Rock crystal reduction at the Early Neolithic site of Dorstone Hill, Herefordshire, and its wider British and European context

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Abstract:

Assemblages of worked rock crystal (pure hyaline quartz) in British and Irish prehistoric contexts are scarce. As a result, the published record contains little in the way of detailed accounts of the technological process and reduction strategies for this material, in contrast to a number of sites in continental Europe. This paper expands on the data from the analysis of a new assemblage of rock crystal from Dorstone Hill, Herefordshire, dating to the Early Neolithic published in Overton *et al.* (2022). Our new analysis focuses primarily on the methods of crystal reduction and identifies a systematic approach to it that demonstrates that Neolithic knappers at this site had an inherent understanding of the specific material characteristics of rock crystal. However, comparison of the reduction strategy employed at Dorstone Hill with European materials demonstrates that rock crystal can be worked in a number of different ways, and that the sequence at Dorstone represents an approach that was not just dictated by the material properties. Furthermore, the absence of utilised pieces or formal tools made from rock crystal, leads us to suggest that it was the act of working the exotic material that was significant, as opposed to its tool-making potential. We conclude by outlining future avenues for British and Irish rock crystal research and re-iterate the importance of technological analysis of rarer and lesser published materials.

Keywords: rock crystal; technology; sequence of flaking; sourcing; exotic materials

1. Introduction and background

In the UK and Ireland 'rock crystal', or pure quartz, is an unusual, rare, and in most sites, exotic material. Due to its scarcity and archaeologists' lack of familiarity with it, this material has received relatively little attention in publications, although the more prevalent vein quartz has been the subject of technological analysis (*e.g.*, Ballin 2008; Driscoll 2010; 2016; Driscoll & Warren 2015; for a more general view see Spry *et al.* 2021) and a consideration of its symbolic significance (for example, Fowler & Cummings 2003; Reynolds 2009). There are a small number of relatively substantial rock crystal assemblages from Britain and Ireland, including two dating to the Mesolithic from Jura (Scotland); Neolithic examples are known from Parc Bryn Cegin, Parc Cybi and Llanfaethlu (North Wales) and Lough Gur,

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Balleygalley and Corbally (Ireland) (Ballin 2008; Driscoll 2010; Kenney 2008; 2011) (Figure 1), however, most sites have very small assemblages, or single pieces (see Overton *et al.* 2022: supplementary material). Furthermore, in contrast to sites on continental Europe (see Fernández-Marchena & Ollé 2016; Rodríguez-Rellán 2016; Tardy *et al.* 2016, among others) little has been published relating to the reduction methods and sequence of reduction of rock crystal in British and Irish contexts. The recent recovery of a large Early Neolithic assemblage of rock crystal artefacts from Dorstone Hill (Herefordshire) presents an opportunity to redress this. The broader archaeological context and deposition of this assemblage has been published in an earlier article (Overton *et al.* 2022), and this new contribution is presented as a companion publication. It builds on the archaeological context presented in Overton *et al.* (2022) by providing greater technical discussion of our methodological approaches, new technological data from the assemblage and a detailed discussion of the exploitation and reduction sequence evidenced in the assemblage, and how it compares to the use of rock crystal in wider British, Irish, and European contexts. Interpretations as to the significance of rock crystal and the practice of working this material at Dorstone Hill will be briefly summarised but has been more fully examined in Overton *et al.* (2022).

Dorstone Hill is a flat-topped hill, forming part of the ridge of hills dividing the Dore and Wye river valleys in Herefordshire. The hilltop, which projects southwards into the Dore river valley (known as the Golden Valley), is the location for an extensive Early Neolithic monumental complex dating to the 39th-35th centuries cal. BCE (Ray *et al*. 2023) (Figure 2). At the northern extent, where the hilltop narrows and joins the ridgeline, three earthen long mounds, built end-to-end, stretch across its width. Each of these long mounds (herein the Eastern, Central and Western mound) overlie the remains of timber structures, each of which had been intentionally burnt down, and the remains used as the 'core' of each long mound. At the southern end of the hilltop, a single-circuit causewayed enclosure was also discovered (see Overton *et al.* 2021; 2022; Ray & Thomas 2020; Ray *et al*. 2023). During excavations at Dorstone Hill between 2011 and 2019, a total of 2,686 chipped stone artefacts were recovered from the structures, long mounds, and causewayed enclosure. The majority were made of flint (86.8%), however a total of 337 rock crystal artefacts accounted for 12.5% of the assemblage. Axes (and fragments thereof) made of volcanic rock make up the remaining 0.7% (see Overton *et al*. 2022: table 3).

Figure 1. Map of the British Isles and Ireland showing the location of Dorstone Hill and other Neolithic assemblages using rock crystal mentioned in the text (see Ballin 2008; Driscoll 2010; Kenney 2008; 2011) (drawn by Nick Overton).

