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Establishing life trajectories for British and Irish Middle Bronze Age palstave axes

Miriam Andrews [a,b,c,*], Tomas Polcar [a], Jo Sofaer [b], Alistair W.G. Pike [b]

[a] Faculty of Engineering and the Physical Sciences, University of Southampton, Highfield Campus, University Road, Southampton S017 1JB, UK
[b] Department of Archaeology, Faculty of Humanities, University of Southampton, Avenue Campus, Southampton SO17 1BF, UK
[c] Institute for Sustainable Heritage, The Bartlett School of Environment, Energy and Resources, University College London, 14 Upper Woburn Pl, London WD1H 0NN, UK

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ABSTRACT

This paper presents the results of chemical characterisation, metallography, metalwork wear-analysis, and damage assessment conducted on 102 British and Irish Middle Bronze Age (c. 1500–1000 BCE) tin-bronze palstave axes. There is uncertainty regarding the role of palstave axes; they very likely facilitated ongoing forest clearances, yet expressed often in hearsay, is the 'pristine' nature of their recovery condition. A better appreciation of underlying metallurgy, combined with insight from prior experimentation with replica palstave axes, has allowed a more nuanced evaluation of wear characteristics and use-intensity. This, alongside available contextual data, has permitted the life trajectories of prehistoric palstave axes found within the archaeological record to be determined, highlighting a common narrative of preparation for, and minimal application in, functional use, with preservation favoured over destruction at deposition, as well as the considerable variability presented within their life histories.

1. Introduction

Palstave axes are a ubiquitous form within the archaeological record of the Middle Bronze Age (c. 1500–1000 BCE) in Britain and Ireland (Rowlands 1976; Schmidt and Burgess 1981). Chronologically speaking, they represent the third major typological development in axe morphology during the Bronze Age and were the first typology to include a stop-ridge (developed from previous mid-ridge arrangements in later flanged axes), which advanced the hafting arrangement significantly. Despite their apparent societal importance, many questions regarding the use of palstave axes remain. Investigations that bring together information about the lives of palstave axes are required to determine the various roles performed by palstave axes and their contribution to the constitution of social practice in the Middle Bronze Age (MBA) (Humphries and Smith 2014, p.486).

To begin to frame why the role of the palstave axe, and indeed, much of Bronze Age metalwork, has presented a conundrum for archaeologists over the years, we must start at the end of the narrative of these objects within prehistory. This, to be precise, is *deposition*. The metal artefacts that currently reside within our museums and stores, only comprise a small proportion of the objects that were consumed in the Bronze Age; they represent pieces that, for some reason or another, have not been included in recycling (Bray and Pollard 2015). These objects were interred in the soil, rivers, seas, and bogs (often in unoccupied locations), as isolated deposits, or as a part of metalwork hoards. The intention behind the interment of these assemblages is complex and likely varies between deposits. In some circumstances, metalwork may have just been lost (with bountiful supplies lowering the incentive for retrieval). It is also probable that material was often collected together and concealed before recycling (Wiseman 2018; Knight 2022, p.115). Some hoards indicate selective and purposeful behaviour, which has been interpreted as ritual convention (Bradley 1979, 1990, 2007, 2013; Fontijn & Roymans 2019; Fontijn 2020). The intensification of this practice (see Griffiths 2023) reflects the growing volume of bronze in circulation as well as major changes to the ontological underpinnings of the Bronze Age world view, particularly in the middle and later Bronze Age (Brück, 2000, Brück, 2001, Brück (2006a), Brück (2006b)).

Specific tendencies in damage and use have been documented within the assemblages of bronze artefacts (Wall 1987; Bridgford 2000; O'Flaherty 2002; Knight 2018; Knight 2022). In his study of damage on Bronze Age metalwork from the south-west of England, Knight emphasises that palstave axes are regularly found in a 'complete' condition (2018a, p. 430; 2022 p.81). This is reflected in the wider corpus of literature (Allen et al. 1970; Rowlands 1976; Schmidt and Burgess

* Corresponding author.
E-mail address: miriam.andrews@ucl.ac.uk (M. Andrews).

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1981), and the vast online database of the Portable Antiquities Scheme. The seemingly ‘pristine’ condition of many palstave axes under the naked eye has, in the past, presented the possibility that they might be unused. While it is possible that these artefacts were produced primarily for ceremonial purposes or, perhaps, were created as ingots, they likely hide a much more diverse use-history.

Before recontextualization at deposition, palstave axes may have been used for a great number of purposes, for example, in wood-cutting, food-processing, mattocking, or digging. Indeed, their name, which originates from the Icelandic, *paalstab*, meaning ‘digging tool’, has meant that connotations about the potential use of palstave axes in digging activities have stuck with the artefact throughout its academic evaluation. However, the evidence, while indirect, does point towards tree-felling and wood-chopping as the primary function of the palstave axe. Data from pollen-inferred land-cover reconstructions suggests substantial deforestation in the Middle Bronze Age – the percentage of deciduous woodland was approximately 10 % by the end of the 2nd century BCE, while in the Neolithic and Early Bronze Age this figure may have been closer to 30–40 % (Woodbridge et al. 2014, p.222). Considering then, that the palstave axe was the dominant typology for approximately five hundred years, it is likely that it catered to the tree-felling designs of communities in Bronze Age Britain.

A key method for deciphering the functional application of an object is the investigation of wear generated on the item during use. Wear is the culmination of deformation and chemical processes at the external interface of a material when it is in relative motion with the surface of another substance. A common approach for metal use-wear analysis involves simulation trials, with replicas, to create a repository of marks that permit identification of similar features on the corresponding ancient specimens. Based on this method, efforts have been made to detail the traces of wood-cutting on a number of variants of Bronze Age axes: Scottish flat axes (Moyler 2007); British and Irish flat axes (Crellin 2017); flanged axes of the North-Alpine region (Kienlin and Ottaway 1998); socketed axes of Yorkshire and Scotland (Roberts and Ottaway 2003); and flat, palstave, and socketed axes (Dolfini et al. 2023). The results of each of these studies have advanced the understanding of the progression and morphology of wear on the above typologies of replica Bronze Age axes, as well as highlighting, typically, the significant proportion of archaeological axes that could be considered as ‘used’. As demonstrated above, there have been few published investigations that incorporate the use-wear analysis of palstave axes, which is likely a legacy of the confusion around their role and their perceived lack of use.

It is possible that the absence of obvious deformations at the cutting-edge of palstave axes compared to other axe typologies is due to changes in mechanical durability. Variations within the processing treatments applied to Bronze Age axes determined the unique response of the material during use; hence, metallurgical investigation is integral to understanding the propagation of wear. However, due to the destructive nature of the analysis, metal use-wear studies often lack metallurgical investigation as part of the examination of both experimental replicas and their ancient counterparts. Equally, until recently, Kienlin & Ottaway (1998) and Soriano Llopis and Gutierrez Sáez (2007) comprised the only studies documenting the progression of wear on replica artefacts with different alloy compositions and manufacturing specifications during experimental work. Mechanised tests with replica palstave axes of 10 % and 14 % tin-bronze and a range of post-production processing have now been conducted by the authors to suggest how wear formation processes manifest at the cutting-edge of palstave axes with different microstructures during simulated use (Andrews et al. 2022).

The majority of palstave axes seem to have been produced by a similar method of production and fine-tuning; this was, smelting, alloying, casting, cycles of localised annealing and hammering, followed by a final cold-hammering. The microstructure of copper-tin alloys adjusts accordingly to these treatments. Alloying of the metal decreases plasticity and, therefore, increases baseline hardness. The most advantageous quantity of tin within a copper-alloy is approximately 10–14 %; a range that is well reflected in characterisation studies of palstave axes (Allen et al. 1970; Needham et al. 1989, p.392). Several annealing and hammering treatments produce small grains of recrystallized copper, a structure that boasts a high elastic limit and improved fracture toughness. Lastly, the final cold-hammering, which can produce a greater hardness in the material by the process of ‘work-hardening’, appears often to have been extensive (Coghlan & Cook 1953; Coghlan 1970a; Coghlan 1970b; Allen et al, 1970; Kienlin et al. 2006).

