Cumann Staidéar Ré Cheathartha na hÉireann
Irish Quaternary Association
Field Guide 24

The Quaternary of Kilkenny (with particular emphasis on the Castlecomer Plateau)

Susan Hegarty

Field Guide no. 24

The Quaternary of Kilkenny
(with particular emphasis
on the Castlecomer Plateau)
(2002)

Susan Hegarty

ISBN: 0947920307
ISSN: 0790410x

PREFACE AND ACKNOWLEDGEMENTS

In recent years, much of the focus of Quaternary field meetings in Ireland has been on areas in the north and west of the country. While it is acknowledged that these areas are both stunning in the beauty and in the complexity of their sediments, we often have the danger of overlooking other areas, equally complex and which were 'under' the heart of the last Irish Ice Sheet. It is in an attempt to in some way repair this that this year's IQUA field excursion heads to Kilkenny. One of the problems with looking at areas in the Midlands is the difficulty in finding adequate exposure, particularly into tills. This problem is also present within Kilkenny. While gravel pits are abundant (although many are now worked out), till exposures are difficult to come by. Sorry for anyone who longs for tills, we'll try our best!

This field guide was compiled for the 2002 Irish Quaternary Association (IQUA) autumn fieldtrip. The information used in the guide was gathered as part of a Ph.D. thesis and the work is therefore ongoing as the final version of this thesis has not yet been submitted. The 'Kilkenny Project' started life as a venture between the geography department in UCD, the Geological Survey of Ireland and Kilkenny County Council as the first stage of mapping for the Kilkenny County Groundwater Protection Scheme. The field guide and field trip will focus mainly on the area of the Castlecomer Plateau. This is due both to time constraints and to a particular focus of thesis work in this area.

Thanks are due to many that have made this field guide possible. The Geography department and all its staff, particularly Dr. Colman Gallagher who has supervised the work; the Geological Survey of Ireland, particularly the staff of the Quaternary section under Dr. William Warren and also Groundwater and all those 'down the corridor'; Kilkenny County Council who sponsored the work; all pit owners and landowners, no matter how small the land but without whose cooperation fieldwork is impossible. Particular thanks are due to Dunmore Cave and the pit managers who have given permission for us to take a look at their sites today. Many, many others have to be thanked, but that will be done at a later stage.

Programme

12th October - The Castlecomer Plateau

9:30 Meet outside the gate of Kilkenny Castle (entrance nearest to town - in the car park)

10:15 Overview of Kilkenny from hillside of the Castlecomer Plateau

10:30 Ballyfoyle channels (the area around NGR S530630)

11:30 Dunmore Cave (NGR S508650)

Box Lunch

2:00 Namurian till site (possibly Ormonde Brick quarry, NGR S572751)

3:15 Limestone till site Croghteenclogh (NGR S601740)

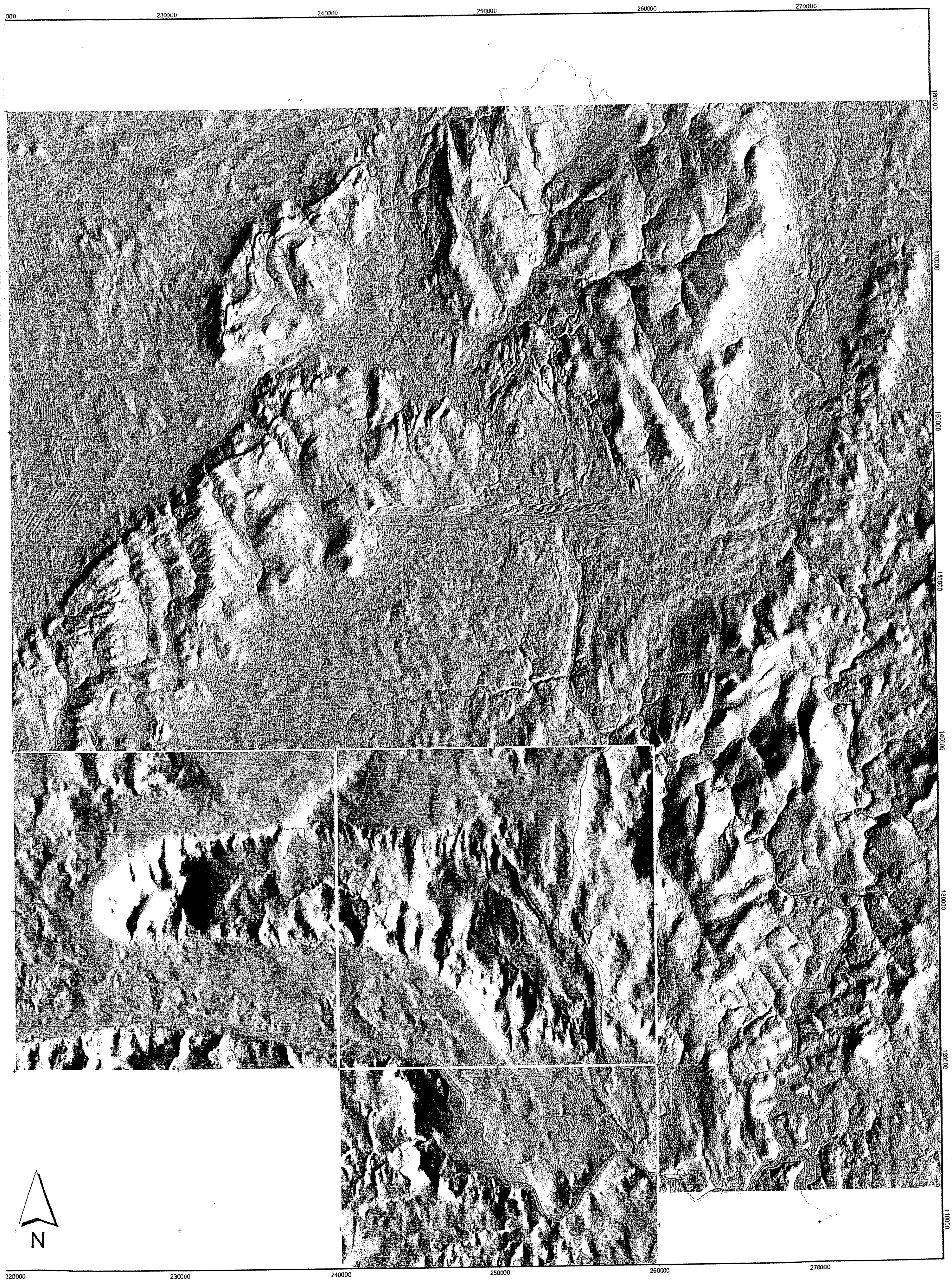
4:30 Nore Gravels - Readymix Gravel Pit, Dunmore (NGR S503598)

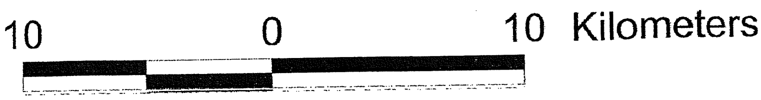
Sunday 13th October

10:00 Meet outside the gate of Kilkenny Castle (entrance nearest to town - in the car park)

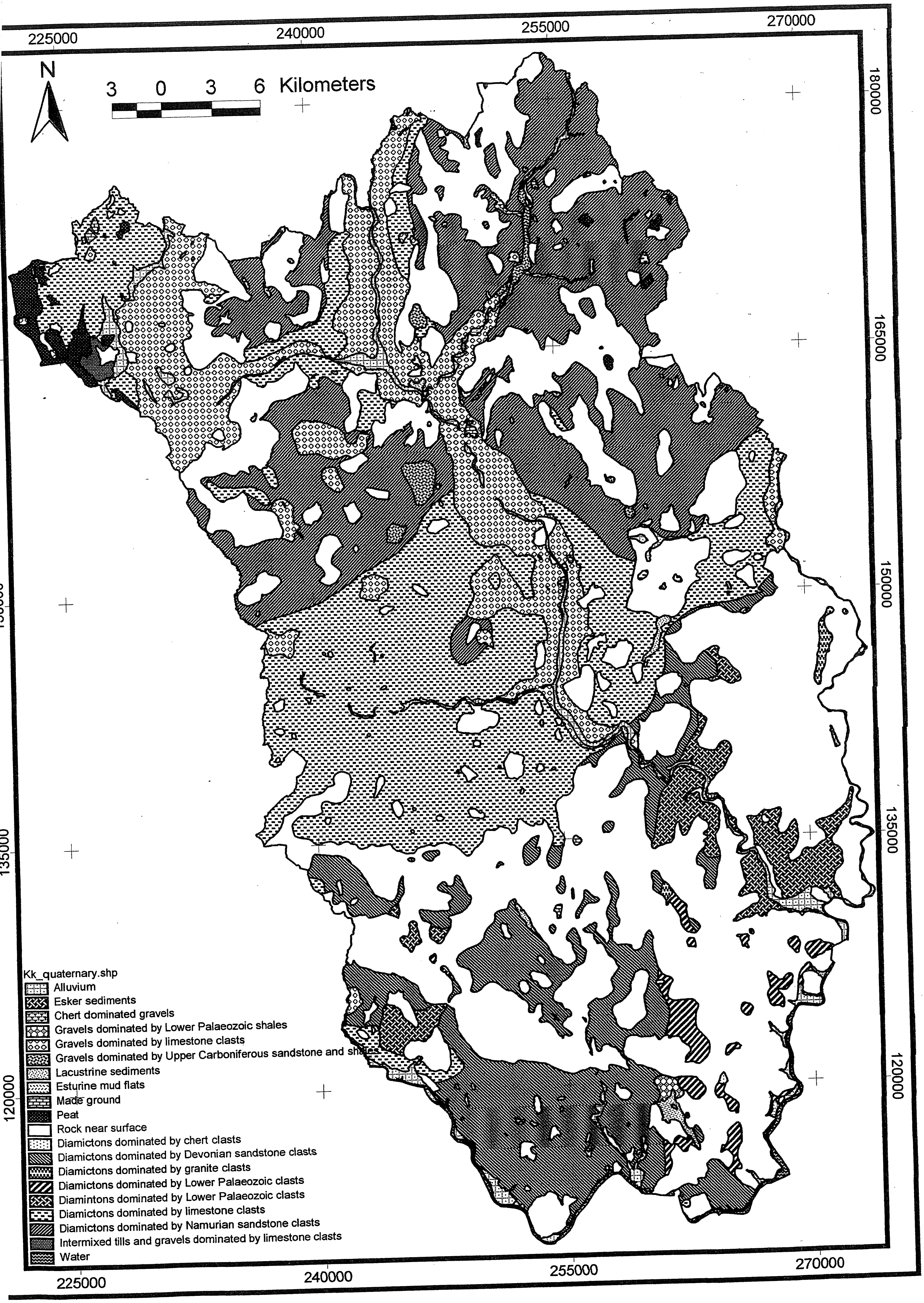
11:30 Hennesy's Gravel Pit, Bennetsbridge (NGR S550507)

12:30 Pingos at Cashel (NGR S496211)