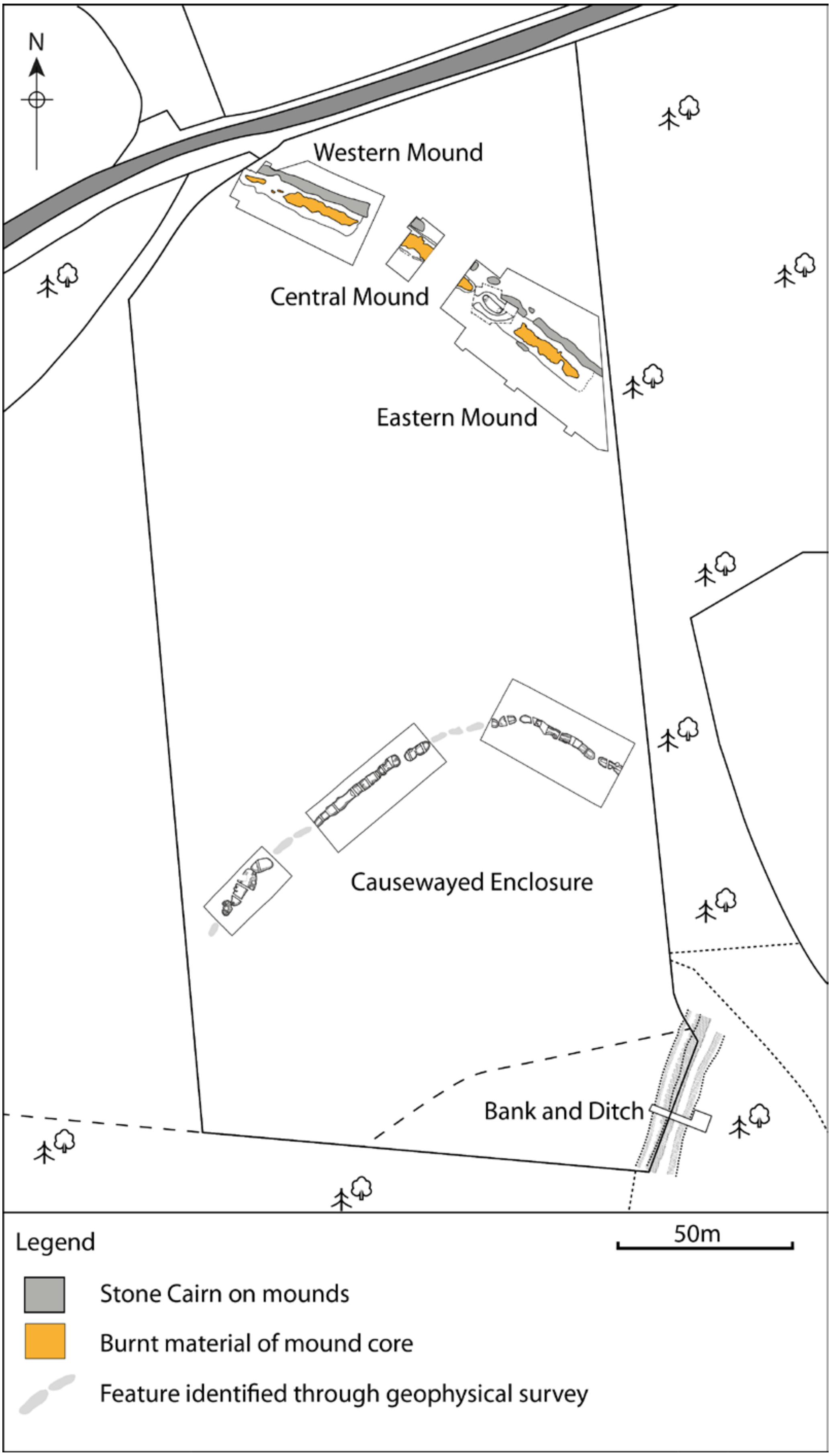

Figure 2. Site plan of Dorstone Hill showing major features and excavated areas (drawn by Nick Overton).

2. The nature and occurrence of rock crystal in the UK

Rock crystal is quartz (silica dioxide, SiO^2) and can form as water-clear crystal in both veins and as single 'hyaline' or 'automorph' crystals. Whilst both forms exist in the UK, veins or lenses of pure transparent crystal within other forms of quartz, such as milky quartz (*e.g.*, Ballin 2008: 47) are usually small; hyaline crystals, either single or double-ended, with a hexagonal cross section, are larger, and therefore offer more opportunity as knappable raw materials. Whilst quartz is a common component of igneous, metamorphic, and sedimentary rocks found across the UK, large, water-clear quartz crystals are much rarer, forming in specific geological conditions, as crystallization in magmatic rocks, or as the solidification of hydrothermal fluids in various host-rock types within 'Alpine type fissures' (Ballin 2008: 44-45; Cotterell 2011). These conditions are restricted to a number of localised areas, including Snowdonia, St David's Head and the area around Merthyr Tydfil in Wales, the area surrounding Tintagel, Cornwall, on the Isle of Jura, and locations in Argyle and Bute, Aberdeenshire and East Lothian, Scotland, and the Dingle Peninsular in Ireland (Cotterell 2011; 2023; Griffiths 2009; National Museum of Wales 2019, quartz; Lewis 1846). The limited distribution means that this material was an exotic at Dorstone Hill, with the closest likely sources (St David's Head and Snowdon) at least 80-100 miles away (Overton *et al.* 2022). The rock crystal used at Dorstone Hill is of very high quality, with the vast majority of the pieces recovered being entirely transparent or 'water-clear' but some crystals and fragments are milkier towards the base. The high quality of the material, combined with the presence of pieces with natural crystal faces (as described below) indicates this material originated in hyaline crystal form, as opposed to lenses of purer quartz within larger milky quartz formations, as present in some other British assemblages (see *e.g.*, Ballin 2008).

Like crypto-crystaline flint and chert, hyaline rock crystal fractures conchoidally. However, the molecular structure of rock crystal is such that whilst some parts of the crystal are isotropic and fracture in an unconstrained way (notably the *pyramidion*), the body of the crystal is anisotropic. As a consequence, the fracture characteristics of rock crystal are not necessarily the same as those of flint and chert (see Fernández-Marchena & Ollé 2016; Rodríguez-Rellán 2016; Tardy *et al*. 2016). Most notably, the differential frequency of Si-O bonds within quartz crystals, which creates the anisotropy in the material, are distributed in such a way that fractures run obliquely through the crystal (that is, parallel to the 'point' faces) cut through fewer bonds, and therefore require less energy to create. In practice, this manifests as more marked bulbs, more pronounced ripples or stepped ventral surfaces and edges with 'denticulate appearance' on removals removed longitudinally (working against the anisotropy), in contrast to oblique or diagonal removals (Rodríguez-Rellán 2016; Tardy *et al.* 2016). The reduction process is also constrained by the shape of the parent crystal. There has been little discussion about how rock crystal artefacts were produced in the UK and little to no experimental replication of the crystal reduction process, so the attributions that follow should be regarded as preliminary; further technological analysis of data from experimental knapping is required to understanding how rock crystal behaves when reduced using the range of reduction techniques and approaches argued for in the British and European material (see section 6.1 below).

3. Approaching the Dorstone Hill rock crystal assemblage

Rock crystal is an unfamiliar raw material in the UK, and this presents analytical challenges. Having no precedents or established published recording procedures for this material specifically, this analysis approached the assemblage from Dorstone Hill in much the same way as most other lithic assemblages, making adjustments where needed. For example, new categories were created for the parent material, termed ‘whole crystal’ and ‘partial crystal’ which are the equivalent of unworked or tested nodules or pebbles of flint.

Each artefact was recorded according to its morphological category. Experimental knapping of rock crystal has suggested that the shapes of knapping products and debitage are at least in part determined or constrained by the shape of the parent crystal (Rodríguez-Rellán 2016; Tardy *et al.* 2016), as opposed to the explicit intention of the knapper. However, the morphological categories were ultimately considered useful for separating the different forms produced, even if they could not be technologically substantiated. Debitage over 10mm were categorised as ‘blades’ (pieces with a length to width ratio of 2:1 or greater, with parallel sides and parallel ridges on the dorsal surface), ‘blade-like flakes’ (pieces with broadly parallel sides and broadly parallel ridges on dorsal surface, but not achieving a length to width ratio of 2:1) and ‘flakes’ (squat pieces with a length to width ratio of under 2:1 lacking parallel sides and parallel ridges on dorsal surface) (see Figure 3). Fragments under 10 mm were categorised as ‘chips’. Other artefacts were classified as cores (pieces with only negative scars), chunks or whole crystals and partial crystals. We also examined each artefact for any evidence of modification.