The above text has examined, albeit in reverse order, various stages within the lives of palstave axes found within the archaeological record. While they do not provide an all-encompassing representation of the life of these objects, these elements, both individually and when combined to produce biographies (Kopytoff 1986; Gosden and Marshall 1999), may contain valuable insights as to how palstave axes were engrained in Bronze Age society (see Blanco-González, 2014; Bjørnevad et al. 2019; Bermejo et al. 2023). Though biographical analysis is usually focused on individual objects to avoid generic interpretations about diverse material, the construction of life trajectories may be a useful way to look for trends in a sample of objects and highlight unusual artefact-specific narratives. As Joy asserts, “by examining object groups it is possible to identify an ‘idealized’ life for a particular artefact type and spot those objects that deviate from the ‘norm’” (2009, p.545). This study collates several life elements for a sample of palstaves, revealing commonalities in life trajectory that reflect socially and culturally conditioned understanding in relation to palstaves, as well as more unusual narratives, suggesting the heterogeneity within this behaviour.

2. Materials

The selected sample of palstave axes is based on the availability of pre-existing metallographic mounts and published metallographic data. Samples from seventy-eight palstave axes that were mounted and chemically characterized by Peter Northover in the 1970 s/1980 s, as part of his analysis on Bronze Age objects from the south-west of England, were made available for this study. The existing data pertaining to twenty-four samples, which was recorded by H.H. Coghlan in several papers (Coghlan 1970a; Coghlan 1970b; Allen et al. 1970) was also re-examined. Tables 1 and 2 summarise the palstave axes examined when divided into the two samples delineated above. Much of the compositional data relating to the axes analysed here-in can now be found within a compiled dataset available from the Archaeology Data Service (Bevan et al. 2024).

The metalwork wear-analysis and damage assessment of the full artefacts was conducted at museums across the south and south-west of England, including: The Ashmolean Museum (Oxford), Bristol City Museum and Art Gallery, The Dorset County Museum (Dorchester), The Newbury Museum, The Pitt Rivers Museum (Oxford), the Royal Albert Memorial Museum (Exeter), the Somerset Museum (Taunton), and the Royal Cornwall Museum (Truro). The preservation of the sample was, generally, quite poor. Many of the palstave axes within the sample were found in the 19th and 20th centuries when conservation techniques were sometimes quite invasive. Equally, since a large proportion of the sample were found on acidic moorland soils, levels of corrosion were sometimes quite severe.

It was possible to find published bibliographic information for nearly all the palstave axes in this study; this information was mostly drawn from Allen et al. (1970), Coghlan (1970a) Coghlan (1970b), Rowlands (1976), and Pearce (1983). Sixteen palstave axes from the Coghlan collection and eight from the south-west sample had very little contextual data to elucidate the find area (specific find spots are difficult to pinpoint due to antiquarian records) or associations. The palstave axes within the south-west sample were all local finds to each of their respective museums and so they represent a geographically discrete sample; thus, the narratives of these artefacts are more likely to be closely related. Whereas, the Coghlan axes were not local finds and came from different areas of Britain, so they do not belong to any particular

Table 1
The chronological, typological, and contextual data for the South-west palstaves. It should be noted that one of the artefacts, RAMM-A385, has been re-accessioned to RAMM-593/2005 since the original metallographic sampling.

Museum	Reg. no.	Primary published reference	Period cal BC	Typology	Find area
Ashmolean	1927.2594	Pearce 1983	1500–1250	Gr.II palstave	Bath Street, Bristol, Somerset
	1927.2567	Pearce 1983	1500–1250	Gr. II palstave	Penzance, Cornwall
	1927.2571	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Crediton, Devon
	1961.498	Pearce 1983	1400–1100	South-western palstave, looped	Wotton Glenville, Dorset
	1961.497	Pearce 1983	1500–1250	Gr. I palstave	Wotton Glenville, Dorset
Bristol	E449	Pearce 1983	1500–1250	Gr. I palstave	Solsbury Hill, Bath, Somerset
	E456	Unknown	1500–1250	Gr. I palstave	n/a Somerset
Dorset County Museum	1948.14.2	Pearce 1983	1250–1000	Transitional palstave, looped	Winterborne Abbas, Dorset
	1963.15.1	Pearce 1983	1250–1000	Transitional palstave, looped	Grimstone, Dorset
	1954.40.1	Pearce 1983	1400–1100	Gr. III palstave	Thorncombe, Dorset
	1902.1.1	Pearce 1983	1250–1000	Transitional palstave	Dewlish, Dorset
	1902.1.5	Pearce 1983	1250–1000	Transitional palstave, looped	Dewlish, Dorset
	1902.1.2	Pearce 1983	1250–1000	Transitional palstave	Dewlish, Dorset
	1902.1.4	Pearce 1983	1400–1100	South-western palstave, looped	Dewlish, Dorset
	1902.1.3	Pearce 1983	1250–1000	Transitional palstave, looped	Dewlish, Dorset
	1955.48	Pearce 1983	1400–1100	South-western palstave, looped	Abbotsbury, Dorset
	1884.9.2	Pearce 1983	1500–1250	Gr. II palstave	Fontwell, Dorset
	1884.9.3	Pearce 1983	1400–1100	Gr. III palstave	Fontwell, Dorset
	1884.9.5	Pearce 1983	1400–1100	South-western palstave	Wareham, Dorset
	1884.9.1	Pearce 1983	1500–1250	Gr. I palstave	Wareham, Dorset
	1893.2.1	Pearce 1983	1250–1000	Transitional palstave, looped	Rew, Dorset
	1884.9.22	Pearce 1983	1250–1000	South-western palstave, variant Crediton	Dorchester, Dorset
Museum of Somerset	12A	Pearce 1983	1400–1100	Gr. III palstave, looped	Rodney Stoke, Somerset
	14A	Pearce 1983	1400–1100	Gr. IV palstave, looped	Ham Hill, Somerset
	63B	Unknown	1250–1000	Narrow-bladed palstave, looped	Stogursey, Somerset
	7A	Pearce 1983	1500–1250	Gr. I palstave	n/a, Somerset
	80C	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Sedgemoor, Somerset
	10A	Pearce 1983	1250–1000	Transitional palstave, looped	Glastonbury, Somerset
	7B	Pearce 1983	1500–1250	Gr. I palstave	Lyng, Somerset
	75.AA.4	Pearce 1983	1250–1000	Transitional palstave, looped	Radstock, Somerset
	14B	Pearce 1983	1400–1100	Gr. III palstave, looped	King's Sedgemoor, Somerset
	75B	Pearce 1983	1400–1100	Gr. III palstave, looped	Milborne Port, South Somerset
	81C	Pearce 1983	1500–1250	Gr. I palstave	Old Ceeve, Somerset
	9B	Pearce 1983	1400–1100	South-western palstave, looped	Ham Hill, Somerset
	4A	Pearce 1983	1500–1100	Flanged axe	Stoke St. Michael, Somerset
	A332	Pearce 1983	1400–1100	Gr. III palstave, looped	South Petherton, Somerset
	A331	Pearce 1983	1400–1100	Gr. III palstave, looped	South Petherton, Somerset
	81D	Pearce 1983	1400–1100	Gr. III palstave, looped	Old Ceeve, Somerset
	17B	Pearce 1983	1250–1000	Transitional palstave, looped	Sherford, Somerset
	12C	Pearce 1983	1250–1100	Double looped palstave	Curland, Somerset
	84B	Pearce 1983	1400–1100	Gr. III palstave, looped	Sedgemoor, Somerset
	13B	Pearce 1983	1250–1100	Double-looped palstave.	South Petherton, Somerset
	81B	Pearce 1983	1400–1100	South-western palstave	Lyng, Somerset
	10B	Pearce 1983	1400–1100	South-western palstave, looped	Glastonbury, Somerset
	8A	Pearce 1983	1500–1250	Gr. I palstave	Wellington, Somerset
	41B	Pearce 1983	1400–1100	South-western palstave, looped	Taunton, Somerset
Royal Albert Memorial Museum	11/1974	Pearce 1983	1400–1100	South-western palstave, looped	Bridford, Devon
	45/1955/1	Pearce 1983	1400–1100	Gr. III palstave	Chagford, Devon
	354/1906/1	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Week, Devon
	355/1906	Pearce 1983	1400–1100	South-western palstave, looped	Week, Devon
	A306	Pearce 1983	1500–1250	Gr. I palstave	Honiton, Devon
	A320	Pearce 1983	1500–1100	Gr. I palstave	Drewsteignton, Devon
	1113/1912	Pearce 1983	1500–1250	Gr. I palstave	Shebbear, Devon
	A6462	Pearce 1983	1400–1100	Gr. III palstave, looped	Cullompton, Devon
	1897/7/6	Pearce 1983	1400–1100	South-western palstave, looped	Bovey Tracey, Devon
	593/2005	Pearce 1983	1400–1100	South-western palstave	Colyton, Devon
	A1951	Pearce 1983	1400–1100	South-western palstave, looped	Colyton, Devon
	A1952	Pearce 1983	1400–1100	South-western palstave	Colyton, Devon
	102/1970	Pearce 1983	1400–1100	South-western palstave, looped	Caton, Devon
	130/1979	Pearce 1983	1400–1100	Gr. III palstave	Upottery, Devon
	70/1974	Pearce 1983	1400–1100	Gr. III palstave	Unknown
	A289	Pearce 1983	1400–1100	Gr. III palstave	Rockbeare, Devon
	A4148	Pearce 1983	1250–1000	Transitional palstave, looped	Washfield, Devon
	A4214	Pearce 1983	1400–1100	South-western palstave, looped	Bovey Tracey, Devon
	A6158	Pearce 1983	1500–1250	Gr. I palstave	Thorverton, Devon
	1891/2/7	Pearce 1983	1500–1250	Gr. I palstave	Chagford, Devon
	1891/2/6	Pearce 1983	1500–1250	Gr. II palstave	Chagford, Devon

