Radiocarbon-dated charcoal from fluvial sediments in the Mourne Mountains, Northern Ireland: Neolithic forest clearance and tin and gold recovery in the Early Bronze Age?

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Two profiles through fluvial sediments associated with the Leitrim River, in the Mourne Mountains, are described and three stratified radiocarbon dates from minute woody-charcoal fragments from one of the profiles are discussed. Two of the dates are Neolithic (early and late), the earliest being, perhaps, the result of slash-and-burn forest clearance. The third date is Early Bronze Age and we suggest, on the basis of the sediment characteristics and metal analyses, that the charcoal in that layer might have been connected with the recovery of tin and gold.
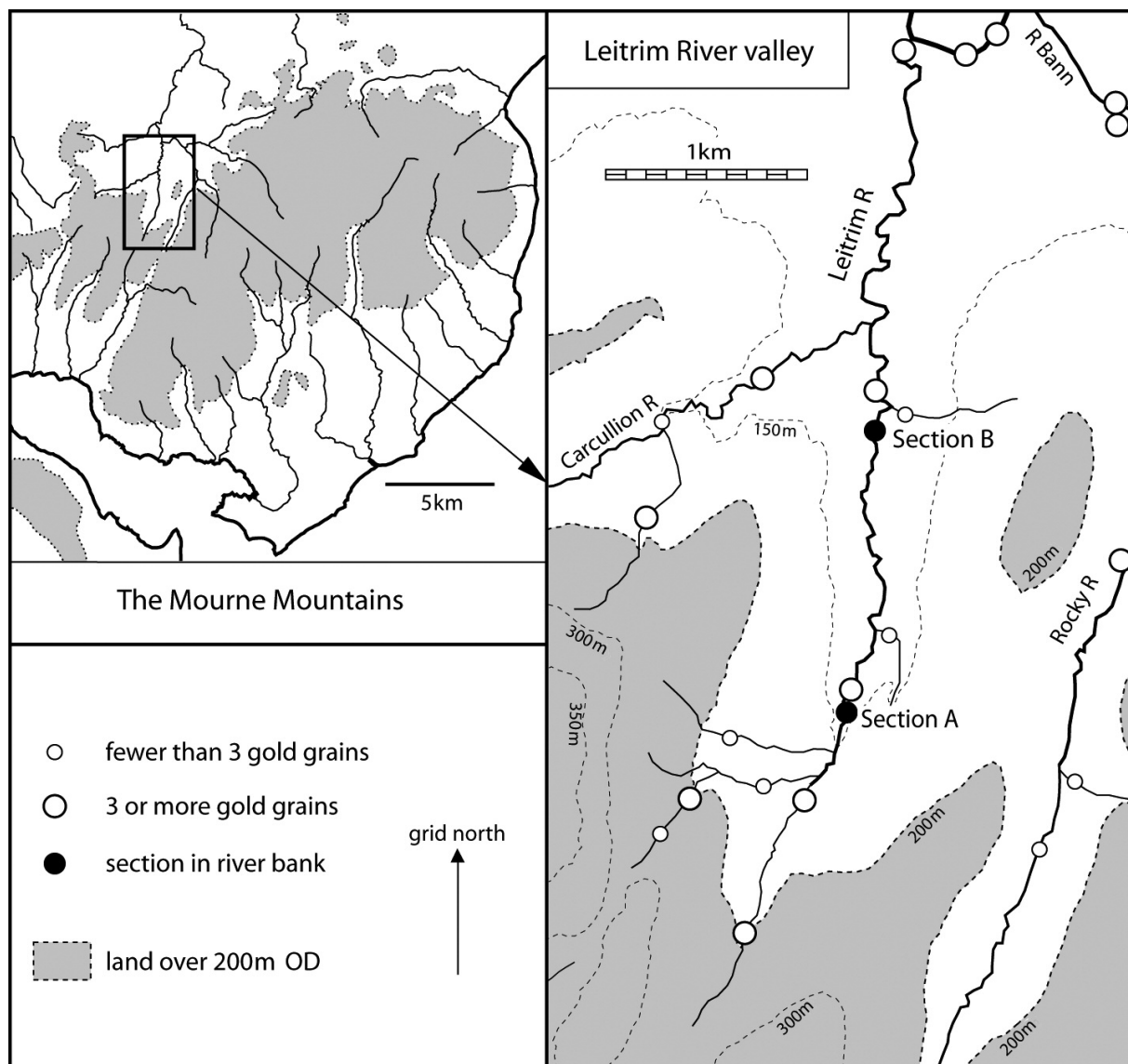
Fig. 1—Maps of the Mourne Mountains and the valley of the Leitrim River.

INTRODUCTION

The granitic massif that forms the core of the Mourne Mountains of County Down ('the Mournes') is drained by a large number of relatively small but occasionally very active streams that fan out from the central highland zone (Fig. 1). Those on the east, south and south-west reach the sea in a short distance, while those on the north-west coalesce into the much more substantial River Bann. Research into the geology of the Mournes has been actively pursued for many years, with an emphasis on the granites and the dykes, and the mechanisms by which the igneous complex was formed (summarised by Cooper and Johnston 2004, 182–7).

Over the last decade, a small team[1] has been systematically recovering, by sluicing and panning, gold and other heavy mineral grains from many Irish watercourses, including those in the Mournes region (we summarise the geological and archaeological significance of the presence of these metallic minerals below). A particularly important area identified by this work was the watershed of the small Leitrim River in the western Mournes (Fig. 1) (Moles *et al.* 2013). It was while engaged in fieldwork on this river that the authors discovered the stratified fluvial deposits that are described in this paper. The collection and analysis of the stratified sediments, and the radiocarbon dating of wood charcoal within those sediments, have opened an adventitious window onto the history of the area. It is hoped that future work will provide greater detail and further insight into the topics discussed herein.

The Leitrim River sections

The small Leitrim River rises in boggy and stony ground that marks the topographical saddle between Hilltown and Rostrevor, and runs northwards down a wide fertile valley to Hilltown, where it joins the River

Fig. 2—View from the west over the middle reaches of the Leitrim River. The horizontal line of trees across the picture marks the course of the river, and section B is close to the centre of the image (photo: N. Moles).

Bann (Fig. 1). For most of its 5km course the Leitrim River occupies a relatively flat-bottomed, formerly glaciated valley. It has a limited catchment area and is fed by only a small number of short streams, their sources not more than a couple of kilometres from the section sites described below (Fig. 2). Before being intentionally confined to a dugout channel, probably in the eighteenth century AD, the Leitrim River is likely to have meandered freely across the narrow, fairly level flood-plain.[2] In normal (low-flow) conditions today, the stream surface is about 1m below the surface of this plain. At times of very high flow the banks are overtopped.

In 2010, at two points 1.3km apart, we found that recent erosion of the bank had created sections exposing pre-canalisation fluvial deposits (sections A and B, Figs 1 and 3).[3] Some discrete layers could be seen (three in A, eight in B) and these were numbered as shown in Tables 1 and 3. Sediment layers of varying thickness were defined visually, based on colour and grain size variations, such that each defined layer was relatively homogeneous internally. Within these layers there was no clear structure justifying the identification of sub-layers. Bulk samples a few kilograms in weight were taken from each numbered layer in both sections. These were dried and sieved, and the sieve fractions (eight for each layer, between <63μm and >4mm) were weighed (Tables 2 and 4). In section B, the downstream exposure, there were several thin, short smears and lenses of black material that appeared to be organic matter. Samples were collected from these lenses in the hope of obtaining radiocarbon dates for the sequence (see discussion below).

Section A

Table 1 and Fig. 3 show the stratigraphy of the upper (i.e. southern) section, in the west bank of the river (all the tables and figures in this paper that detail the sections have the lowest layer at the bottom).

