past. It may be that some, whose present form is due to man's activity, have been dug on the sites of depressions which originated as natural features. Hollows in Norfolk may be formed by several different natural processes but, in the absence of directly observed evidence of their formation, we



Fig. 1:

Aerial view of pits and ponds near Swaffham from Grid ref 125/788104 looking north-east towards Castle Acre.  
(Photo J. K. S. St. Joseph, copyright reserved)

can do no more than suggest which areas offer, or formerly offered, favourable conditions for certain processes to operate. As a basis for further discussion it seems appropriate to consider some possible origins of pits, ponds and other enclosed depressions in relation to their geographical setting. What is attempted is to present an exercise in map interpretation.

#### *The form and distribution of pits and ponds in Norfolk*

The current 1 : 25,000 Ordnance Survey maps mark 27,015 hollows of different shapes and sizes (Fig. 3). Ponds or other water-filled hollows, coloured blue on the Ordnance map, are distinguished from dry pits, indicated by hachures. Most pits and ponds are situated in areas where the cover of glacial drift is more than three feet thick (Fig. 4). If the areas of thin drift deposits in west Norfolk be included, the correspondence

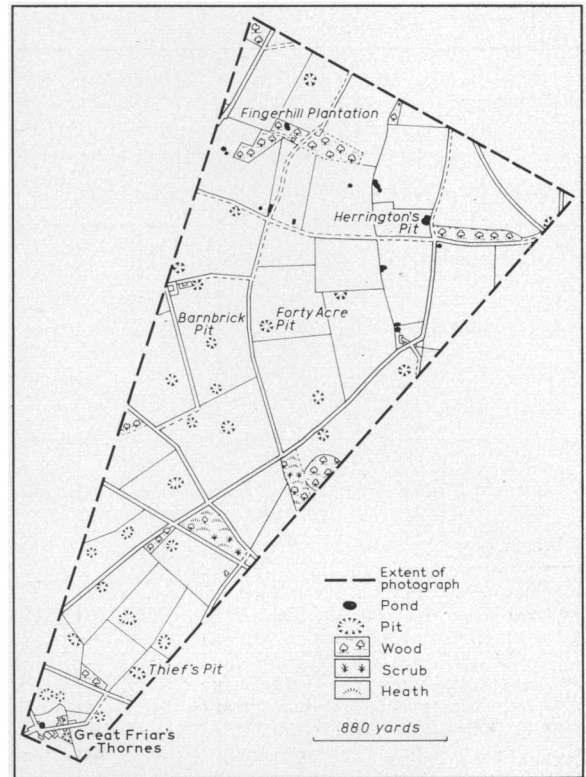


Fig. 2: Map of pits and ponds shown on Fig. 1.

between areas of hollows and glacial drifts is almost exact<sup>1</sup>). Within these limits the density of hollows varies considerably, and appears to differ from one soil region to another (Fig. 5)<sup>2</sup>). The number of pits and ponds and their density

<sup>1</sup>) In discussing the drift deposits of Norfolk I have followed the terminology and interpretations proposed in BADEN-POWELL, D. F. W.: *The Chalky Boulder Clays of Norfolk and Suffolk*. *Geological Magazine* 85, 1948, 279—296; CHATWIN, C. P.: *East Anglia and Adjoining Areas*. *British Regional Geology*. Geological Survey. 2nd edit. London 1954; WEST, R. G. and DONNER, J. J.: *The Glaciations of East Anglia and the East Midlands*. *Quart. Journ. Geol. Soc.* 112, 1956, 69—91; WEST, R. G.: *The Pleistocene Epoch in East Anglia*. *Journ. Glaciology* 3, 1958, 211—216. Fig. 4 is based on the Geological Survey Quarter-Inch Drift Geology Sheets 12 and 16.

<sup>2</sup>) The regional divisions (Fig. 5) have been drawn with the aid of ARTHUR YOUNG's *Map of the Soil of Norfolk. General View of the Agriculture of the County of Norfolk*. London 1804, and J. E. G. MOSBY's *map of the regions of Norfolk*. *Land of Britain. Norfolk*. London 1938, 193. The Soils of Norfolk are described in NEWMAN, L. F.: *Soils and Agriculture of Norfolk*. *Transactions of the Norfolk and Norwich Naturalists' Society* 9, 1914, 349—393; and NICHOLSON, H. H. and HANLEY, F.: *Soil Conditions in East Anglia*. *Guide Book for the Excursion round Britain*. *Third International Congress of Soil Science*. Oxford 1935, 60—74.

Table I: Pits and Ponds in Norfolk

Region	Surface Area sq. mls.	Number of Dry Pits	Number of Wet Ponds	Number of Pits & Ponds	Density of Dry Pits	Density of Wet Ponds	Density of Pits & Ponds
Fenland	212	3	518	521	0.01	2.4	2.4
Greensand Region	123	192	1244	1436	1.5	10.1	11.6
Good Sand Region	389	2484	1701	4185	6.4	4.3	10.7
Breckland	224	1125	754	1879	5.0	3.4	8.4
Mid-Norfolk	391	932	8616	9548	2.4	22.0	24.4
South Norfolk	279	600	6790	7390	2.1	24.3	26.4
Loam Region	339	645	1340	1985	1.9	3.9	5.8
Broadland	97	28	43	71	0.3	0.4	0.7
Total Norfolk	2054	6009	21006	27015	2.9	10.2	13.1

have been calculated for each region (Table I). In areas of light soils, particularly in the Good Sand Region, the hollows are generally large, occasionally more than 100 feet across, but not as numerous as in areas of heavy soils in mid-Norfolk and south Norfolk, where small pits and ponds abound. In the densely pitted central districts, where blue chalky boulder clay of the Lowestoft till attains a considerable thickness and the level of ground water is high, most hollows are permanently water-filled. In the Fenland and Broadland there are notably fewer than elsewhere, for they are, in fact, absent in areas of deep peat and recent alluvium.

During the summer of 1958 an attempt was made to record the shape and size of the hollows by visiting each pit or pond marked on the six-inch map, Sheet 25, covering 24 square miles around Fakenham in north-west Norfolk (Fig. 6). To compare the hollows in an area of light sandy soils in the Fakenham district with those in an area of heavy soils in mid-Norfolk, another 6 square miles around Scarning was surveyed in the spring of 1959. The hollows are circular, elliptical or irregular in shape, except where two or three occur together at the same site as multiple hollows (Table II). The great majority are less than 300 feet across and few are more than 30 feet deep. The

hollows in the Fakenham district are somewhat larger and deeper than those in mid-Norfolk. To find what kind of material lies at the bottom of the hollows is far from simple. They are thickly overgrown, partly filled with downwashed,

Table II: Shape and size of pits and ponds in the Fakenham district

	Shape				Surface Area			
	Circular	Elliptical	Irregular	Multiple	Median (sq. ft.)	Upper Quartile (sq. ft.)	Lower Quartile (sq. ft.)	
Gravel pits	26	0	4	17	5	43500	—	—
Other pits on arable land	468	139	215	28	86	3600	6300	1500
Other pits on non-arable land	150	37	74	30	9	1200	3600	300
Total	644	176	293	75	100			

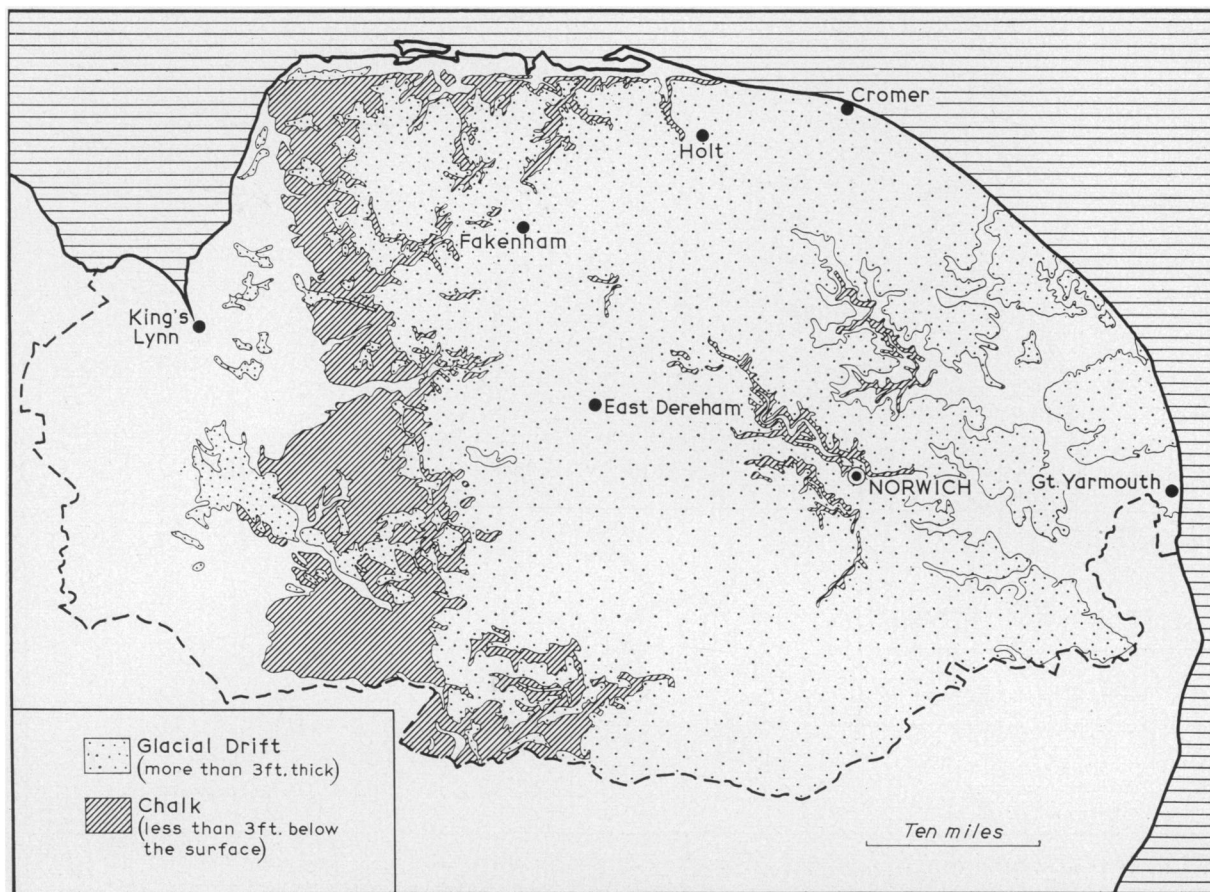


Fig. 4: Glacial drift in Norfolk. Based on Geological Survey 1/4" Drift Geology Sheets 12 and 16.

weathered debris, and often contain a considerable depth of water. Most of them have not been disturbed for a long time. In the Fakenham district 619 of the hollows recorded on the six-inch map of 1904 can still be identified; and of those that have disappeared five have been filled in as refuse tips. With the exception of six recent gravel workings, only four other new hollows have appeared since 1904. The evidence of the six-inch map convincingly shows that they cannot be explained as bomb craters or other twentieth century phenomena.

#### *Mineral workings*

Of the pits and ponds shown on 1:25,000 maps, 404 are named and distinctively represented as chalk pits, lime kilns, gravel pits, sand pits or brick kilns. The map (Fig. 7) shows that, apart from the Fenland and Broadland, mineral working in Norfolk is almost ubiquitous. Its limits correspond closely with the limits of all types of hollows, but, unlike other hollows, quarries are not concentrated in south and mid-Norfolk. The

map also shows remarkably little differentiation in the working of different materials. Sand, gravel and brick pits are situated in every part of the county except in the Fens<sup>3)</sup> and the Broads. Chalk pits and lime kilns extend from the western edge of the chalk outcrop as far east as Southrepps near Mundesley, Neatishead on the edge of Barton Broad and Whitlingham cliffs below Norwich. Some deep pits such as those at Thorpe produce sand, gravel, clay and chalk at different levels, and adjoining pits at several places in mid-Norfolk, south Norfolk, the Good Sand Region, the Breckland and the Greensand Belt produce different materials. A variety of materials are now being extracted from all districts where hollows occur, and it is pertinent to ask whether other hollows, not named on maps, are the result of mineral working.

Pits at present in use are not difficult to recognize (Fig. 8). Most are dry or well drained. Those being dug with mechanical excavators are irregu-

<sup>3)</sup> A brick works at Terrington St. Clement in the silt fen is marked on current maps.

