which was 3.5 km, and rather against an increase by 10 km.

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¹ Jeffreys, H., *Nature*, **208**, 675 (1965).

² Landisman, M., Sato, Y., and Nafe, J. E., *Geophys. J. Roy. Astron. Soc.*, **9**, 439 (1965).

³ Bullen, K. E., and Haddon, R. A. W., *Nature*, **213**, 274 (1967).

⁴ Buchbinder, G. G. R., *Bull. Seism. Soc. Amer.*, **55**, 441 (1965).

Age of the Irish Sea Glaciation of the Midlands

THE red till (or tills) with erratics from the Lake District and south-west Scotland, found in Lancashire, Cheshire, Staffordshire and Shropshire, has been ascribed to what has been called the Irish Sea Glaciation. That more than one ice advance could be represented by similar material has long been recognized, but the southward limit of the Lake District and Scottish boulders lay along a line Church Stretton-Wolverhampton-Burton on Trent, and this "Wolverhampton Line" could be taken as the southernmost extension of the Irish Sea Glacier¹. The date of this advance has been variously claimed to be Late-Würm, Early-Würm and Riss (Saale). I have ascribed it to the Early-Würm^{2,3} and accepted the view of Boulton and Worsley⁴ that the Wrexham-Barr Hill Moraine was the most southerly extension of the Late-Würm glaciation as corroboration of this. Now, as the result of work here—stratigraphy by Mr A. V. Morgan, palaeontology by Dr G. R. Coope and radiocarbon dating by Mr R. E. G. Williams—it can be demonstrated that the advance of the Irish Sea Glacier to the Wolverhampton Line occurred in Late-Würm times, that is, it probably centred around a date of about 25,000 yr ago.

In the region of Four Ashes (SJ 9208) about 5 miles north of Wolverhampton and thus north of the Wolverhampton Line but well south of the Wrexham-Barr Hill Line, sheet 153 of the Institute of Geological Sciences shows an extensive cover of boulder clay. This is typical Irish Sea till with characteristic erratics, often very large. The map does not reveal the existence beneath this till of a great spread of water-deposited gravels and sands now worked commercially on a large scale. Working faces change rapidly but there is always a three-fold succession, in descending sequence, of till (from as little as 1 to as much as 8 ft. thick) on gravel and sand (4–15 ft. thick) on Upper Bunter Sandstone. The till undoubtedly overlaps the gravel and rests directly on the Bunter beyond the area of gravel working. Nowhere have we seen a till beneath the gravels, but it is significant that the latter, although almost entirely derived from Bunter Pebble Beds, contain rare pebbles of rhyolites, rhyolitic ashes and andesites, and also brown flints testifying to the presence, somewhere to the north, of an earlier source of Irish Sea material.

Interbedded with the gravels are layers of organic silt and peat, at the base in hollows on the Bunter Sandstone, and at various levels within the body of the gravels. Two peaty samples, taken from different layers within the gravels, have been dated at the Radiocarbon Laboratory here with the following results

Birm. 24 36,340 ± 770 years B.P.
— 700

Birm. 25 30,655 ± 765 years B.P.
— 700

These dates indicate that the gravels belong to the Mid-Würm or Upton Warren Interstadial^{3,5}, a conclusion which I believe Dr Coope would have maintained in the absence of any dates, from a comparison of the large insect fauna from the organically rich layers with that from other

known sites of this interstadial. It therefore follows that the overlying till must be Late-Würm in age.

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¹ Whitehead, T. H., Robertson, T., Pocock, R. W., and Dixon, E. E. L., *Mem. Geol. Surv. Engl. Wales* (1928).

² Coope, G. R., Shotton, F. W., and Strachan, I., *Phil. Trans. Roy. Soc., B*, **244**, 379 (1961).

³ Shotton, F. W., *Quart. J. Geol. Soc.*, **122**, 357 (1967).

⁴ Boulton, G. S., and Worsley, P., *Nature*, **207**, 704 (1965).

⁵ Coope, G. R., and Sands, C. H. S., *Proc. Roy. Soc., B*, **165**, 389 (1966).

Nannofossils in Eocene Eugeosynclinal Limestones, Olympic Peninsula, Washington

LIMESTONE lenses occur within a thick sequence of Eocene volcanic rocks (known as the Crescent or Metchosin Formation) that border the northern, eastern and southern sides of the Olympic Peninsula in north-western Washington State. These carbonate rocks have previously been thought to have a largely inorganic origin¹, but electron microscopy, which I report here, indicates the presence of abundant nannofossils and suggests a different origin.

The volcanic rocks are predominantly basalts, apparently principally the products of submarine eruptions, and they occur as pillow-lavas, flows, breccias and tuffs. Associated with them are discontinuous layers of argillite and hard, most commonly red to pink, and locally manganeseiferous limestone. Limestone bodies appear to be lensoid, between a few inches and 200 ft. thick, and with lateral dimensions from a few tens of feet to more than 2 miles. These bodies usually lie between volcanic layers, but limestone sometimes occurs within cores of basalt pillows or forms a matrix enclosing pillows. Limestone is also present as angular fragments in volcanic breccias and as xenolith like inclusions in basalt flows.

These close spatial associations of limestones and volcanics led Park¹ to propose a direct relationship between submarine volcanism and limestone genesis. Referring to an earlier hypothesis of Kania², he suggested that agitation and heating of sea water above sites of submarine eruptions led to local inorganic precipitation of calcium carbonate, a process which was perhaps enhanced by release of calcium during early spilitization of the volcanic rocks.

As seen in thin sections, many of the limestones comprise 5–15 per cent planktonic Foraminifera embedded in a fine-grained calcitic matrix. This matrix also contains a few dispersed coccospheres and pentaliths of the nannofossil genus *Braarudosphaera*, as well as tiny spherical shells which can be assigned to the coccolithophorid genus *Thoracosphaera*³. The remainder of the predominant matrix appears in thin sections and at high optical magnifications as a largely unresolvable mixture of abundant small calcite grains and smaller amounts of non-carbonate grains such as clay minerals, iron oxides, and secondary, microcrystalline quartz.

Electron microscopy confirms the presence of nannofossils and indicates that they are far more numerous than would be suspected from examination of thin sections alone. Ten limestone specimens from widely separated parts of the Olympic Peninsula were studied with the electron microscope using the two-stage peel-replica method of sample preparation⁴. Coccoliths and fragments of coccoliths (Fig. 1) are the most abundant form observed. Other common nannofossils are *Thoracosphaera* shells (Fig. 1a, left), *Braarudosphaera* pentaliths and discoasters (Fig. 1b). These forms are further illustrated by Fischer, Honjo and Garrison⁵. All of the specimens investigated contain abundant nannofossils, and the matrix in many comprises up to 60 per cent nannofossils with abundances of $3\text{--}4 \times 10^6/\text{mm}^3$ of limestone. In some