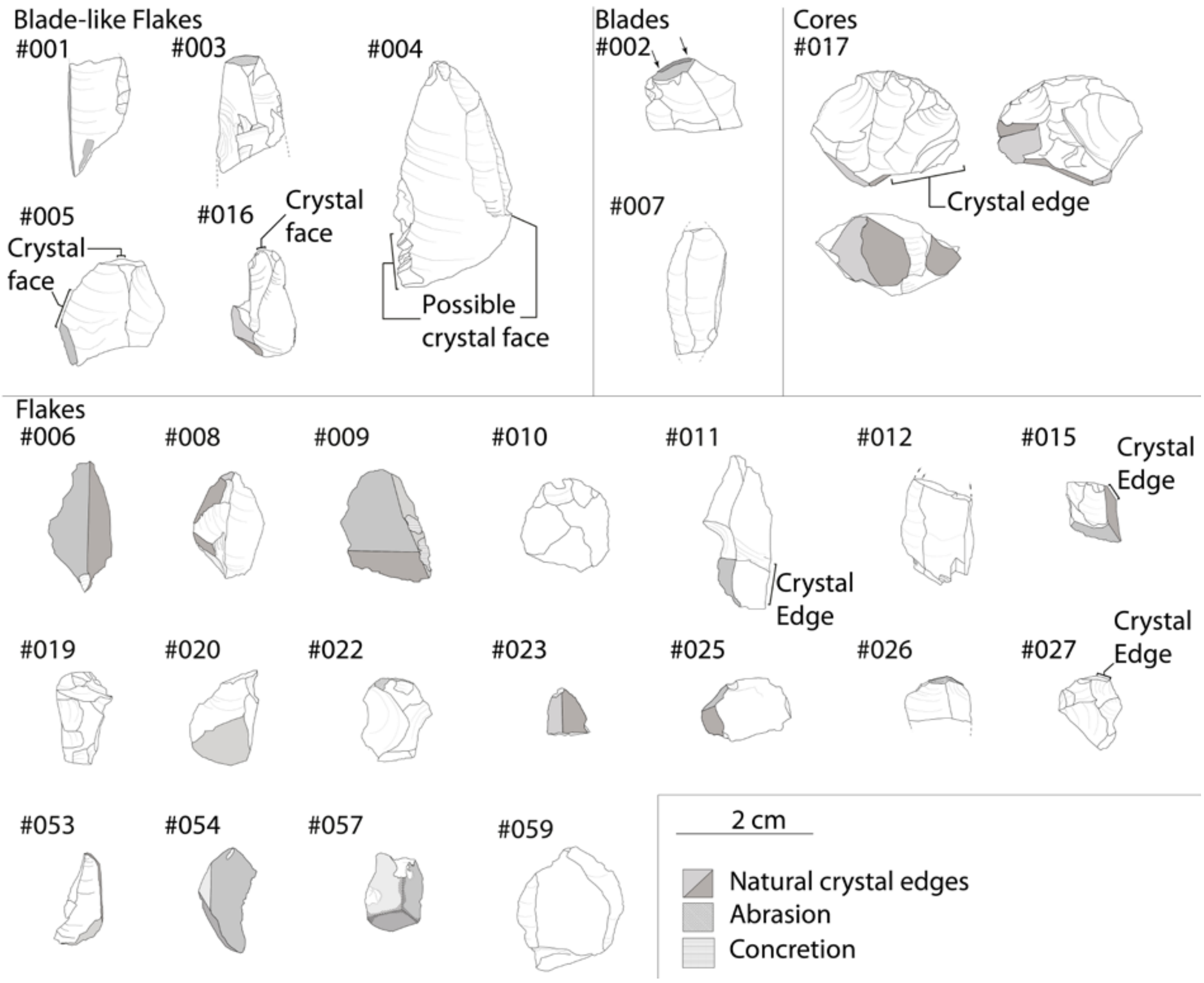

Figure 3. Examples of rock crystal artefacts (drawn by Elizabeth Healey). Note the artefacts are oriented with the bulbar end at the top and the dorsal surface uppermost so as to conform to the reconstruction of the reduction sequences suggested in Figure 6.

The completeness of each artefact and its metrical details (length, width, thickness in millimetres and weight in grams) were recorded. Length was defined as the maximum measurement perpendicular to the striking platform and width the maximum dimension at right angles to this axis. Thickness refers to the maximum thickness of the artefact. Variations relating to the quality of the crystal such as clarity, texture, and inclusions, which may relate to the quality of the parent crystal, or the original position of the piece within the parent crystal, and any potential evidence for alteration by heat were also noted. For those pieces over 10mm a range of technological details were recorded including attributes relating to the striking platform, the bulb of force, any treatment of the platform edge, and the form of the distal termination and aspects of the dorsal surface including scarring pattern and the presence of the natural edge or face of the crystal (the equivalent to cortex on flint) in terms of its supposed position (tip, body or base) within the crystal. 'Body' faces (those that run along the length of the crystal) are identifiable by the presence of growth lines, which run perpendicular to the longitudinal axis of the crystal; 'point' faces (the faces that make up the pyramidion of the crystal) are notable for the lack of growth lines; and 'base' pieces (*i.e.*, at the opposite end to the *pyramidion*), are characterised by more complex formations where the crystal joins other crystals and the vein quartz substrate and may be slightly milky in appearance. This detail was useful for positioning the artefact within the parent crystal, and for determining the direction of the removal in relation to the crystal, thus allowing us to locate it in the reduction sequence.

4. Results

The full descriptive and technological data for individual artefacts is freely available the supplementary data published in Overton *et al.* (2022), to which the reader is referred. Here we summarise the relevant results.

4.1. Composition of the assemblage by context

As noted, rock crystal artefacts constitute only a small proportion of the lithic assemblage (about 12.5 %) but were notable in being present across the Dorstone Hill monumental complex, from contexts spanning the 39th-36th century BCE (Overton *et al.* 2021; 2022; Ray & Thomas 2020; Ray *et al.* 2023; also see below). Most of the material was recovered from the timber structure and later phases of the three long mounds, with smaller assemblages being recovered from the causewayed enclosure and deposits sealed beneath a later Iron Age to Roman bank and ditch, which are associated with a potential continuation of the earlier causewayed enclosure (Table 1).

Table 1. Distribution of rock crystal artefacts across the site.