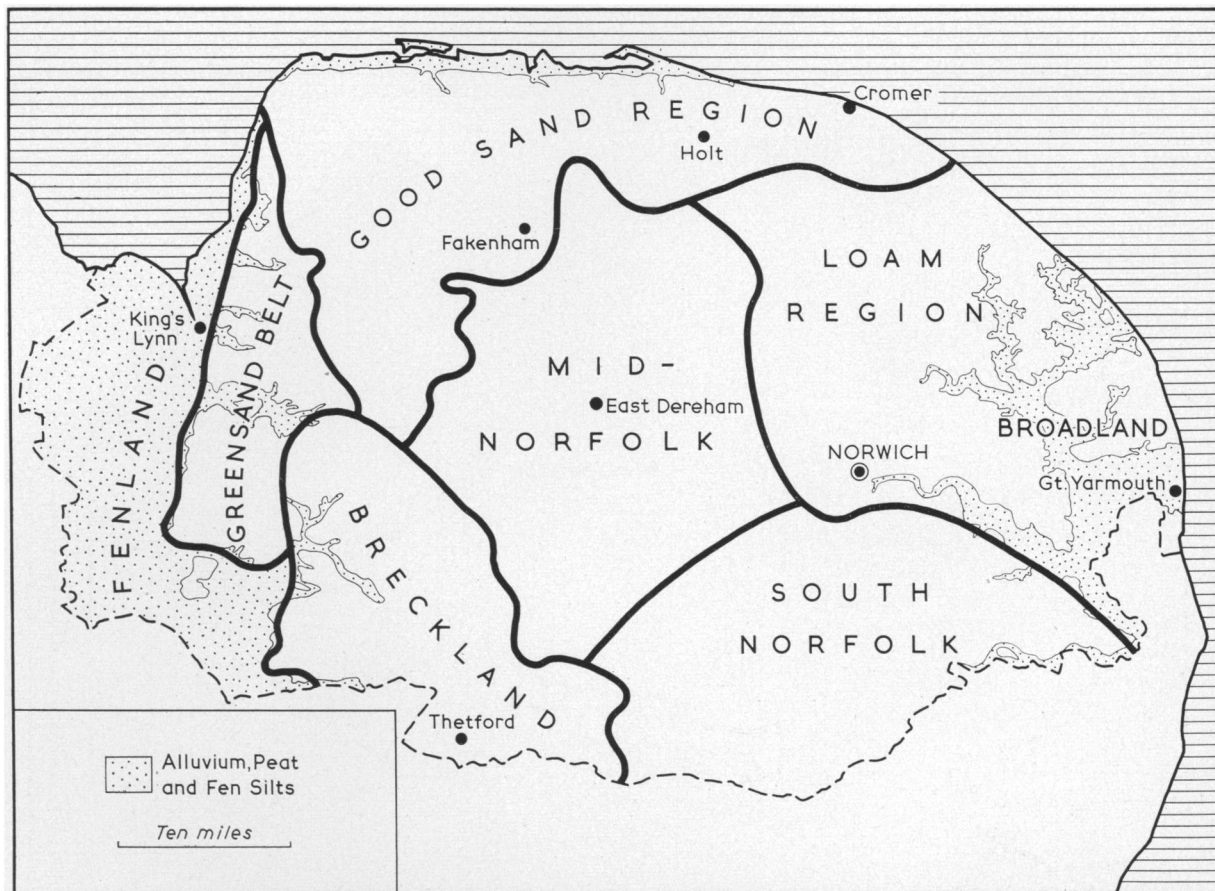


Fig. 5: Soil regions of Norfolk. Based on maps of Arthur YOUNG (1804) and J. E. G. MOSBY (1938).

lar in shape and occupy large areas, the largest more than 100 acres. They are situated either at the side of public roads or are served by tracks. Fresh exposures of material quarried, or derelict remains of tramways, graders, sheds and kilns provide unmistakable evidence of recently abandoned workings. Modern diggings present a very different appearance from the great majority of small, regularly shaped hollows situated in the middle of fields (Fig. 9).

Present day mineral workings account for barely 1.5% of all pits and ponds, but archaeology and historical records enable us to identify pits which were formerly dug for flints, building materials and road stone. Many were very small scale workings. The earliest diggings in the Breckland may be traced at least as far back as Neolithic times<sup>4</sup>). Until the end of the nineteenth century gunflints were obtained from pits at Catton and Whitlingham as well as from the Brandon district<sup>5</sup>). Subterranean workings in the chalk near Norwich at St. Giles Gate, Stone Hills

on the Dereham road, Catton and Whitlingham probably provided much of the chalk and fresh flints used in the medieval buildings of Norwich<sup>6</sup>). Building stone has also been obtained from the Lower Greensand, and since the thirteenth century from the hard beds in the Lower Chalk in west Norfolk<sup>7</sup>). By the seventeenth century almost every village had its small pits for supplying gravel for road making and material for brick making. W. G. CLARKE noted that many of the small disused pits, which are one of the most characteristic features of commons and village greens in Norfolk, existed at the time of enclosure<sup>8</sup>). Others are not reached by present day metalled roads. A survey of 1779 records hun-

<sup>6</sup>) WOODWARD, H. B.: The Geology of the Country around Norwich. Mem. Geol. Survey. London 1881, 28—30, 129—130.

<sup>7</sup>) The walls of Marham nunnery, founded in the thirteenth century, were built of clunch almost certainly derived from the neighbouring pits. BLOMEFIELD, F.: An Essay towards a Topographical History of the County of Norfolk. Vol. VII (by CHARLES PARKIN). London 1807. 392.

<sup>8</sup>) CLARKE, W. G.: The Commons of Norfolk. Transactions Norfolk. Nat. Soc. 9, 1910, 52—70.

<sup>4</sup>) CLARKE, R. R.: East Anglia. London 1960, 51—58.

<sup>5</sup>) SKERTCHLY, S. B. J.: On the Manufacture of Gun-Flints. Mem. Geol. Survey. London 1879, 10, 14.



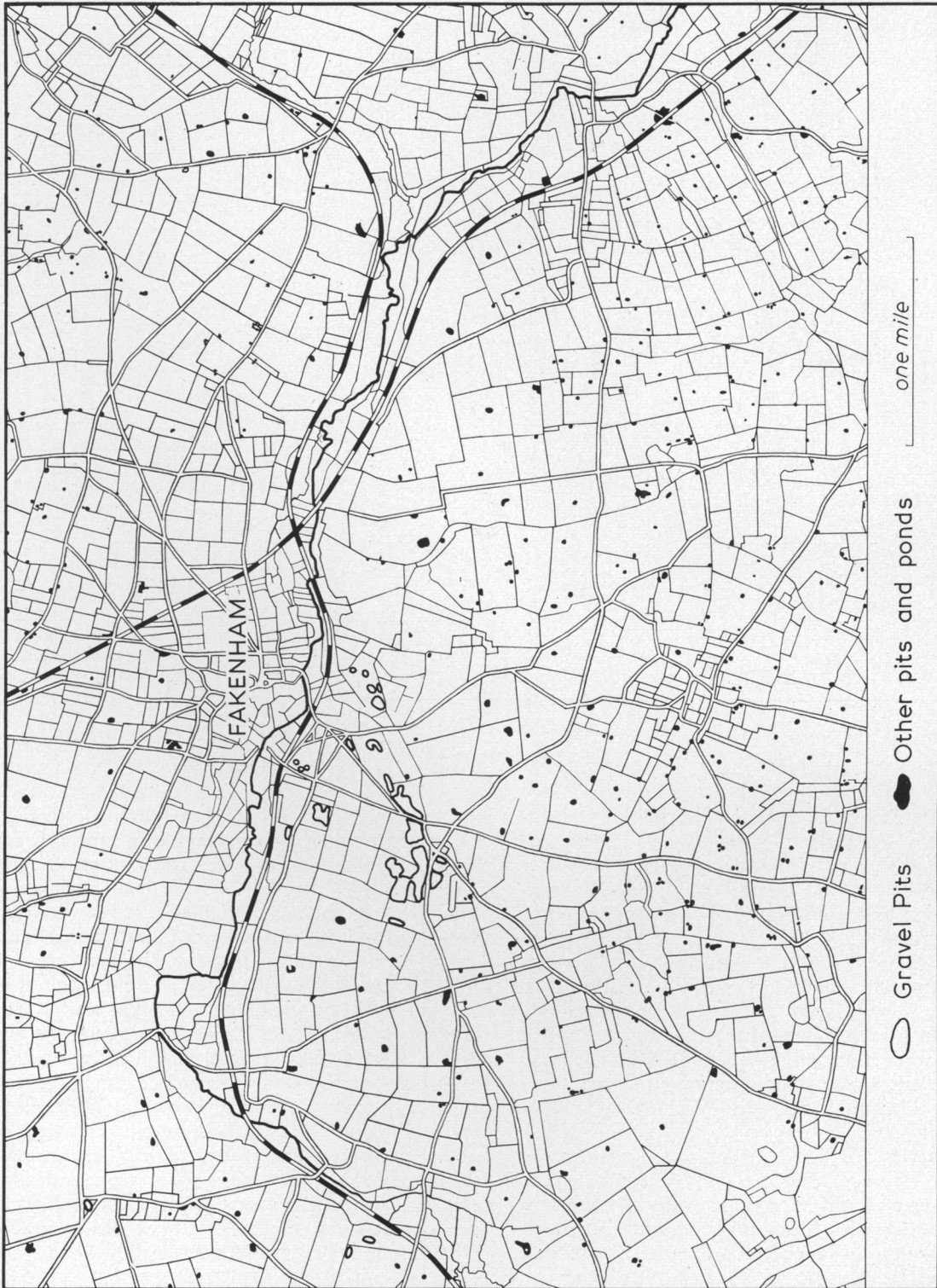


Fig. 6: Pits and ponds in the Fakenham district showing their relation to roads and field boundaries.  
Based on field survey in August 1958.

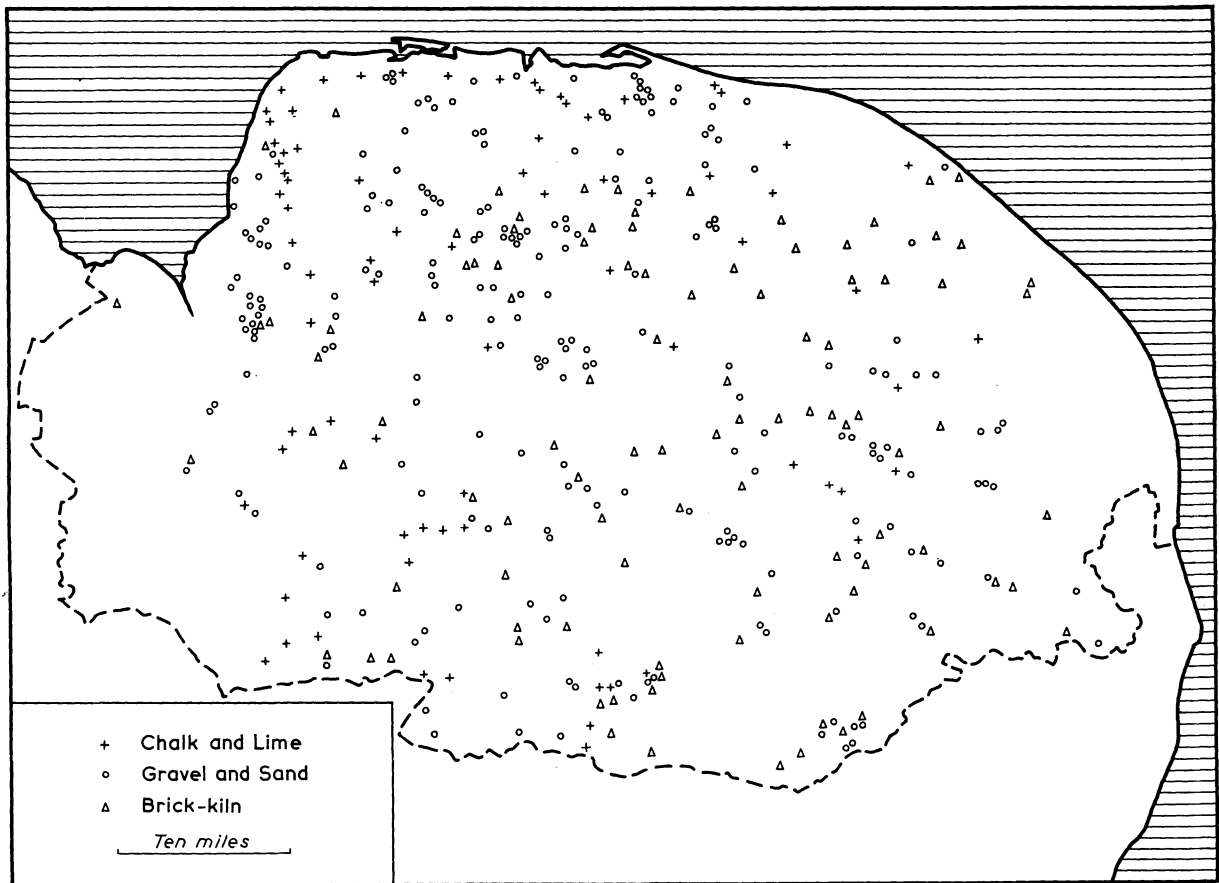


Fig. 7: Mineral workings in Norfolk.  
Based on Ordnance Survey 1:25,000 maps.

dreds of such pits in different parts of the Holkham estate. It shows two small brick kilns and a lime kiln in the outlying parts of Great Massingham, two gravel pits and a chalk pit in Weasenhams, and at least two gravel pits and a sand pit in Castle Acre<sup>9</sup>).