(*continued on next page*)

Table 1 (*continued*)

Museum	Reg. no.	Primary published reference	Period cal BC	Typology	Find area
	10/1980	Pearce 1983	1400–1100	Gr. III palstave, looped	Dawlish, Devon
	50/1971	Pearce 1983	1400–1100	Gr. III palstave, looped	Tiverton, Devon
	60/1954	Pearce 1983	1400–1100	Gr. III palstave, looped	Hemyock, Devon
Royal Museum of Cornwall	1910.22 2	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Truro, Cornwall
	1910.21	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Truro, Cornwall
	9.1919.5	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Lanherne, Cornwall
	1909.15.3	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Veryan, Cornwall
	1880.16	Pearce 1983	1400–1100	South-western palstave, variant Crediton	Lelant, Cornwall
	1974.10.1	Pearce 1983	1400–1100	South-western palstave	St. Mellion, Cornwall
	9.1919.6	Pearce 1983	1250–1000	Double-looped palstave	Helston, Cornwall
	1909.74	Pearce 1983	1400–1100	South-western palstave, variant Crediton	North Crofty, Cornwall

Table 2
The chronological, typological, and contextual data for the Coghlan sample. It should be noted that several of the artefacts have been re-accessioned since their original metallographic sampling, these include: PR-1887.1.1099, PR-1887.1.1123, PR-1887.1.1124, which have since become, PR-1892.67.86, PR-1892.67.120, and PR-1892.67.121, respectively.

Museum	Reg. no.	Primary published reference	Period cal BC	Typology	Location
Pitt Rivers	1884.119.105	Allen et al. 1970	1400–1100	Gr. III palstave	Worstead Common, Norfolk
	1884.119.106	Allen et al. 1970	1400–1100	Gr. III palstave, looped	Suffolk
	1884.119.108	Allen et al. 1970	1500–1250	Gr. I palstave	Holme, Cambridgeshire
	1884.119.113	Allen et al. 1970	1500–1250	Gr. II palstave	Wandsworth, London
	1884.119.114	Allen et al. 1970	1400–1100	South-western palstave, variant Crediton	Weyhill, Andover
	1884.119.12	Allen et al. 1970	1400–1100	Irish palstave	Ireland
	1884.119.135	Allen et al. 1970	1400–1100	Gr. III palstave	Ireland
	1884.119.136	Allen et al. 1970	1250–1000	Narrow-bladed palstave	Ireland
Royal Berkshire Museum	1892.67.120	Coghlan 1970a	1250–1000	Transitional palstave, looped	Mettingham, Suffolk
	1892.67.121	Coghlan 1970a	1400–1100	Gr. III palstave	Cambridge Fens
	1892.67.86	Coghlan 1970a	1400–1100	Gr. III palstave	Suffolk
	1904.31.2	Coghlan 1970a	1400–1100	Gr. III palstave, looped	Tackley, Oxfordshire
	1962.12	Coghlan 1970a	1250–1000	Transitional palstave, looped	England
	OA331	Coghlan 1970a	1400–1100	Gr. III palstave	Ireland
	OA325	Coghlan 1970a	1250–1000	Transitional palstave, looped	Co. Antrim, Ireland
	OA324	Coghlan 1970a	1500–1250	Gr. I palstave	Weybridge, Surrey
	OA322	Coghlan 1970a	1500–1100	Flanged axe	Ireland
	OA264	Coghlan 1970a	1500–1250	Gr. II palstave	Newbury, Berkshire
	OA351	Coghlan 1970a	1500–1100	Flanged axe	Ireland
	OA93	Coghlan 1970a	1500–1100	Flanged axe	Ireland
	OA265	Coghlan 1970a	1500–1250	Gr. II palstave	Speen, Berkshire
	OA63	Coghlan 1970a	1500–1250	Gr. II palstave	Weybridge, Surrey
	1968.68.Y2	Coghlan 1970b	1500–1250	Gr. II palstave	Yattendon, Berkshire
	1968.63.Y3	Coghlan 1970b	1250–1000	Transitional palstave	Yattendon, Berkshire

geographic or culturally specific area. Instead, they consist of a highly uncorrelated sample, containing artefacts from diverse cultural backgrounds.

The classification system for palstave axes proposed by Schmidt and Burgess (1981) was used to categorise the artefacts into types. The sample consists of twenty-eight palstave axes identified as early typologies; for example, Group I or 'Shield Pattern' types that have leaf-shaped flanges that descend past the stopridge to form a decorated 'U shaped' platform on the upper blade face, and Group II or 'Mid-ribbed' types that exhibit side-flanges that extend from the butt, all the way to the blade edge (producing a distinctive 'H' outline) (Schmidt and Burgess 1981: 27). Over half of the sample is comprised by palstave axes dating to the core of the MBA, for example, Gr.III, Gr IV palstaves and South-western typologies. Group III or 'Low-Flanged' types are defined by the significant height of the stopridge, which is a departure from the 'leaf-shaped' flanges seen in other variants (ibid.). The South-western palstave group possess characteristic lozenge-shaped flanges (Schmidt and Burgess, 1981, p.142). The South-western group, Crediton type, have a distinctive crinoline blade shape, and rarely exhibit a side-loop. The remaining 20 % of the palstave axes in the sample are typologies that date to the latter stages of the MBA; for example, Transitional palstave axes that have a narrow butt and blade, side-loop, and sloping flanges (Schmidt and Burgess, 1981, pp.145–146), Narrow-bladed palstave axes that demonstrate a narrow and elongated blade, and Double-looped palstave axes that have two side-loops (Schmidt and Burgess, 1981, pp.163–164).

3. Methods

Peter Northover conducted the chemical characterisation of the south-west sample using Electron probe microanalysis (EPMA) with energy-dispersive spectrometry (pers. comm 2019). No details are given by Coghlan about the type of chemical characterisation analysis that was undertaken to elucidate the elemental composition of the palstave axes included in his analyses. It is worth noting here that compositional analysis is usually only taken at one location on the surface of the object, this creates sampling bias as composition varies across the object.

The mounting of the south-west samples was completed by Peter Northover; small segments of the cutting-edge were extracted from each axe and cold-mounted (pers. comm 2019). Mounted samples from sixty-seven palstave axes were available for re-analysis as four samples were found to be absent from the collection and a further seven were only drilled samples. The mounted samples were ground by the authors using a fine-grained silicon carbide sandpaper. They were then polished using a 6 μm diamond suspension on a Buehler Texmet cloth and, subsequently, a 1 μm diamond suspension on a Buehler MasterTex cloth. Finally, an acidified ferric chloride solution (100 ml of ethanol, 20 ml of HCL, and 5 g of Iron(III)-chloride) was used to etch the samples over several light applications. The identification of microstructural characteristics was based on the criteria for the metallographic assessment of tin-bronze outlined by Scott (1992). The metallographic drawings and descriptions published by H.H. Coghlan in several papers (Coghlan 1970a; Coghlan 1970b; Allen et al. 1970) were used to infer the microstructural properties pertaining to a further twenty-four palstave axes.