	Eastern Mound	Central Mound	Western Mound	Causewayed Enclosure	Bank and Ditch	Total	%
Blade	1		1			2	0.59
Blade-like flake		3	2			5	1.48
Flake	6	6	7	5		24	7.12
Core			1	1		2	0.59
Chips & fragments	23		268	3	1	295	87.54
Whole crystal				1		1	0.30
Crystal fragment				2		2	0.59
Chunk				6		6	1.78
Total	**30**	**9**	**279**	**18**	**1**	**337**	**100.00**

The detailed contextual analysis of rock crystal deposition at Dorstone Hill (Overton *et al.* 2022) identified that whilst the rock crystal artefacts constitute a minority of the chipped stone component, within primary contexts they make up 34% of the recovered material (see Table 2). It also noted the differential deposition of rock crystal and other lithic materials; the vast majority of the rock crystal artefacts were deposited within discrete pits within or on the edge of the long mounds, whilst other lithic artefacts were recovered from a range of contexts, with layers of the long mound containing the most. However, the distribution of formal tools made from other lithic materials also demonstrated a focus on discrete pits (Table 2), suggesting that similar intentional deposition was practiced for (all) rock crystal and for formal tools made on other lithic material (see Overton *et al*. 2022).

Table 2. Occurrence of rock crystal in primary contexts compared to flint and volcanic rock.

	Rock Crystal		**Flint and other lithic material**					
			Overall		**Flakes**		**Tools**	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**	**Frequency**	**%**
Cist	0	0.00	27	4.53	26	4.50	1	5.56
Land surface	0	0.00	13	2.18	12	2.07	1	5.56
Mortuary structure	19	6.17	19	3.18	19	3.29	0	0.00
Mound	9	2.92	259	**43.45**	256	**44.36**	3	16.67
Pit	278	**90.26**	238	39.93	226	39.16	11	**61.11**
Structure	2	0.65	40	6.71	38	6.58	2	11.11
Total	**308**	**100**	**596**	**99.98**	**577**	**99.96**	**18**	**100.01**

4.2. Crystals, chunks and cores

A single, almost complete, crystal (Supplementary catalogue: #70) and two thickish body fragments with natural crystal facets on two or more faces (Supplementary catalogue: #65 and #68), indicate that the crystals were introduced to the site in an unmodified state. The almost complete crystal is missing its tip, which may be due to an initial attempt to reduce the crystal, but which was then abandoned because of internal fractures. A further six fragments from the base of the crystal complex have been termed ‘chunks’ (Supplementary catalogue: #035; #056; #069; #071 and #072). They show some evidence of working and represent what remained once the crystal had been removed from its parent cluster. None of these objects are of particularly good quality, exhibiting extensive internal fractures, which is probably why they were discarded.

No laminar or other cores were observed in the Dorstone Hill rock crystal assemblage. However, two small lentoid-shaped pieces (Figure 3: #017; Supplementary catalogue: #64) have only negative scars and thus are technically ‘cores’. The remnants of the crystal faces left on them suggest that, unlike the flakes and blades, they can be positioned horizontally within the crystal. They are quite small (Figure 3: #017 measures 15 x 20 x 9.4 mm and weighs 2.0 g, and #64 measures 18 x 15 x 19 mm and weighs 2.87g) and have had small flakes removed from the upper and lower surfaces in a systematic manner. The small size and limited utility of the flakes which would have been generated suggest that the parent piece could have been the intended product (or a preform for a bead or similar), rather than being a ‘core’ for the production of flakes or blades. There is, however, no evidence for use of these ‘cores’, or of any finished products for which they may have served as preforms.

4.3. Blades, flakes and chips

The bulk of the rock crystal assemblage is comprised of flakes and blades (Table 3). Most (295 or 87.5%) are best described as micro-debitage, that is small flakes and fragments or chips under 10 mm in maximum dimension and are not discussed further in this paper. Here we focus on the 31 artefacts over 10 mm in length, as they show different stages in the reduction process. Based on the categories defined in the methodology (see above), the assemblage contains 2 blades, 5 blade-like flakes and 24 flakes (see Figure 3 for illustrations of the different types). The completeness, surviving portion and dimensions of these pieces are presented in Table 3 and Figures 4 and 5, the scarring pattern on the dorsal surfaces, evidence of crystal preparation and crystal quality are summarised in Table 4, and the presence of crystal faces and interpreted direction of reduction in Table 5.

Table 3. Completeness of flakes and blades.

Type	Complete	Proximal fragment	Distal fragment	Medial fragment	Total
Blade	1	1			2
Blade-like flake	2	2	1		5
Flake	11	5	7		23
Possible crested piece	1				1
Total	**15**	**8**	**8**		**31**

Table 4. Summary of technological attributes of blades and flakes over 20mm (based on Overton *et al*. 2022: suppl. table). *: 3 unidirectional with truncated orthogonal scars; **: 2 outer crystal surface (no scars); ***: one faceted.

Category		Blade	Blade-like pieces	Flakes
	No. complete	1	2	12
Dorsal scarring pattern	uni-directional	2	4	4
	bi-directional		1	1
	orthogonal			1
	multi-directional			8*
	indet or n/a			10 **
Flake removal surface (striking platform)	crystal faces		1?	2
	plain		1 + 2	6 ***
	linear	1	1	0
	abraded			2
	splintered			2
	indet or n/a	1		12
Distal termination	crystal facets			2
	overshot		1	2
	thin		2	6
	hinge			2
	splintered			1
	n/a	2	2	11
Crystal clarity		clear x 2	clear x 5	clear x 24
Texture		all smooth	all smooth	12 smooth, but 12 billowy or rough
	Total	**2**	**5**	**24**

4.3.1. Dimensions

The complete pieces are quite small, ranging from 10 to 34 mm in length although only two are longer than 17 mm, the longest being a blade-like piece #004 which is 34 mm (Figure 4). None are larger than the complete crystal (#70, which is 39.5 mm in length).