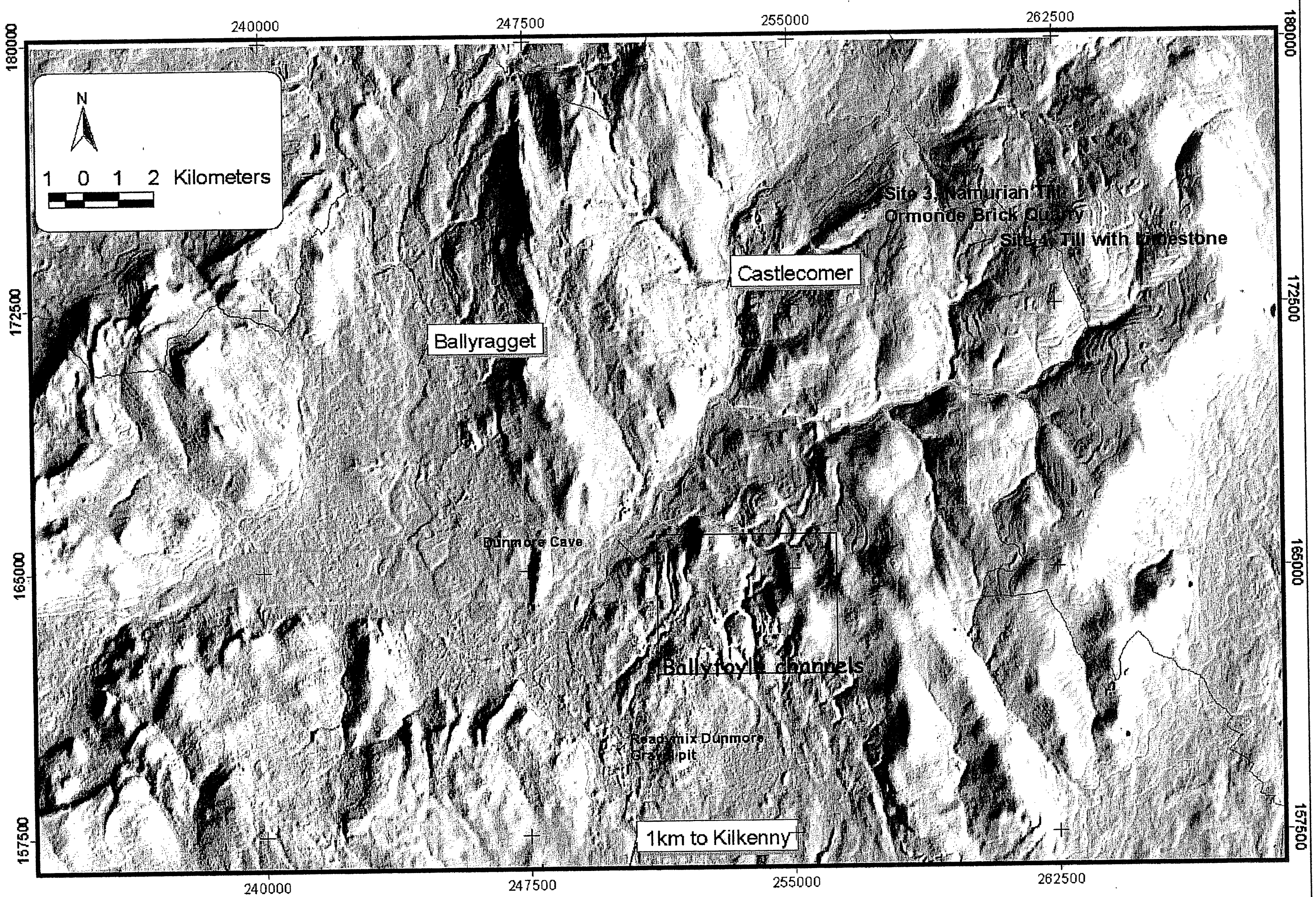




igital Elevation Model of County Kilkenny and adjacent eas.
ie majority of the DEM is 10m resolution, although the ea in the southwest is a 50m resolution DEM. Source: rdnance Survey of Ireland data



Map of the Quaternary sediments of Kilkenny. Source: S. Hegarty.



Field sites, day 1. The 10m DEM is shaded from 90 degrees with an azimuth of 60 degrees.

Introduction

Study area

County Kilkenny is a county of 2,062 km^2. The largest urban area in the county, Kilkenny City, is located in the centre of the county, while other important towns in the area include Callan, in the west, Castlecomer in the north and Graiguenamanagh in the east. The county stretches as far south as Waterford City, parts of which are slowing encroaching on the county of Kilkenny, leading at times to conflicts between the two local authorities.

The three major rivers of the area are the Nore, the Suir and the Barrow, collectively known as the 'Three Sisters'. The Nore, on which Kilkenny City is built, flows through the centre of the county over Carboniferous limestones and swings eastwards at Thomastown to enter the gorge in the upland area of Devonian sandstone and Ordovician rocks of the south. It continues to flow within this deeply incised valley, on through Inistioge, until its confluence with the Barrow, 2km to the north of New Ross.

The Barrow forms a great part of the eastern boundary of the county, where Kilkenny boarders counties Carlow and Wexford. It flows for the most part from north to south, through the towns of Goresbridge and Graiguenamanagh. Nine kilometres to the north of Graiguenamanagh, the Barrow enters the upland area of the Leinster granites. It flows, like the Nore, within a deeply incised gorge firstly though the granites and later through the Ordovician shale rocks to where it joins the Suir at Cheekpoint.

The River Suir forms Kilkenny's southern boarder with County Waterford. It enters the county over the limestones of the Carrick-on-Suir syncline 2km to the east of Carrick-on-Suir. From here it flows eastwards through the northern part of Waterford City to Cheekpoint, where it is joined by the River Barrow. From Cheekpoint onwards, the newly augmented river Suir flows on to enter the sea at Waterford Harbour.

Topographically, the area can be divided into five distinct regions:

- Northern Uplands
- Galmoy Lowlands
- Central Kilkenny Lowlands
- Southern Uplands
- Carrick-on-Suir syncline

The Northern Uplands, composed of Upper Carboniferous rocks, are made up of the Castlecomer Plateau in the north of the county and the Slieveardagh Hills, a ridge running southwest – northeast in the northwest of the county with a further section to the north of the main ridge around Gattabaun. The highest points of the Castlecomer Plateau are on the Upper Carboniferous sandstones at Mountnugent Upper (334m OD), while the Slieveardagh Hills reach heights of 333m OD at Ballybeagh and 340m OD at Knocknamuck, in County Tipperary.

Glacial and De-glacial studies of Kilkenny.

Relatively little has been written on the glacial history of the southeast of Ireland, and in particular on the area around county Kilkenny, since Quaternary studies came to light in Ireland in the mid nineteenth century.

Southern Irish End Moraine

Following an initial period of mapping by the Geological Survey of Ireland in the nineteenth century, Kilkenny, and indeed the south east as a whole, was largely ignored by glacial geologists as attention focused on more accessible areas such as the Wicklow mountains, or areas of distinct landform assemblages, such as Clare or the drumlin region. This mindset has prevailed largely up to recently, with the exception of a small number of articles on the southeast.

One article, however, which was to almost define the Late Quaternary history of Kilkenny, and of the south of Ireland, was Charlesworth's 1928 article on 'The Glacial Retreat from Central and Southern Ireland'. Charlesworth largely followed the ideas of Hull (1870), who described a model of Irish glaciation in which Ireland was covered by an ice sheet consisting of one lobe, with an ice-divide in the north-west of the country and ice flowing from north to south in the study area. Charlesworth, however, went further, describing and charting the end moraine of this glaciation (Fig 1). He describes the feature in general as '*a typical kettle-moraine, a tangle of marginal accumulations, presenting with its rolling, choppy and knobby surface, pitted with countless hillocks and hollows, a most striking appearance in the landscape of the country*' (p. 295) which runs across Ireland from the Irish Sea, near Wexford, to the Atlantic at Kilrush and Kilkee. The moraine is said to run through the middle of the study area, '*a striking feature, a few miles in width, east of [...] Goresbridge, by Dungarvan, across the Barrow near Borris (its outwash extends to near Craiguenamanagh), across the Nore north of Thomastown (the outwash spreading as far south as Inishtioge), whence it ranges north-westwards on to the northern shoulders of the Slieve Ardagh Hills, its highest limit here attaining an elevation of about 900 feet O.D.*' (p. 297). While other areas described in the article may be accurately described, it is worthwhile noting at this point that Charlesworth was naïve in his interpretation of some of the hummocks of county Kilkenny as morainic. One example of this is the hummocky area around Dungarvan (S490616), where many of these hummocks are indeed craggy limestone bedrock hummocks.

Drift', as the limestone would have weathered out by the periglacial churning of the sediments.

The idea of the Southern Irish End-Moraine (S.I.E.M.), proposed by Charlesworth, was accepted by many and became part of the general theory of the last glaciaton of Ireland (cf. Mitchell, 1976; Synge, 1979; McCabe, 1987; Lambeck, 1996; Mitchell & Ryan, 1997). Further refinements to the model within the study area were made by Finch (1971) and subsequently by Collins (1982). Both of these authors used soil types to map what they considered as the Southern Irish End-moraine in the extreme south-west of the study area (Figure 2).

Finch (1971) describes Elton and Baggotstown series soils, usually developed on calcareous glacigenic sediments, occurring on both sides of the S.I.E.M. as described by Charlesworth (1928) to the south of the Slievenamon inlier. These soil types were mapped by Finch to an area approximately 1km to the east of Piltown which he argues marks the limit of the last glaciation in this area (Fig 2), although he says a morainic feature is barely perceivable on the landscape. The moraine is then said to pass around the west and north face of Slievenamon to the county boundary between Kilkenny and Tipperary.

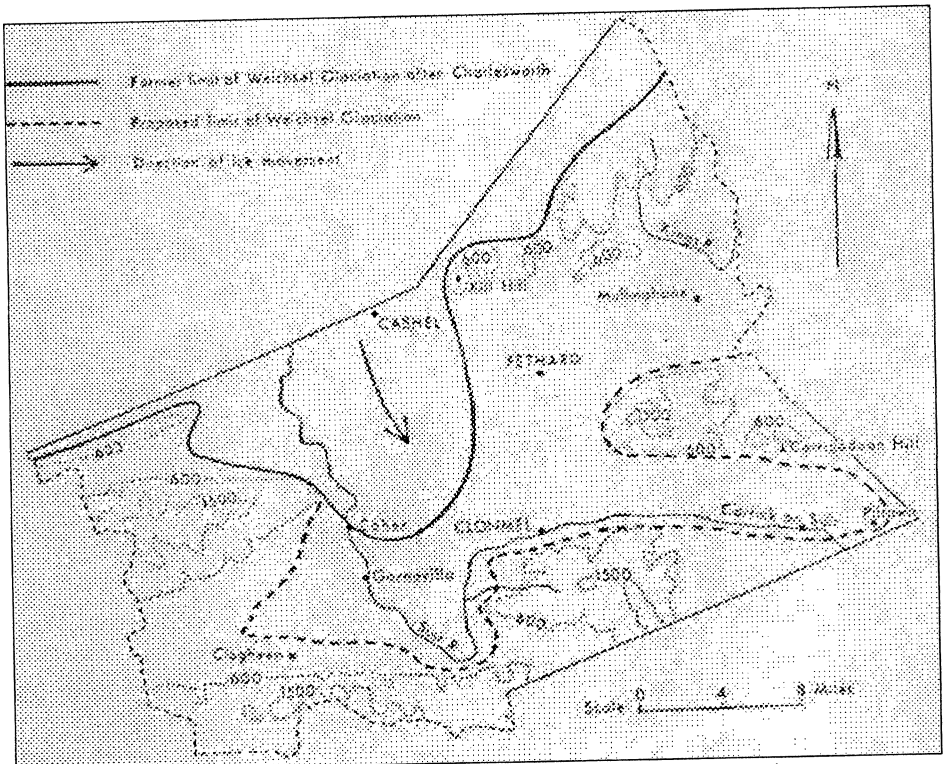


Figure 2: Limits of last glaciation according to Finch (1971).