The analytical protocols adopted for the metalwork-wear analysis were an amalgamation of the approaches outlined by Dolfini (2011) and Crellin (2017). The objects were inspected visually, and the attributes of any corrosion product were described, as well as the prevalence of modern cleaning processes, to assess whether the cutting-edge was well enough preserved for microscopic analysis. The objects were then measured, photographed, and drawn. Subsequently, a Dino Lite 2.0 microscope was used, in conjunction with the Dino Capture 2.0 software, to analyse the entire cutting-edge of each palstave axe at x25 and x50 magnification so that features of interest, for example, evidence of sharpening, use, and hafting marks could be pinpointed. All microscopic traces were imaged, then recorded, on illustrations, and in a datasheet. The data categories recorded during analysis replicated those adopted by Crellin (2017), although some categories have been omitted from the results presented here-in to simplify the discussion. The direction and depth of striations was used to determine their origin; for instance, deep, patinated grooves that lay parallel to the cutting-edge were identified as sharpening grooves, while light, patinated scratches perpendicular to the cutting-edge were considered to have been a result of use (Andrews et al. 2022). Micro-level analysis at the cutting-edge was possible on thirty-three palstave axes. The remaining sixty-nine axes were deemed unsuitable due to issues like the absence of the cutting-edge, varnishing, modern cleaning/regrinding, and corrosion.

Blade symmetry was analysed using the following criteria. The blade was labelled as 'Symmetrical' if no material loss could be discerned, suggesting none or very little use had occurred. The blade was labelled as having 'Slight asymmetry' if some minor material loss from one corner of the blade could be observed, indicating around one sharpening event and, therefore, minimal use. The blade was labelled as having 'Moderate asymmetry' if it was clearly skewed by several sharpening events, i.e., it had sustained considerable use. The blade was labelled as having 'Severe asymmetry' if it was completely lopsided due to extensive use and a large number of sharpening events.

To ensure that wear was correctly identified, any deformations observed at the cutting edge of the palstave axes were compared to those generated during prior highly controlled mechanised testing with replicas (see Andrews 2021). The most frequent type of wear mark recorded during experimentation was a localised bending or curl of the cutting-edge that indicates mechanical failure due to sustained use. As such, areas of deformation with a similar morphology to that seen during testing were labelled as 'Bending' failures. It was also recognised that this feature may be represented by a 'Depression' in prehistoric palstave axes as they could have since been sharpened (which may not fully erase the area of failure), or corrosion might have culminated in the loss of the mechanically weakened area. Deeper notches were not produced during wood-chopping experiments and could be seen to represent marks left after impact with an opposition material with a greater hardness than wood. The only specimens that were not suitable for macro-level analysis were those where the blade had completely broken off, and so this method was successfully implemented on 91 % of the sample.

The approach developed by Knight (2018a; 2021) for the determination of the types of breakages observed on palstave axes was followed here-in. Particular areas of fracture that are well-documented for palstave axes, for example, the flanges, side-loop, and stopridge, were discounted as accidental. Similarly, objects that demonstrated trapped gases and casting flaws at the zone of breakage were assumed to have been damaged accidentally, as the presence of cavities or design flaws would have undoubtedly weakened the microstructure. If the break occurred in an unusual place, for example, across the body of the blade, or across the lower section of the blade, it was seen as probable that the break was deliberate. It was possible to define a break as intentional with some certainty if percussion marks were evidenced at the location of fracture. Visual inspection of the zone of breakage also involved an assessment of patination and corrosion to assess whether these were comparable with the overall condition of the axe; if not, it was considered likely that the breakage occurred sometime after deposition.

4. Results

4.1. Characterisation and metallography

The results of the chemical characterisation for the south-west sample can be found in Table 3. The full composition and microstructural data for the Coghlan axes can be found within Coghlan (1970a), Coghlan (1970b), Allen et al. (1970). The south-west sample has a range in tin percentage from 6.44 % to 19.7 %, and a median of 13.26 % (see Fig. 1). In contrast, the Coghlan collection has a range in tin percentage from 1.3 % to 13.8 %, and a median of 10.1 % (Coghlan 1970a; Coghlan 1970b; Allen et al. 1970). This data suggests a preponderance for higher levels of tin within the palstave axes of the south-west. As seen in Fig. 1, most of the palstave axes demonstrate a well-fitting negative relationship between copper and tin content suggesting that only a few contain a substantial amount of impurities or deliberate additions of other minerals.

The median for arsenic suggests that the south-west sample contained only 0.35 %, while the Coghlan sample contained a slightly higher value of 0.61 %. Additions of lead are generally low throughout both samples of palstave axes. The median averages for lead content indicate that the south-west sample contained only 0.15 %, while the Coghlan sample contained a slightly higher value of 0.59 %. Within the Coghlan collection there are two palstave axes containing high values of lead, i.e., WBM-OA324 (Gr.I palstave) and PR-1884.119.113 (Gr.II palstave) (Coghlan 1970a; Coghlan 1970b; Allen et al. 1970). Interestingly these are both earlier variants, in which it is generally more unusual to find such inclusions. Palstave axes with notable additions of lead from the south-west sample fall within typologies with a later chronology, i.e., DOR-1902.1.3 and MoS-75.AA.4 (Transitional) and MoS-63B (Narrow-bladed), conforming to the generally accepted idea that lead was introduced into Bronze Age metalwork at the end of the MBA (Britton 1961; Darvill 1987). Another metal that is commonly found is nickel, which contributes an average value of 0.36 % within the metal composition of the south-west axes. This is consistent with the nickel content within the Coghlan sample, which was found to be 0.37 %.

Other elements that variably feature within the make-up of the palstave axes from both samples were, cobalt, antimony, silver, gold and zinc. When impurities are examined in close detail and compared to the likely trace element signatures of the Great Orme copper mine, Wales, it is clear that many of the axes within this sample may been formed from metal extracted from these ores (Williams 2023). At least fifteen early MBA palstaves (Group I and Group II) out of twenty-five in the sample conform to the make-up of impurities suggestive of a Great Orme origin, with a further four possibly from the mine. This trend continues into the mid MBA palstave axes (Group III and south-western variants), with around half of the sample most likely originating from Great Orme (and another 20 % potentially from this source).

Just over half of the sample contained no signs of porosity, indicating that these palstave axes had gone through refining and recasting by a highly skilled craftsperson. In contrast, relatively few axes ($n = 14$) showed evidence of substantial porosity. A recrystallized, twinned, microstructure, was exhibited by 74 % of the palstave axes (both

Table 3
The results of the composition and metallographic analysis for the south-west palstave axes.