Many disused mineral workings are much less than one acre in extent and cannot be distinguished from other hollows. A few can be recognized by their somewhat irregular shape and traces of tracks leading to them. Gravel and sand pits may be colonized by bracken, gorse, birch, oak and hawthorn, but rarely by ash (Fig. 10).

#### *Ponds and Pits*

The great majority of hollows in Norfolk are much smaller than one acre in extent and much more regular in shape than modern mineral workings. In clay country such hollows may be

expected to collect water from ditches and field drains, and some may have been dug expressly for this purpose. But in sandy districts, where the soil is naturally well drained and artificial drainage is absent, there are some 10,000 hollows, half of them filled to within a few feet of the surface with water. Some, which are very shallow and lie within or close to farmyards or in fields of permanent grass, are ponds used, or formerly used, for watering stock. Some large ponds, such as the Brooke meres, may have been excavated as reservoirs for water for cattle or even for the human population<sup>10</sup>). But more than 70% of the pits and ponds in the Fakenham district are situated in arable fields, about half of them in the middle of fields, away from roads or farm buildings. A farmer in Great Ryburgh near Fakenham has at least one pit in 20 of his 24 arable fields, one hole being over 80 feet deep. These are evidently neither drainage sumps nor ponds.

<sup>9</sup>) The 1779 survey is contained in a bound volume of plans kept in the Holkham Estate Office.

<sup>10</sup>) WOODWARD, H. B.: *Geology. Victoria County History. Norfolk. Vol. I. Westminster 1901, 20.*



Fig. 8: Recently abandoned sand and gravel pit at Hempton Green south of Fakenham, Grid ref. 125/911286. (Photo A. R. H. Baker)

The modern farmer regards them as a nuisance. They occupy much valuable space; in the 24 square miles around Fakenham they occupy 127 acres, or 0.8% of the surface area (Table III).

Table III: Area occupied by pits and ponds in the Fakenham district<sup>11)</sup>

	Surface Area Acres	Pits and Ponds			
		Area Acres	Per cent of surface area	Number	Per cent
Arable land	10752	66.9	0.62	471	73.1
Other land	4608	59.8	1.29	173	26.9
Total	15360	126.7	0.82	644	100.0

The operation of machinery is hindered by their presence in the middle of fields, and as a result it is impossible to plough straight furrows or drill straight rows. The cover of trees casts its shade on surrounding land and harbours multitudes of pests and vermin, notably rabbits. Crops are stunted or severely depleted in an area which may extend ten or fifteen feet beyond the edge of a hollow. On the other hand, the task of filling

<sup>11)</sup> The total area occupied by pits and ponds represents the sum of the areas of 644 ellipses whose lengths and breadths have been estimated on the ground and checked against the six-inch map. The proportion of arable land occupied by hollows represents the total area of hollows in fields that were ploughed or growing arable crops in August, 1958, expressed as a percentage of the total area of those fields shown on the current Ordnance Survey 1:2,500 plans. The 10,752 acres of arable includes land occupied by hedges, ditched, footpaths, bridleways and also by pits and ponds themselves.

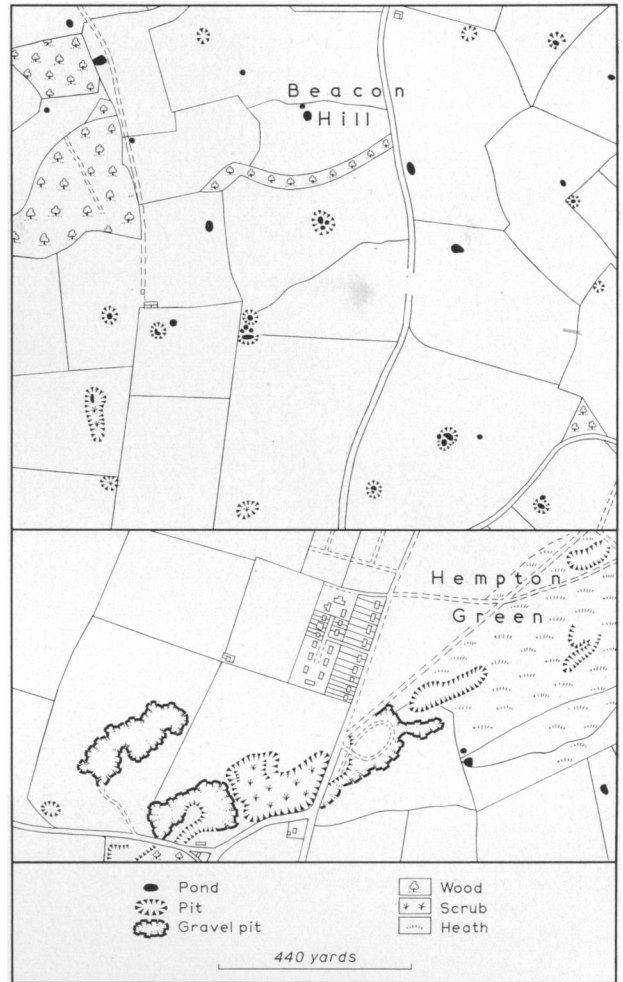


Fig. 9: The contrast between small regularly shaped hollows in the middle of fields at Beacon Hill and large irregular gravel workings at Hempton Green near Fakenham. Based on field survey in August 1958.



Fig. 10: Old disused gravel pit covered with gorse and elder at Hempton Green near Fakenham. (Photo A. R. H. Baker)



them is expensive and has not always proved successful. The thicket of trees and shrubs has first to be cleared; then several hundred cubic yards of material have to be found and carried across fields. When this is done, a wet patch may remain incapable of producing a normal crop (Fig. 11).



Fig. 11: Wet patch remaining after a pit had been filled in near Colkirk.  
Photograph taken on 3rd August 1958 after a prolonged period of drought. (Photo A. R. H. Baker)



Fig. 12: Pit on side of a hill covered with ash, hawthorn and oak near Raynham Park.  
Grid ref. 125/884 276.

### *Marl pits and marling*

In areas of flat arable land pits and ponds are regularly spaced in each field, except where two or three occur side by side as multiple hollows; on sloping ground they are generally situated near the highest point in a field. Some, cut into the side of a hill, are approached by a gentle incline which may look like a natural depression, backed by a steep face ten or twenty feet high (Fig. 12). Others, whose presence on a level surface is often revealed by a dense thicket of trees and shrubs,

have a vertical shaft penetrating to a depth of at least ten feet (Fig. 13). Ash, hawthorn and oak are the commonest trees, but elder, willow, blackthorn, holly, alder, elm, sycamore, hazel and Scots pine are also frequently present (Fig. 14). Trees of all ages from young saplings to mature specimens are found on the sides of many pits,



Fig. 13: Pit on level ground covered with ash and hawthorn near Great Ryburgh.  
(Photo A. R. H. Baker)



Fig. 14: Pit on level stony ground supporting Scots pine and elder near Pudding Norton.  
Grid ref. 125/935 281. (Photo A. R. H. Baker)

showing how little they have been disturbed in recent times. Yet the reports of people now living and the records of marling activity up to the end of the nineteenth century suggest that many were dug for mineral manures.

For the present purpose the term "marling" is used to refer to the digging of any mineral substances from beneath the surface soil to correct soil acidity or to improve soil texture. Geologists define marl as a calcareous clay containing more than 10% calcium carbonate, but in Norfolk the term "marl" is generally reserved for soft white materials containing a very high proportion of

calcium carbonate. JOSHUA TRIMMER applied the term exclusively to almost pure calcium carbonate obtained from the Upper Chalk, transported or disturbed masses of chalk, or the intensely chalky boulder clay of north-west Norfolk<sup>12</sup>). In mid-Norfolk and south Norfolk sandy substances rich in lime are also called "marl". The term "clay" is applied to other substances with a lower lime content<sup>13</sup>). In its local meaning, "clay" includes grey, blue or yellow chalky till, some of which contains more than 80% calcium carbonate and is pure enough to be burnt for lime<sup>14</sup>). It also includes sandy loam, as well as true clay from the Gault and Kimmeridge formations. The value of all these materials, except the true clays, for improving light soils may be attributed largely to their lime content. On the light sandy soils in west Norfolk "clay" or "marl" is used to reduce acidity, to increase the water-retaining capacity, to retard the leaching of plant nutrients from the topsoil and to prevent soil erosion. On heavy soils sandy calcareous material, the "marl" of south Norfolk, can be used to improve soil texture. The sand fraction helps to break down stiff, tenacious clods by a mechanical process; while the lime fraction not only reduces acidity, but also imparts an easily worked crumb structure by a chemical process of flocculating the clay colloids. At least eleven different substances were used to improve different types of land in Norfolk in the mid-nineteenth century but the method of obtaining them was much the same in all districts.

The digging of mineral manures was practised in England over two thousand years ago. PLINY described how such material was raised by windlass from depths of as much as 100 feet. This method of sinking a deep shaft and excavating a bell shaped cavity below is described by many later observers and has been reported in the present century by several authorities<sup>15</sup>). On a

sloping surface it was occasionally possible to cut back into the slope far enough to reach the material by way of an inclined ramp and draw it out in carts with the aid of a capstan<sup>16</sup>). The first method would account for the depth and funnel shape of pits on level surfaces; the second would explain the wedge shape of the few pits on sloping surfaces. Raising material from a deep vertical shaft is a laborious operation, but less costly than opening a broad pit. The cost of digging and loading the material into carts is often no greater than the cost of carting and spreading it with wheelbarrows or cumbrous carts. To carry it the shortest distance, a pit should be situated in the middle of a field or at the top of a slope, so that loaded carts may run downhill. A further advantage of digging a shaft is that a minimum quantity of "uncallow" overburden needs removing. The "uncallow" is generally spread on the land with the "callow" marl and not thrown back into the pit after the marl has been taken. When ten or more feet of overburden has to be removed to reach a productive bed, a vertical shaft is most appropriate. The shape, size and position of many present day pits correspond faithfully with these specifications.

The earliest documentary evidence of marling in Norfolk is derived from medieval field-names and minor place-names which indicate the presence of marled land, marl pits, clay pits, loam pits or pit holes. One of the earliest references is a grant of five acres of land, called Marlepitlond, at Saxthorpe in north-east Norfolk made in 1277<sup>17</sup>). In the sandy districts of west Norfolk the fertilizing value of white chalk marl was known and widely exploited in the thirteenth, fourteenth and fifteenth century. W. G. CLARKE states that "*land which is now apparently primitive heathland was profitably cultivated*" at that time<sup>18</sup>). Among other places he identifies the present Lambpit Hill in Thetford Warren as the Lampythowe referred to in 1338, in which the element "lam" means "loam". Another pit near Thetford is referred to in 1535 as Fryers Calkepitt. Place-names containing the element "cork", as in the present Corkmere Bottom, Wretham, or Corkes Pitte, on the

<sup>12</sup>) TRIMMER, JOSHUA: On the Geology of Norfolk as illustrating the laws of the distribution of soils. Journ. Roy. Agric. Soc. 7, 1847, 444—485.

<sup>13</sup>) In other counties these terms have different meanings. What is described in west Norfolk as "marl" would probably be called "chalk" in Hertfordshire; while much of what is called "clay" in Norfolk would be described as "marl" in Hertfordshire or Kent.

<sup>14</sup>) WOODWARD, H. B.: The Geology of the Country around Fakenham, Wells and Holt. Mem. Geol. Surv. London 1884, 23, reports that chalky boulder clay in a pit near Holt was found to contain 91% calcium carbonate, a material so free from other detritus as to be readily mistaken for pure chalk.