Collins (1982) further narrows down the limit of the Southern Irish End-moraine in this area of county Kilkenny to field level. While he agrees with Finch (1971) that the area of the S.I.E.M. runs further south than described in Charlesworth, he puts the limits of ice at Last Glacial Maximum as running through the Bessborough Estate to the north of Piltown. He also argues, from petrographic analysis carried out on the soils which he regards as older than last glaciation (those to the east of the estate), that during the 'Munsterian' glaciation, ice flowed up the Suir from Waterford to Piltown. He argues that the high quantity of acid volcanic clasts within the soil in these fields

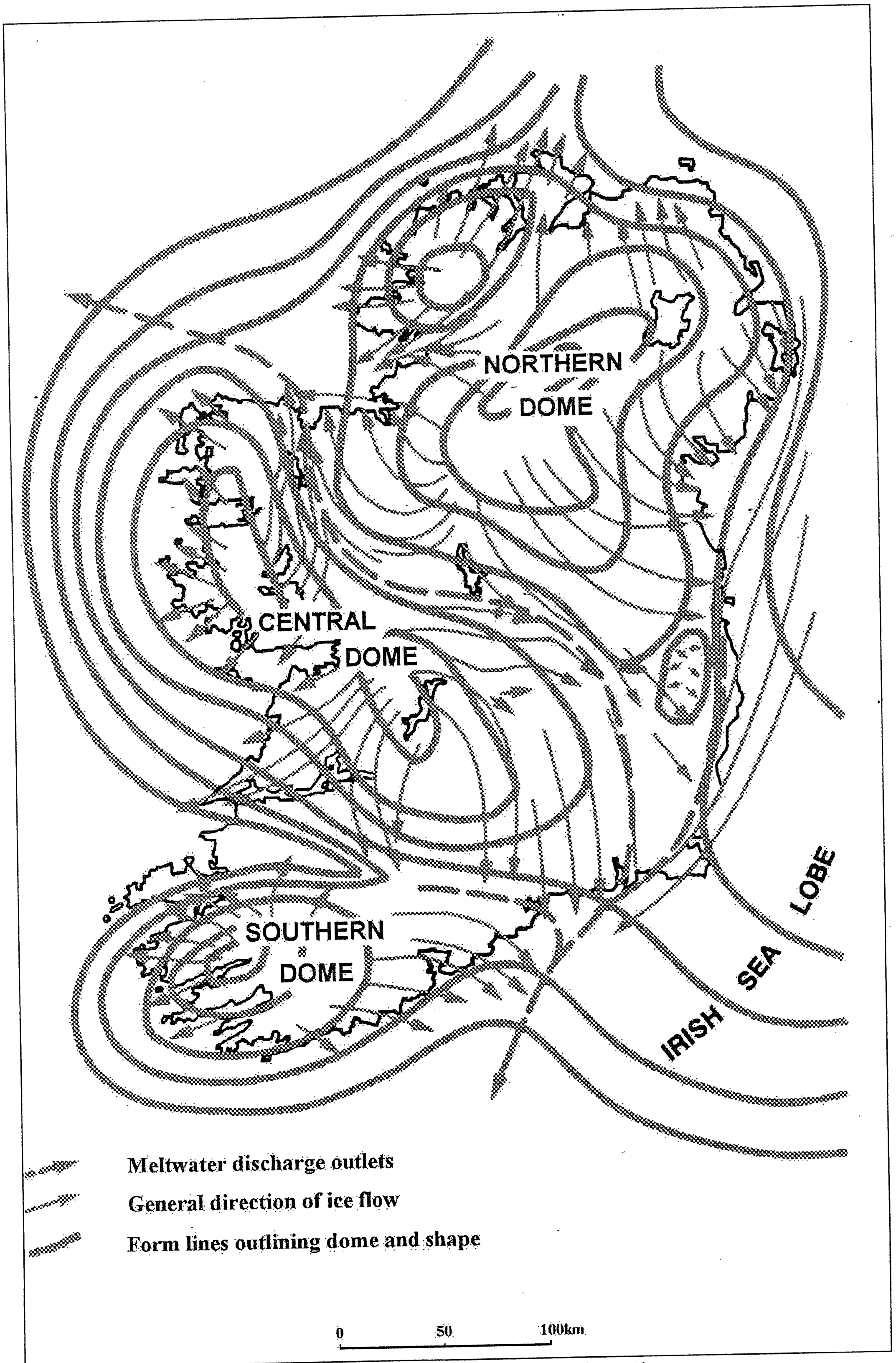


Figure 3: Extent of glaciation according to Warren (1992).

While not working directly on the study area, Ó Cofaigh and Evans (2001) describe sites on the south coast of Ireland, in the area of the Celtic Sea. From their sedimentological descriptions of the sections within their study, they conclude that the sediments were deposited by ice during the last glaciation of Ireland. From this work

More recent publications

Further studies of the Quaternary of County Kilkenny have been very local in their scope, concentrating on descriptions of one site only. The scarcity of these field site descriptions also makes it impossible to relate them to each other, or to the general theories of the glaciation of the area. This is the overall problem with what has become known as the 'bottom-up approach' in Quaternary geology (Clark & Meehan, 2001).

Coxon & Flegg (1985) describe at Ballyline a laminated clay deposit located within a limestone solution feature concealed beneath the Quaternary cover of the area and oriented north-south. The clay deposit was discovered during groundwater well drilling by the Geological Survey of Ireland drill rig. Within the borehole, 3.5m of a sandy clay till, 3.5m of gravels and a further 4m of silty clay till were passed through before encountering laminated clays which also contained plant remains. These were recovered to a depth of 39.6m. The hole was not bottomed. The clay is described as dark grey and rubbery, and contains occasional silty laminae. Vivianite also occurs within the clays to the full depth of the boring, indicating a reducing environment with organic remains present. From a depth of 24m the silty laminae decrease and the amount of organic remains, including apparent wood and leaf fragments become noticeably more abundant (Figure 5).

A further hole was drilled 150m to the west-south-west of the first hole. Here limestone bedrock was encountered at a depth of 15m, above which glacial tills were intermixed with sand and gravel beds. No clays were found in this borehole.

The sediment and associated organic material are interpreted as a sub-aerial cavity fill in the limestone. The zone of organic matter is interpreted to indicate a proximal shore, possibly a pool or a lake within this karstic cavity. As this pool got deeper, organic matter became less visible within the sediments deposited on the lake bottom, and silt beds became included within the lacustrine sediments. The increasing water level is interpreted as due to inhibited drainage through the sink which possibly formed within this karst depression. The age of the sediments is put at 'Middle Pleistocene'. Traditional correlation of sediments of this type required the discovery of particular pollen taxa and assemblages indicative of particular interglacial periods. Thus in the Gortian interglacial period (Mitchell, 1976; Coxon, 1996), the important species of pollen include *Pinus, Betula* and *Quercus. Abies* however does not play a part in the pollen diagrams of Gortian sites within Ireland. At Ballylane, although *Pinus, Betula* and *Quercus* are present, the abundance of *Abies* throughout the section and the absence of taxa such as *Buxus* and *Azolla* places the site within an uncertain age-range. Only its interglacial status can be confirmed, as it is overlain by glacial tills.

striae pre-date the S.I.E.M. stratigraphically, McCabe argues that the striae represent ice moving south from an ice dispersal centre to the north early in the last glaciation. He suggests that the absence of moraines and ice-contact landforms in what was previously mapped as "older drift" is due to rapid advance of ice over the area followed by a rapid stagnation zone retreat of one ice margin. The absence of glacigenic deposits in that area he owes to the ice not maintaining steady-state position long enough to form constructional topography. The topography recorded at the S.I.E.M. area, he argues, was formed when ice-marginal re-equilibration occurred following this rapid retreat of the ice margin from the south.

McCabe goes on to describe some of the glaciological conditions necessary for the formation of these striae. The fact that "the truncation of extremely competent quartzite cobbles requires erosion by clasts embedded in the basal layers of ice over a period of time" and the presence of parallel striae rules out the possibility of a deforming sediment layer being present at the base of the warm-based ice mass when the striae were produced.

To be noted is the possible influence of ice sheet equilibrium in the formation or lack of formation of glacigenic deposits in the area of "Munsterian drift". McCabe argues that the lack of moraines or ice-contact landforms in the south of Ireland, and by default in the south of Kilkenny, was due to a debris-deficient marginal zone which, as it was more sensitive to frequent climate shifts, did not maintain a steady state position for long. Rapid advance of ice across the south of Ireland was followed, according to McCabe, by rapid, stagnant zone retreat.

All these observations McCabe made on one set of striae in County Kilkenny, along with his knowledge of the sediments on the Irish Sea coast. He again questions the idea of the S.I.E.M. as the limit for the last glaciation. However, we are little nearer to deciphering exactly what did happen in Kilkenny during the last ice-age and know little about the nature of the ice mass in the area during that glaciation. From McCabe's article, we do know that a deforming layer was not present at St. Mullin's cave at the time when the striae were scratched, as described above. As a deforming layer requires high hydrostatic pressure, and in particular high pore water pressure, then the absence of a deforming layer in the vicinity of St. Mullin's cave during formation of the striae suggests that pore water pressures and hydrostatic pressures were low at the time.

As can be seen from the above discussion of work carried out in the study area over the past 150 years or so, although some discussion has taken place about the limits of glaciation in the study area, even this has been sketchy and without any field evidence to back up the statements. Less again is known about the characteristics of the ice mass covering the area during the last glaciation. The work carried out by Charlesworth (1928) was sketchy and tells us little about the ice mass. Nevertheless, this work was taken as a benchmark and elaborated on by Finch (1971) and Collins (1982). Work by McCabe (1998) does go some way to look at the conditions and characteristics of the ice mass. However, this paper focused on one small site within the study area and drew implications for this site. Therefore, a broader picture is needed of the ice mass in County Kilkenny, as within Ireland as a whole.