Museum	Museum no.	%Cu	%Sn	% As	%Pb	Microstructural features
Ashmolean	1927.2594	84.59	14.06	0.39	0.13	Drilled sample
	1927.2567	84.49	14.09	0.62	0.38	Drilled sample
	1927.257	87.18	12.24	tr	tr	Drilled sample
	1961.498	84.33	14.79	0.35	–	Drilled sample
	1961.497	89.34	10.50	0.13	tr	Drilled sample
Bristol	E449	88.27	11.73	–	2.20	Drilled sample
	E456	88.03	11.97	—	—	Drilled sample
Dorset County Museum	1948.14.2	85.24	13.40	0.33	0.10	Recrystallized, twinned grains. Many strain lines and grains are quite misshapen.
	1963.15.1	86.26	12.29	0.42	0.14	Recrystallized, twinned grains. Most grains contain strain lines. Grains are misshapen.
	1954.40.1	88.79	9.70	0.81	0.22	Recrystallized. All grains contain strain lines.
	1902.1.1	86.79	11.87	0.28	0.07	Dendritic – fairly fine dendrites.
	1902.1.5	87.58	11.39	0.25	0.13	Dendritic – coarse structure. Many pinky inclusions.
	1902.1.2	82.70	15.67	0.36	0.37	Dendritic – dendrites have been deformed.
	1902.1.4	84.33	14.00	0.64	0.09	Recrystallized twinned grains. Strain-banding is present in some grains.
	1902.1.3	78.59	12.50	0.48	8.10	Dendritic
	1955.48	85.11	13.37	0.51	0.26	Recrystallized twinned grains. Dense strain lines.
	1884.9.2	84.21	14.75	0.40	–	Recrystallized twinned grains. Strain lines are present in some grains.
	1884.9.3	81.07	17.82	0.39	–	Recrystallized twinned grains. Not many strain lines in grains on one side, much more dense strain lines in grains on other side.
	1884.9.5	86.19	12.68	0.30	0.12	Recrystallized twinned grains. Many strain lines are present, grain is misshapen.
	1884.9.1	84.14	14.53	0.31	0.13	Recrystallized twinned grains. Lots of strain lines in grains.
	1893.2.1	86.48	12.91	0.27	0.08	Recrystallized twinned grains. Lots of strain lines.
	1884.9.22	81.52	16.94	0.58	0.15	Recrystallized twinned grains. Strain lines are present.
Museum of Somerset	12A	83.79	14.87	0.45	0.33	Recrystallized, twinned grains. Many strain lines are prevalent.
	14A	83.78	14.91	0.45	0.19	Recrystallized, twinned grains. Crystals exhibit many strain lines and are very deformed.
	63B	78.01	10.65	0.26	10.80	Sample lost
	7A	87.91	11.83	0.09	0.03	Recrystallized grains. Crystals exhibit many strain lines and are very deformed.
	80C	85.46	13.19	0.62	0.23	Recrystallized grains. Many strain lines and many grains are very deformed.
	10A	89.57	10.06	0.25	0.03	Recrystallized, twinned grains. Many crystals exhibit strain lines.
	7B	83.14	12.66	0.64	3.10	Recrystallized, twinned grains. All grains have strain lines, some are very deformed.
	75.AA.4	79.35	8.23	0.24	11.50	Recrystallized, twinned grains. Strain lines. Crystals near exterior are deformed.
	14B	84.43	14.34	0.43	0.21	Recrystallized, twinned grains. Very deformed crystals.
	75B	81.79	14.00	0.32	0.51	Recrystallized grains. Crystals are very deformed.
	81C	85.06	13.27	0.71	0.61	Recrystallized grains. Most crystals have lost shape and all have strain lines.
	9B	85.11	13.38	0.31	0.37	Could be dendritic or possibly just have a lot of eutectoid.
	4A	84.87	14.44	0.34	tr	Recrystallized, twinned grains. Lots of strain lines.
	A332	84.37	14.65	0.38	0.06	Recrystallized, twinned grains. Strain-banding and deformed crystals near edge.
	A331	88.71	10.30	0.38	tr	Recrystallized, twinned grains. Strain-banding in all crystals and many are deformed.
	81D	88.89	9.61	0.18	0.40	Looks dendritic but hard to tell.
	17B	84.42	12.81	0.41	0.16	Sample lost
	12C	87.81	11.56	0.15	0.09	Recrystallized, twinned grains. Crystals are deformed on one side of the sample.
	84B	83.78	14.84	0.35	0.16	Recrystallized, twinned grains.
	13B	91.15	8.41	0.32	–	Recrystallized, twinned grains. Crystals are completely deformed.
	81B	84.66	14.11	0.32	0.25	Recrystallized, twinned grains. Crystals have strain lines and are deformed in places.
	10B	87.84	11.79	0.08	0.07	Recrystallized, twinned grains. Most crystals contain strain lines – many are deformed.
	8A	85.17	14.67	0.07	0.03	Recrystallized, twinned grains. Strain lines throughout most of sample.
	41B	84.07	14.43	0.63	0.15	Sample lost.
Royal Albert Memorial Museum	11/1974	84.68	14.61	0.20	0.05	Recrystallized, twinned grains. Strain-banding throughout sample.
	45/1955/1	86.52	13.09	0.28	–	Recrystallized, twinned grains. Strain-banding throughout sample.
	354/1906/1	85.01	14.56	0.30	0.04	Recrystallized, twinned grains. Strain-banding in some crystals.
	355/1906	85.72	13.25	0.20	0.11	n/a too corroded
	A306	86.02	12.35	0.90	0.29	Recrystallized, twinned grains. Strain-banding near the exterior of the sample
	A320	84.52	11.34	1.06	2.60	Recrystallized grains. Many crystals are strain-banded.
	1113/1912	87.90	11.73	0.23	0.08	Recrystallized, twinned grains. Strain-banding, complete deformation on one side.
	A6462	84.65	14.37	0.58	0.03	Recrystallized, twinned grains. Strain-banding and many deformed grains at edge.
	1897/7/6	84.82	13.85	0.32	0.11	Recrystallized, twinned grains. Much strain-banding.
	593/2005	79.03	19.70	0.22	0.15	Dendritic microstructure.
	A1951	84.54	14.39	0.23	0.33	Recrystallized, twinned grains. Some strain-banding near edge of sample.
	A1952	83.44	15.53	0.26	0.11	Dendritic microstructure.
	102/1970	84.00	15.04	0.39	0.19	Recrystallized, twinned grains. Strain-banding in some crystals.
	130/1979	84.72	15.12	0.09	–	Recrystallized, twinned grains. Strain-banding throughout sample.
	70/1974	83.65	15.35	0.39	0.17	Recrystallized grains. A few crystals with strain-banding.
	A289	88.47	10.80	0.20	0.03	Recrystallized, twinned grains. Some strain-banding in crystals.
	A4148	85.10	13.61	0.39	0.15	Recrystallized, twinned grains. Strain-banding in only a few crystals.
	A4214	86.49	12.27	0.42	0.05	Sample lost.
	A6158	85.27	13.13	0.92	0.14	Recrystallized – corrosion prohibited a full assessment.

(*continued on next page*)

Table 3 (*continued*)

Museum	Museum no.	%Cu	%Sn	% As	%Pb	Microstructural features
	1891/2/7	82.89	15.76	0.51	0.32	Recrystallized, twinned grains. Strain-banding near the exterior.
	1891/2/6	88.12	7.96	0.42	3.30	Recrystallized grains. Strain-banding is present in most of crystals.
	10/1980	83.29	14.50	0.31	0.07	Recrystallized, twinned grains. Strain-banding in some crystals.
	50/1971	84.96	14.52	0.19	0.14	Recrystallized – corrosion prohibited a full assessment.
	60/1954	86.06	12.50	0.73	0.25	Recrystallized, twinned grains. No strain-banding is visible.
Royal Cornwall Museum	1910.22 2	84.12	13.94	0.17	1.00	Dendritic microstructure.
	1910.21	87.02	12.31	0.10	0.20	Recrystallized, twinned grains. Strain lines and significant deformation near edge.
	9.1919.5	88.08	11.52	0.20	–	Dendritic microstructure.
	1909.15.3	87.19	11.60	0.56	0.16	Dendritic microstructure.
	1880.16	85.29	13.21	0.44	tr	Deformed dendrites.
	1974.10.1	88.67	10.46	0.45	0.08	Dendritic microstructure.
	9.1919.6	93.06	6.44	0.28	–	Recrystallized, twinned grains. Some grains contain some strain lines.
	1909.74	84.45	14.30	0.59	0.09	Recrystallized, twinned grains. A few strain lines are exhibited within the grains

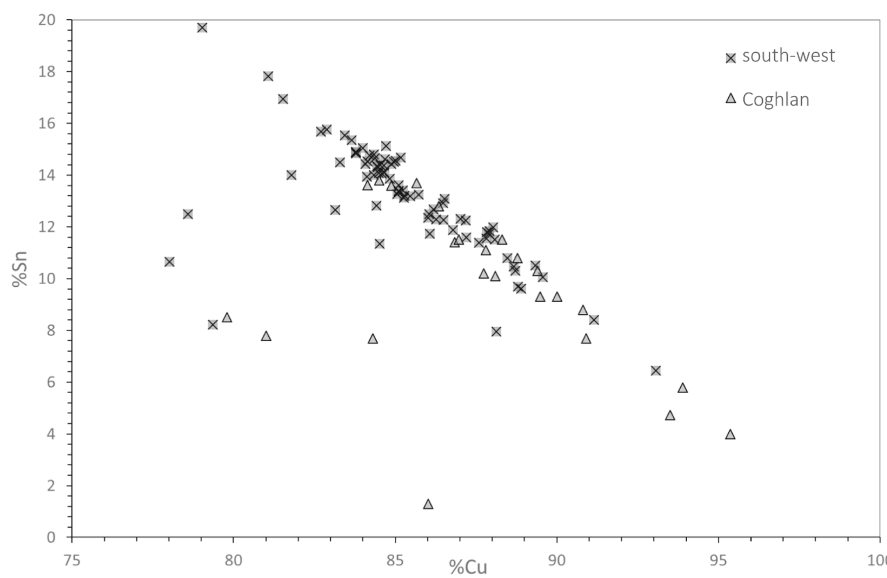

Fig. 1. Percentage copper and tin in each palstave axe within both datasets. Compositions for the Coghlan axes were taken from Coghlan (1970a), Coghlan (1970b), Allen et al. (1970).

samples), suggesting that they had been produced by a process of hammering and annealing. Only one in every ten of these did not demonstrate evidence of strain-lines within their microstructure and, thus, did not receive a final hammering. For many axes, the crystal grains had become deformed due to cold hammering. A small proportion (15 %) of palstave axes demonstrated a dendritic microstructure, which indicates that they were largely left in an as-cast form. The range of microstructures within the sample can be seen in Fig. 2.