A1, the lowest sediment above the glacial-till substrate, consists of stony gravel (>2mm) and coarse sand (less than 50% by weight). The sediment contained rust-coloured water and the relatively large silt and clay fraction is probably due to ferruginous precipitate. There was no evidence of leaching, podsolisation or relocation of the clay-silt fraction within the section. It should be noted that until the canalisation of the stream in recent times all these layers would have been below the water-table. A2, the next layer up, has much less ferruginous silt/clay, less gravel and slightly more sand than A1. The uppermost sampled horizon, A3, is pebbly sand with scattered cobbles and only one-quarter gravel.
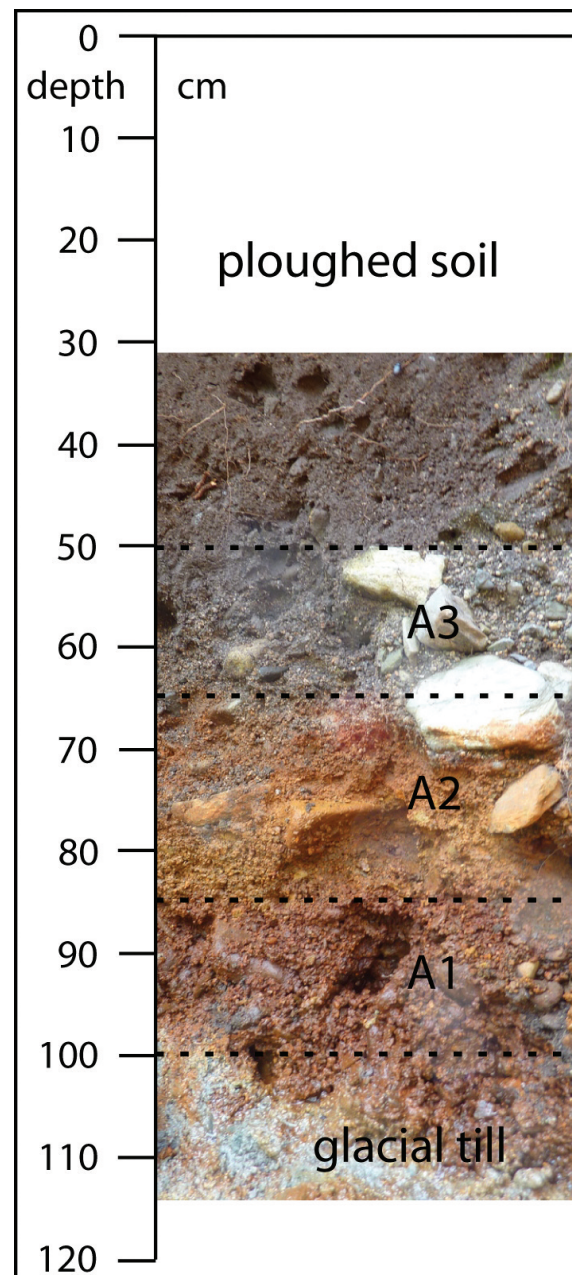

Fig. 3—Section A. The layer boundaries are indicated. The upper part of the ploughed soil is not shown on the photograph.

Table 1—Basic description of section A (for detailed description see text). The interface depths are approximate.

Layer	Approximate depth (cm)	Brief description
	0–50	Deep-ploughed soil, A-horizon
A3	50–60	Pebbly sand
A2	60–80	Stony gravel
A1	80–100	Ferruginous, stony gravel
	>100	Glacial till

Table 2—The percentage weights of the sieved fractions in section A.

	<63µm	63–125µm	125–250µm	250–500µm	500–1000µm	1–2mm	2–4mm	>4mm
A3	0.1	0.5	5.1	19	23.8	26.5	13.6	11.3
A2	0.1	0.5	1.5	4.4	11.5	33.6	27.9	20.6
A1	1.1	1.2	2.1	4.2	8.9	25.5	27.9	29.1

Fig. 4—Collapsed bank of river at site B. Section B is marked by the 1m ranging pole.

Table 3—Basic description of section B (for detailed description see text). The interface depths are variable.

Label	Depth (cm)	Thickness (cm)	Brief description	'Organic' laminae
Turf	0–20	20	Deep-ploughed soil, A-horizon	
B8	20–40	20	Sandy soil/coarse sand lenses	
B7	40–52	12	Sandy soil	
B6	52–62	10	Medium + coarse sand layers, increasingly orange upwards	
B5	62–72	10	Medium sand	Many
B4	72–75	2–3	Coarse sand bed 2–3cm thick	Few
B3	75–85	10	Laminated fine sands/grey clayey silts	Many
B2	85–105	20	Pebbly sand	
B1	105–115	110	Stony gravel below present normal stream water-level	Fragments

Table 4—The percentage weights of the sieved fractions in section B.

	<63μm	63–125μm	125–250μm	250–500μm	500–1000μm	1–2mm	2–4mm	>4mm
B8	0.3	1.1	10.7	35.4	37	13.2	2.2	0.1
B7	0.8	2.5	17.4	38.4	31.8	8.5	0.5	0.1
B6	0.4	2.4	12	27.2	36.3	15.5	3.5	2.7
B5	0.3	3.7	21.6	39.1	20.6	6.6	3.1	5
B4	0.4	2.4	14.9	27	32.4	19.3	2.3	1.3
B3	0.7	4.3	24.4	34.5	15.4	8.2	5.6	7
B2	0.1	0.4	1.2	7.2	31.3	44.5	10.6	4.7
B1	0.3	1.3	5.3	17.2	28.4	29.2	11	7.2

Section B

This section was 1.3km downstream from section A and in the eastern bank. As shown in Table 3 and Fig. 5, it contrasted markedly in appearance with section A.

B1 is a cobble- and stone-rich sandy gravel whose <4mm fraction has a particle-size distribution similar to A3. It contained some black 'organic' fragments. Overlying this, layer B2 is pebbly sand with some cobbles, similar to B1 and perhaps belonging to the same unit. Above this rather coarse streambed (layers B1 and B2) is a sequence of fine, well-stratified fluvial sediments (sands; B3 to B6). A clear discontinuity separates B2 from the laminated sand-and-silt layer, B3, which contained some very thin organic lenses. B3 has a much larger proportion of fine to medium sand than the basal layers, the size range 125–500μm accounting for over half the sample weight. Overlying this, B4 is a thin, distinctly light-coloured bed of relatively coarse sand, which contained a small amount of organic material. Above this, B5 is very similar to B3 in appearance and particle-size range, and also in the large amount of fine organic matter it contained in dark lenses. B6 is dominated by coarse sand that is very similar in size range to that in B4. B7 appears to be a homogeneous sandy soil, the absence of lamination suggesting agricultural homogenisation (ploughing?), and its particle-size distribution is similar to that of B5. The uppermost layer that was sampled, B8, consists of laminated sand and soil (with abundant grass rootlets) and has a particle-size distribution similar to that of B4 and B6, i.e. with coarse sand dominating.

Observations on the nature of the 'organic' lenses or laminae in section B

Layers B1, B3 and B5 contained many distinct, but very irregular, laminae or lenses of silt/fine sand that appeared to contain black organic material (Fig. 6). In this, very fine particles of what appeared to be charcoal could be seen with a hand-lens.[4] Samples were taken
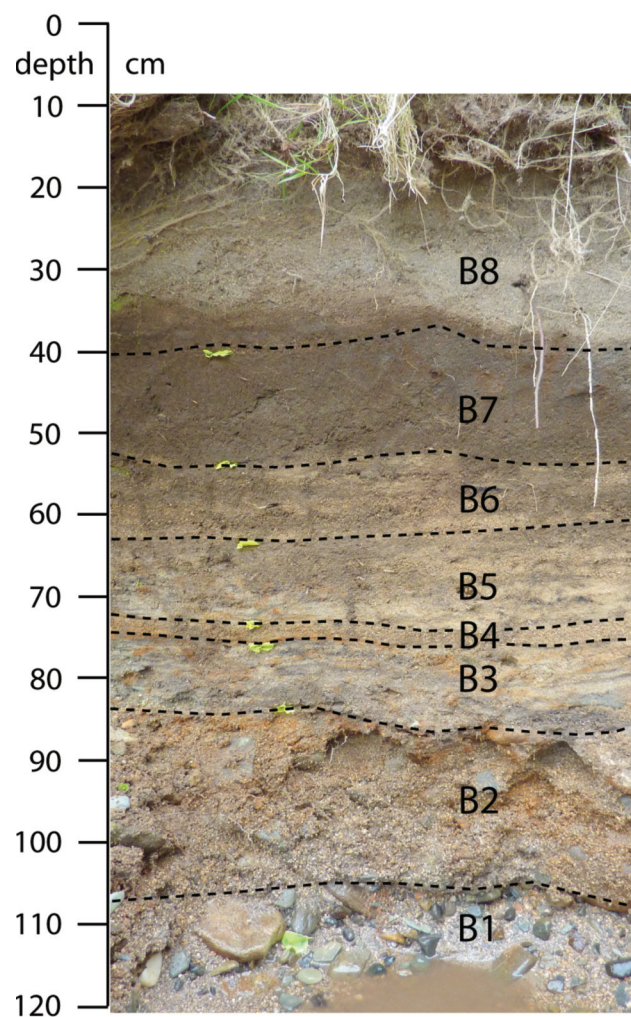

Fig. 5—Section B. The layer boundaries are indicated.