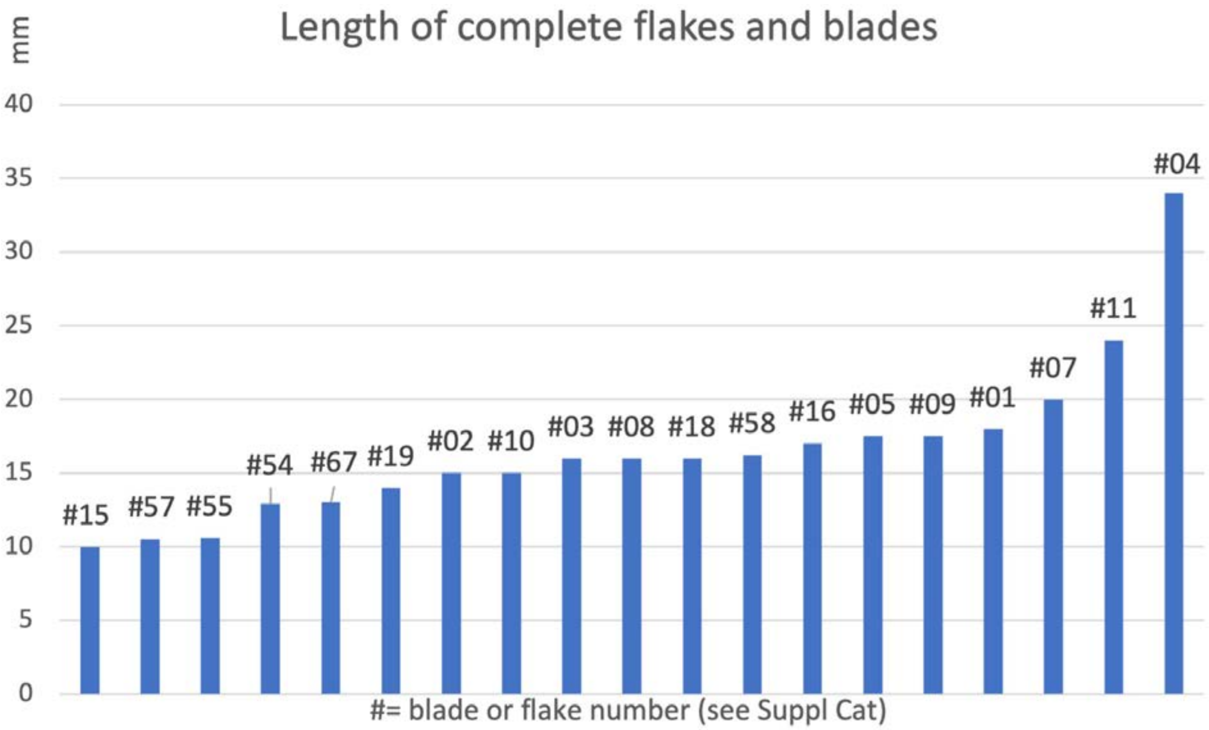

Figure 4. Chart showing length distribution in mm of the complete blade and flakes compared to the crystal.

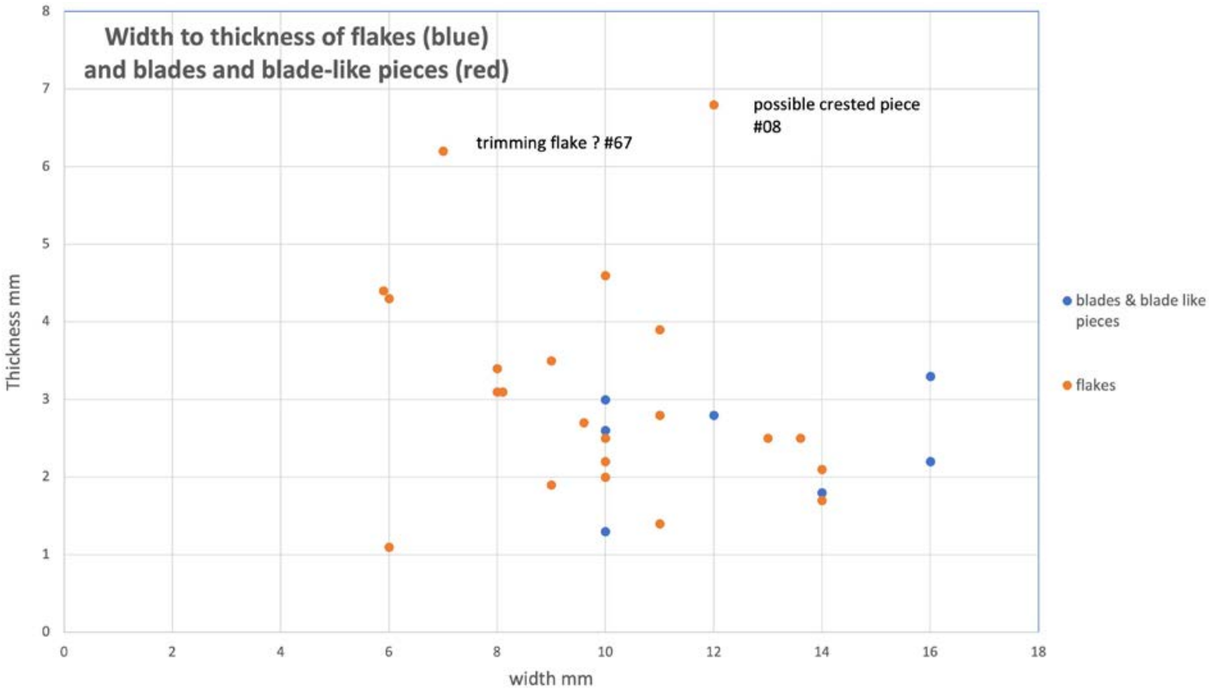

Figure 5. Chart showing width to thickness (in mm) of flakes and blades over 10 mm.

The width to thickness ratio of the flakes and blades (Figure 5) is more varied but most are between 8 and 10 mm wide which corresponds to the width of the facets on the complete crystal. The larger elongated pieces also tend to be more robust than the smaller flakes. Thickness seems to vary a lot, but this may be due to a combination of the nature of the rock crystal, the position in the reduction sequence, and method of detachment rather than something that could be controlled by the knapper.

The two pieces described as 'blades' are designated as such on the basis of their morphology rather than as part of a formal blade production process (Figure 3: #007 and

#002); there is no evidence of the preparation of the crystals for blade production within the assemblage. The 'blades' are of regular thickness and have parallel sides as well as parallel ridges from previous blade-like removals from the same platform; Figure 3: #002 (the proximal end of a blade) has traces of crystal faces on each side and the parallel ridges from previous removals which had been struck diagonally from the tip of the crystal (see full discussion of reduction direction below), thus maximising its potential length. Figure 3: #007 seems to be from a more advanced stage of production as no crystal faces were detected and at least three other flakes had been removed from the same platform prior to this one. It is noticeable that the quality of the crystal is very clear. Five other pieces have been separated out as blade-like flakes (Figure 3: #001; #003; #004; #005 and #016) because they have parallel flake ridges on their dorsal surfaces and the ratio of their dimensions are more elongated that the rest of the pieces, which also show less regular scarring patterns.