<sup>15</sup>) RUSSELL, Sir E. JOHN: The World of the Soil. London 1957, 172, quotes a passage from PLINY's Natural History describing the method of extracting marl from bell pits in Britain two thousand years ago. RUSSELL observed the same method used by a gang of itinerant workmen at Rothamsted in 1915. The observations of agricultural writers on this subject are reviewed by FUSSELL, G. E.:

Marl, an ancient manure. Nature 183, 1959, 214—7. One of the best twentieth century accounts is by SHERLOCK, R. L.: The Geology of the Country around Aylesbury and Hemel Hempstead. Mem. Geol. Survey. London 1922, 55.

<sup>16</sup>) YOUNG, ARTHUR: Annals of Agriculture. 19. Bury St. Edmunds 1793, 478.

<sup>17</sup>) *Historical Mss. Comm.*: Report on the Mss. of the Marquess of Lothian at Blickling Hall, Norfolk. London 1905, 50. The marlpit is also referred to in a grant of 1252 cited on p. 48.

<sup>18</sup>) CLARKE, W. G.: In Breckland Wilds. 2nd. edit. revised and re-written by R. RAINBIRD-CLARKE: Heffer, Cambridge 1937, 97.

Holkham map of the Manor of Farnworth Hall in Ashill, 1581, probably refer to the hard chalk of that name described by ARTHUR YOUNG<sup>19</sup>). Many hundreds of early forms of place-names have yet to be studied before a geography of marling in medieval Norfolk can be written, but it is evident from the earliest farm and estate maps that marl pits were a widespread feature of the landscape of north-west Norfolk by 1600.

A remarkable collection of maps and plans of the Holkham estate dating back to 1575 show many marl pits and clay pits<sup>20</sup>). Most were located in minutely subdivided fields and small closes of two or three acres immediately surrounding villages and hamlets, and it would seem that before 1660 most marling in north-west Norfolk on lands that were regularly under cultivation. It is not certain how extensive the practice was at this period in the rest of the county, particularly in the old enclosed districts of mid-Norfolk, although it is clear it was not entirely an innovation of the early eighteenth century. In east Norfolk chalk shipped from Greenwich, Erith and Northfleet in Kent was carried as much as ten or fifteen miles inland from the ports, where DEFOE observed it was eagerly sought by farmers "to lay upon their land, and that in prodigious quantities"<sup>21</sup>). Although this trade may have contributed to the fertility of the coastal fringe of east Norfolk, it is unlikely that imported chalk was used outside the Loam Region. In other parts of the county marl was generally dug in the field in which it was used.

After 1660 it is evident that marling was extensively practised on lands newly won from "breaks", from sheepwalks and from heaths<sup>22</sup>). It came to play a leading role in the reclamation of light sandy soils in west Norfolk, notably on the great estates of RAYNHAM<sup>23</sup>), HOUGHTON<sup>24</sup>),

HOLKHAM and probably several others<sup>25</sup>). Marling was usually paid for by the tenant himself, except when new land was being enclosed and improved. The Audit Account Books of the Holkham Estate, which begin in 1707, record only the payments made by the landlord as a contribution to the initial cost of reclamation; the tenant, for his part, generally agreed to pay an increased rent<sup>26</sup>). A typical entry in the Audit Account, under "Holkham, 1712", referring to such an agreement, reads:

*"Allow'd Thos Magnus for filling and spreading 500 load of marle laid upon 10 acres in High Close as by agreement when he took the farme which was part of the consideration of his increase of rent . . . £ 7.10. Od."*

Marling, together with hedge planting and the building of farms, was carried out on newly enclosed land in every part of the Holkham estate during the first half of the eighteenth century (Fig. 15). By 1750 marling on a large scale had come to be regarded as an essential step in the reclamation of land from sheepwalks<sup>27</sup>). To more than one writer marling was the cornerstone of the improvements made in west Norfolk husbandry during the early eighteenth century. One asserted that "all the country from Holkham to Houghton was a wild sheepwalk before the spirit of improvement seized the inhabitants. What has wrought these vast improvements is the marling; for under the whole country run veins of a very rich soapy kind, which they dig up and spread upon the old sheepwalks; and then, by means of inclosure, they throw their farms into a regular course of crops, and gain immensely by the improvement"<sup>28</sup>). It is an oversimplification to say that marl occurs in veins under the whole county, but the effect of its application on many types of land was spectacular. "The fertility of this land is

<sup>19</sup>) YOUNG, ARTHUR: Annals of Agriculture 39. Bury St. Edmunds 1803, 172.

<sup>20</sup>) They show, for example, that there were no less than 28 pits in Tittleshall in 1596, 10 in Longham in 1580 and 4 in West Lexham in 1575.

<sup>21</sup>) DEFOE, DANIEL: A Tour through England and Wales (1724). Everyman. London 1927. Vol. I, 99.

<sup>22</sup>) "Breaks", "brakes" or "brecks" are temporarily cultivated enclosures from sheepwalks or heaths, which are cropped for a year or two, then allowed to revert to rough grazing. They are described in SALTMARSH, JOHN, and DARBY, H. C.: The Infield-Outfield System on a Norfolk Manor. Econ. Hist. 3, 1935. 30—44 and MOSBY, J. E. G.: op. cit. 127—131.

<sup>23</sup>) SAUNDERS, H. W.: Estate Management at Rainham in the Years 1661—1686 and 1706. Norfolk Archaeology 19, 1917. 39—66 shows that marling began on the Raynham Estate before 1664, much earlier than suggested by PROTHERO, R. E. (Lord Ernle), English Farming Past and Present. London 1912, 174.

<sup>24</sup>) PLUMB, J. H.: Sir Robert Walpole and Norfolk Husbandry, Econ. Hist. Rev. 2nd. Ser. 5, 1952. 86—89, refers to marling 1701, p. 87. CHINNER, G. A.: A Hand-

list of the Cholmondeley (Houghton) MSS. Cambridge 1953. lists marl under the General Estate Accounts, 1718—1745, 3 vols.

<sup>25</sup>) "N": The State of Husbandry in Norfolk. Gentleman's Magazine 22, 1752. 453, credits Mr. Allen of Lyng House, north-east of Dereham, with initiating large-scale marling as a means of reclaiming heathland in west Norfolk; YOUNG, ARTHUR: op. cit. 1804. 365, adds the names of Lord Townshend and Mr. Morley to the list of pioneer improvers.

<sup>26</sup>) The nature of these agreements is discussed, p. 165 in PARKER, R. A. C.: Coke of Norfolk and the Agrarian Revolution, Econ. Hist. Rev. 2nd. Ser. 8, 1955. 156—166. Marling on the demesne lands was normally charged to the Farm Account, referred to in ROGERS, J. E. T.: A History of Agriculture and Prices in England, vii, 1703—1793. Part I. Oxford 1902, 646.

<sup>27</sup>) The role of marling in the reclamation of light soils during the early eighteenth century is discussed at length in RICHES, NAOMI: The Agricultural Revolution in Norfolk. University of North Carolina, Chapel Hill 1937, 33, 77—81, 152.

<sup>28</sup>) A Society of Gentlemen: England Displayed. Revised by RUSSELL, P., and PRICE, OWEN. London 1769. i, 318.

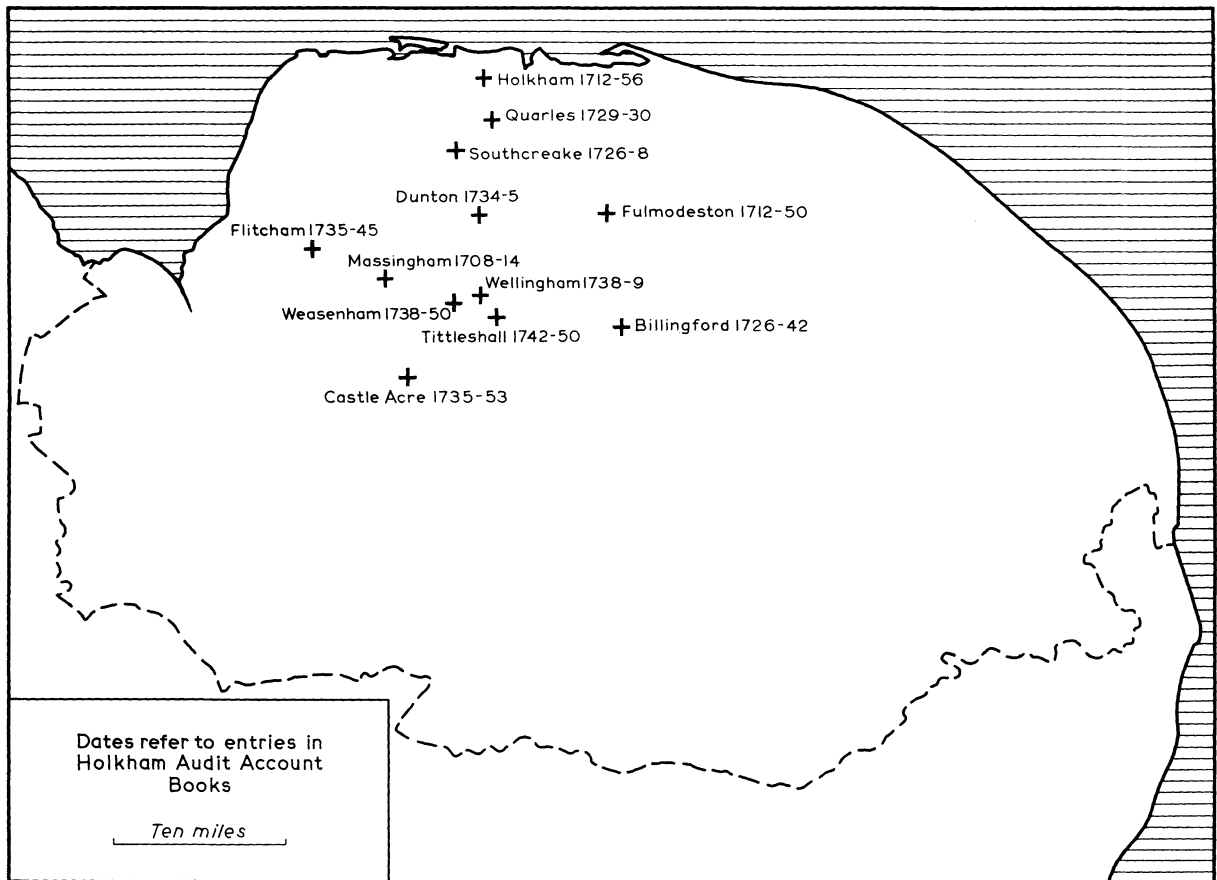


Fig. 15: Marling on the Holkham estate between 1712 and 1756.

Based on Holkham Audit Account Books record payments for the initial improvement of land.

wholly artificial”, declared the young DUC DE LA ROCHEFOUCAULD after visiting a prosperous farm at Dunton in 1784<sup>29</sup>). In the course of his visit he learned that this and many other farms in the district had been uncultivated waste fifty years earlier and owed their high state of cultivation “to the discovery of marl”. On estate maps of the mid-eighteenth century pits appear frequently in the midst of “breaks”. In the 1750’s a pit is marked in Marl Break in Great Massingham; in 1779 there is a New Marl’d Break in Rougham and a Claypit Break in Tittleshall, to name but three examples from maps of the Holkham estate.

While newly reclaimed intakes in west Norfolk were being marled possibly for the first time, the activity was being revived in the old enclosed lands in east Norfolk. WILLIAM MARSHALL, who acquired a knowledge of the practice from two

years’ residence in east Norfolk (1780–1782), made a careful study of the properties and mode of occurrence of the marls and clays used in different parts of the county<sup>30</sup>). Samples of chalk marl from Thorpe Market on the northern edge of the Loam region, clay marl from Hemsby in East Flegg, soft chalk from Thorpe-next-Norwich, and hard chalk from Swaffham on the borders of the Breckland and the Good Sand Region were analysed and all were found to contain a high proportion of calcium carbonate. But their usefulness also depended on the rate at which they weathered and mixed with the soil; and on the nature of the soil itself. It was recognised locally that the presence of buddle or corn marigold (*Chrysanthemum segetum*), smartweed (*Polygonum Hydropiper*), quick or couch grass (*Agropyron repens*) indicated that the land needed marling. It was also observed that the

<sup>29</sup> ED. MARCHAND, JEAN: A Frenchman in England 1784, being Melanges sur l’Angleterre of Francois de la Rochefoucauld. Translated with notes by ROBERTS, S. C. Cambridge 1933, 230; other observations on marling appear on p. 172–173, 217, 218–219.

<sup>30</sup> MARSHALL, WILLIAM: The Rural Economy of Norfolk. London 1788. i, 16, 18–27, 150–157, 217; ii, 193, 363–364.