from these laminae and fragments of carbonised material were recovered by manual extraction under a microscope. The collected organic material consisted of two variants, the dominant type being tiny, almost spherical pellets of cemented grey and black grains.
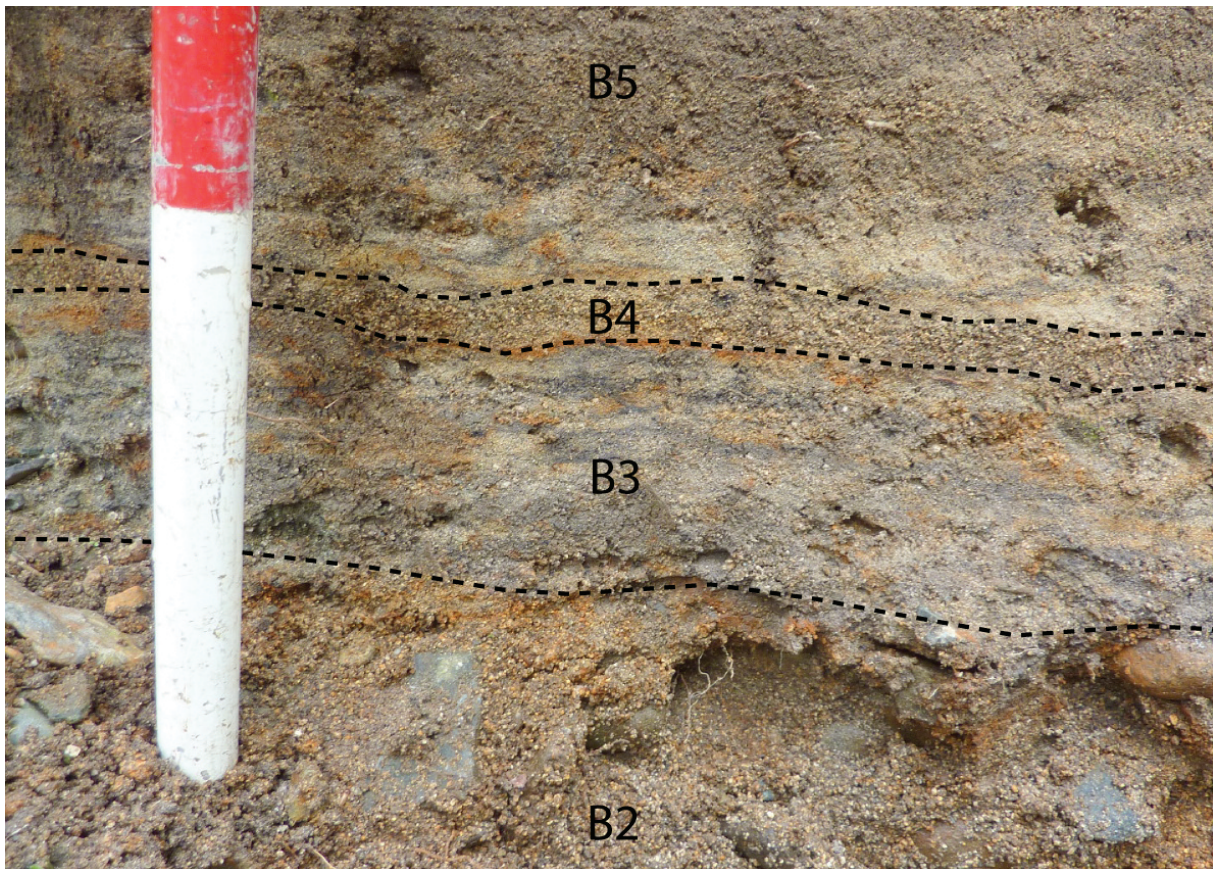
Fig. 6—Close-up of section B, showing, across the centre, layers B3 and B4, with B5 in the upper part.

These pellets were rejected for dating purposes because their origin is likely to be from post-depositional biological activity and/or illuviation subsequent to canalisation of the river. The other, less common, type of material consisted of very small angular fragments with clear striae. These appeared to be woody charcoal and were therefore selected for AMS dating.[5] Because of the scarcity of these woody fragments, those from the same numbered layer were combined. The three resultant charcoal samples (for B1, B3 and B5) retain their relative stratigraphic integrity. The radiocarbon dates from section B are shown in Table 5.[6]

It is notable that the physical character of the minute charcoal fragments collected from the three layers B1, B3 and B5 is identical. We would ascribe this to their having been mechanically fragmented, either before being washed into the river or by fluvial transportation.

INTERPRETATION OF THE SECTIONS

The present stream surface at low flow is just below A1 and just below B2. The tops of the sections are therefore at approximately the same relative height—just over 1m—above the present low-flow water-level. At section A, the top of the glacial till was found some 30cm below low water-level, but it was not reached in section B. There is a striking contrast between the two sections studied, both visually and in terms of the particle-size distributions. Section B is similar to partially visible alluvial profiles noted by us in other exposures in the Leitrim River, and may well be typical of the river profile. Section A, on the other hand, appears anomalous and, we believe, shows material derived from slumped river terrace or hillslope deposits.

We provisionally interpret the sections as follows. During the early Holocene, hill-wash from, and the slumping of, the steep slopes on either side of the valley deposited conglomeratic sediments represented by the layers of section A. These coarse deposits created a relatively level, narrow plain in the valley bottom. Later, a probably fairly wide and shallow stream cut a channel into this material, laying down coarse basal layers (B1 and B2), overlain by sandy overbank sediments (B3 to B8). Layers B7 and B8 contain soil and organic material, which we would explain as indicating periodic flooding and drying of the flood-plain—a typical water-meadow, with agricultural activity when conditions allowed. In recent times (?eighteenth

Table 5—Radiocarbon ages and calibrated date ranges of charcoal in section B.

Label	Lab. no. UBA-[7]	Radiocarbon age	Calibrated range-1 cal. BC[8]	Calibrated range-2 cal. BC	$\delta^{13}C$ ‰
B5	27867	3842 ± 28	2460–2200	2380–2000	−31.0
B3	27866	4153 ± 30	2880–2630	2820–2440	−32.0
B1	26268	5155 ± 31	4040–3810	4000–3660	−26.4

century AD) the stream bed was intentionally lowered and confined to its present channel, cutting through the original deposits (B1–8) as far down as the coarse conglomeratic sediment and glacial till.

THE RADIOCARBON DATES FROM SECTION B

Discussion of the dates (above)

The first observation is that the date order is consistent with the stratigraphy (see Fig. 7); the second is that the calibrated ranges (see below) do not overlap, although the dates for B3 and B5 come close. It is important to bear in mind that the dated charcoal samples consisted of numerous tiny fragments whose contemporaneity *cannot be assumed*. The measured age for each layer is therefore the mean of these individual samples, and neither the radiocarbon ages (before calibration) nor the date ranges (after calibration) tell us anything about the distribution or spread of the dates of the individual pieces—which might be far greater or much narrower than the calibrated range. Furthermore, range-1 dates are the means of the *growth dates* of the fragments, and it is unsafe to assume that the individual fragments all have a minimal own-age: it is more likely that a significant own-age bias is present (the *old-wood* or *own-age effect*) and we have adjusted the dates for that potential bias.[9] This adjustment gives 'range-2' in the table, which, in our opinion, more realistically represents the 95.4% probability range of the mean date of the multiple fragments of each sample.

Layer B1

Both the unadjusted date range of this sample (range-1: 4040–3810 cal. BC) and that adjusted for the potential old-wood effect (range-2: 4000–3660 cal. BC) match the rounded, conventional date range for the Irish early Neolithic: about 4000–3500 BC (Sheridan 1995).[10] To this phase of the Neolithic belong the first major forest-clearance episodes, for which the so-called elm decline[11] might serve as a proxy for dating purposes. Parker *et al.* (2002, appendix) have listed 34 radiocarbon ages associated with the elm decline in Ireland: these show a marked clearance peak between 4800 and 5200 BP (approximately 4000–3600 cal. BC). Within the range of this peak lies the B1 age range. Despite this useful agreement we do not claim that our B1 charcoal was connected to whatever mechanisms explain the elm decline. While it is possible—indeed, in our opinion, probable—that the charcoal in B1 derives from intentional forest clearance and burning in the local area, specific evidence of prehistoric occupation or agricultural activity has not been found, as far as we are aware, in the Leitrim River valley itself or within its watershed.[12] Characteristic of the Irish early Neolithic are court tombs, of which there are several in the lowlands on the margins of the western Mournes, as well as examples to the south and to the north of the Mournes (Jope *et al.* 1966, 16, fig. 11; Ó Nualláin 1983, fig. 84), and portal tombs, which occur to the north and to the south of the Mournes (Ó Nualláin 1983, fig. 84). Recent dates from the Poulnabrone portal tomb in western Ireland indicate that portal tombs can date from as early as 3885–3710 cal. BC (Lynch 2104), while Schulting *et al.* (2012) have shown that the most likely start-date for court tombs is between 3700 and 3550 cal. BC. McSparron (2003) has argued that the rectangular wooden houses that are a feature of this period in Ireland appear to be confined to the century between about 3700 and 3600 cal. BC. The B1 sample date, within 4040–3810 cal. BC (or 4000–3660 with the 'own-age' adjustment), falls just prior to most of this early Neolithic activity phase, and possibly overlapping with some of its earliest manifestations.