4.2.2. Dorsal scarring patterns

The dorsal scarring pattern of 21 of the 31 pieces was readable (Table 4), and two others show only the outer surface of the crystal. The scars on 11 of the artefacts show multiple (up to four) removals from the same platform and on three further pieces the main scars were unidirectional but somewhat irregular truncated scar or scars originating from a different platform were also noted (Figure 3: #012 and #022). Only two exhibit scars from an opposed platform, one is orthogonal and four flakes have scarring from more than two directions. It is not clear whether this is the result of intentional change of orientation, the rebound from a holding device or due to an inherent fracture property of the crystal. Even if not completely conclusive, the scarring patterns on the removals indicate that several flakes were removed from each crystal and that as many as four flakes were on occasion removed from the same platform (Figure 3: #002 and #004).

4.2.3. Flake removal surface (striking platform)

The nature of the flake removal surface (or striking platform) left on the flakes and blades may provide some indication of means of detachment. Eighteen retain the remnants of a platform (Table 4). Three utilise the crystal facets and their intersection seems to provide a good initiation point. Others are quite crushed but show slivers of a crystal face but the proximal ends of 13 others are crushed or abraded so it is not possible to determine the type removal surface. There is little evidence of platform preparation, but what appears to be abrasion on the edge of the platform was noted in several instances. However, it is unclear whether this is due to deliberate abrasion or the result of the natural fracture properties of the crystal when subjected to force. Determining the form and character of removal surfaces is an important avenue for future experimental research. Points of impact were only observed on two small flakes (#26 and #57). Bulbs of force, where present, are diffuse (#13, #15, #19); on flint diffuse bulbs are associated with direct percussion using a soft hammer (Whittaker 1994: 180, 187, fig. 8.8; see also Hess *et al.* 2021) but this needs to be tested more extensively for rock crystal (as Tardy *et al.* 2016).

4.2.4. Distal terminations

The way a flake terminates may be affected by the force of the blow detaching the piece or the shape of the parent piece. 23 flakes and blades retain their distal ends. Only the longer narrower pieces end naturally (for example, Figure 3: #007); others are overshot or remove the crystal edge (*e.g.,* Figure 3: #009; #015; #020; #053 and #057) following the natural shape of the crystal (Table 4c). The juddering or stepping seen on some pieces towards the distal end (*e.g.*, Figure 3: #003 and #004) appears to be an amplification of the ripples caused by the anisotropy of the crystal (Tardy *et al*. 2016: fig. 17) rather than being indicative of the force of the blow.

Preparation of the crystal for the removal of flakes is suggested by a single thick (6.8 mm), keel-sectioned flake (Figure 3: #008). It removes the edge of the crystal and there is a scar of an orthogonal removal struck prior to the removal of this flake. The flake however, is rather short measuring only 16 mm. The removal of a flake such as this would have opened up the flaking surface by removing the edges of the prism, thus enabling the removal of wider pieces. None of the flakes and blades so far recovered from Dorstone Hill seem to have been intended for modification into formal tools. Some of the larger pieces have chipping on part of an edge, but this tends to be discontinuous and may be damage rather than deliberate retouch; none show any signs of sustained use; however, this needs to be examined in more detail and confirmed by use-wear analysis.

5. Interpretation

The results presented above indicate the intentional reduction of quartz crystals at Dorstone Hill. The data evidences examples of multiple pieces being knapped from the same platform, primarily in an unidirectional manner, but with some bidirectional, orthogonal and multi-directional working, which may have been at least in part the result of constraints imposed by the unique shape and properties of the material. The presence of larger removals, smaller debitage and micro-debitage, pieces exhibiting natural crystal edge and partial and whole crystals indicated that whole crystals were being brought to Dorstone Hill and reduced there. This is supported by the recovery of a dump of micro-debitage within pit 518 on the southern edge of the eastern mound (see also Overton *et al.* 2022). The technological observations of the larger pieces described in Section 4 indicate that all stages of reduction are represented; the next sections (5.1 and 5.2) will consider the specifics of the reduction process.

5.1. Order and directionality of crystal reduction

No refitting of the materials recovered from Dorstone Hill has been possible, so the reduction history of the crystals has been deduced from technological attributes, dorsal scarring patterns and the identification and location of crystal faces. Here we use the data from the 31 flakes, blade-like flakes and blades over 10mm in length, as well as the cores and whole crystals, to determine whether the reduction of the crystal was approached systematically or was *ad hoc.*

A total of 27 pieces exhibited portions of the natural crystal edge, 17 of these being flakes, blade-like flakes and blades. As outlined in section 3 above, the specific characteristics of the natural facets of the hyaline quartz crystal can be used to identify crystal faces as either 'point', 'body' or 'base' facets and to re-locate and orientate pieces exhibiting crystal faces within the parent crystal (Figure 3). By using the horizontal growth lines of body faces, the pyramidion morphology, or a combination of the two, pieces can be positioned and orientated within the parent crystal. This, combined with the position of the striking platform or evidence of striking direction allows the identification of the direction of flaking (in relation to the longitudinal axis of the crystal) and the direction of reduction (*i.e.*, tip first, or base first). Within the >10 mm category (including cores, whole and partial crystals, and chunks), a total of 27 specimens exhibited one or more crystal faces (Table 5), and in 23 of these, the crystal face could be identified as point, body or base (or a combination of these). A total of 13 pieces could be confidently orientated within the parent crystal; of these three were struck longitudinally down the long axis of the crystal, two were struck horizontally across the parent crystal, and eight were struck diagonally across the parent crystal. The predominance of diagonal removals suggests that the knappers were aware of the anisotropic qualities of the crystal, and intentionally worked along the planes of greater cleavage.

Table 5. Summary by category of pieces exhibiting crystal edges, the angle of flaking, and the overall direction of reduction.

	Pieces with crystal edge	Angle of flaking			Direction of reduction	
		Diagonal	Horizontal	Longitudinal	Tip first	Base first
Blade	1	1				
Blade-like flake	3	1		1	1	
Flake	13	6	2	2	7	1
‘Core’	2				2	
Whole crystal	1				1	
Partial crystal	2					
Chunk	5					
Total	**27**	**8**	**2**	**3**	**11**	**1**

Furthermore, by orientating pieces within the parent crystal we were able to determine that 11 had been initiated from the tip end, and only one from the base. The artefacts evidencing tip-first reduction were pieces with one or multiple faces of the pyramidion, either as potentially the first removal taken from the tip of the crystal (for example Figure 6: #009) or pieces that exhibit the area where the point and body faces meet, which were removed after the tip had been initially reduced (for example Figure 6: #005; #054 or #057). The two exhausted ‘cores’ show complex face formations associated with the base of the crystal, but also indicate a reduction sequence that began with the tip of the crystal. The predominance of tip-first reduction, which utilises the surface of the pyramidion as an initial platform, and which also naturally allows for pieces to be struck diagonally across the crystal’s longitudinal axis, further suggests that the knappers understood the anisotropic properties of this material.