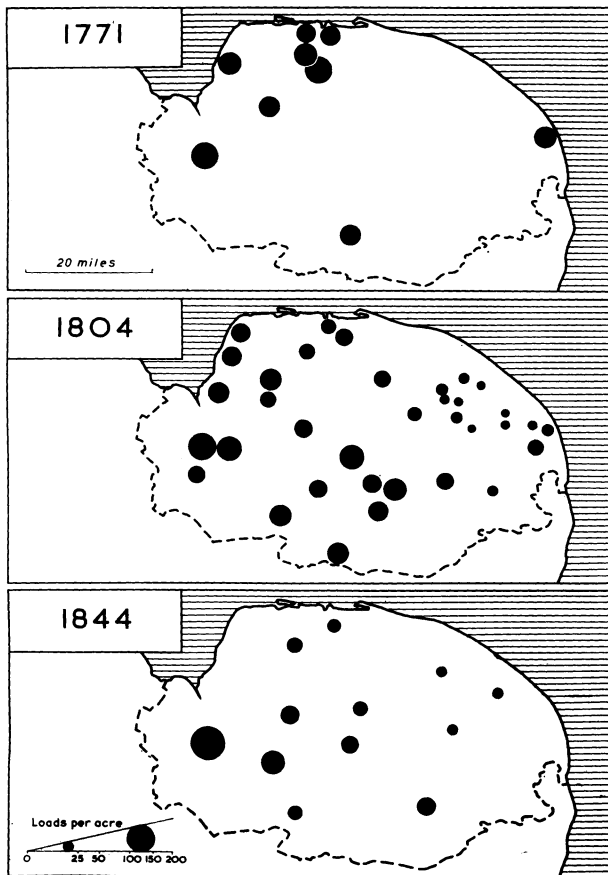


Fig. 16: Quantities of marl spread in Norfolk.

The circles are proportional to the number of loads of marl spread per acre. Information derived from ARTHUR YOUNG (1771 and 1804) and R. N. BACON (1844) and other accounts.

disease “anbury” or “clubroot” or “finger-and-toe” (Caused by the organism *Plasmodiophora brassicae*) in turnips and members of the cabbage family did not occur on recently marled land<sup>31</sup>). On the other hand, it was noted that coltsfoot (*Tussilago Farfara*) thrived where marl lay close to the surface. When WILLIAM MARSHALL wrote, the extent and variety of workable deposits in east Norfolk was already well known from exposures in existing marl pits, and attention was being directed to using the material as effectively as possible.

In the second half of the eighteenth century in west Norfolk marling was still regarded as a pioneering activity. ARTHUR YOUNG asserted that the high standard of farming for which that part

<sup>31</sup>) More recently GARDNER, H. W., and GARNER, H. V.: The Use of Lime in British Agriculture. London 1953. 28–31, names a number of other reliable indicators of acidity which are common in Britain, including sheep’s sorrel (*Rumex acetosella*), spurrey (*Spergula arvensis*) and knawel (*Sceleranthus annuus* and *perennis*).

of the county was justly famous had been achieved by the institution of 21-year leases, by the enlargement of farms, by the enclosing of heathland, by strict adherence to regular rotations of crops and by marling, which he claimed to be “the most important branch of Norfolk improvements”<sup>32</sup>). In 1804 marling or claying was practised on a large scale in most parts of the county (Fig. 16), but the quantities used were no longer as great as in 1771, at the time of ARTHUR YOUNG’s Tour<sup>33</sup>). Experience was beginning to demonstrate the advantages of smaller dressings. In the country between Warham and Holt where it was customary to spread 60 loads<sup>34</sup>) per acre in 1771, good results were obtained with 25 to 30 loads in 1804; and land in Massingham that received 70 loads per acre in the 1770’s derived no less benefit from 35 to 40 loads per acre 25 years later<sup>35</sup>). But there were still great differences between the amounts used in different localities. Much larger quantities were applied in west Norfolk than in the east. In the west dressings of “clay” ranged from 40 to 140 loads per acre; in the Loam Region dressings were not more than 40 loads per acre, and the widely dug white chalk “marl” of east Norfolk was generally spread at a rate of 8 to 12 loads per acre.

To appreciate the scale of these operations we may reckon that a forty-acre field clayed at the rate of 60 loads per acre, which was quite typical for west Norfolk, required 2,400 loads, or about 3,200 cubic yards of material. To provide this quantity, a hole 60 feet in diameter and over 30 feet deep would have to be dug; for a ten-acre field a hole 30 feet across and over 30 feet deep would be required. Similar diggings might be repeated at intervals of twenty or thirty years, usually at or near the site of the original pit. Observations confirm that the pits are roughly proportional to the size of fields, that their capacity corresponds very roughly with the amounts reported by ARTHUR YOUNG, and that multiple hollows could have been produced by repeated digging.

The benefits of marling were never so widely publicised as they were during the first half of the nineteenth century. In 1811 claying was recommended to improve fen peat, although it was generally obtained from trenches rather than deep

<sup>32</sup>) YOUNG, ARTHUR: General View of the Agriculture of the County of Norfolk. London 1804. 402. Other references to marling on pp. 364, 366, 402–412, 476.

<sup>33</sup>) YOUNG, ARTHUR: The Farmer’s Tour through the East of England. London 1771. ii: 17, 31, 40, 152–156, 161.

<sup>34</sup>) A “load” varied in quantity from place to place and time to time, but in Norfolk in the early nineteenth century it was generally reckoned to be about 36 cubic feet, or 1½ cubic yards, or approximately 1¾ tons.

<sup>35</sup>) YOUNG, ARTHUR: op. cit. 1804, 402.

pits<sup>36</sup>). In 1826 WILLIAM WITHERS advocated the use of marl to promote the growth of trees on poor light soils<sup>37</sup>). But these were small extensions of a well-established practice which was strongly urged by the foremost agricultural writers of the period and actively encouraged by wealthy improving landlords such as THOMAS WILLIAM COKE OF HOLKHAM<sup>38</sup>). Most farms in west Norfolk were occupied by tenants whose interests in making improvements were protected by long leases. During the period of a 21-year lease an initial outlay of less than fifty shillings per acre secured a handsome return by ensuring high yields. In other parts of the county, where leases seem to have been granted for short periods, tenants were less certain of a return on their investment; but the existence of many thousands of pits in mid-Norfolk and south Norfolk suggests that farmers willingly ventured their capital in marling enterprises with confidence.

R. N. BACON, writing in 1844, firmly advocated the use of marl or clay<sup>39</sup>). In his opinion, no county "*has been indebted more, if so much, to manures obtained from its subsoils, as Norfolk, and by none has a larger quantity been used, or with greater increase of production*"<sup>40</sup>). The practice was evidently still being extended. A map of a farm at Castle Acre (Fig. 20) containing 46 fields marks 35 "new" and 17 "old" marl pits; another of a farm at Weasenham (Fig. 19) containing 26 fields shows 25 "new" and 10 "old" pits; yet another of a newly enclosed farm at Mileham shows several new pits dug there in the course of improvements after 1814. In the Loam Region marl and chalk were being shipped in small wherries from staithes near the pits, and in many areas farmyard manure was being composted with marl.

The dressings of marl or clay recommended by BACON are smaller than those generally applied at the beginning of the nineteenth century, partly as a measure of economy, and partly because it was then recognised that excessive applications were harmful to the land. On light soils from 30 to 40, on heavy soils not less than 40, and on newly broken land upwards of 100 loads were consid-

ered adequate. This view was supported by BARUGH ALMACK who stated that it was better to clay more frequently than to run the risk of putting on too large a quantity at once<sup>41</sup>). But he weakened his argument by selecting, "*as a favourable specimen of what has been done for the soil of Norfolk, and to account for its present productive state*", a 287-acre farm at South Runcton on which no less than 54,055 loads of clay had been spread at one dressing, an average of 188 per acre<sup>42</sup>). Again, at two farms in West Lexham, light sandy soils were clayed at the rate of 40 or 50 loads per acre, and at another near Swaffham, on the edge of the Breckland, at the rate of over 80.

The digging of marl ceased in most parts of Norfolk before the First World War, after declining for about half a century. H. B. WOODWARD's report on the geology of the country around Fakenham, Wells and Holt discusses marling as if it were still practised there in 1884<sup>43</sup>); but geological survey memoirs for other districts leave no doubt that it was almost discontinued<sup>44</sup>). If lime in some form was to be used at all, it was evidently cheaper to bring it from a distance than to dig it on the farm<sup>45</sup>).

The practice of marling has now been entirely superseded by other means of improving soil texture and correcting acidity, notably by the use of pure lime or chalk. Since the passing of the Agricultural Act of 1937, which authorised the payment of subsidies on lime delivered to a farm, much has been done to restore the losses caused by more than half a century of neglect. The subsidy, paying half the cost of the material and its delivery but nothing towards the cost of spreading, favours the use of light dressings of lime or chalk rather than heavy dressings of impure marl dug on the farm. Many farmers in the Fakenham district now obtain kiln-dried ground chalk from Wells; others use small lump chalk or lime waste from beet sugar factories. These materials are light, easy to handle and can be spread by manure drill or rotary spreader. Moderate dress-

<sup>36</sup>) PARKINSON, R.: *General View of the Agriculture of the County of Huntingdon*. London 1811. 299, cited in DARBY, H. C.: *The Draining of the Fens*, 2nd. edit. Cambridge 1956. 238.

<sup>37</sup>) WITHERS, WILLIAM: *A Memoir addressed to the Society for the Encouragement of Arts . . . on the Planting and Rearing of Forest-Trees*. Holt 1826. 18.

<sup>38</sup>) The marling activity is frequently alluded to by YOUNG, ARTHUR, and highly praised by BACON, R. N., but RIGBY, EDWARD: *Holkham, its Agriculture*. Norwich 1818, does not refer to the practice.

<sup>39</sup>) BACON, R. N.: *The Report on the Agriculture of Norfolk*. London 1844, discusses marling on pp. 7, 94, 267—273, 290—293.

<sup>40</sup>) *IBID*, 267.

<sup>41</sup>) ALMACK, BARUGH: *On the Agriculture of Norfolk*, *Journ. Roy. Agric. Soc.* 5, 1845. 307—357, esp. 307—313.

<sup>42</sup>) *IBID*, 312.

<sup>43</sup>) WOODWARD, H. B.: *The Geology of the Country around Fakenham, Wells and Holt*. London 1884. 21—22.

<sup>44</sup>) WOODWARD, H. B.: *The Geology of the Country around Norwich*. London 1881. 115; REID, C.: *The Geology of the Country around Cromer*. London 1882. 3, 132; BENNETT, F. J.: *The Geology of the Country around Attleborough, Watton and Wymondham*. London 1884. 9; BLAKE, J. H.: *The Geology of the Country around East Dereham*. London 1888. 51; WHITAKER, W., SKERTCHLY, S. B. J., and JUKES-BROWN, A. J.: *The Geology of the Borders of the Wash*. London 1899. 74.

<sup>45</sup>) COPLAND, SAMUEL: *Agriculture, Ancient and Modern: A Historical Account of its Principles and Practice*, I. London 1864. 694—699, 774.



ings of not more than three to eight tons per acre, depending on the acidity of the soil, may be expected to benefit the land for at least ten years. On light sandy soils with a pH value as low as 4.6, a single dressing of five tons of soft lump chalk is sufficient to ensure normal crops of sugar beet and other sensitive plants for more than 17 years in this part of England<sup>46</sup>). In 1950 a total of 228,156 tons of liming materials was consumed in Norfolk, or about 4¾ cwt. per cultivated acre, which was rather more than the average for England and Wales<sup>47</sup>).

The evidence for marling in the eighteenth and nineteenth century is abundant and decisive. Estate accounts, surveys and the reports of contemporary observers show that many pits and ponds owe their present form to the digging of mineral manures.

#### *Shallow depressions*

The evidence for marling does not dispose of the problem of the origin of hollows. It does not tell us whether the pits we see are entirely man-made or natural hollows deepened by digging.