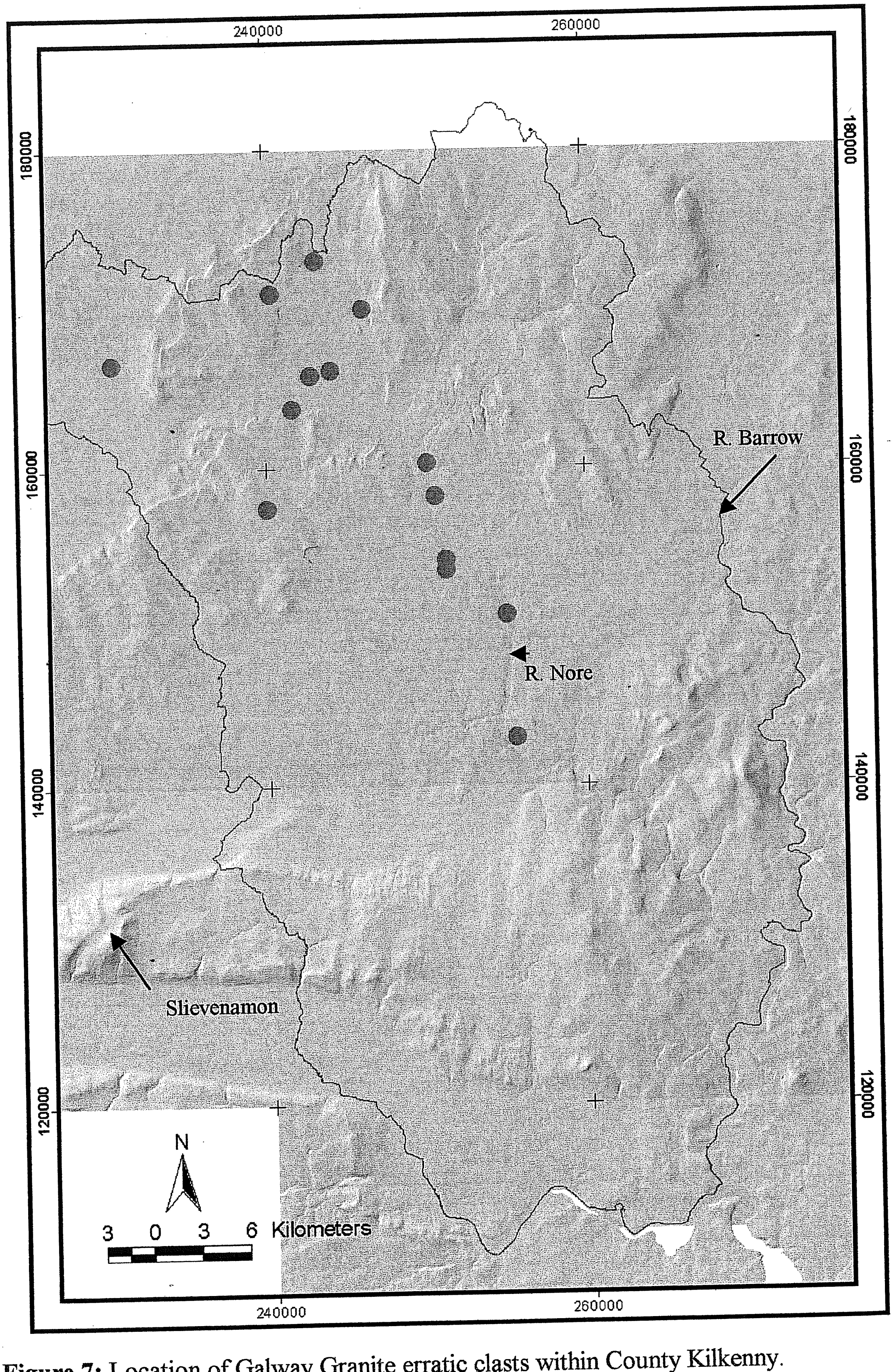


Figure 7: Location of Galway Granite erratic clasts within County Kilkenny.

While the west and northwest of the county shows evidence for ice flow directions from the north northwest, in the east there is some evidence for ice flow from north to primary structures preserved and 'disturbed', secondary tills in which few structures can be seen. Fresh tills generally contain an amount of limestone clasts also. Some areas of till to the south, even as far south as Ferrybank (NGR S617127), vary little in their characteristics from their genetic counterparts in the north of the county. They are overconsolidated, contain non-weathered limestone clasts and exhibit shear structures and fissility. Another site of limestone lodgement tills occur approximately 1km^2 to the south of Windgap. The stream cutting at NGR S395324 displays a red, overconsolidated diamicton. The matrix is sandy silt and fissile. Shear structures are also visible at the base of the section. Clasts are sub-rounded, lightly striated, pebble-gravel limestone clasts, while some Devonian pebble-gravel clasts are also present. In the stream bed there are some very heavily striated Devonian sandstone boulders which have possibly fallen out of the diamicton. This diamicton is interpreted as a lodgement till.

A more extensive area of limestone-dominated diamicton occurs on the Devonian sandstone bedrock to the south of Callan. This can be regarded as an extension of that area of limestone-dominated lodgement till in the Callan area mentioned earlier. Again this area is characterised by overconsolidated tills with shear structures visible. The exposure at Seskin (NGR S409367) shows 2m of a light brown overconsolidated clayey silt till with cobble-gravel to pebble-gravel sub-angular to sub-rounded heavily striated limestone clasts and some Devonian clasts. Shear structures are visible within the till.

As these sites are located in the south and a till fabric analysis carried out on one of the sites at Ferrybank (NGR S617127) indicates ice movement from the north, seems unlikely (on that sample of one) that they were glaciated from ice coming from any other area other than from the area of Kilkenny to the north of these locations. Furthermore, no area of extensive 'end moraine' gravels, stretching across the study area, was found during field mapping. Indeed, some of the landforms interpreted by others (Charlesworth, 1928) to represent major glaciofluvial morainic systems were found to be bedrock ridges. Thus, it is suggested that the whole of the study area must have been glaciated during the last glaciation.

Interpretation and conclusions

From the descriptions and discussion above it seems clear that two distinct patterns of ice flow are evident within Kilkenny. Ice flowed from northwest to southeast in the west and northwest of the county, while a north-south ice flow is recorded in the east and south of Kilkenny. Ice seems to have streamlined around the Castlecomer Plateau also, as is indicated by the till fabric at Dysart Bridge and the striae to the southeast of the Plateau.

The evidence described in this chapter also suggests that ice reached the south of Kilkenny during the last glaciation. Contrary to some descriptions of tills to the south of the S.I.E.M. (Mitchell, 1976 among others), limestone clasts are present within tills in the south of Kilkenny. This idea of ice from the last glaciation reaching the south coast is further strengthened by cosmogenic dating of bedrock outcrop on the

Therefore it is suggested that the whole of Kilkenny was ice-covered during the last glaciation. If this is so, then the whole of the bedrock of Kilkenny must have influenced the glaciers passing over it and therefore the study does not have to be limited to the area of the north of the county.

However, it does not necessarily follow that all areas were glaciated by the same ice sheet, or that different ice sheets that may have existed within the area were coeval. As has been described, two directions of ice flow seem to exist within the study area. This would suggest that two ice sheets may have been present within the study area during the last glaciation. One of these ice sheets originated in the west of the country, in the area around Galway, as is suggested by the presence of Galway granite clasts within the sediments of the study area. It is suggested that a further ice sheet, originating to the north of the study area, also flowed over the study area. This ice left indicators of an ice flow from north to south in the east of the study area. The postulated zone of suitor of these two ice lobes is in the area of the Nore Valley. This would also explain the depth and the quantity of glaciofluvial sediment in this valley that makes it different from the modern-day more important Barrow Valley.

channels and mapped them for his South of Ireland End Moraine paper (Charlesworth, 1928; Figure 8). Charlesworth mapped sixteen channels to the north of Kilkenny. During recent field mapping, at least eighteen were seen. They are also picked up on the 10m OS Digital Elevation Model of the area.

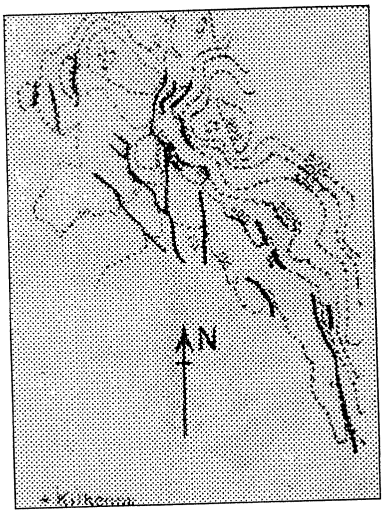


Figure 8: Meltwater channels on the Castlecomer Plateau, mapped by Charlesworth (1928) (p.300).

These channels are cut into bedrock. They are steep sided, generally 30m deep and begin and end suddenly. They have flat bottoms. Many of them are now dry, while those that do contain streams are totally outsized for the small stream that they host. The largest of these channels are the suite of three at Ballyfoyle (NGR 25300 16350, Plate 3.35). These sinuous channels, cut into the Namurian sandstone bedrock, run west northwest - east southeast and widen to the south (Plate 1). Their length ranges from 1.5 to 2.5km long and they average 20m to 30m in depth, with steep, almost vertical sides. Three other channels occur just to the east of Dunmore Cave. These slightly less spectacular channels run north-south for lengths of 1.5 to 2km. The depth of these channels averages 20m and the sides are very steep. As with the previous channels, these are cut into bedrock (Plate 2). A number of smaller, shallower channels cut into the bedrock occur around these six (Figure 9). All these channels generally trend north - south, with minor variations, such as found within the channel at Kilmademoge which trends north northeast - south southwest. Figure 10 shows cross section profiles of the one of the channels on the Plateau. It can be sent that no significant development is followed and the depth does not significantly change along the length of the channel.