Layer B3

Range-1, 2880–2630 cal. BC, falls within the conventional bracket for the Irish late Neolithic: 3100–2450 BC (Sheridan 1995). Although we think that this charcoal derives from local forest-burning during the late Neolithic, we are unaware of any archaeological sites in, or finds from, the Mournes that have been shown to be of that date. Range-2 for this sample, 2820–2440 cal. BC, is also mostly within the late Neolithic bracket, but it is possible that the sample belongs to the very earliest part of the Bronze Age (around 2500/2400 BC) and reflects clearance associated with, and just pre-dating, whatever activities are represented by the B5 date.

Layer B5

At this stage it is necessary to clarify our position on a terminological problem for which there is no general
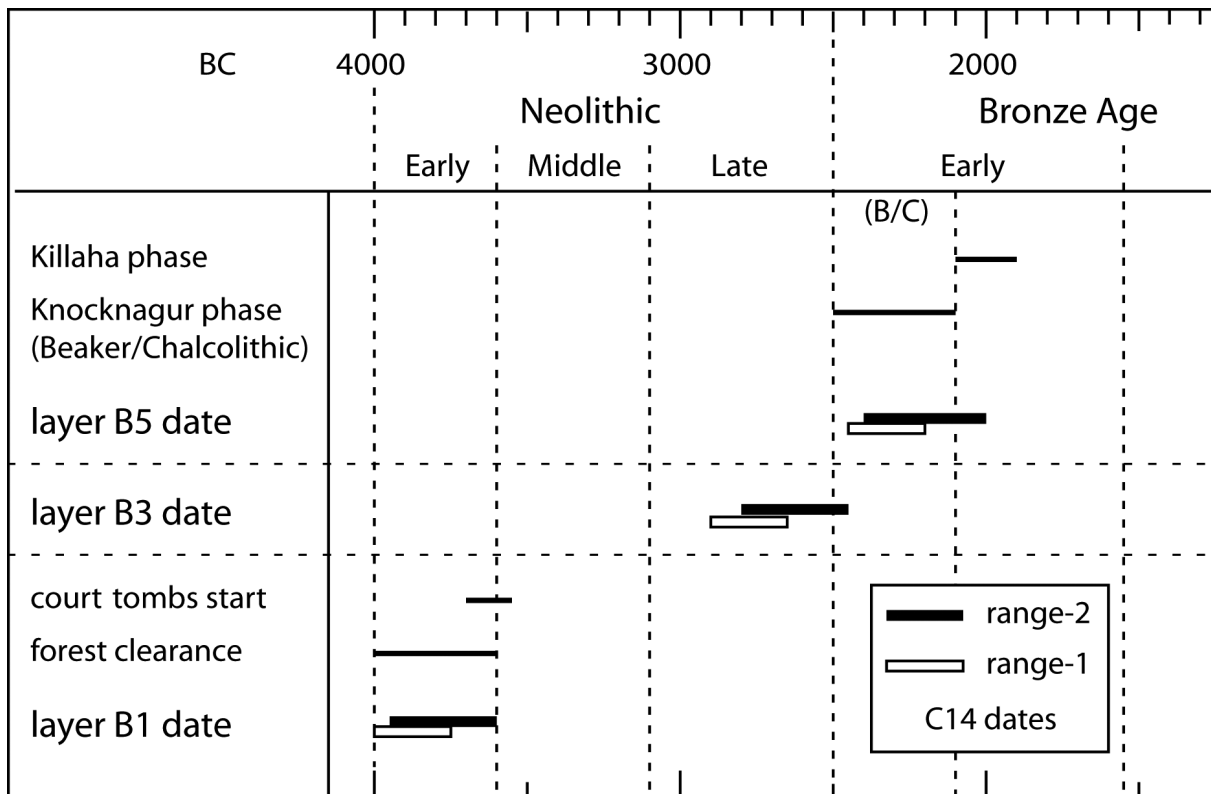
Fig. 7—Summary chart of the calibrated radiocarbon dates from section B (unfilled and thick filled bars for ranges 1 and 2 respectively), and presently accepted date ranges for the relevant Neolithic and Early Bronze Age events and phases (narrow bars).

scholastic agreement. The first phase of the traditionally defined Early Bronze Age in Britain (techno-cultural 'period 1') is (as will be found detailed below) characterised by copper rather than tin-bronze artefacts. For this reason that phase is now frequently called the 'Chalcolithic', and is regarded as being separate from the Bronze Age (see Sheridan 2008). Cogent arguments have been put forward (for instance by O'Brien 2012) for following this practice in Ireland, where the Knocknagur phase (synchronous with period 1) is also almost completely copper-using. There are also strong opinions against the use of the term (Roberts and Frieman 2012), however, and we believe that this paper, which will draw a much wider readership than Bronze Age experts, should follow convention on this matter. Accordingly, we will use 'Early Bronze Age' throughout the paper, with the understanding that the first phase (Knocknagur) can also be called the Chalcolithic. On the chronological charts, however, we have included reference to 'Beaker/Chalcolithic' and 'B/C' in parentheses, for the sake of clarity. In all cases, reference by us to the Early Bronze Age includes the Chalcolithic.

The range-1 calibrated date of this sample, 2460–2200 cal. BC, falls into the Knocknagur phase, the earliest phase of the traditionally defined Irish Early Bronze Age: about 2500/2400–2100 BC.[13] To this phase belongs the introduction of metalworking to Ireland—both gold and copper—associated with the cultural package known as 'Beaker'. The more realistic range-2 (taking account of the potential 'old-wood' effect), 2380–2000 cal. BC, extends as far as the start of the use of tin-bronze in the Killaha phase, conventionally 2100–1900 BC. Warner *et al.* (2010a; 2010b) suggest that gold and tin were both being exploited in the western Mournes in the Early Bronze Age, and the B5 radiocarbon date would place the mean of this sample within the period discussed by them. We discuss the B5 date at greater length below.

GOLD AND TIN IN THE MOURNES

Chapman *et al.* (2006) described their search for secondary fluvial sources of natural Irish gold from watercourses across much of Ireland. From this gold they obtained analytical signatures and were able to characterise natural gold types on both a regional and a local basis. In particular, they found that the natural (alluvial) gold from the stream sediments in the

Mourne Mountains contains, on average, around 10% silver and 0.3% copper. Gold grains are found in the sediments of most of the watercourses panned in the western Mournes, being particularly abundant in the Leitrim River and the nearby section of the River Bann for about 2km above the confluence of the two rivers.[14] Several south-western Mournes stream sediments have also yielded alluvial gold, although in much lower abundance (Warner *et al.* 2010a).

Analysis of heavy mineral concentrates, which were collected from the stream sediments during panning to recover gold, has demonstrated that cassiterite (tin oxide) is common, and occasionally abundant, in some Mournes watercourses (Warner *et al.* 2010b; Moles *et al.* 2014).[15] Cassiterite is found in some of the north-western Mournes streams that also produce gold, both being especially evident in the Leitrim River—the subject of this paper. Cassiterite, however, is more commonly present in the stream sediments in the central Mournes, such as those of the Trassey River, where gold has not been found (Moles *et al.* 2014) but *in situ* cassiterite has been located in bedrock (Arthurs and Earls 2004, 263). This dual nature of the metal contexts has been discussed (Moles *et al.* 2013), the conclusion being that the gold originates mainly from non-igneous rocks in marginal contact with the intrusive granites of the Mourne massif, while the cassiterite was released from mineralisation within the granite itself. Mixing of heavy mineral grains from these spatially separate sources is attributed to a combination of glacial and fluvial transportation in the Leitrim/Bann area of the north-west Mournes (Moles *et al.* 2013).

Stream sediments in the central reach of the Leitrim River have produced the greatest amount of gold found in the Mournes—over 100 grains reported by Moles *et al.* (2013). They suggest that the angularity of a large proportion of the gold grains indicates that the bedrock source or sources are, or were, fairly close to the river. The river has also produced the highest proportion of tin (as cassiterite), relative to other heavy minerals in the heavy mineral concentrate, yet found in Ireland—up to 60% w/w (Warner *et al.* 2010b).