Several agricultural writers have noted that the surface of the ground was patterned with broad shallow hollows before marl pits were excavated. THOMAS HALES writing in 1756 believed that such hollows marked the sites of former diggings and he instructs the reader, "When he has found any such Hollows let him mind the Course wherein they run, for that Way probably the Vein of Marle runs also"<sup>48</sup>). HALES draws upon a wealth of observations made in the Midlands and southern England, but does not refer specifically to Norfolk. That Norfolk also had a pitted surface in the early eighteenth century is confirmed by an account of husbandry in Norfolk in 1752. It states, "we have an abundance of old pits, and many of them have gone by the name of marle pits, and inclosures have been denominated from them above two hundred years"<sup>49</sup>). It is clear that at least some eighteenth century marl pits were dug on a pitted not a smooth surface, and because some of them were named marl pits it was assumed that they had been dug for that purpose at some earlier period. But a great many hollows bear names which do not tell us

how they originated. Names such as Hell Pit, Hag's Pit, Smokers Hole, Dunfer Hole and Thief's

Pit tell us only that they have been landscape features since their names were first recorded. Early estate maps likewise show that many hollows existed in the sixteenth and seventeenth century, not how they came to be there. On the other hand, eighteenth and nineteenth century records fail to state precisely the location of the pits. Account books generally state what quantities were spread on a particular farm, but rarely from which field the material was obtained. Again, there is much less documentary evidence for marling in the densely pitted areas in mid-Norfolk, east of Attleborough, Dereham and Fakenham, than in west Norfolk. All that can be stated with certainty from available historical records is that many hollows of uncertain origin existed in Nor-

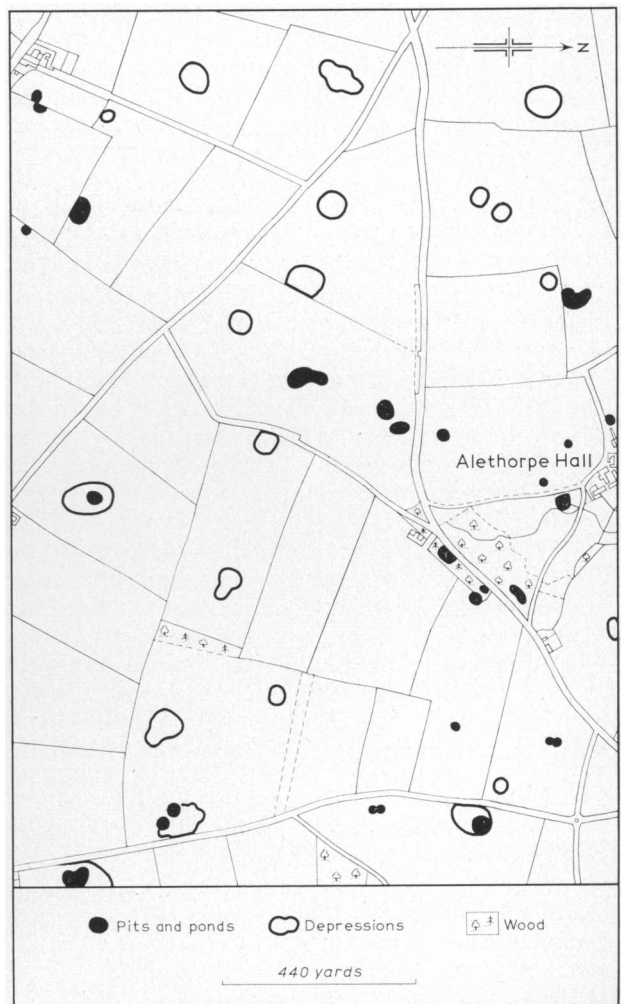


Fig. 17: Pits, ponds and shallow depressions near Alethorpe Hall.

Grid ref. 125/950310. Based on examination of Air Ministry air photograph taken in 1946 and field survey in August 1958.

<sup>46</sup>) OLDERSHAW, A. W., and GARNER, H. V.: Light Land Experiments at Tunstall, Suffolk. Journ. Roy. Agric. Soc. 105, 1944. 98; OLDERSHAW, A. W., and GARNER, H. V.: Liming Experiments on Light Land at Tunstall. Journ. Roy. Agric. Soc. 110, 1949. 89.

<sup>47</sup>) Statistics collected by the Agricultural Lime Department of the Ministry of Agriculture, cited in GARDNER, H. W., and GARNER, H. V.: The Use of Lime in British Agriculture. London 1953. 197.

<sup>48</sup>) HALES, THOMAS: A Compleat Body of Husbandry. London 1756. 46.

<sup>49</sup>) "N": The State of Husbandry in Norfolk. Gentleman's Magazine 22, 1752. 453.

Table IV: Comparison of pits marked on early maps with those shown on 1946 air photographs

	GREAT MASSINGHAM				WEASENHAM				CASTLE ACRE					
	Shown as Pits on 1946 air photographs	Shown as Depressions on 1946 air photos	Pits on early maps not shown in 1946	Total pits shown on early maps	Shown as Pits on 1946 air photographs	Shown as Depressions on 1946 air photos	Pits on early maps not shown in 1946	Total pits shown on early maps	Shown as Pits on 1946 air photographs	Shown as Depression on 1946 air photos	Pits on early maps not shown in 1946	Total pits shown on early maps		
1728-44 Pits	9	3	0	12	1779 Pits	1	0	0	1	1779 Pits	3	2	2	7
1833 New Pits	5	2	3	10	1844 Old Pits	1	2	7	10	1844 Old Pits	11	3	6	20
1884 New Pits	24	1	1	26	1844 New Pits	17	7	1	25	1844 New Pits	17	10	8	35
1946 Hollows not shown on early maps	0	17			1946 Hollows not shown on early maps	14	11			1946 Hollows not shown on early maps	15	16		
Total shown on 1946 air photographs	38	23			Total shown on 1946 air photographs	33	20			Total shown on 1946 air photographs	46	31		

folk at the end of the sixteenth century; and a great deal of marl was dug from unidentified pits in west Norfolk during the eighteenth and nineteenth century.

In north-west Norfolk close inspection of the ground and recent air photographs reveals that in addition to steep-sided pits and ponds there are many broad shallow depressions which are ploughed over and cultivated (Fig. 17). The shallow depressions appear to be smoother, rounder and generally larger than the steep-sided pits, which are occasionally situated within them or at their edges. They may be explained in two different ways: either they mark the sites of man-made pits that have been abandoned and perhaps deliberately filled in; or they are natural hollows. If they are filled-in pits we may expect to find some of them marked as pits on early maps; indeed, all pits marked on early maps, except those obliterated by buildings, embankments and cuttings, ought to be discernible on air photographs either as pits or as shallow depressions.

Recent air photographs of parts of three west Norfolk parishes show that steep-sided pits are about 50% more numerous than shallow depressions (Table IV); but whereas about three-quarters of the present pits can be identified on early estate maps, only about two-fifths of the shallow depressions are represented. At Great Massingham (Fig. 18), all present day pits are recorded on previous surveys, but only 6 of the present 23 shallow depressions are previously mapped as pits or ponds. Some of the oldest

hollows are still steep-sided pits. Of 12 pits marked on a map of 1728-1744, 9 are pits at the present time, and the others can be recognised as shallow depressions. If evidence for the other two estates were as clear as this we might conclude that a large number of shallow depressions originated before eighteenth and nineteenth century marling began. This is much less certain at Weasenham (Fig. 19). A comparison of R. N. BACON'S map in 1844 with recent air photographs shows that almost half the present pits are not recorded in 1844, and 8 out of 35 pits marked on the 1844 map cannot be located on air photographs. Digging during the past century may account for some new pits appearing on air photographs, but how are the 8 missing nineteenth century pits to be accounted for? If we dismiss the possibility that the surveyor erroneously recorded non-existent pits, we must acknowledge that not all hollows or traces of hollows may be detected on air photographs. Some may be concealed by crops or woodland vegetation, others may have been completely erased by filling in, weathering and cultivation. At Castle Acre (Fig. 20), 16 pits marked on early surveys are not shown on air photographs, and nearly one-third of the present pits are not previously recorded. At both Weasenham and Castle Acre over half the present shallow depressions are not accounted for on early maps. Some, if not all these, may be filled-in pits dug before the eighteenth century, but some may well be the result of natural processes.

### Sink Holes

Solution or ice action may have contributed to the formation of depressions. The presence of sink holes due to solution of calcium carbonate by rainwater and other weak acids, and the collapse of the surface into underground cavities is suggested by the fact that chalk lies beneath the most densely pitted parts of Norfolk. Pipes, subsidences and the Breckland meres are cited as visible evidence of the effect of chemical weathering.

Enclosed depressions have been described repeatedly as the fundamental and essential units of limestone topography and are also characteristic of the English chalklands<sup>50</sup>). In Norfolk most hollows lie to the east of the chalk outcrop and are underlain by chalk at depths increasing from a few inches in the Breckland to about 100 feet between Norwich and Cromer. East of Norwich the chalk plunges beneath a thick cover of Eocene and more recent crag formations to a depth of almost 600 feet at Yarmouth<sup>51</sup>). There are very few hollows in the eastern coastal areas, but no less than 2000 in the west lie beyond the edge of the chalk in the Greensand Belt. Many of the latter are situated on intensely chalky boulder clay containing almost as much calcium carbonate as chalk itself and similarly subject to chemical weathering<sup>52</sup>). The few hollows present on exposures of Lower Greensand and other non-calcareous rocks older than chalk are unlikely to have been formed by solution. The sink hole hypothesis cannot therefore claim to account for all hollows. Again, if solution features are formed in solid chalk they should be most numerous in the Breckland where the chalk lies close to the surface and is exposed to the maximum effect of weathering processes.

Solution undoubtedly produced the vertical or diagonal pipes exposed in quarries and other sections cutting through the chalk<sup>53</sup>). Varying in size from 6 inches to 100 feet across, they are filled with material derived from overlying strata

or from the surface soil. Nests of gravel or coarse sand, known locally as "sand galls", are a distinctive feature of Norfolk pipes<sup>54</sup>). The surface above is sometimes level with the surrounding country but sometimes forms a circular depression several feet in diameter. Depressions may be smooth and regular in outline, or broken and fissured where recent subsidence has disturbed the surface.

Sink holes may subside with dramatic suddenness. H. B. WOODWARD reports many eye-witness accounts of hollows appearing in the country around Norwich, and similar incidents in other parts of Norfolk observed in past centuries are recorded by WILLIAM WHITAKER<sup>55</sup>). A "cave in" may be precipitated by the passing of a farm cart or a heavy downpour of rain, and may be accompanied by an eruption of water displaced by the sudden fall of earth from the roof of a cavity. By contrast, the ground may subside slowly over a wide area. This is how Mannington Mere is reported to have originated in 1704<sup>56</sup>). Subsidence may be a result of human activity caused by the collapse of galleries of ancient flint mines and bell pits, producing a pitted surface like that at Grimes Graves near Brandon or Broom's Hill near Thetford<sup>57</sup>).

The steep-sided circular or elliptical meres in the Breckland have been described as "*swallow holes due to solution of the chalk, and possibly in some cases collapse of the surface into underground cavities*"<sup>58</sup>). The largest of these hollows are situated on a flat surface some 120 to 180 feet above sea level where the chalk is very thinly covered with deposits of sand, flint gravels and yellowish chalky boulder clay. Between the large meres such as Fowlmere (Fig. 21) are hundreds of small depressions, less than one acre in extent, but similar in form. Within an area of three square miles around Fowlmere lie 50 such hollows which are

<sup>54</sup>) WOODWARD, H. B.: *The Geology of England and Wales*. 2nd. Edit. London 1887. 422.

<sup>55</sup>) WOODWARD, H. B.: *Earthquakes and Subsidence in Norfolk*. Trans. Norfolk and Norwich Naturalists' Society 3, 1884. 637—643; WOODWARD, H. B.: *Geology of Soils and Substrata*. London 1912. 64; WHITAKER, WILLIAM: *The Water Supply of Norfolk*. Geol. Survey Memoir. London 1921. 40.

<sup>56</sup>) WOODWARD, H. B.: loc. cit. 1884. 641.

<sup>57</sup>) EVANS, SIR JOHN: *On some cavities in the gravel of the valley of the Little Ouse in Norfolk*. Geol. Mag. 5, 1868. 443—447; CLARKE, R. R.: *East Anglia*. London 1960. 51—58.

<sup>58</sup>) JONES, O. T., and LEWIS, W. V.: *Water levels in Fowlmere and other Breckland meres*, Geog. Journ. 97, 1941. 158. Reference is made to the earlier work done by MARR, J. E.: *The Meres of Breckland*, Proc. Camb. Phil. Soc. 17, 1913. 58—61, which also concluded that the meres originated as solution depressions.

<sup>50</sup>) The fullest recent account appears in CORBEL, JEAN: *Les karsts du nord-ouest de l'Europe et de quelques régions de comparaison*, Inst. Etudes. Rhodan. Lyon 1957. COLEMAN, A., and BALCHIN, W. G. V.: *The origin and development of surface depressions in the Mendip Hills*. Proc. Geol. Assoc. 70, 1959. 291—306, reviews English studies of karstic depressions.

<sup>51</sup>) WOODLAND, AUSTIN W.: *Water Supply from underground sources of Cambridge-Ipswich district*. Geological Survey Wartime Pamphlet 20, Parts I—X. London 1942—1946, provides details of well borings in south Norfolk.