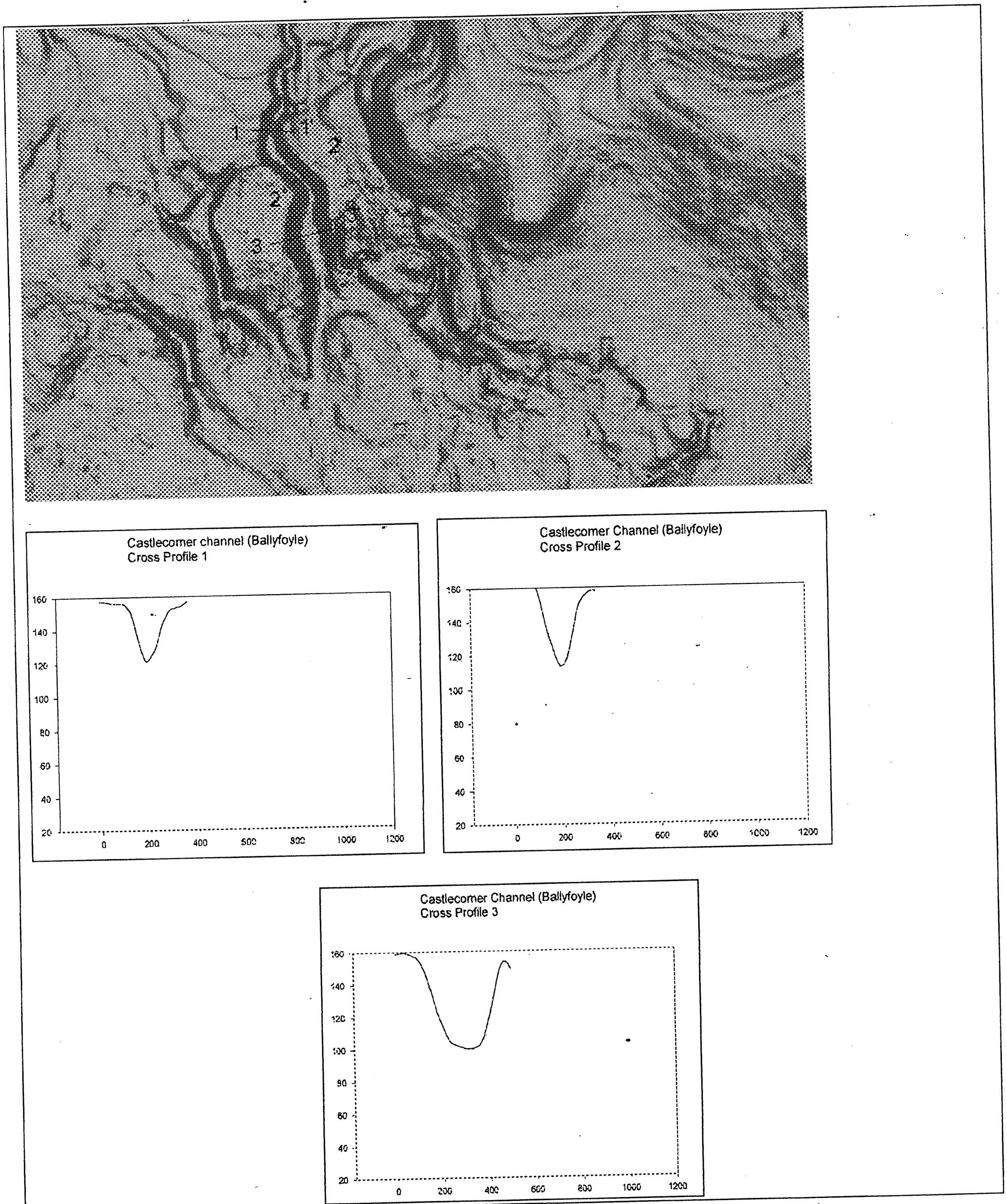


Figure 10: Cross section profiles of one of the meltwater channels on the Castlecomer Plateau. The channel is located at NGR 253000 162000. All cross sections of channels included within this chapter use the same scale on both the x and y axes. The scale is in metres with the y-axis showing metres OD. Data source: OS DEM.

Figure 11 shows the location of these channels with respect to the bedrock types within the study area. As can be seen, the channels are mostly incised into the Killeshin sandstone and shale Formation, with a significant group of them occurring near the village of Ballyfoyle. As the formation is a flaggy siltstone formation, it is friable and would have been easily eroded by glacial meltwater.

pressure would have built up beneath the glacier. A conduit system would have removed this excess pressure.

Once these channels have been eroded into the bedrock, they become a permanent feature of the subglacial conduit system, unless they become infilled with sediment. However, as the channels in the Castlecomer Plateau are not infilled, it is interpreted that the meltwater flows through them were sufficiently powerful so as to prevent infilling with sediments.

Interestingly, the termination of the channels on the Castlecomer Plateau coincides with the boundary between the poor aquifers of the Killeshin Formation and the Lower Limestone shale Formation and the karstified limestone formations to the south (Figure 12). The coincidence of the termination points of these channels with the change in aquifer classification adds significantly to the evidence that these channels developed on areas of low permeability bedrock which is friable enough to be more easily eroded than the overlying ice and not on areas of karstic bedrock.

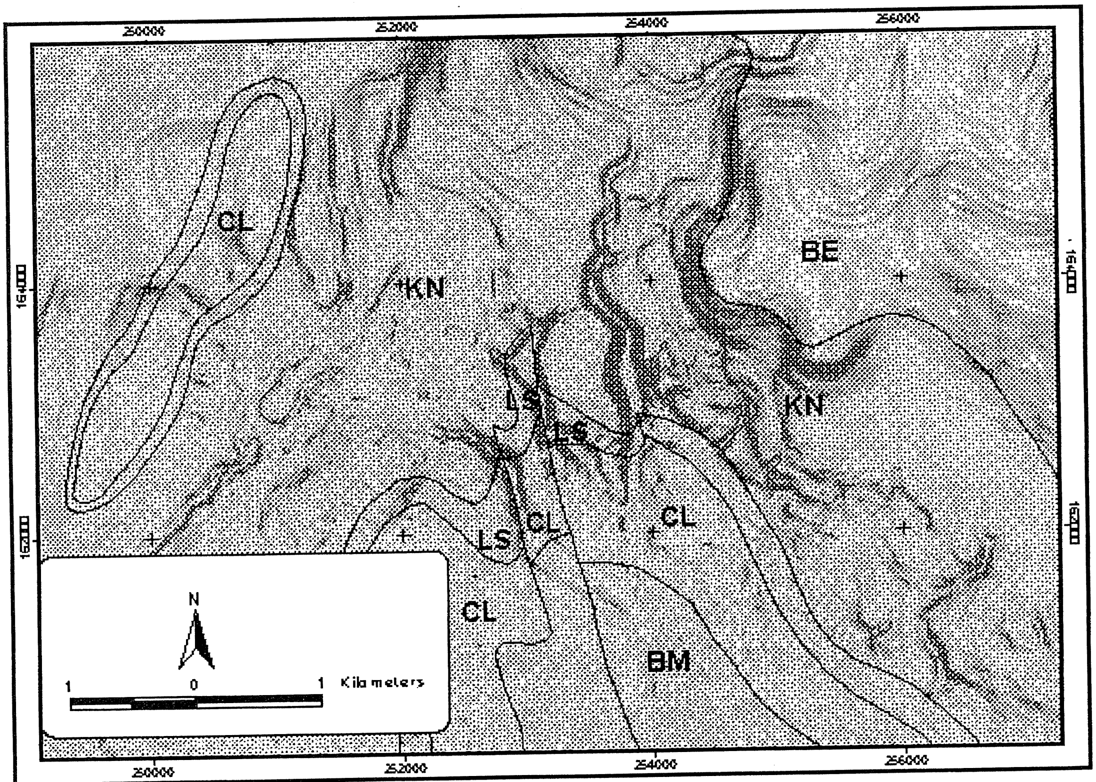


Figure 12: Area of channels around Ballyfoyle and bedrock geology. The channels are picked out by deep shades of red, indicating steepness of slope. The bedrock geology is labelled using the GSI labels detailed in Chapter Four. The important boundary in the figure is that between the CL or the 'Clogrennan Formation' karstified limestone, and the LS or the 'Luggacurren shale' Namurian formation. Data sources: OS DEM and the GSI bedrock maps (Map 2N, Appendix 1).

Another spectacular channel which occurs to the west of the town of Castlecomer can be viewed from the R694. This channel, now occupied by a tributary of the Dinin River, is approximately 3.6km long and averages 30m deep. It runs northwest - southeast. Again, bedrock is seen at the base and at the walls of the valley and so it appears that this channel too is incised into bedrock. A further channel occurs to the east of the village of Coolbaun (NGR 25550 17450). This channel, again cut into bedrock, runs east-west for 2km and is again between 25m and 30m deep.

All the channels have a characteristic 'box' shape and do not obey pre-existing topography. Instead, they cut across pre-existing ridges. These characteristics are typical of subglacial meltwater channels. They begin and end suddenly, as is also characteristic of subglacial channels (Menzies & Shilts, 1996). Due to these characteristics, the channels have been interpreted as subglacial meltwater channels. The lack of glaciofluvial sediments at the end of the channels would also support the interpretation of these channels as subglacial. If the channels were proglacial meltwater channels, glaciofluvial sediments would be found at the channel termination, as a drop in energy when meltwater exits the channel would lead to deposition. However, if the channels are subglacial, it is thought that any glaciofluvial material would be incorporated into the base of the glacier after exiting from the channel. This may lead to an increased sandiness in the till down ice. Proglacial channels would also obey topography, which these channels do not do, as described above.

Site 2: Dunmore Cave (S508650)

With 300m of explored passages, Dunmore Cave is the largest cave in County Kilkenny. It is also the most explored cave and consequently that with most material published on it. It is the most accessible cave within the study area, as most other known caves are now infilled (approximately six known caves exist within the county). This cave was opened to the public in the 1960's.

It is located in a very narrow inlier of horizontally bedded limestone within the Upper Carboniferous shales of the Castlecomer Plateau. It is thought (Drew & Huddart, 1980) that the anticlinal nature of the north-south oriented ridge structure within which Dunmore Cave is located was the reason for denudation of the Upper Carboniferous rocks which would once have overlain the Middle Carboniferous limestones. The cave is mainly formed within a joint system oriented at 160°-170°, with a secondary development at 080° and 140° (Drew & Huddart, 1980). The cave is entered via a scree slope created when the roof collapsed at that point.

The cave has the form of a number of chambers located at two levels (Figure 13). On the upper level, a passage 10m wide and 3m high is roofed by a bedding plane which in some areas has collapsed. The lower level of the cave was formed by enlargement of the 160° – 170° joints (Drew & Huddart, 1980). Further collapse of the floor between these two levels has caused large caverns to form in the area of the entrance and the Main Chamber (Figure 13). Collapse has also occurred in the upper area of the Crystal Hall. The average modern water level is 20m from the top of this chamber.

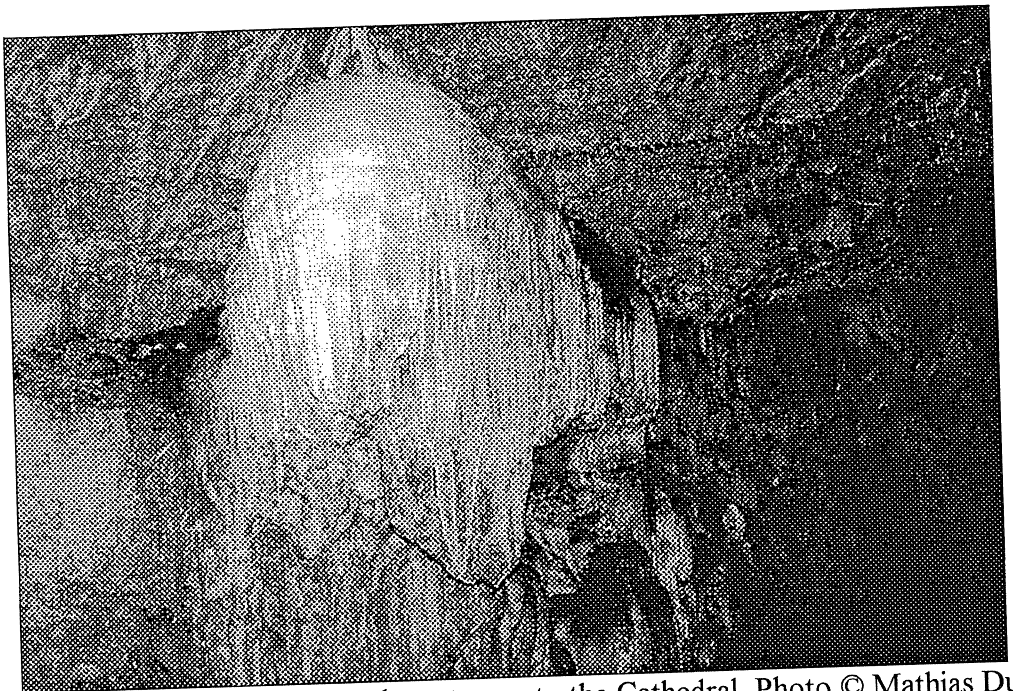


Plate 5: Calcite formation at the entrance to the Cathedral. Photo © Mathias Dukeck.