ABUNDANCES OF TIN IN THE SEDIMENTS

The five sieved and dried sediment fractions from <63μm to 500–1000μm, from all the layers, were analysed with a portable X-ray fluorescence spectrometer (PXRF) to determine the abundance of the tin and other metal elements.[16] Use of a PXRF was chosen in preference to conventional XRF analysis, which would have required grinding the samples, precluding further mineralogical study, and also because the analytical precision and detection limits of the PXRF equipment employed are comparable to those of a benchtop XRF.[17] Only the tin values are
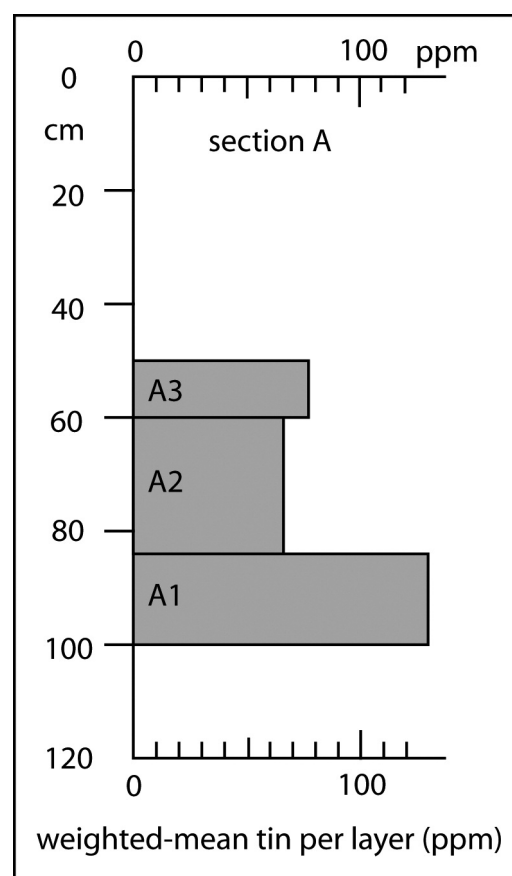

Fig. 8—*The approximate weighted-mean values (ppm) for tin for each layer in section A. Only the three fractions below 250μm were used in the weighting.*

Table 6—*Values of tin in parts per million (ppm) in the fractions and layers of section A (the limit of detection was 16ppm). The fraction ranges are in microns. The weighted means (w-means) for the fractions assume 8 for any value described as '<16', and those for the layers (the right-hand column) include only the fractions up to 250μm.*

	<63	63–125	125–250	250–500	500–1000	W-means (layers)
A3	476	339	39	<16	<16	130
A2	148	59	64	93	<16	67
A1	122	179	107	<16	23	76
W-mean (fractions)	158	194	59	22	11	

considered here, and the values for gold were too low for the PXRF to measure.[18] From the abundance of tin (the element rather than the oxide in which it naturally occurs) from each sieve fraction (Tables 6 and 7)[19] a weighted-mean value for each layer was obtained, shown in Figs 8 and 9.[20] The limit of detection (LOD) for most of the analyses is around 16ppm, which means that several of the low-abundance values are unknown. This is especially problematic for the fractions of coarser material (>250μm, or ¼mm); indeed, most of the results from the 500–1000μm fractions are lower than the LOD. Another problem is the 'nugget effect', which can cause increasing unreliability of element measurements in coarser fractions.[21] Furthermore, the coarser fractions contained far more material than the finer, and the uncertainties within their invariably low tin values were greatly magnified by the weighting procedure. For all these reasons we decided that it was unacceptable to include the two fractions above 250μm (ten of the sixteen values in these fractions were below the LOD) in the weighting calculations.

Section A

Layer A1 has the highest weighted-mean value for A (at 130ppm) by a factor of almost two. A2 and A3 are very similar at around 70ppm. The marked discontinuities in the individual layer values for the fractions (and the fraction weighted means), separating the finer from the coarse material, suggest a low level of stream-winnowing of the finer sediments. We suspect that the hillslope materials that we proposed above to have provided the sediment contained mostly fine-grained cassiterite, the grain size being the result of either (or both) the primary crystallisation processes or the grinding action of the ice that eroded and deposited these materials.
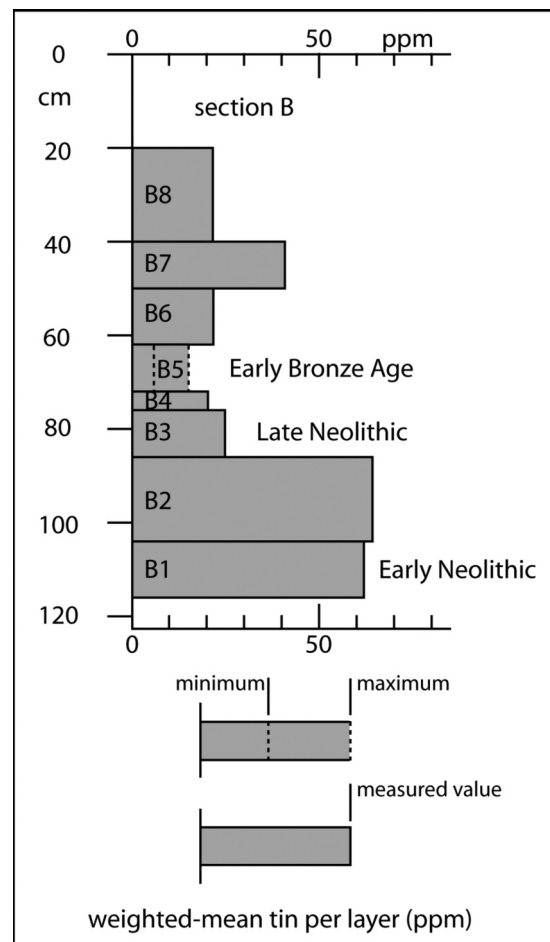

Fig. 9—The approximate weighted-mean values (ppm) for tin for each layer in section B. Only the three fractions below 250μm were used in the weighting. The techno-cultural period labels, which are based on the radiocarbon dates described in this paper, apply only to section B.

Table 7—Values of tin in parts per million in the fractions and layers of section B. The limit of detection (LOD) was 16ppm (the exception being B5, 125–250). The fraction ranges are in microns. The weighted means (w-means) for the fractions use a value of LOD/2 for any value described as '<X', and the weighted means for the layers include only the fractions up to 250μm.

	<6.3	63–125	125–250	250–500	500–1000	W-means (layers)
B8	92	63	14	<16	<16	20
B7	126	72	32	21	<16	41
B6	49	19	22	<16	<16	22
B5	54	38	<10	<16	20	6–15
B4	110	30	16	<16	20	20
B3	80	59	17	20	<16	25
W-means (B3 to B8)	83	44	15	–12	–12	
B2	60	74	61	33	<16	64
B1	67	55	63	94	<16	62
W-means (B1 & B2)	66	59	63	76	8	

Section B

Layers B1 and B2 are very similar in tin content at around 65ppm (shown also by the weighted means of the fractions) except in the 250–500μm fraction of B1, which is relatively tin-rich. As with section A, we regard this as indicating minimal stream-sorting of these basal sediments, which were released from the valley slopes into the streams owing to the increased outwash of disturbed hillside sediments. This explanation is completely in accord with our observation that the radiocarbon date of B1 corresponds well with the date of 'forest clearance' and the beginning of early Neolithic settlement and associated agricultural activity.

In complete contrast to this pattern, each of the layers B3 to B8 (and the weighted means of their fractions) shows a marked and regular decrease in tin values from the finest to the coarsest fractions. We explain this as the result of the winnowing action of the current, whereby the fine particles of lighter minerals such as quartz and feldspar are removed in the suspended load, thus concentrating heavy minerals in the sediment remaining in the bed of the stream. In addition, we note that the mean tin values for layers B3 to B6 are far lower than those of the basal layers, all except B5 showing about 22ppm. On the basis of the pattern of tin values and the absence of coarse sediments, we reject forest clearance as an explanation for the charcoal in B3–B5. Instead, we interpret the low tin levels in B3–B6 as indicating the normal flow situation, with no extra load of mineral-rich sediment entering the stream.