4.2. *Metalwork wear-analysis*

The majority of the sample exhibited casting seams, which suggests that they were most likely cast using a bivalve mould. This reinforces the idea that it is probably not possible to cast a palstave in a one-part mould. Just six of the analysed palstave axes presented any casting defects, suggesting that objects with irregularities were not deposited and were most likely recycled. It should be noted that evidence of hammering upon the surface of the axe was rarely observed despite the clear prevalence of such practices (as demonstrated by the metallographic analysis). Only seven palstave axes presented an unfinished surface (see Fig. 3) – interestingly, while three of these were axes with a dendritic microstructure, the remaining four had been, otherwise, fully processed. Finally, just over half of the palstave axes with cutting-edges examined by microscopy showed evidence for sharpening (n = 17), indicating that attempts had been made to ready the cutting-edge for use or display on at least one occasion. The full results of the examination of production features on the surface of the palstave axes can be found within the supporting data repository.

Visual assessment of use-wear (as seen in Tables 4 and 5) revealed evidence of asymmetry on just over half of the axes deemed suitable for analysis, with the majority of these (n = 30) exhibiting only a very minor amount of material loss from one blade tip. Palstave axes that were more overtly asymmetrical were fewer in number (n = 17). In terms of use-intensity, the these results suggest that 32 % of the palstave axes were used minimally. Whereas just 4 % of axes could be described as demonstrating signs of extensive use (as seen in Fig. 4), with the remaining 13 % falling somewhere in between these two categories. Indications of contortion or depression at the cutting-edge were presented on only 16 % of the sample, while the rest were free of any features that resembled, or may have once resembled, an area of bending.

Micro-scale analysis revealed use-striations, as exemplified in Fig. 4, on eleven of the palstave axes that were suitable for analysis. Since the experimental work conducted by the authors demonstrated that use-striations could be easily detected after only 500 impacts (Andrews

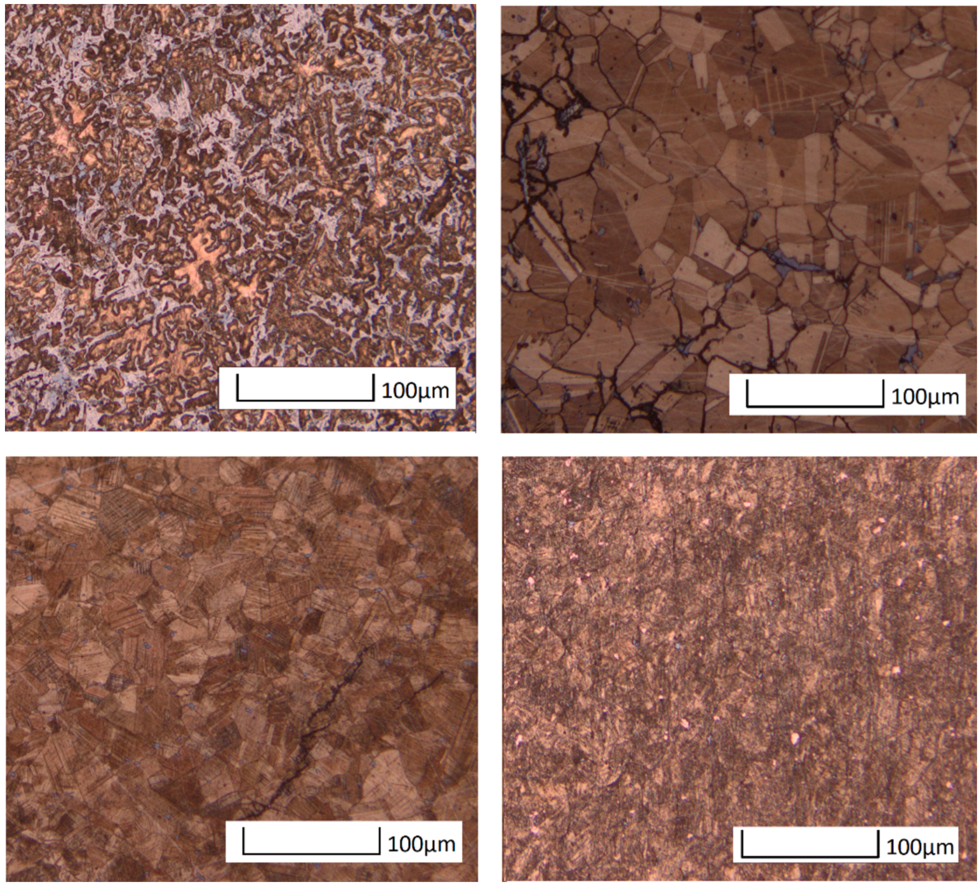

Fig. 2. Metallographs demonstrating various microstructures found in tin-bronzes. Top left: DCM-1902.1.2, dendritic microstructure. Top right: RAMM-60/1954, twinned recrystallized microstructure with no strain-lines. Bottom left: RAMM-45.1955.1, twinned, recrystallized microstructure with evidence of strain-banding. Bottom right: MoS-12C, heavily deformed recrystallized microstructure. (Images: Miriam Andrews, courtesy of the Dorset County Museum, the Royal Albert Memorial Museum & Art Gallery, Exeter City Council, and the Somerset Archaeological and Natural History Society and South West Heritage Trust).

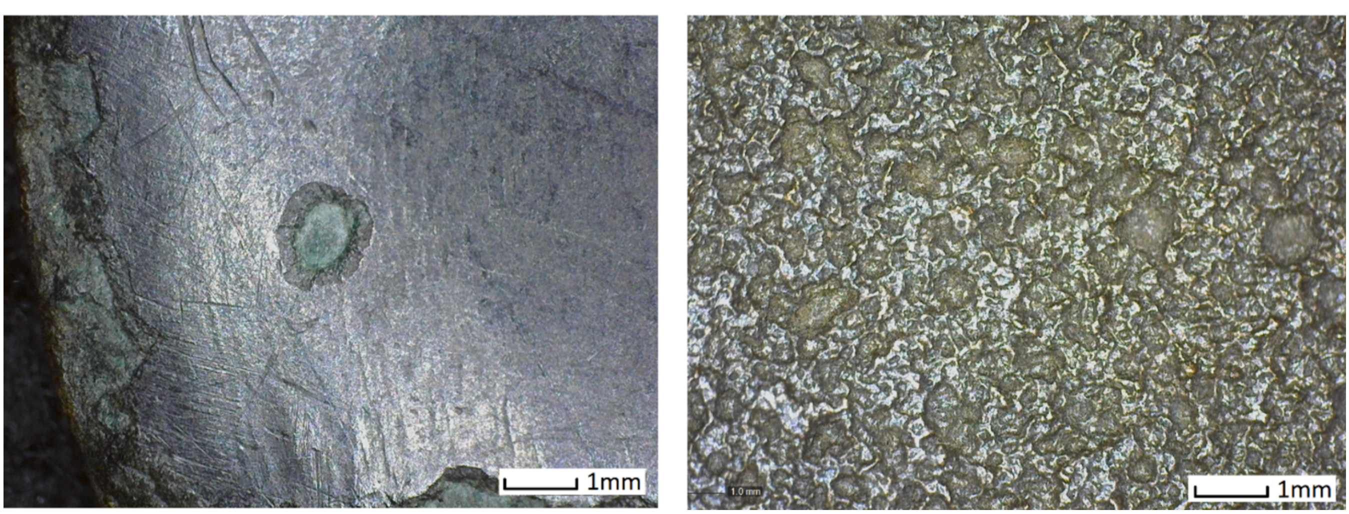

Fig. 3. Microscope images depicting various features left by production and use. Left: DCM-1884.9.2, sharpening marks (parallel to the cutting-edge), and use-wear (perpendicular to the cutting-edge). Right: MoS-12C, mottled surface left by casting (no finishing or sharpening applied). (Images: Miriam Andrews, courtesy of the Dorset County Museum and the Somerset Archaeological and Natural History Society and South West Heritage Trust).

et al. 2022), the limited observation of this feature is probably related to preservation issues. Hafting striations were somewhat easier to detect as the septum and butt were often in better condition than the cutting-edge, and marks were detected on a further twenty-one artefacts. Hence, a total of thirty-two palstave axes showed some evidence of use at the micro-scale.