<sup>52</sup>) WOODWARD, H. B.: *The Geology of the Country around Norwich*. Mem. Geol. Survey. London 1881. 120, 134, refers to an abundance of pipes in glaciated chalk and chalky boulder clay.

<sup>53</sup>) WOODWARD, H. B.: op. cit. 1881. 9.



Fig. 21: Air view of Fowlmere.

Grid ref. 136/879895.

(Photo J. K. S. St. Joseph, copyright reserved)

also claimed to be sink holes<sup>59</sup>). Fluctuations in the level of water in these meres are related to long-term changes in the height of water in the underlying chalk, from which they are presumed to be fed by pipes.

Apart from the sink holes in the Breckland few hollows in Norfolk penetrate deeply into solid chalk, and there is little evidence that any solution took place in the long interval between the end of Cretaceous times and the beginning of the Pleistocene. It has long been noted that pipes examined in chalk quarries contain few traces of material derived from strata older than glacial drift<sup>60</sup>). Among the oldest solution features in Norfolk are the tubular stacks on the coast at Sheringham, containing sand of Weybourne Crag age<sup>61</sup>). If the formation of hollows was initiated by solution we should expect to find evidence of the process at work in Eocene and later times, because the surface of the Upper Chalk appears not to have been bevelled, nor can it have lain below water throughout this period.

#### *Kettle holes and thaw sinks*

Almost all the hollows in Norfolk are situated in areas covered by glacial drift. They are most numerous where the drift attains a thickness of more than ten feet, least numerous where it is

thinnest. They occur infrequently on older formations, and are absent from areas covered by post-glacial deposits of peat and alluvium. The possibility that they were formed under glacial or periglacial conditions cannot be ignored.

Under glacial conditions kettle holes may be formed by detached masses of stagnant ice embedded within the drift melting slowly to cause a gradual subsidence of the surface<sup>62</sup>). Such hollows are frequently larger in size than the majority of Norfolk hollows, and also irregular in shape. They are characteristic features of outwash plains not boulder clay plains such as those of Norfolk. They frequently follow the courses of buried pre-glacial valleys as kettle-chains; whereas the majority of hollows in Norfolk are situated on flat interflaves.

In 1868 OSBORNE FISHER suggested a glacial origin for some of the Breckland meres on the basis of his examination of Rockland Mere, an enclosed depression about 8 feet deep, excavated in boulder clay<sup>63</sup>). The floor of the mere is covered with unsorted masses of clayey gravel and large flints derived from the boulder clay, upon which lies a layer of peat. The validity of the glacial hypothesis here rests on two essential conditions: that the hollows are cut entirely into glacial drift; and that they have been produced during the last glaciation of the district because hollows formed during the deposition of older drifts would have been filled in or modified by erosion during subsequent glaciations. It is now established that neither of these conditions is fulfilled in the Breckland, nor in other parts of the county. The floors of several meres notch the surface of the chalk, below the level of the glacial drift which might have contained embedded ice masses. The meres also lie beyond the limit of most recent drift deposits in north Norfolk. Indeed, enclosed depressions are most numerous in areas of Lowestoft till and are present in areas of yet older North Sea drift.

If hollows were formed after the glacial drifts had been laid down, their presence in older as well as newer drift might be accounted for. In Poland, Germany, Holland, Belgium and France, yet not in comparable situations in England, hollows similar to those in Norfolk have a periglacial origin ascribed to them<sup>64</sup>). In order to

<sup>62</sup>) Their mode of origin is discussed at length in THWAITES, F. T.: *Outline of Glacial Geology*. Madison 1953, 47—49, and THORNBURY, WILLIAM D.: *Principles of Geomorphology*. New York 1954. 392.

<sup>63</sup>) FISHER, OSBORNE: *loc. cit.* 1868. 557—558.

<sup>64</sup>) References to previous work are cited in CAILLEUX, ANDRÉ: *Les mares du sud-est de Sjælland, Danemark*. S. R. S. de l'Acad. Sciences 245, 1957. 1074—1076; and PISSART, A.: *Les dépressions fermées de la région parisienne*. *Rev. Géom. Dyn.* 9, 1958. 73—83.

<sup>59</sup>) JONES, O. T., and LEWIS, W. V.: *loc. cit.* 166.

<sup>60</sup>) FISHER, OSBORNE: *On the Denudations of Norfolk*. *Geol. Mag.* 5, 1868. 546.

<sup>61</sup>) BURNABY, T. P.: *The Tubular chalk stacks of Sheringham*, *Proc. Geol. Assoc.* 61, 1950. 226—241.

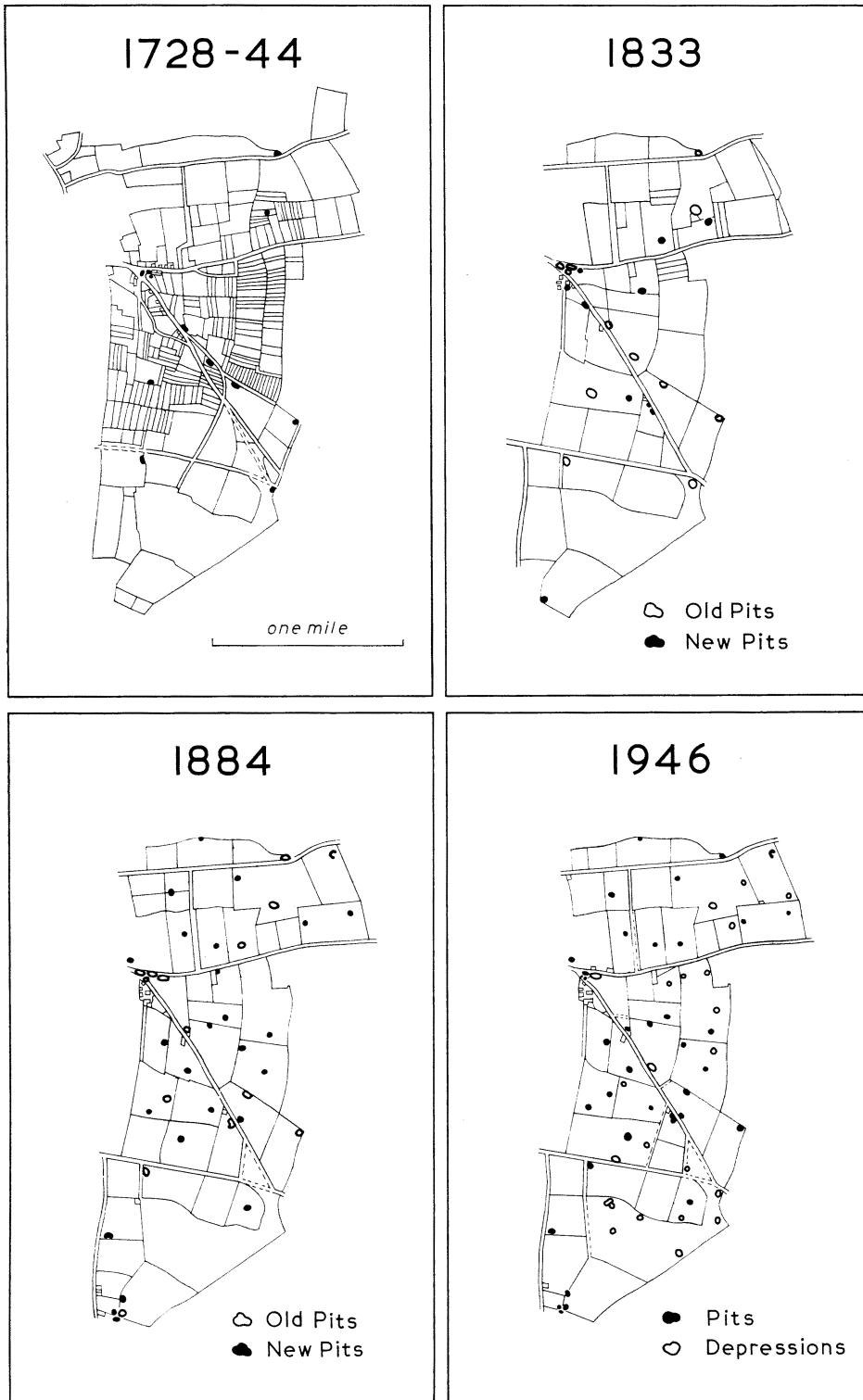


Fig. 18: Pits, ponds and shallow depressions at Great Massingham.  
Based on Holkham Estate maps (1728-44, 1759, 1779, 1833), Ordnance Survey maps (1884) and air photographs (1946).

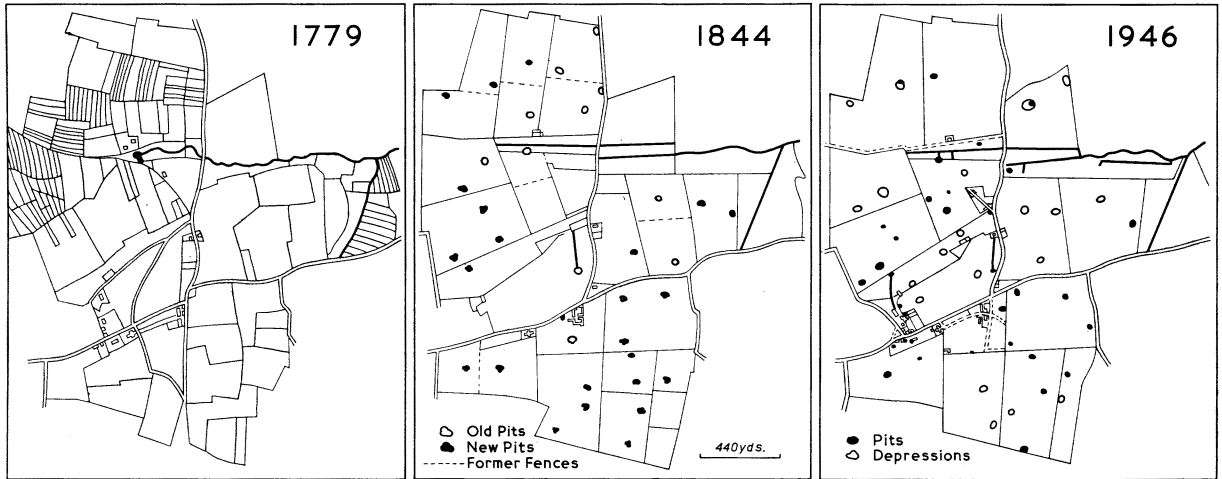


Fig. 19: Pits, ponds and shallow depressions in Weasenham. Based on Holkham Estate maps (1779), R. N. BACON'S map (1844) and air photograph (1946).

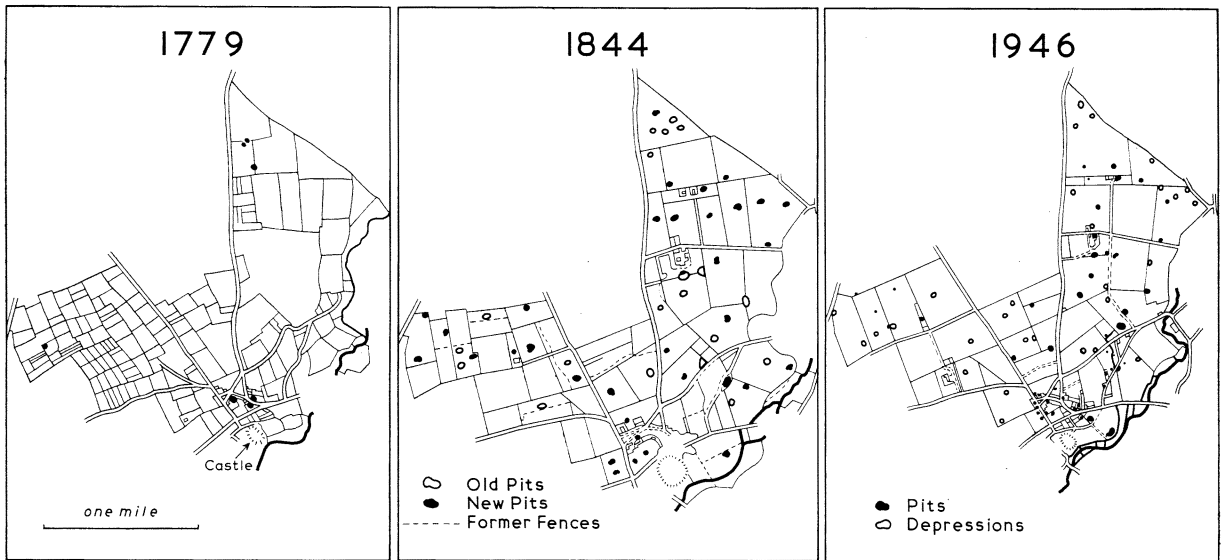


Fig. 20: Pits, ponds and shallow depressions at Castle Acre. Based on Holkham Estate maps (1779), R. N. BACON'S map (1844) and air photographs (1946).