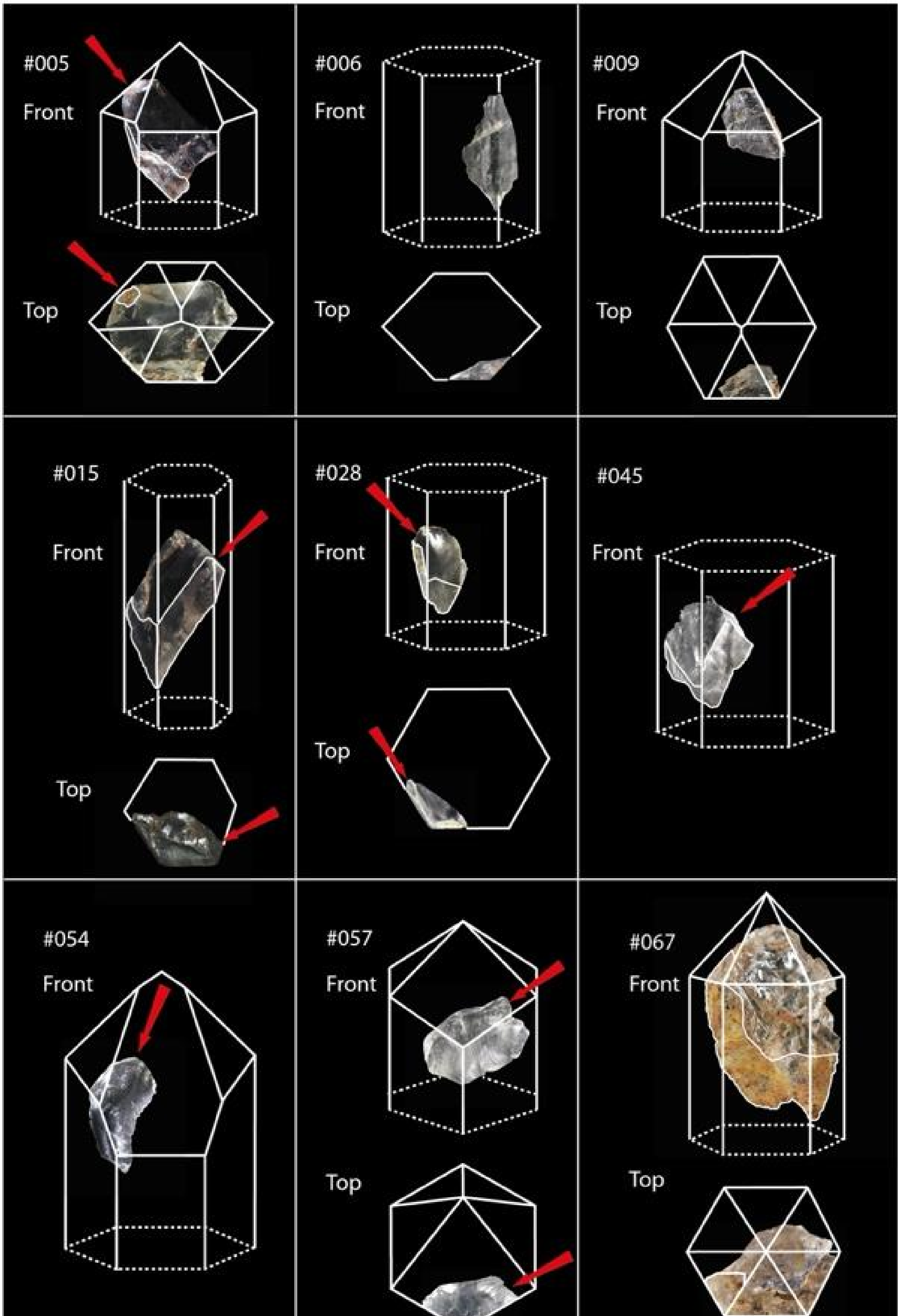

Figure 6. Diagram showing orientation and directionality of flaking in relation to the parent crystal (not to scale); (compiled by Nick Overton).

5.2. Reduction methods over space and time

Following recently published Bayesian modelling of the Dorstone complex (Ray *et al.* 2023), the methods of rock crystal reduction can now be considered chronologically, as well as spatially. A total of eight pieces that exhibit evidence of reduction direction are from primary, contexts. Two are from the western mound; #017 from pit 015 cut through the burnt core of the mound and sealed by the earthen mound, and #028 from pit 519 positioned at the edge of the earth mound. The estimation for the construction of the western mound is 3,785-3,670 cal. BCE (95% probability, *construct Western mound*; this and all following date estimations are taken from Ray *et al.* 2023; see supplementary material for full discussion of original radiocarbon measurements and Bayesian modelling choices), and pit 518 provided a direct date of 3,895-3,650 cal. BCE (SUERC_77956). Two further pieces are from the central mound; #009 from the fill of pit 136 at the edge of the earth mound and #015 within the fill of revetment slot 020 revetting the earthen mound. Pit 136 has no clear stratigraphic relationship with the mound to provide an accurate date estimate, however, an estimate of 3,825-3,650 cal. BCE (95%, *Construct Central mound*) provides a date for #015 within the revetment slot. The eastern mound also produced two pieces, both coming from the fill of ditch 1066, surrounding the linear mortuary structure and sealed by the later Eastern earth mound. The earliest filling of this ditch dates to 3,800-3,720 cal. BCE (95%, *first mortuary structure ditch)* and the latest material dates to 3,770-3,675 cal. BCE (95%, *last mortuary structure ditch),* indicating the pieces date between these two estimates. Finally, two pieces are from the secondary fills 2187 and 2341 of two recuts of Causewayed Enclosure ditch segments. The primary fills of the Causewayed Enclosure estimate the earliest activity at 3,770-3,640 cal. BCE (95%, *first Dorstone Enclosure*), however, as the pieces were recovered from secondary fills of recuts of this enclosure, this estimate provides the very earliest possible date. The latest activity at the enclosure was 3,495-3,125 cal. BCE (95%, *last Dorstone Enclosure*), indicating the material within the later recuts could be notably later.

All eight of these pieces indicate tip-first reduction, indicating that the specific intentional method of crystal reduction identified above (Section 5.1) was shared across both the mounds and the causewayed enclosure, and spanned a period of time that may have been multiple generations, but may have been centuries. This demonstrates that the method of working rock crystal evidenced at Dorstone Hill was an established tradition of working which was maintained over time.