The total number of palstave axes demonstrating evidence of at least one form of use-wear was fifty-seven. Both macro and micro indicators of use were determined on twenty-four palstave axes. Macro indicators such as asymmetry and bending confirmed the use of another twenty-six

Table 4
The results of the use-wear analysis for the south-west palstave axes. It should be noted that the full assessment of use-wear included an expanded number of data collection categories, for example, butt asymmetry and butt rounding, which have not been included here; due to unknown interactions with processing and maintenance practices, these types of wear were not taken into account when determining whether the object was used or not.

Museum	Museum no.	Use-striations	Hafting striations	Contortions to the cutting-edge	Blade sharpness	Asymmetry
Ashmolean	1927.2594	Yes	n/a	No	Medium	Yes, moderate
	1927.2567	n/a	n/a	No	Sharp (regrinding)	Yes, moderate
	1927.257	n/a	n/a	No	Blunt	Symmetrical
	1961.498	n/a	n/a	No	Medium	Symmetrical
	1961.497	n/a	Yes	No	Sharp	Yes, slight
Bristol Museum	E449	n/a	n/a	No	Medium	Symmetrical
	E456	n/a	n/a	No	Blunt	Yes, slight
Dorset County Museum	1948.14.2	n/a	No	No	Medium	Yes, slight
	1963.15.1	n/a	n/a	Yes	Sharp (regrinding)	Yes, slight
	1954.40.1	n/a	No	No	Sharp (regrinding)	Symmetrical
	1902.1.1	n/a	No	No	Blunt	Symmetrical
	1902.1.5	n/a	No	No	Blunt	Symmetrical
	1902.1.2	n/a	No	No	Medium	Symmetrical
	1902.1.4	n/a	n/a	Yes	Medium	Yes, moderate
	1902.1.3	n/a	No	No	Sharp	Symmetrical
	1955.48	n/a	n/a	Yes	Medium	Yes, slight
	1884.9.2	Yes	Yes	No	Sharp	n/a
	1884.9.3	n/a	Yes	Yes	Sharp	Yes, slight
	1884.9.5	n/a	n/a	No	Medium	Yes, moderate
	1884.9.1	No	Yes	No	Sharp	Yes, slight
	1893.2.1	n/a	n/a	No	Sharp (regrinding)	Yes, slight
	1884.9.22	n/a	n/a	No	Medium	Yes, slight
Museum of Somerset	12A	No	Yes	No	Medium	Yes, slight
	14A	n/a	n/a	No	Blunt	Yes, severe
	63B	No	n/a	No	Medium	Symmetrical
	7A	No	No	No	Medium	Symmetrical
	80C	n/a	n/a	Depression	Sharp	Yes, slight
	10A	n/a	No	No	n/a	Symmetrical
	7B	n/a	n/a	No	Medium	Symmetrical
	75.AA.4	n/a	n/a	No	Medium	Yes, moderate
	14B	No	No	No	Blunt	Symmetrical
	75B	Yes	Yes	Depression	Blunt	Yes, slight
	81C	n/a	n/a	No	Sharp	Yes, moderate
	9B	No	n/a	No	Sharp	Yes, slight
	4A	n/a	n/a	No	Blunt	Yes, slight
	A332	yes	n/a	No	Blunt	Symmetrical
	A331	n/a	n/a	n/a	n/a	n/a
	81D	No	No	No	Very blunt	Symmetrical
	17B	Yes	Yes	No	Sharp	Symmetrical
	12C	No	No	n/a	Blunt	Symmetrical
	84B	n/a	Yes	No	Blunt	Yes, severe
	13B	No	Yes	No	Very blunt	Yes, slight
	81B	n/a	No	No	Sharp	Symmetrical
	10B	No	Yes	Depression	Medium	Yes, moderate
	8A	n/a	n/a	No	Sharp	Yes, moderate
	41B	Yes	Yes	Yes	Medium	Symmetrical
Royal Albert Memorial Museum	11/1974	n/a	n/a	No	Blunt	Symmetrical
	45/1955/1	n/a	n/a	No	Medium	Symmetrical
	354/1906/1	n/a	Yes	No	n/a	n/a
	355/1906	n/a	Yes	No	Medium	Yes, slight
	A306	n/a	No	No	Blunt	Symmetrical
	A320	n/a	n/a	No	Very blunt	Symmetrical
	1113/1912	No	No	No	Sharp	Symmetrical
	A6462	n/a	n/a	No	Blunt	Symmetrical
	1897/7/6	n/a	n/a	No	Blunt	Symmetrical
	593/2005	No	n/a	Depression	Medium	Yes, slight
	A1951	Yes	Yes	No	Blunt	Yes, moderate
	A1952	n/a	n/a	n/a	n/a	n/a
	102/1970	n/a	n/a	Bending	Medium	Yes, slight
	130/1979	n/a	n/a	No	Medium	n/a

(*continued on next page*)

Table 4 (*continued*)

Museum	Museum no.	Use-striations	Hafting striations	Contortions to the cutting-edge	Blade sharpness	Asymmetry
	70/1974	n/a	n/a	Depression and bending	n/a	Symmetrical
	A289	No	n/a	No	Blunt	Symmetrical
	A4148	n/a	n/a	n/a	n/a	n/a
	A4214	n/a	n/a	No	Blunt	Yes, slight
	A6158	n/a	No	No	Sharp	Symmetrical
	1891/2/7	No	n/a	No	Sharp	Symmetrical
	1891/2/6	n/a	Yes	Depression	Medium	Yes, moderate
	10/1980	n/a	n/a	Depression	Medium	Yes, slight
	50/1971	n/a	n/a	n/a	n/a	n/a
	60/1954	No	Yes	No	Sharp	Yes, severe
Royal Museum of Cornwall	1910.22 2	n/a	n/a	no	Medium	Symmetrical
	1910.21	n/a	n/a	No	Blunt	Symmetrical
	9.1919.5	No	No	No	Sharp	Yes, slight tdefinitely related to casting
	1909.15.3	No	No	No	Blunt	Symmetrical
	1880.16	n/a	Yes	No	Medium	Yes, slight
	1974.10.1	n/a	n/a	No	Medium	Yes, slight
	9.1919.6	n/a	No	no	Blunt	Symmetrical
	1909.74	n/a	n/a	Yes	Sharp	Yes, slight

Table 5
The results of the use-wear analysis for the Coghlan sample. It should be noted that the full assessment of use-wear included an expanded number of data collection categories, for example, butt asymmetry and butt rounding, which have not been included here; due to unknown interactions with processing and maintenance practices, these types of wear were not taken into account when determining whether the object was used or not.

Museum	Museum no.	Use-striations	Hafting striations	Contortions to the cutting-edge	Blade sharpness	Asymmetry
Pitt Rivers	1884.119.105	n/a	Yes	No	Sharp	Yes, slight
	1884.119.106	yes	No	No	Medium	Symmetrical
	1884.119.108	n/a	Yes	No	Sharp (regrinding)	Yes, slight
	1884.119.113	No	No	No	Medium	Yes (shoddy casting)
	1884.119.114	No	Yes	Depression	Blunt	Symmetrical
	1884.119.12	n/a	n/a	No	Sharp (regrinding)	Symmetrical
	1884.119.135	n/a	Yes	Depression	Sharp	Yes, slight
	1884.119.136	n/a	Yes	n/a	Blunt	n/a
	1892.67.120	n/a	Yes	No	Blunt	Symmetrical
	1892.67.121	n/a	n/a	No	Sharp (regrinding)	Yes, moderate
	1892.67.86	n/a	n/a	No	Sharp (regrinding)	Symmetrical
	1904.31.2	Yes	Yes	No	Blunt	Yes, severe
Newbury	1962.12	Yes	Yes	No	Blunt	Symmetrical
	OA331	n/a	n/a	No	Blunt	Yes, slight
	OA325	n/a	n/a	No	Sharp	Symmetrical
	OA324	No	Yes	No	Sharp	Yes, moderate
	OA322	n/a	Yes	No	Medium	Yes, slight
	OA264	n/a	Yes	No	Sharp	Yes, slight
	OA351	Yes	Yes	No	Medium	Yes, moderate
	OA93	n/a	No	No	Sharp	Symmetrical
	OA265	No	No	No	Sharp	Symmetrical
	OA63	n/a	n/a	No	Sharp	Symmetrical
	1968.68.Y2	n/a	n/a	No	Medium	Symmetrical
	1968.63.Y3	n/a	n/a	n/a	n/a	n/a

axes, and the use of a further seven axes was suggested by micro-scale analysis alone.