establish a relationship between the continental hollows and those in Norfolk we must determine their age. Stratified deposits of mud, fossil soils, peat containing appropriate flora and fauna have not yet been examined in this context, but evidence for other forms of periglacial action in Norfolk is accumulating. Festooning and contortions in the drift have been widely reported and extensively discussed<sup>65</sup>). An explanation proposed

1865. 324; TAYLOR, J. E.: On a disturbance of the chalk at Swainsthorpe. *Geol. Mag.* 3, 1866. 44; FISHER, OSBORNE: On the Warp (of Mr. Trimmer), its age and probable connection with the last geological events. *Quart. Journ. Geol. Soc.* 22, 1866, 553—565; WOOD, S. V., Jun: On a section at Litcham affording evidence of land glaciation during the earlier part of the glacial period in England. *Geol. Mag.* 4, 1867, 78—79; WOOD, S. V., Jun: and HARMER, F. W.: The glacial and post-glacial structures of Norfolk and Suffolk. *Geol. Mag.* 5, 1868. 452—456; WOOD, S. V., Jun: On a peculiar instance of interglacial erosion near Norwich. *Geol. Mag.* 6, 1869. 226—227; TAYLOR, J. E.: On certain phenomena in the drift near Norwich. *Geol. Mag.* 6, 1869. 508—509; WOODWARD, H. B.: On a disturbance of the chalk at Trowse near Norwich. *Geol. Mag.* Decade II 6, 1879. 380; WOODWARD, H. B.: Disturbances in the chalk of Norfolk. *Geol. Mag.* Decade II 8, 1881. 93—94.

<sup>65</sup>) The data on superficial disturbances in the drift collected in the nineteenth century has been largely neglected in recent studies and might prove worth re-examining in the light of present knowledge of periglacial phenomena. Such notes appear in TAYLOR, J. E.: On a displacement of the chalk at Whitlingham. *Geol. Mag.* 2,



during the nineteenth century was that they were formed by pressure and displacement by ice and superincumbent drift, but GEORGE SLATER in 1926 demonstrated that this explanation failed to account for the whole structures and preferred to interpret them as features of "fossil glaciers"<sup>66</sup>). The "erratic warp" and "trail" of coarse materials filling throughs and hollows are now considered by G. G. DINES, S. E. HOLLINGWORTH and others to be solifluction deposits composed of detached and comminuted rocks rearranged after the thawing of ice<sup>67</sup>). Fossil ice wedges, polygonal structures and solifluction deposits are described in the Cambridge region<sup>68</sup>). Stone stripes are observed in the Breckland<sup>69</sup>). In other parts of southern England and the Midlands many comparable surface features are now identified as periglacial phenomena. The evidence for such conditions having existed in Norfolk is beyond reasonable doubt.

Circular or elliptical depressions ranging from 10 to 1000 feet across are characteristic of areas of perennially frozen ground in Siberia and Alaska<sup>70</sup>). They are most frequent on flat surfaces and are not known to occur on slopes of more than 5°. Depressions are most numerous where the top of the perennially frozen zone, the tjaele, lies between 10 and 75 feet below the surface; none occur where the frozen ground is more than 100 feet below<sup>71</sup>). Depressions are observed in deep residual soils, lake clays, fine silts, clay loams and other fine-grained porous materials. They rarely occur in sands and are not found in gravel. Silt, which in its unfrozen state has a porosity of about 20—30%, may contain as much as 80% ice by volume when frozen<sup>72</sup>). It is banded with horizontal layers of clear ice, sometimes in the form of tabular or lenticular masses, broken

vertically by ice veins or wedges<sup>73</sup>). Horizontal ice lenses tend to concentrate in the upper layers of frozen ground and may coalesce with the thick ends of ice wedges. In fine-grained materials highly charged with ice any difference in the rate and depth of thawing may be expected to produce local subsidence from shrinkage in volume. Differences in the thermal conductivity of bodies of peat, silt, gravel, ice or water in the surface layer would cause differences in the depth of thawing<sup>74</sup>). HOPKINS illustrates a hypothetical example of frozen ground initially blanketed by a well insulated layer of peat, in which a disturbance of the peat by frost heaving, exposes a patch of bare ground. The greater conductivity of the bare ground results in deep thawing and consequent subsidence. Water collects in this hollow and further increases the extent of thawing. Small areas of exceptionally deep thaw tend to be self-perpetuating and self-enlarging and may eventually penetrate beneath the zone of permanently frozen ground to form thaw sinks of great depth and funnel-like shape. HOPKINS believes that the form of such hollows "could be achieved only by the removal of considerable material from the floor" by small streams carrying it into subterranean channels below the frozen zone<sup>75</sup>). If underground drainage takes place the presence of a permeable substratum below the frozen zone is assumed.

In shape and size the hollows observed in Alaska closely resemble those in Norfolk, and their situation is comparable. Norfolk hollows are most frequent on level or gently sloping ground. They are absent on recent deposits of peat and alluvium and are densely concentrated on the retentive boulder clay soils of mid-Norfolk and south Norfolk. An appreciable number, however, occur in west Norfolk where the chalk is thinly mantled with sand. It is possible that the finely disintegrated frozen chalk, often described by Norfolk geologists as disturbed or glaciated chalk, would have some capacity for holding ground ice but less than silt or clay. The underlying chalk would also provide a permeable substratum into which thaw sinks might drain.

Many Norfolk hollows appear to be almost as deep and steep-sided as those observed in Alaska; but the Alaskan hollows are now being formed

<sup>66</sup>) SLATER, GEORGE: Glacial tectonics as reflected in disturbed drift deposits. Proc. Geol. Assoc. 37, 1926. 392—400.

<sup>67</sup>) DINES, H. G., HOLLINGWORTH, S. E., EDWARDS, W., BUCHAN, S., WELCH, F. B. A.: The Mapping of head deposits. Geol. Mag. 77, 1940. 202—203.

<sup>68</sup>) PATERSON, T. T.: The effects of frost action and solifluction around Baffin Bay and in the Cambridge district. Quart. Journ. Geol. Soc. 96, 1940. 99—130.

<sup>69</sup>) WATT, A. S.: Stone stripes in Breckland, Norfolk. Geol. Mag. 92, 1955. 173.

<sup>70</sup>) TRICART, JEAN: Le Modele periglaciaire. Cours de geomorphologie. T. II, i. Paris n. d. 230—234, reviews recent accounts of periglacial depressions, the most important being HOPKINS, DAVID M.: Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska. Journ. Geol. 57, 1949. 119—131.

<sup>71</sup>) ROCKIE, W. A.: Pitting on Alaskan farmlands, a new erosion problem. Geog. Rev. 32, 1942. 134.

<sup>72</sup>) TABER, STEPHEN: Perennially frozen ground in Alaska, its origin and history. Bull. Geol. Soc. America 54, 1943. 1518.

<sup>73</sup>) WERNECKE, L.: Glaciation, depth of frost and ice veins of Keno Hill and vicinity, Yukon Territory. Eng. and Mining Journ. 133, 1932. 41.

<sup>74</sup>) Conversely, PORSILD, A. E.: Earth mounds in unglaciated arctic northwestern America. Geog. Rev. 28, 1938. 46—58, suggests that differences in the rate of ice accumulation may cause upheaval, producing ground ice mounds or pingos. SHARP, ROBERT P.: Ground ice mounds in the Tundra. Geog. Rev. 32, 1942. 417—423 adds that the collapse of ground ice mounds accounts for the small pools characteristic of the tundra surface.

<sup>75</sup>) HOPKINS, DAVID M.: loc. cit. 1949. 130.

by periodic thawing above perennially frozen ground. In Norfolk the ground has long ceased to be deeply frozen and we must consider what changes may have taken place as a result of complete thawing. If fine-grained materials shrink and subside uniformly on thawing, the result of complete thawing may be to equalise the local differences initiated by uneven thawing. In other words, we should expect remnants of frozen silt eventually to subside to more or less the same level as the original depressions. Only over-deepened thaw sinks may persist because of the sapping of their floors by underground streams presumed to exist in a permeable substratum.

If thaw sinks initiated by mechanical processes under periglacial conditions survived eventual thaw of ground ice they may have become greatly enlarged by chemical weathering under colder climatic conditions than those now prevailing<sup>76</sup>). Solution varies directly with the amount of water and carbon dioxide available, and these are present in greater quantities under cold conditions than warm. Air within a snow bank is concentrated with carbon dioxide; rain or meltwater passing through snow is at the optimum temperature for absorbing it; and the ground beneath, while unfrozen, is likely to be nearly saturated. In

<sup>76</sup>) WILLIAMS, JOSEPH E.: Chemical weathering at low temperatures. *Geog. Rev.* 39, 1949. 129—135; CORBEL, JEAN: *op. cit.* 1957. 11, 496.

addition, the solubility of calcium carbonate increases very slightly with a decrease in temperature. Under the present warm dry climate of Norfolk solution must operate less vigorously than formerly, yet it is still evident. It is possible that many natural depressions originated under periglacial conditions and were enlarged by chemical weathering.

#### *Conclusions and conjectures*

Apart from the distinctive irregular modern quarries and large circular Breckland meres, the pits and ponds of Norfolk appear to be much alike in shape and size. What distinguishes them is their uneven distribution: their presence upon glacial drifts, their absence from recent peat and alluvium; their concentration on heavy land, their sparseness on light land; their abundance on flat surfaces, their fewness on steep slopes. No single explanation adequately accounts for all hollows in these different situations. It seems certain from historical evidence that many pits owe their present form to man's activity, either as mineral workings or as marl pits. It may yet be proved that most marl pits have been dug on the sites or depressions which originated under periglacial conditions or on hollows formed by the solution of underlying chalk or chalky drift. In that case it may be demonstrated that man has merely adapted these hollows for his own use.

## "SÖLLE" AND "MARDELLES"

### Glacial and Periglacial Phenomena in Continental Europe

CARL TROLL

*Zusammenfassung:* „Sölle“ und „Mardellen“ in der Glazial- und Periglaziallandschaft des festländischen Europa.

Die meisten der von H. C. PRINCE im vorstehenden Artikel beschriebenen Hohlformen aus Norfolk entsprechen den sog. Söllen (Sing. Soll) der nordmitteleuropäischen Grundmoränenlandschaften. Über sie gibt es eine ausführlichere ältere Literatur, die von W. RÖPKE (1929) zusammengefaßt wurde. Von den Möglichkeiten der Erklärung waren zwei noch in neuerer Zeit übriggeblieben: die Sölle als subglaziale Strudellöcher oder als Toteiskessel. Die Erklärung durch Toteis-Ausschmelzung war von RÖPKE zu der „Intramoräneneis-Schmelztheorie“ variiert worden.

Der Toteistheorie steht entgegen, daß die in geschichteten fluvioglazialen Ablagerungen vorkommenden, einwandfreien Toteisformen meist verschieden große und unregelmäßig geformte, vielfach zerlappte Senken sind, während die Sölle immer kleine, kreisrunde oder ovale Kessel darstellen.

Gerade dies kann eine neue „Pingo-Theorie“ erklären. Nach ihr sind die Sölle die Reste von periglazialen Eischwellungshügeln (Eskimoname „Pingo“), die nach der Abschmelzung eine kreisrunde Mulde mit einem sie um-

gebenden flachen Ringwall hinterlassen, also Austauseen („Thaw lakes“) im Sinne von D. M. HOPKINS. Der Nachweis dieser Entstehung ist von MAARLEVELD und VAN DEN TOORN für ein Soll in holländisch Friesland, also in der Altmoränenlandschaft geführt worden. Für die Mardellen des Pariser Beckens, des Hohen Venns, der Landes und Lothringens ist die neue Pingo-Theorie ebenfalls herangezogen worden. Für die Sölle der Jungmoränenlandschaften in der Umgebung der Ostsee müßte man bei dieser Erklärung annehmen, daß sich nach dem Rückzug des letzteiszeitlichen Inlandeises in das Ostseebecken noch Dauergefrorenis gebildet habe.

Most of the Norfolk pits and ponds described by H. C. PRINCE in the preceding paper are circular or elliptical basins of regular shape and little extent, usually smaller than an acre. They fully correspond to the "sölle" of the ground-moraines of Northern Central Europe, which are found all over the Netherlands, Denmark, Northern Germany and Poland. The "sölle"