The 125–250μm fraction for layer B5 was counted for 240 seconds, giving a lower limit of detection of 10ppm, at which level tin was still not recorded. The weighted-mean tin value for layer B5 lies between 6ppm and 15ppm, indicating a reduction even beyond the normal level. While this might reflect a (climate-related) reduced run-off, we note that there is not a general reduction in tin but one which (compared with the neighbouring layers) is very specific to the 125–250μm fraction. In our opinion, such selective reduction implies a human agency, for it is only the fractions above 125μm that would have been collectable with primitive techniques. We therefore consider that B5 (and its charcoal) shows the intentional collection of tin, as cassiterite, from sediments either in the stream or in the valley slopes (this is discussed further below). B7 appears to represent a return to the enhanced tin level of B1/2, but showing the decreasing pattern (fine to coarse) of the other layers. We interpret this as indicating an enhanced land disturbance in early recent times, but with not enough extra sediment input to prevent normal stream flow and sorting. Finally, the tin value for B8 (20ppm) is typical of normal conditions, as we propose above for B3, B4 and B6.

A SUMMARY OF THE HYPOTHESIS THAT THE MOURNES WERE A SOURCE OF EARLY BRONZE AGE GOLD AND TIN

The natural-gold project was closely coupled with a parallel project[22] to analyse the gold of Irish Bronze Age ornaments, one aim being the identification of possible gold sources. The first results of the two projects suggested that the western Mourne Mountains were a possible source for some, though probably not all, of the Irish Early Bronze Age ornaments (Warner *et al.* 2009). The gold of these ornaments was found to have a silver/copper signature that is highly compatible with that of the natural gold from the Mournes but incompatible with all other major sources of gold in Ireland (and Britain) for which we have comparative information (*ibid.*, 24 and charts). This apparent correlation is indicative rather than demonstrative and, despite some confirmatory evidence (see below), the Mournes gold hypothesis remains only a hypothesis.[23]

Almost all Irish Early Bronze Age gold ornaments contain tin, often at surprisingly high levels (up to 0.5%; Hartmann 1970, *passim*; Warner 2004, 73–6). As tin is not a significant constituent of natural gold, Hartmann (1970, 11) suggested that it had become incorporated as cassiterite grains into the gold-grain collections ultimately obtained from fluvial deposits in which they were found together. In other words, the gold that was used in the Irish Early Bronze Age had been collected in cassiterite-rich areas. Based on the presumption that there is no significant natural tin in Ireland, it has long been believed that Cornwall was both the source of the gold used in Ireland and the source for the tin used here as an additive to copper to make bronze.[24] The discovery that the Mournes gold is associated with cassiterite, while it does not prove a local origin, certainly removes any barriers to that conclusion. It has been shown (Warner 2004, fig. 11.2) that the Irish Early Bronze Age ornaments containing a high level of tin (greater than 0.035%) tend to be northern, and those with lower tin are mostly in the south. As the Mournes streams are the only potential Irish sources yet found for the exploitation of tin, we might expect, as a test of our hypothesis, that those Early Bronze Age ornaments which contain a relatively high level of tin would match the Mournes natural gold better than low-tin ornaments (although, of course, low tin is also quite possible in Mournes-collected gold). As can be seen in Fig. 10, this prediction seems to be supported, and we suggest that the Mournes gold hypothesis is strengthened by this consideration of the accidental inclusion of cassiterite.
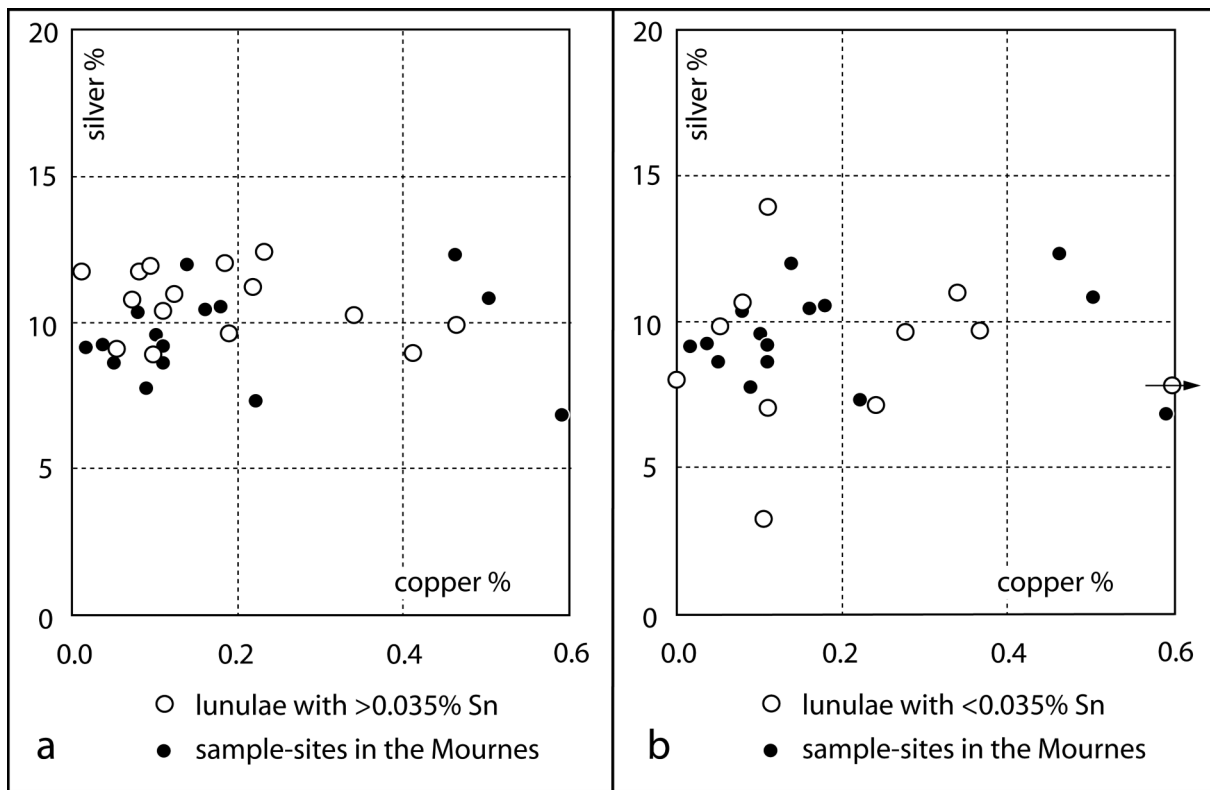
Fig. 10—The mean values of silver and copper in Irish Early Bronze Age ornaments containing (a) >0.035% Sn and (b) <0.035% Sn, plotted against the mean values for Mournes natural-gold sites (with more than three grains analysed).[25]

THE CHRONOLOGY OF TIN AND GOLD IN THE IRISH EARLY BRONZE AGE

It is generally agreed that British copper and gold metallurgical traditions began at about the same time, between 2500 and 2400 BC[26] (the start of Needham's period 1; Needham 1996), and were almost certainly connected with Beaker-culture material and practices.[27] The Irish Early Bronze Age copper industry was among the most significant in western Europe and does not seem to have lagged behind the British, which is why it is quite a reasonable assumption, and is generally accepted, that the Irish Knocknagur phase should equate to the British period 1. The range-1 date of sample B5 lies within this phase, as does most of the range-2 date. Although Beaker material (*sensu stricto*) is absent from the area around the Mournes (as it is over much of Ireland), it is interesting that one of the very few examples of a gold basket-earring from Ireland was found 19km north of the centre of the Mournes on the southern slope of Slieve Croob.[28] It is probably an import from Britain, where these objects are fairly common and where it would certainly belong to the Beaker tradition (period 1) (Needham and Sheridan 2014, 906).

True tin-bronze, and therefore the intentional use of tin, was appearing in Ireland near the end of the

Knocknagur phase but became widespread only at the beginning of the Killaha phase,[29] now put at around 2100 BC.[30] It is clear that the use of tin began locally before the start of the Killaha phase, for bronze daggers were found with bowls dating from the later part of the Knocknagur phase (between 2200 and 2000 BC) at Corkey, Co. Antrim, and Carrickinab, Co. Down (20km north-east of the Mournes) (Brindley 2007).[31] As tin was being used by 2100, and probably earlier, and as the B5 range-2 date takes us up to 2000, we see no serious barrier to the hypothesis that the activity that

Table 8—Irish Early Bronze Age chronology (rounded; from several sources—see text).

Irish phase	Needham period	Date bracket (Lanting & van der Plicht 2007)	Main copper alloy	Gold use
Knocknagur	Period 1	2400–2100	Arsenical copper	Yes
Killaha	Period 2	2100–1900	Tin-bronze	Yes
Ballyvally	Period 3	1900–1700	Tin-bronze	?
Derryniggin	Period 4	1700–1550	Tin-bronze	

produced the charcoal in B5 was connected with the recovery of tin in the Leitrim valley.