The cave is now fossil, development only occurring through seepages. A number of passages within the cave contain sediments (Rabbit's Burrow, Market Cross, Fairies' Floor), some of which appear to be glaciofluvial in origin. No scalloping or meander niches are present within the cave and it has been suggested that the cave is phreatic in origin (Coleman, 1965). However, this is not in agreement with the fact that the modern water table is 30m below the higher passages within the cave. Drew & Huddart (1980) conclude that an increase of 15m - 25m in the water table would be required to form these passageways. They suggest that formation of the passageways was initiated by near-static water at the end of the Pliocene, which would create a series of largely unrelated chambers. These chambers were subsequently modified by water that Drew & Huddart suggest was glacial meltwater from receding ice masses to the north. This phase of cave-building was halted when collapse was initiated, according again to Drew & Huddart (1980).

In a number of locations in Kilkenny glaciofluvial sediments occur at depth, sometimes buried beneath overlying diamictons, while at other times occurring within karstic hollows. In the case of Dunmore Cave (Drew & Huddart, 1980), one passage, the "Rabbit's Burrow" (Figure 13), a north-south running phreatic passage at a depth of approximately 5m below ground level, has been filled with sediments which appear to be of glaciofluvial origin (Plate 6). These sediments are generally greater than 1m in thickness and comprise horizontally bedded, medium to coarse sands with pebble to small cobble-gravel clasts of Westphalian shale and chert origin mostly (Plate 6, Figure 14). On top of the sands, in hollows on the sand surface, pockets of silt and clay occur. These small areas of silt and clay are interpreted to represent ponding on the surface of the sand and gravel sediments soon after these were laid down.

These sediments of sand and gravel continue north until they eventually clog up the passage. It is not known how far north they continue. Similar sediments have been encountered further south in other reaches of the cave, but these have not been mapped (Drew & Huddart, 1980). However, the sediments found in other parts of the cave contain far more local material than those within the Rabbit's Burrow (Drew & Huddart, 1980). The presence of a large percentage of allogenic material from the Rabbit Burrow section of the cave suggests that the deposits and hence the water which deposited them, originated outside the cave itself. The input point has not been identified and it is hypothesised that it is now covered by glacial material. The presence of large, rounded boulders in some parts of the cave, particularly in the Faries' Floor (the passage between the Side Hall and the Main Hall, Figure 13) and the Town Hall (Figure 13), would suggest that a large river once flowed through the cave. Drew and Huddart (1980) conclude from this that the sediments within the Rabbit Burrow were laid down by meltwater during deglaciation.

These sediments are greater than one metre in depth and are composed of horizontally bedded coarse sands and angular gravels (Figure 14). The clasts are mainly Upper Carboniferous shale pebble gravels (77%) with some cherts also encountered. Some angular Namurian cobble gravels were also within the section. The allogenic nature of the majority of the clasts within the gravel sequence points to the deposits being laid down from a stream which originated outside of the limestone cave. The shale bedrock outcrops 500m to the north of the cave. If the sediments had been transported as sediment load within a modern stream system that passed over the Upper Carboniferous sandstones and shales and subsequently disappeared through a sink into the karstic system the clasts should be more rounded. However, because of the angular nature of the clasts, it is suggested that they were transported within a glacier and found their way into the cave beneath this glacier. Meltwater released at the base of the glacier would contain the same clasts of the same characteristics as those carried within the glacier. This meltwater may subsequently have found its way into the karstic system *via* a sink.

The cave is developed within the Clogrennan Formation, which lies unconformably beneath the Carboniferous shales (Figure 15). The formation is composed mainly of crinoidal clean to argillaceous wackestones. This has lead to karstic features being developed within the rock. The development of Dunmore Cave has been outlined in Chapter Four. The sediments which infill the Rabbit's Burrow area within the cave must have been intruded through an entrance to the north, perhaps a sinkhole, as some of the clasts are cobble sized (8% of clasts are above 0.02m a-axis) and are incapable of finding their way into the system *via* permeable flow through the bedrock. This sinkhole has not been identified and no sign of it is seen on the surface to the north of the cave. This again points to the sediment having been deposited from subglacial meltwater, as a glacier passing above the cave at the time of deposition may also have deposited till on the surface and this would blanket the entrance to any subterranean sink. Nonetheless, the presence of glaciofluvial deposits within the cave system points to the fact that subterranean conduits were in use beneath the ice sheet in the study area. The accessibility of these deposits within this one particular cave system means that these deposits can be seen and described. However, due to the subterranean nature of these conduits, it is possible that similar deposits exist within the study area and within many other karstic areas of Ireland but lie undiscovered, evidence for their existence not being obvious on the surface. Geophysical surveys, particularly

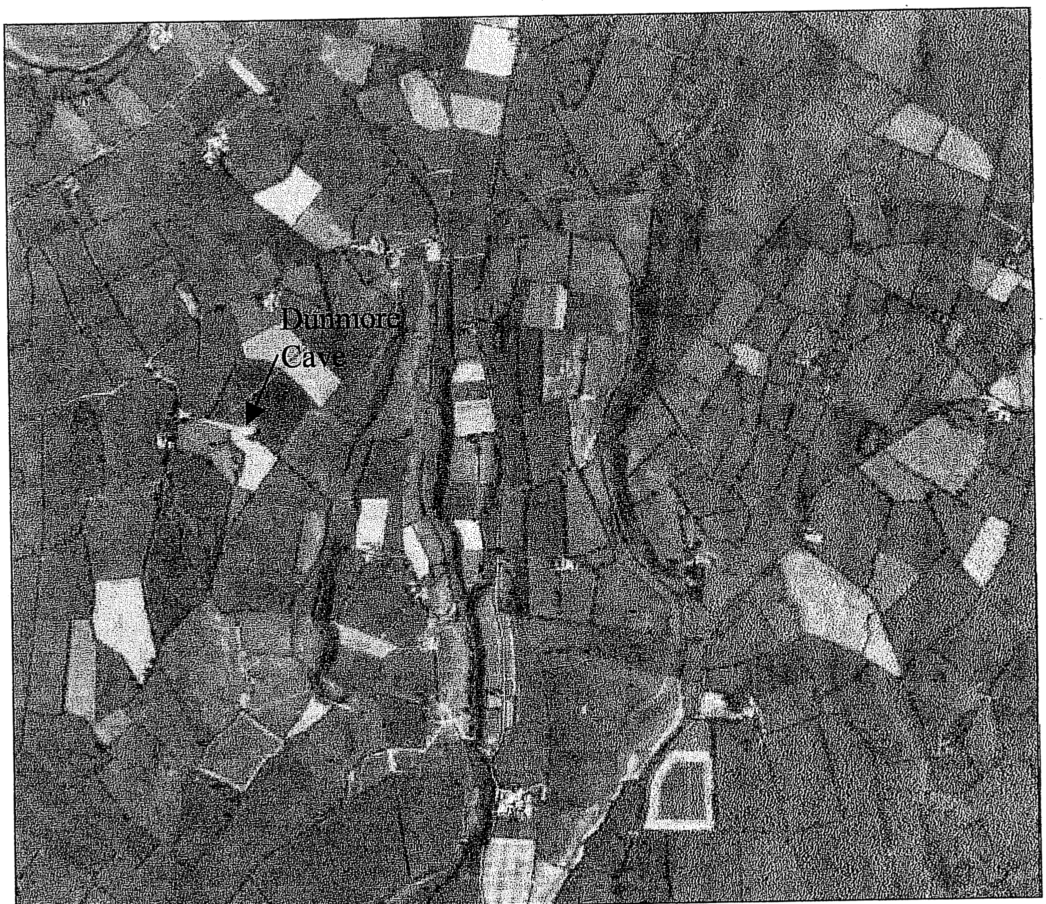


Figure 16: Location of Dunmore Cave with respect to the meltwater channels of Ballyfoyle. Source: GSI 1:30,000 aerial photograph.

The formation of the Nye channels described above has been attributed to high subglacial hydrostatic pressures. The termination of these channels just on the geological boundary suggests that, at this point, the high hydrostatic pressure dissipated. One explanation for the dissipation of high subglacial water pressures at this point is that another conduit system was initiated. There is no evidence (such as the presence of tunnel-fill eskers) to suggest the formation of R-channels. One other type of subglacial conduit system that seems probable within this area of karstic bedrock is groundwater flow. Evidence for this has been found within Dunmore Cave, as described above.

by poor agricultural land. Coalmines have made this area one of the most populated rural areas in Ireland.

Two possible explanations for these sediments are that either the diamictons are periglacially-altered tills or they are the result of periglacial churning of the soft shale bedrock. However, because the diamictons contain a small number of erratic clasts (Figure 17), they have been interpreted as tills. The erratic clasts they contain are usually cherts derived from the lowlands of limestone bedrocks to the north. If these have been incorporated into sediment high on the Castlecomer Plateau, then these sediments must be glacial sediments of some form. This chert can only have been incorporated into the sediments by ice action from the north and deposited as the ice passed over the Castlecomer Plateau. However, the tills show no further characteristics of primary glacial tills. One possible explanation for these sediments is that, as the ice thinned, the Castlecomer Plateau emerged as a nunatak (as suggested by Charlesworth, 1928) soon after Last Glacial Maximum. The Castlecomer Plateau is a syncline, with the harder, older Namurian sandstone formations at the edges of the Plateau standing above the more friable Westphalian shale formations in the centre of the Plateau. As ice downwasted around the sandstone, ice which remained in the centre of this 'bowl' was cut off from the main ice-cap. This dead ice melted producing ponds and pockets of lacustrine sediments, with other pockets of sand and gravel deposits . The now-periglacial nature of the Castlecomer Plateau meant that it became an ideal location for periglacial activities, with saturated sediments slumping off the slopes, sediments in valleys being subjected to cryoturbation etc. These processes would have the power to destroy any primary structures which were to be found within the diamictons on the Castlecomer Plateau and imprint their own structures on the sediments. These processes together have produced the sediments found on the Castlecomer Plateau today.