6. Discussion: The Dorstone rock crystal assemblage and its wider context

It is clear from the presence of a whole crystal, fragments of other crystals, pieces with base, body and point faces, as well as blades, flakes, cores and small flakes and chips that whole crystals were brought to Dorstone Hill with the intention of intentional reduction. Furthermore, the technological data presented in section 4, and the interpretation of reduction direction in section 5 demonstrates that this intentional reduction method incorporated knowledge of the material properties of rock crystal. The similar approach to working rock crystal across multiple areas of the site, with a multi-generational duration, also indicates this was an established tradition of working (see also Overton *et al.* 2022). This reconstruction of rock crystal reduction at Dorstone Hill allows an examination of the broader understanding of technological approaches to this material in Europe.

6.1. Rock crystal technology in the wider context

Within the UK context, very little has been published relating to the reduction technique of rock crystal on prehistoric sites. In Scottish prehistoric assemblages, the main approach to reduction appears to be the application of the bi-polar technique, which shatters the crystal into smaller usable nodules (Ballin 2008), and which is in clear contrast to the Dorstone material. Within the wider European context, a number of more detailed studies offer grounds for more detailed comparisons. At Fuorcla da Strem Sut in the Swiss Alps, the Mesolithic rock crystal technology is represented by flakes and blades produced mostly on multi-directional cores (Cornelissen *et al.* 2022). At Fiescheralp Valais, also in the Swiss Alps, the Mesolithic assemblage evidenced bladelet production using direct pressure using soft hammers. The cores were mainly polyhedral because they had been continually rotated along the main axis leading to multi-directional negatives, although some unidirectional reduction is present (Hess *et al.* 2021). In the Neolithic assemblage from the same site, crystals were reduced using organic soft hammers to produced flakes and blades that were later bifacially retouched into formal tools (Hess *et al.* 2021). At Promachonas-Topolniča in Northern Greece, the Late Neolithic technology was focused on the production of micro-blades from hyaline crystals, which had the pyramidion removed to create a horizontal platform, before using the natural edges of the crystal prism to guide micro-blade removals down the longitudinal axis of the crystal using pressure (Tardy *et al*. 2016). Similarly, in the Copper Age of Southern Iberia, there is evidence for the extraction of microblades prepared through faceted pressure planes, again running along the length of the crystal (albeit with the initial surface removal being performed using a saw) (Morgado *et al.* 2016). The 'beheading' of the crystal, and subsequent use of the prism facets of the crystal to guide bladelet production around the perimeter of the crystal at these two sites is a reduction sequence that is replicated in a number of other assemblages (see Fernández-Marchena & Ollé 2016: 173, and references therein). In all cases, the multidirectional or longitudinal removals contrast with the predominantly diagonal removals apparent in the Dorstone assemblage. However, there are other European sites which exhibit reduction methods more akin to those evidenced in the Dorstone assemblage. In a review of five sites in Northwest Iberia, ranging from the Neolithic to Bronze Age in date, Rodríguez-Rellán (2016) identifies that longitudinal reduction strategies are uncommon, and cores show a clear oblique inclination of the flaking surface, indicative of diagonal removals. This oblique inclination has been recorded in other prehistoric assemblages and appears to demonstrate that prehistoric knappers choose to take removals along the lines of greater cleavage caused by the materials anisotropy (*e.g.*, Novikov & Radililovsky 1990). The variety of reduction strategies in the wider European material demonstrates that whilst the anisotropy of hyaline quartz effects the fracturing of this material, it can still be reduced in different directions along and across the crystal. Therefore, the predominantly diagonal approach at Dorstone can be understood as an intentional choice by the knappers, as opposed to being entirely dictated by the material (this is reinforced by low frequencies of longitudinal removals, showing that on occasion, this reduction direction was employed).

As well as similarities and differences in the reduction sequence, the use of rock crystal at Dorstone Hill also contrasts with assemblages in the wider European context. The most notable difference is that whilst sites from multiple periods show the reduction of rock crystal to produce formal tools, including retouched blades and bladelets, denticulate blades, points and borers (Cornelissen *et al*. 2022), microliths, microscrapers and retouched pieces (Hess *et al*. 2021), systematic blade production (Morgado *et al*. 2016; Tardy *et al*. 2016) and the exceptional arrowheads and dagger from Spain (Morgado *et al.* 2016), there is no evidence of use or tool production at Dorstone Hill. Moreover, as discussed above, the distribution of rock crystal on the site strongly indicates that the products of knapping were being intentionally deposited in pits flanking the edge of the long mounds. This pattern was echoed by the distribution of formal tools made of more common lithic materials and other notable materials including cremated bone and ceramics, suggesting these were materials selected as suitable for important acts of deposition (Overton *et al*. 2022). Therefore, the importance of rock crystal at this site appears to be related more to the material itself, and the act of working it in a specific and long-standing way, as opposed to the useable flakes, blades and tools that could be made from it.

7. Conclusions

Our analysis of the Dorstone Hill rock crystal assemblage has demonstrated the importance of technological analysis of all types of lithic raw materials, especially those that have had received relatively little coverage in publication. Our technological study of the Dorstone Hill rock crystal assemblage suggests that this exotic material was transported to the site across substantial distances, it was then reduced on site using a systematic method initiated from the crystal tip, taking primarily diagonal removals using soft hammer percussion. This echoes the oblique inclination observed in some other European assemblages, but starkly contrasts others that 'behead' the crystal to create suitable platforms for longitudinal bladelet removals. The reduction method employed at Dorstone Hill demonstrates an inherent understanding of the fracture properties of the material, and, given that it was used at this site across multiple generations, and potentially centuries, can be understood as an intentional and maintained local tradition of working this material. The selective deposition of this material within mortuary contexts at the site may suggest this material was tied into understandings of local identity and place (Overton *et al.* 2022). Further work on British rock crystal assemblages should progress along four avenues. Firstly, detailed technological analysis of rock crystal reduction, as has been employed here (see also Overton *et al.* 2022) needs to be applied to other rock crystal assemblages from Britain and Ireland to identify the presence of similar or varying technological traditions across time and space. Secondly, experimental working of crystals will hopefully help to more clearly determine (or eliminate) the specific methods and techniques employed in the Dorstone Hill reduction sequence, and the reduction sequences identified in other British and Irish assemblages. Thirdly, use-wear analysis of material (see Fernández-Marchena & Ollé 2016) should elucidate more clearly the biography of artefacts, and their use, or lack of use. Fourthly, the use of chemical element analysis of the crystal inclusions (*e.g.*, by Raman spectroscopy; Sachanbiński *et al*. 2008) to examine the potential to identify specific sources of material used in British prehistoric contexts, from which we can trace possible lines of trade, exchange and movement and to compare this with the use of other exotic materials such as the volcanic rocks.

Data accessibility statement

The data on which this work is based is available on reasonable request to the authors and as a supplementary file in Overton *et al*. 2022.

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