The date of the first Irish gold ornaments
The chronology of early gold in Ireland is not founded on particularly solid evidence. The Irish sun–discs (the British flat-discs) are placed into the Beaker period (period 1) in Britain by most writers, including Needham and Sheridan (2014, 906). But for reasons that are not clear (to us at least) they call the identical Irish discs late and place them into period 2, the Killaha phase in Ireland. Perhaps this is based on the association of two discs and a lunula found at Coggalbeg, Co. Roscommon (Kelly and Cahill 2010), and Needham and Sheridan's belief (2014, 912) that lunulae date from period 2/Killaha. Of course, this association works in reverse, and both could belong to period 1,[32] which would remove any need for a dual date for the discs. Most Irish lunulae are highly decorated, and Taylor (1980, 36–44) has proposed that the decoration was derived from that on Beakers (although mostly demonstrated by British Beakers). This would place the inception of lunulae, and probably the floruit of the 'classical' variant, into the Knocknagur/Beaker phase.[33] In fact, there is now a direct date for the lunula from Crossdoney, Co. Cavan (Figs 11 and 12), which was found in a wooden (alder) box (Coffey 1909; Taylor 1980, CoCv11). The wood has been radiocarbon-dated (GrA-13982) to 3800 ± 50 BP (Cahill 2006, 277). This calibrates[34] to 2460–2040 cal. BC (range-1) or 2400–2000 cal. BC (range-2, as defined above[35]). While this date range might marginally allow the lunula into the Killaha phase, the bulk of the calibrated range is clearly in the Knocknagur phase. We therefore propose that Irish lunulae belong within the Knocknagur phase, and we are unaware of any sound evidence that they should be placed solely, or at all, into the Killaha phase.[36]

GOLD, TIN AND THE LAYER B5 CHARCOAL
It is striking how similar are the uncalibrated dates for layer B5 and the Crossdoney lunula box (3842 ± 28 BP and 3800 ± 50 BP),[37] and we must emphasise the fact that both are within Lanting and van der Plicht's (2007) uncalibrated[38] range of 3900–3700 BP (at 2sd) for Needham's period 1 (Knocknagur). Our general conclusion is that the floruit of Irish Early Bronze Age goldwork was during (perhaps the later part of) the Knocknagur phase, and that this coincided with the beginning of tin use for bronze and our date of the B5 charcoal.
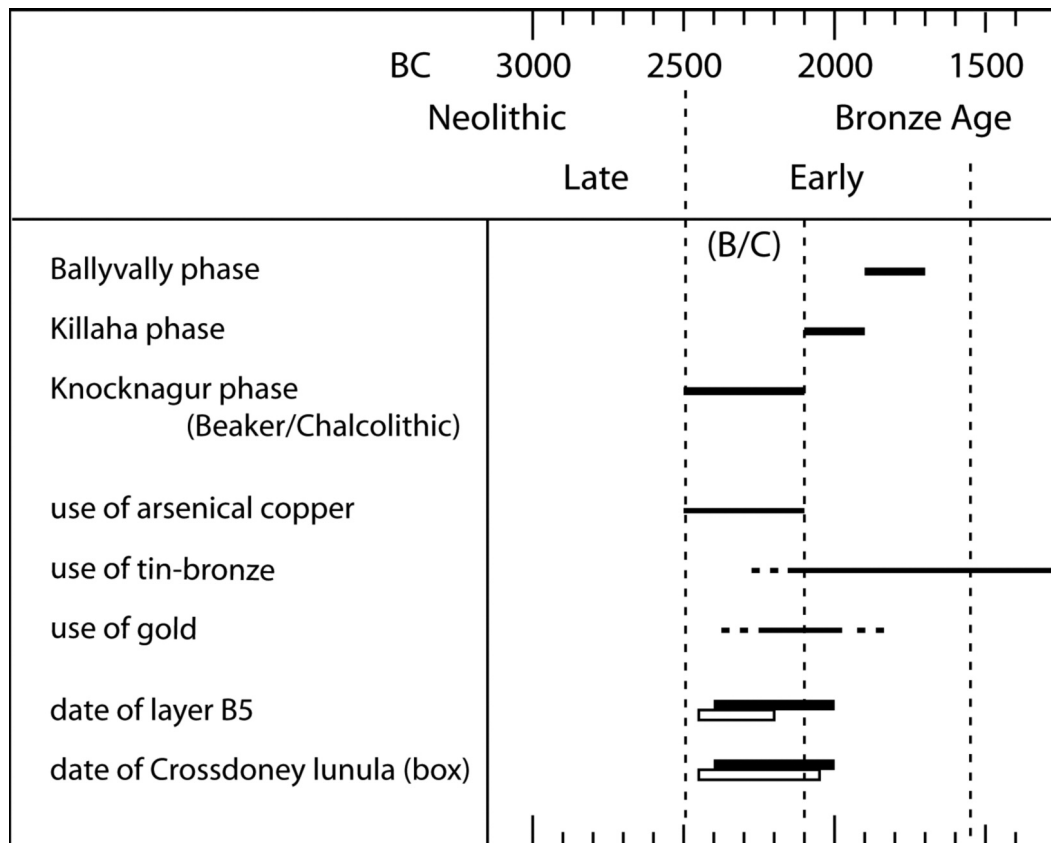

Fig. 11—Date of layer B5 and comparative Irish phases. B/C means Beaker/Chalcolithic. The layer B5 and Crossdoney dates are cal. BC radiocarbon dates reported in this paper, shown as range-1 and range-2 (both 95.4%).

Fig. 12—Gold lunula from Crossdoney, Co. Cavan (greatest diameter 21 cm) (photo courtesy of the National Museum of Ireland).

As Table 9 shows, the lunula from Crossdoney is analytically compatible with Mournes natural gold in its silver and copper content, and also contains measurable tin.[39] While we cannot exclude another origin, the metal of the Crossdoney lunula is consistent with a Mournes source.

Table 9—Analytical results for two Mournes natural-gold sources, the Crossdoney lunula and the mean for all lunulae.

Source	%Silver	%Copper	Cassiterite
Leitrim R., Mournes[40]	10.2	0.23	Yes
Ballincurry R., Mournes	10.8	0.49	No
			%Tin
Crossdoney lunula[41]	9.9	0.45	0.01
Mean, all Irish lunulae	10.1	0.35	0.06

There is, of course, no reason why we should expect the recovery of metals in the Mournes to be reflected by a local concentration of metal products. The hills from which the metals are believed to have derived are not as suitable for settlement and farming as the fertile lowlands away from the Mournes. Although bronze flat axes have been found outside, but close to, the Mournes, they probably represent the periphery of the heavy north–eastern concentration of these (and other) Early Bronze Age metal objects (see the maps in Harbison 1969, fig. 3). We know from the discovery of stone moulds that Early Bronze Age axes were being made in the north as well as in the south–west of Ireland (Eogan 1993), and it seems most likely that metal ingots, or bags of gold/cassiterite grains, were all that were produced in the vicinity of the exploitation.[42]

To sum up, it is our opinion that gold was being locally collected ('streamed') from suitable secondary deposits (including riverbeds) in the western Mournes during the later part of the Knocknagur phase and the succeeding Killaha phase, and perhaps earlier and later

(a century or two on either side of 2000 BC). It was being used to make discs, lunulae and other Irish Early Bronze Age objects. Furthermore, we have presented evidence that tin, as cassiterite, was readily available in the Mournes, and we suggest that this source was the main—probably only—Irish source for tin, which might explain the large number of bronze axes, especially of the Ballyvally type, that have been found in the north-east of Ireland.[43]

We have, above, detailed our reasons for rejecting the explanation of forest clearance for the charcoal in B5, choosing instead an explanation connected to the collection of tin and gold. We do not assume that the metals were collected from the river itself, or that the streaming pits were adjacent to the river, although we would expect that outwash from such pits would eventually enter the river. The fall in proportion of cassiterite grains greater than 125μm in B5 would appear to have been caused by the removal of sand-sized cassiterite upstream from section B. This removal was possibly from postulated cassiterite-bearing deposits in the valley slopes rather than from the alluvial sediments in the river, as described below.

The Mournes gold and tin hypotheses remain just that, albeit they may be significantly strengthened by the evidence we have outlined herein. We must point out, however, that although we believe that gold and tin were both being extracted, the arguments are not interdependent. If the Mournes gold hypothesis is disproved by the recently reported lead isotope measurements (Standish *et al.* 2014; 2015), the Mournes tin hypothesis is quite unaffected. Our discovery that, of three significant wood-burning events in the catchment area of the upper Leitrim River, one clearly dates from the earliest phase of the Bronze Age at least provides us with evidence of activity on a large scale, either agricultural or industrial, at around the time that both gold and tin were first being used and, we believe, sourced in Ireland.