This scenario of the Castlecomer Plateau soon after LGM could also explain the lack of limestone clasts found within the central-Plateau sediments. The percentage of chert clasts is quite significant (Figure 17). This would indicate that at one stage there was a relative amount of limestone within the ice laying down the sediments, as the chert was picked up from the limestone bedrock. While there is limestone in the sediments to the east and south of the Plateau, as has been seen, there is a lack of limestone in the central area (Figure 17). Thus it is hypothesised that limestone was once present within the sediments, as the same ice would have deposited both these limestone-lacking sediments and the limestone-containing sediments to the south. If the tills or other sediments on the Plateau were cryoturbated, this would enhance the acidity of the general deposit, by breaking down further the acidic shales and increasing acid waterflow through the sediments. This would enhance the chemical weathering out of the limestone within the deposits.

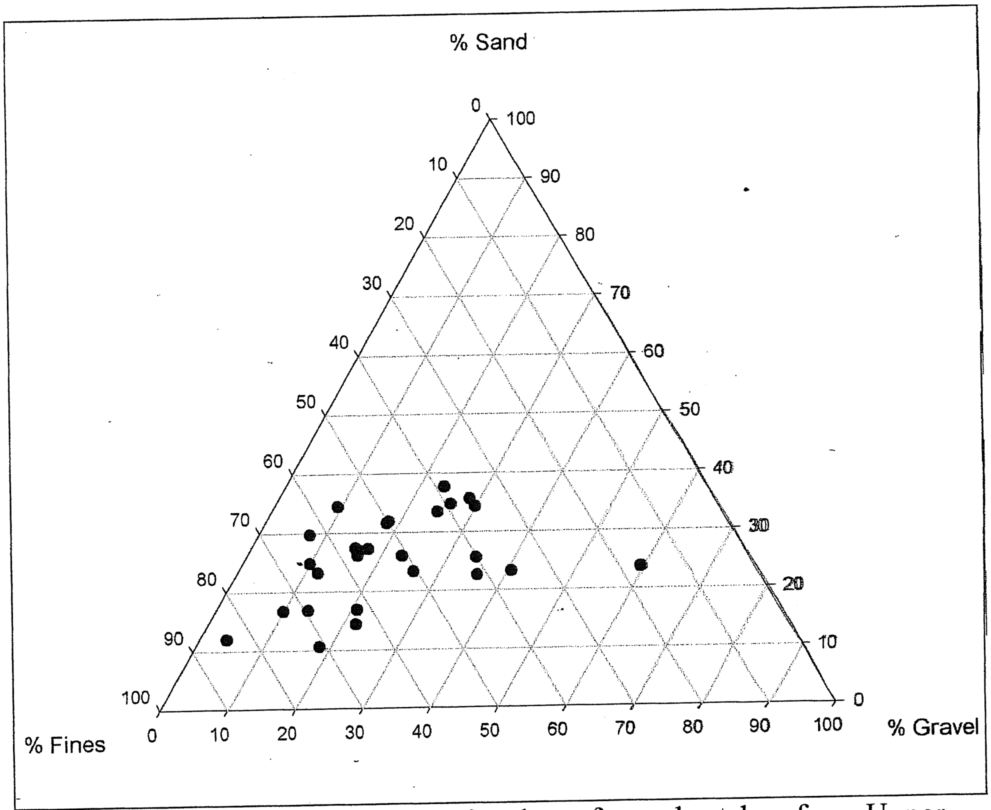


Figure 18: Ternary diagram of particle size data of samples taken from Upper Carboniferous sandstone and shale dominated diamictons collected on the Castlecomer Plateau.

The exposure at Croghteenclogh (NGR S601740) is in one of the few areas of lodgement tills on the Castlecomer Plateau. The till is silty clay in texture with mostly sub-angular Namurian shale pebble and cobble gravel clasts. Rounded limestone clasts are also present within the exposure. As mentioned previously, the preservation of limestone clasts is unusual within the context of the Castlecomer Plateau. This will be discussed on the day.

DAY TWO

Site 1: Hennessy's Gravel Pit

At Hennessy's gravel pit to the north of the town of Bennetsbridge (NGR S550507, Plates 8, 9), approximately 15m of sub-horizontally bedded gravels are exposed. The working faces are some 15m in height and, according to the pit owners, the gravels extend vertically below the present bed of the Nore River which flows approximately 100m to the east of the pit.

The exposures around this pit display sub-horizontally bedded, rounded pebble-gravels to cobble-gravels. Few layers of pure sand exist within the gravels. Clasts are generally rounded limestones, although Namurian sandstone and shale, cobble-gravel clasts are common. There is a significant quantity of boulder gravel rounded limestone clasts also present. Sub-rounded clasts of Namurian boulder-gravels are also visible within the pit. Some cobble to pebble-gravel rounded clasts of Galway granite were recovered from within the beds. These granite clasts differ from the Leinster Granite clasts found within the tills mentioned earlier in the feldspars contained in the clasts and in their degree of micaceousness. The granites interpreted as Leinster granites are composed of white to clear feldspars, and contain a lot of mica, while granites interpreted as Galway granites are composed of pink to green feldspars, and the mica content is not as high as within the Leinster granites. The presence of Galway granites in this area would indicate that meltwater which laid down these sediments was tapping an ice mass which contained amounts of Galway granite clasts, and had possibly come into contact with the source area of this bedrock, in the west of Ireland.

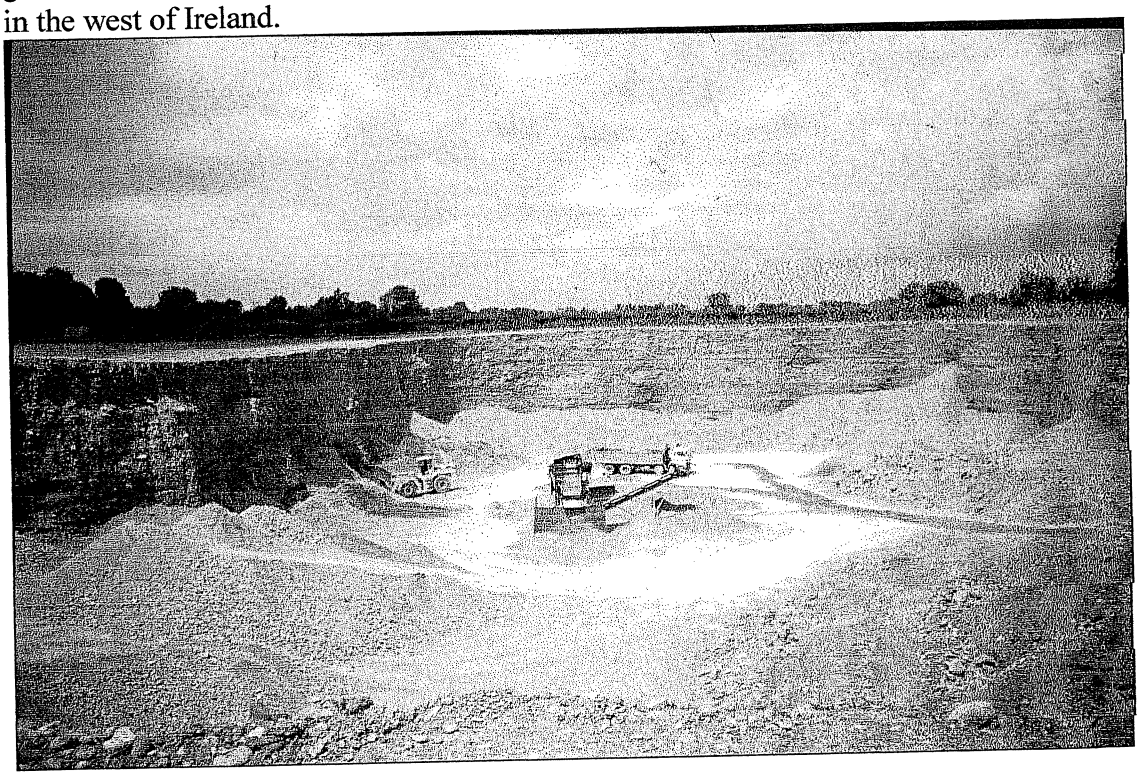


Plate 8: Hennessy's gravel pit (NGR S550507). Beds within the gravels are horizontal to subhorizontal. The direction of flow varies from east – west to west-east, but generally trends north – south (from the photo out to the viewer).

the north of the pit, some broadly cross-cutting beds can be seen (Plate 9). A beautifully developed boulder pavement was exposed during field work to the west of the pit, just below the entrance road (Plate 10). Some collapse structures are visible in the northeast of the pit, where beds of sand dip steeply and are contorted. This deformation is thought to be associated with a kettle hole close by.

Site 3: Pingos at Cashel (NGR S496211)

Cashel, near Owning in the south of County Kilkenny is the site of a number of circular rimmed structures approximately 2m high (NGR S496211, Plate 12). These structures are located at the base of a substantial slope with the Devonian sandstone Plateau to the northeast and on the limestone lowlands of the Carrick-on-Suir syncline to the southwest.

A number of rimmed structures are clustered and overlap within two fields (Plate 11). One of the features was trenched from the centre of the ring to the outer edge of the rim (Figure 19). This exposed a normally consolidated diamicton throughout the rim structure itself, with Devonian sandstone cobble-gravel clasts which are angular to subangular, along with Lower Palaeozoic pebble-gravel clasts. Many of the clasts appear to have a manganese coating and manganese staining occurs throughout the sediments, at times chemically concreting the diamicton. Mitchell (1973) described similar structures in Camross, Co. Wexford, which he interpreted as pingos, although he did not trench through the features. Coxon (1986) also describes similar geomorphological features as pingos, although again no trench was dug. The features within the study area at Cashel are interpreted as periglacial pingos. The clustering and overlapping which they exhibit is typical of open-system pingos (French, 1995).

Plate 11: One of a series of rimmed structures interpreted as periglacial pingos to the south of Owning (NGR 24969 12111).

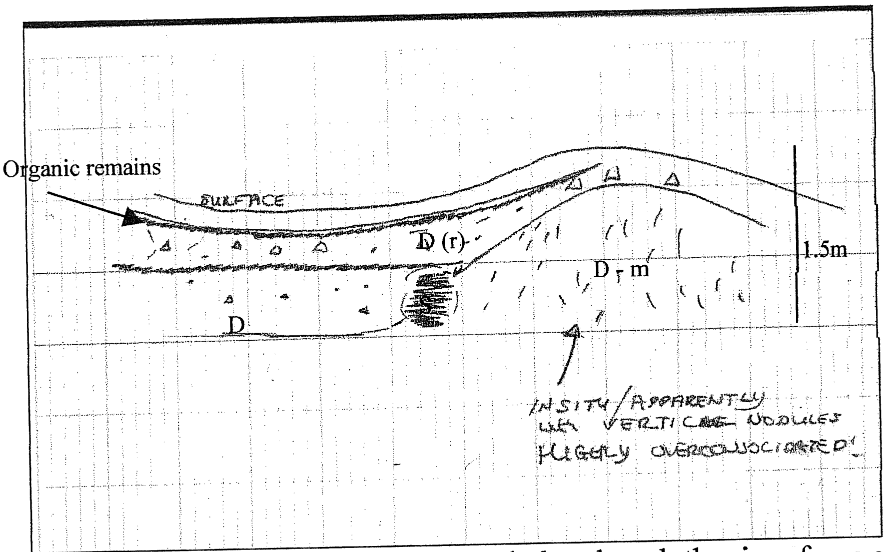


Figure 19: Sketch from field notebook of trench dug though the rim of one of the circular features. (D = diamicton; D – m = massive diamicton, D (r) = redeposited diamicton, S = sand).

Optional site: Knockbarron South (NGR S733459)

The largest area of gravels to the south of Goresbridge along the Barrow occurs at Knockbarron South (NGR S733459).

This extensive gravel pit displays a bimodal sediment assemblage (Plates 13 & 14). Faces within the pit are approximately six metres high. At the base of the exposures lie white, coarse, granitic sands that are steeply bedded at an angle of 45^{o} and dip to the east southeast. These sands are interpreted as foresets. Above the sands, three metres of crudely horizontally bedded, rounded, limestone cobble-gravels, with some rounded, granite cobble-gravels and rounded, Devonian sandstone cobble gravels are found. The limestone cobble-gravel sediment indicates flow from the north northwest. The contact between the two facies is erosional (Plate 14), with the upper gravels eroding the underlying coarse sand foresets.

The steeply dipping foresets are interpreted as representing a sub-aqueous fan. This is due to their steeply dipping nature, which is indicative of fan sediments and the lack of any topsets. From the directional change indicated within the upper gravels, as well as the difference in petrography of these sediments, it is thought that this sediment does not represent topsets, but rather a different depositional event following sedimentation of the fan. The erosional nature of the contact between the two facies strengthens this interpretation, as for erosion to occur relatively suddenly, high energy flows are required. If the upper gravels were to represent topsets, a gradation from foresets to topsets would be expected. This does not occur at this site.

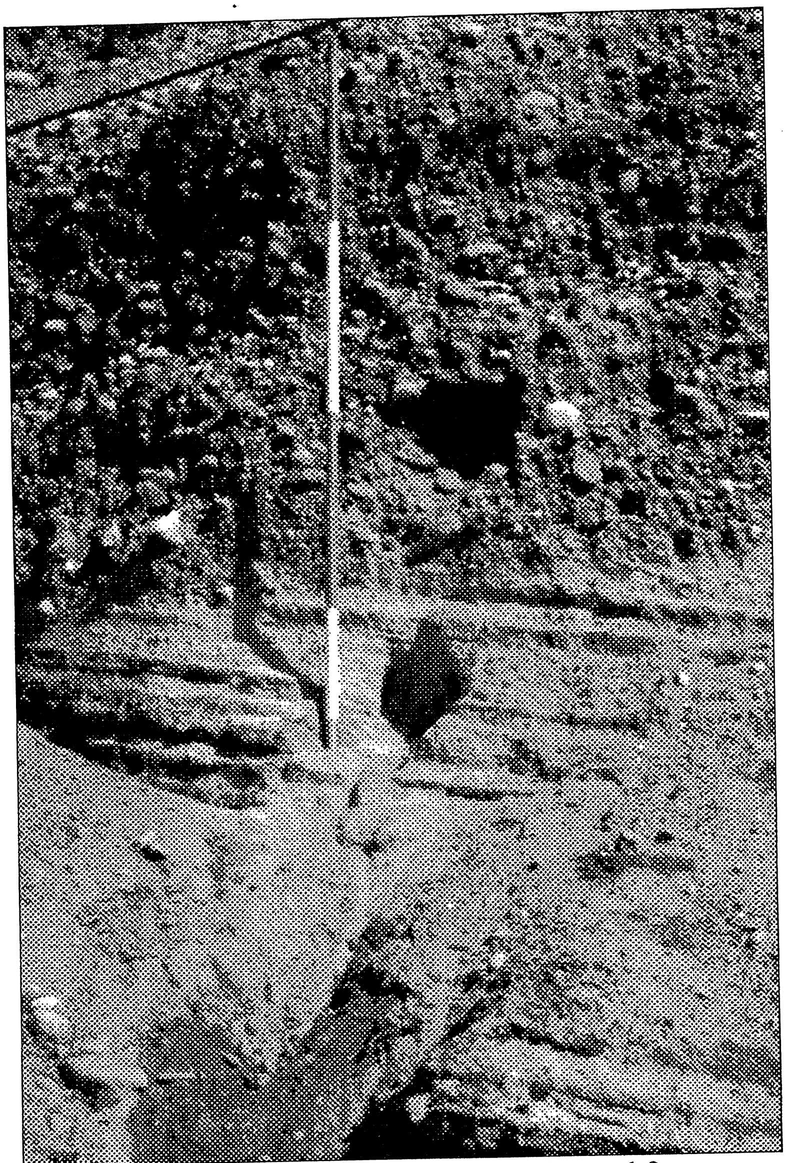


Plate 14: Close-up of erosional contact between granitic sand foresets and overlying limestone clast dominated cobble gravels.

For a fan to be deposited in this area, an area that is within the narrow gorge of the Barrow River, the Barrow had to be blocked as some point downstream. This would have been easily achieved as the ice retreated. As the modern river is only at 25m OD at Knockbarron, any blockage downstream would cause considerable build-up of water upstream and so cause a temporary lake. When this blockage was released, water flowed freely again. This phase is thought to be represented by the overlying cobble-gravel deposit.

CONRY, M. (1974) Kilkenny's 'Golden Vein': its soils, land-use and agriculture, *Irish Geography*, VII, 21-28.

COXON, P. (1986) A radiocarbon dated early post glacial pollen diagram from a pingo remnant near Millstreet, County Cork, *Irish Journal of Earth Sciences*, 8, 9-20.

COXON, P. (1996) The Gortian Temperate Stage, *Quaternary Science Reviews*, 15, 425-436.

COXON, P. and FLEGG, A. (1985) A Middle Pleistocene interglacial deposit from Ballyline, Co. Kilkenny, *Proceedings of the Royal Irish Academy*, 85B; 107-120.

CULLETON, E.B. (1978) Limits and directions of ice movement in south County Wexford, *Journal of Earth Science Royal Dublin Society*, 1, 33-39.

DALY, E.P. (1984) *Groundwater Resources of the Nore River Basin: Hydrogeology of the Kiltorcan Aquifer System*, Unpublished internal GSI report.

DALY, E.P. (1988) The Kiltorcan Sandstone Aquifer. Paper presented at the *8th Annual Groundwater Seminar of the IAH,* Portlaoise. IAH (Irish Group).

DALY, E.P. (1993) *Hydrogeology of the Dolomite Aquifer in the southeast of Ireland.* A lecture presented to the 13th Annual IAH Seminar on Basin Management and Information Technology, held in Portlaoise on 20th-21st of April.

DALY, E.P. (1994) *Groundwater Resources of the Nore River Basin*, Geological Survey of Ireland, Report Series RS 94/1 (Groundwater). Unpublished internal GSI report.

DREW, D.P. and HUDDART, D. (1980) Dunmore Cave, County Kilkenny: A reassessment, *Proceedings of the Royal Irish Academy*, 80B, 1-23.

DUNNINGTON, N.J., and COLEMAN, J.C. (1950) Dunmore Cave, Co. Kilkenny, *Proceedings of the Royal Irish Academy*, 53B, 15-24.

FINCH, T.F. (1971) Limits of Weichsel glacial deposits in the South Tipperary area. *Scientific Proceedings Royal Dublin Society*, 3(B), 35-41.

FRENCH, H.M. (1995) *The Periglacial Environment*, Longman, London.

GALLAGHER, C. (1997) Alluvial Heavy Minerals as Indicators of Late Pleistocene Ice Flow in the Irish Midlands. *Irish Geography,* 30(1) 37-48

GLANVILLE, C. (1997) Glaciolacustrine and glaciofluvial deposits defining the margins of uncoupling ice lobes in the southeastern midlands of Ireland. *Quaternary Science Reviews,* 16, 685-703.

GOLDER ASSOCIATES (1992) *Environmental Impact Statement for Arcon mines*, unpublished report for Arcon Mines Ltd.

NYE, J.F. (1973) The motion of ice past obstacles. In Whalley, E., Jones, S.J. and Gold, L.W. (eds), *The Physics and Chemistry of Ice*, Ottawa, Royal Society of Canada, 387-394.

NYE, J.F. (1976) Water flow in glaciers: jökulhaups, tunnels and veins. *Journal of Glaciology*, 17(76), 181-207.

O'COFAIGH, C. and EVANS, D. (2001) Sedimentary evidence for deforming bed conditions associated with a grounded Late Devensian Irish Sea glacier, southern Ireland. *Journal of Quaternary Science*, 16, 435-454.

SYNGE, F.M. (1969) The Würm ice limit in the west of Ireland. In *Quaternary Geology and Climate*. Publication 1701, 89-92. National Academy of Sciences, Washington.

SYNGE, F.M. (1979) Glacial landforms. In Royal Irish Academy, *Atlas of Ireland.*

SYNGE, F.M. (1981a) Quaternary Glaciation and changes of sea level in the south of Ireland. In van Loon, A.J. (ed.) *Quaternary Geology: a farewell to A.J. Wiggers - Geologie en Mijnbouw*, 60, 305-315.

SYNGE, F.M. (1981b) *The Quaternary Geology of Laois*. Unpublished essay. Geological Survey of Ireland.

TIETZSCH-TYLER, D., SLEEMAN, A.G., BOLAND, M.A., DALY, E.P., FLEGG, A.M., O'CONNOR, P.J., WARREN, W.P. (1994a) *Geology of South Wexford. A geological description of South Wexford and adjoining parts of Waterford, Kilkenny and Carlow to accompany the bedrock geology 1:100,000 scale map series, sheet 23, South Wexford.* Geological Survey of Ireland, 62pp.

TIETZSCH-TYLER, D., SLEEMAN, A.G., MCCONNELL, B.J., DALY, E.P., FLEGG, A.M., O'CONNOR, P.J. and WARREN, W.P. (1994b) *A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 19, Carlow - Wexford*, Geological Survey of Ireland, 57pp.

WARREN, W.P. (1979) The stratigraphic position of the Gortian interglacial deposits, *Bulletin of the Geological Survey of Ireland*, 2, 315-332.

WARREN, W.P. (1985) Stratigraphy. In Edwards, K.J. and Warren, W.P. (eds) *The Quaternary History of Ireland*, Academic Press, London, 39-65.

WARREN, W.P. (1992) Drumlin orientation and the pattern of glaciation in Ireland. *Sveriges Geologiska Undersökning*, 81, 359-366.

WARREN, W.P. (2000) *Quaternary of County Carlow*, unpublished maps, GSI.

WARREN, W.P. and ASHLEY, G.M. (1994) Origins of ice-contact stratified ridges (eskers) of Ireland, *Journal of Sedimentary Research*, 64(3), 433-449.