Finally, we reiterate the caution that we stated in earlier papers: although panning in the minor streams was undertaken by us in order to obtain samples, we do not believe that this would have been the Bronze Age method of collection. Rather we would argue that 'streaming' (the washing away of surficial deposits in the valley slopes to uncover metal-rich basal layers), as described by Penhallurick (1986, 159ff) and Warner *et al.* (2010b), would have been the most likely method of extraction. Because the Leitrim River and the adjoining River Bann are now areas of farmland, physical evidence of streaming is far less likely to be preserved as clearly as seems to have been the case on the upland slopes of the Ballincurry River in the south-western Mournes (Warner *et al.* 2010a; 2010b).

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NOTES

1. Led by Dr Norman Moles and Dr Rob Chapman.
2. A high lynchet, marking the western edge of the flood-plain, is sporadically visible along the middle stretches of the river, some 100–200m from the present riverbank.
3. Section A: Irish Grid reference J 2145 2582. Mournes site 53 (near site 17 of Moles *et al.* 2013). Section B: Irish Grid reference J 2160 2713. Mournes site 54 (near site 14 of Moles *et al.* 2013).
4. B4 contained too little organic matter for dating purposes.
5. The woody pieces proved to be too small for Professor Jon Pilcher to identify the species.
6. The charcoal samples were dated by the [14]CHRONO laboratory of Queen's University Belfast. Pretreatment was by 'Acid' only. No extra error-multiplier is required and the corrections for $\partial^{13}C$ were made by the laboratory.
7. We gratefully acknowledge the School of Environment and Technology, University of Brighton, for funding the radiocarbon dates.
8. The ranges represent the 95.4% (2sd) probability level rounded outwards to the nearest decade. The range-1 calibrations were provided by the laboratory, which used the CALIB calibration program and the data of IntCal13 (Reimer *et al.* 2013). The range-2 calibrations were made using OxCal 4.2 and the same dataset.
9. A *maximum possible* own-age (oa) is assumed, based on sample characteristics and species, and for unidentified charcoal should be 250 years (Warner 1990). The adjustment has been made using the 'offset' procedure of OxCal 4.2 with the Gaussian offset (towards the present) at oa/2 ± oa/4.
10. This rounded range for the early Neolithic remains a sound generalisation, despite recent modifications (e.g. Sheridan 2010; Cooney *et al.* 2011).
11. The 'elm decline' is not now assumed to be a synchronous event, and it remains unclear whether it was anthropogenic or natural—or both (discussed by Parker *et al.* 2002).
12. Surprisingly, early Neolithic porcellanite axes, though plentiful throughout north-eastern Ireland, are not recorded from the Mournes (Sheridan 1986, 21, fig. 2).
13. Lanting and van der Plicht 2007, 378; Waddell 2010, ch. 4, for a useful summary of the phases of the Irish Early Bronze Age.
14. Near Hilltown. The River Bann below the confluence was unsuitable for panning, as was the Leitrim River for 2km above the confluence (the 'lower Leitrim').
15. The Tellus project (Geological Survey of Northern Ireland) has mapped the geochemistry of sieved stream sediments across northern Ireland and its map for tin shows that, against a background level of less than 5ppm for most of the province, that for the mountainous area of the Mournes is almost all above 30ppm and often rises to 400ppm (0.04%) (Lister *et al.* 2007).
16. We are grateful to the technical staff of the School of Environment and Technology, University of Brighton, for undertaking these analyses.
17. The PXRF used was an Olympus Innov-X Delta owned by the University of Brighton, using the 'Geochem' mode, inbuilt calibration, and count times of 90 to 140 seconds. Individual sieve fraction samples were measured between two and ten times at different locations to approximate a representative analysis of each.
18. Panning of the sink fraction of the alluvium samples from section B yielded heavy mineral concentrates. From these, gold grains were found only in layers B2 (one grain) and B3 (two grains), a point to which we attach little significance, given the small volume of alluvium that was processed (1–2kg) in comparison

to our previous panning of the active stream sediment (up to 500kg processed from each site). The abundance of gold and cassiterite grains recovered during the previous panning cannot be directly related to those metals in the identified layers of the alluvial profile, as the former were recovered from the more recent sediment of the historically deepened channel.

19. These results should not be compared with the Tellus figures referred to above, as the analysed samples were quite differently collected and treated.

20. The weighted mean combines the percentage of tin with the inverses of the weights of material in each fraction below 250μm. For the calculations we set each value that was reported as '<16ppm' to 8ppm.

21. The nugget effect describes the high variability of analytical measurements when the element (tin, in this case) occurs as discrete and relatively large particles (of cassiterite) rather than being dispersed homogeneously through the sample medium. It can be circumvented by taking large samples and measuring the element content without subdividing these samples.

22. The Irish Prehistoric Gold project, hosted by the National Museum of Ireland, which has analysed over 400 prehistoric gold ornaments by XRF. These data, which show gold-silver-copper signatures that appear to characterise the Irish techno-cultural phases, have not yet been fully published, but signature charts are shown in Warner and Cahill 2012, 96, fig. 1.

23. Recent work on lead isotopes in Irish natural and artefact gold has led Standish *et al.* (2014; 2015) to reject the Mournes hypothesis and to propose a return to the prevailing opinion (e.g. Penhallurick 1986, 113 and 163) that the Irish Early Bronze Age gold might have come from Cornwall.

24. Budd *et al.* (1994) and Penhallurick (1986, 113) have dismissed all claims of exploitable deposits of tin in Ireland, and most writers would now see south-west England as the source for Irish tin (discussed by Penhallurick, *loc. cit.*).

25. The data for the natural gold were supplied by Rob Chapman; the silver values for the ornaments are from the Irish Prehistoric Gold project; the copper and tin values for the ornaments are from Hartmann 1970.

26. We have rounded the ranges for the cultural phases to the nearest century.

27. A useful overview of the position in Ireland is provided by O'Brien 2012. Taylor 1994 is also a helpful summary of gold use.

28. Either Dehommed or nearby Benraw; Taylor 1980, 22; O'Connor 2004, 208; Briggs 2004.

29. Indeed, the first extensive use of tin-bronze in Ireland

defines the Killaha phase.

30. Opinions on the chronology of the British Early Bronze Age are highly variable, by up to 200 years for the interfaces between the techno-cultural phases. This is even more the case for Ireland. We have used the interface dates suggested by Lanting and van der Plicht (2007) (rounded to the nearest century), which we show in Table 8.

31. We note Sheridan's opinion (2008, 67) that 'Britain and Ireland switched to a full bronze-using tradition as soon as the existence of abundant tin in the south-west [of Britain] was realised (before the 22nd century), and earlier than on the Continent'.

32. As Needham (2000, fig. 2) has suggested.

33. Eogan (1994, 33) raised the possibility of an artistic borrowing not from Beakers but from Irish bowls, which would still allow a later Knocknagur phase date.

34. Using the calibration program OxCal4.2 and the database IntCal13 (Reimer *et al.* 2013).

35. Adjusted with a maximum own-age of 100 years.

36. O'Connor (2004, 210) suggests an equally early date for their start.

37. Adjusted for old-wood effect, 3720±70 and 3750±60 BP.

38. The process of calibration, although necessary for placing events or artefacts into real (sidereal) time, adds further uncertainties to the dates. It is therefore often more meaningful, when comparing dated events or artefacts, to use the uncalibrated radiocarbon ages (usually referred to as 'BP').

39. The tin value for the Crossdoney lunula is much less than the mean value for Irish lunulae. But as the addition of any tin was, we argue, purely an accident of collection, this fact is not of any significance. Low tin is as likely as high tin in Mournes-collected gold.

40. The EPMA values of natural gold were provided by Rob Chapman of Leeds University. They are the mean values of many grains from each site.

41. These XRF values are courtesy of Mary Cahill and Paul Mullarkey of the National Museum of Ireland.

42. We know of no evidence that copper was available for exploitation in the Mournes. However, the Geological Survey of Northern Ireland has a file card ('134 Rosstrevor Upper td.') containing the following information: 'Quartz vein with possible traces of copper. Excavation called The Copper Mine.'

43. Including four bronze axes found together on Ballyvally Mountain (Armstrong 1917, 512 and pl. 46, 4–7; Harbison 1969, nos 843, 844, 1252 and 1253), a mere 3km west of the Leitrim River. These axes name the Ballyvally phase (Needham's period 3), following the Killaha phase, between about 1900 and 1700 BC.