4.3. Damage and deposition characteristics

It was only possible to confidently determine nine axes with evidence of deliberate damage. The type of breakage observed was quite diverse: RAMM-354/1906/1, DCM-1884.9.2, WBM-1968.68.Y3 and RAMM-50/1971, all exhibited a removal of some part of the blade, as did PR-1884.119.136, alongside damage to the butt; MoS-7A had also lost a section of the butt; RCM-9.1919.5 was broken across the body and refitted, with WBM-1968.68.Y2 and RAMM-A1952 exhibiting the same type of breakage, but displaying no refitting. A further twenty-nine axes demonstrate signs of accidental damage, i.e., fracture through the flanges, side-loop, or stopridge. The full damage analysis dataset can be found within the supporting data repository. The seventy-eight axes that have enough contextual data to elucidate exact find location and associations are split almost exactly between single and group finds. There are a high prevalence of group finds from dryland areas, as none were found within wetland zones (although this could be a result of sampling issues).

5. Discussion

By drawing upon several elements of their narrative, the commonalities within the life trajectories of palstave axes can be reconstructed. It appears that many of the early and mid MBA palstaves in this sample may have been formed from copper mined at Great Orme during its most active period (Williams 2023). The results support existing analysis regarding 10–14 % being the average addition of tin to MBA palstave

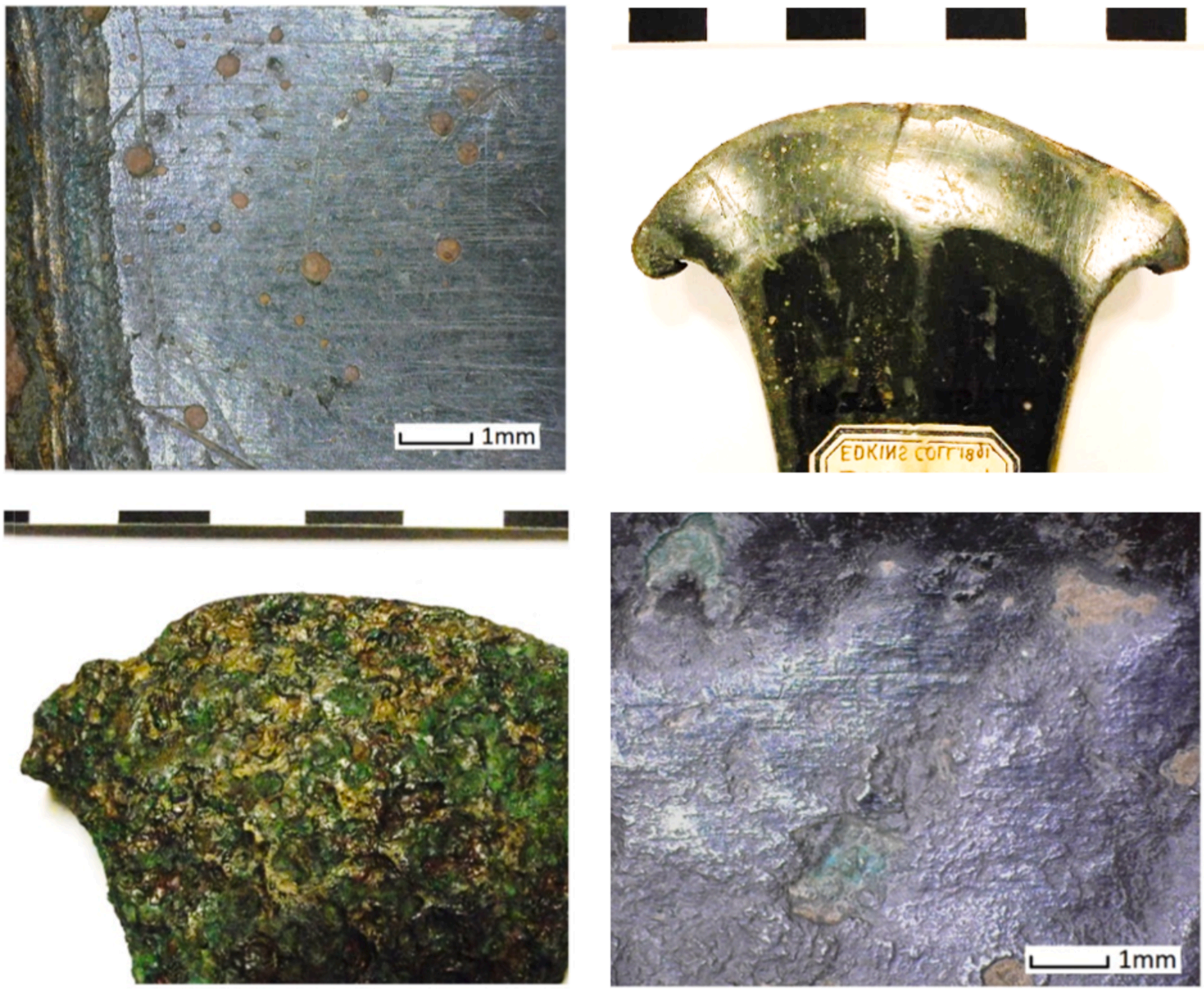

Fig. 4. Micrographs and photographs of types of use-wear found on axes within the sample. Top left: ASH-1927.2594, use-striations at the cutting-edge. Top right: ASH-1927.2594, cutting-edge presenting a moderate amount of asymmetry. Bottom left: RAMM-1955.48, depression at the cutting-edge. Bottom right: DCM-1884.9.3, hafting striations found on the septum. (Images: Miriam Andrews, © Ashmolean Museum, University of Oxford, courtesy of the Dorset County Museum and the Royal Albert Memorial Museum & Art Gallery, Exeter City Council).

axes (Needham et al., 1989, p.392). It is well appreciated that this level of tin produces the most optimum mechanical properties for functional application of the tool (Kienlin and Ottaway 1998; Soriano Llopis, I. and Gutierrez Sáez 2009; Andrews et al. 2022). Hence, this suggests that many of the palstave axes within this study were produced with the potential for use. The observations produced from the metallographic data also reinforce that the majority of palstave axes within the sample were created with the capacity to be used as a working axe. The recrystallized, twinned, microstructure presented by most palstave axes within this sample has demonstrated superior resistance to deformation throughout experimental work (Andrews et al. 2022). Furthermore, many palstave axes had been subjected to a final hammering; a treatment that has been shown to substantially increase the durability of the blade, and safeguard against the damaging effects of high-energy hits (ibid.).

Just over half of the axes that were analysed demonstrated evidence of use. Though, the presence of use-wear cannot be confidently ruled out for much of the remaining sample due to the large number of axes that had to be excluded from micro-scale analysis. As a result, it is likely that the proportion of palstave axes that can be classified as used within this study is a low estimation. Dolfini et al. (2023) found evidence of woodworking on all ten of the palstave axes analysed during their analysis, reinforcing our belief that sampling issues may have prohibited a full assessment of use for the palstave axes presented here-in. Regardless, the results indicate that palstave axes that are unused or seemingly unused are most commonly found within metalwork deposits. This could suggest that most palstave axes were reworked or recycled before becoming very asymmetrical, removing the opportunity for axes exemplifying heavy use from entering the soil. Given the output of copper from Great Orme during 1500–1300 BCE (estimated to be the equivalent of about 2600 to 9200 palstaves per year) (Williams 2023; 286), an economy with an ample supply of bronze was likely in place, leading to many axes within circulation that were not heavily used. Alternatively, palstave axes with relatively well-retained cutting-edges may have been purposely removed from circulation for use in deposition practices. The limited prevalence of palstaves with evidence of bending or depressions at the cutting-edge suggests that these objects were either recycled or sharpened to the point where this fault was no longer visible at some point before deposition.

In terms of the damage assessment data, the prevalence of damage to flanges and side-loops likely indicates that these are areas of weakness that are fragile and break regularly during use (Knight 2018a, p. 170). Given that few palstave axes were deliberately broken, a clear tendency towards 'completeness' is also present within the data relating to damage (Knight 2022, p. 81). Hence, the results provided here-in suggest that the common life trajectory of a palstave axe used in deposition practices is a complex story of both preparation for, and minimal application in, functional use, with preservation favoured over destruction at deposition.

As well as highlighting the common life trajectory of palstave axes, the data reveals considerable variability in the life paths of these objects. A minority of palstave axes (n = 15) were left in an as-cast state and were not finished, sharpened, or used. It has been suggested by Williams (2023; 259) that palstaves may have acted as ingots (which were easier to transport than ore) that were moved from production centres down riverine networks and were subsequently re-cast as local variants or copies of the original form (a similar trend has also been identified in Norman-type palstaves in Northern France, see Forel et al. 2009, Monna et al. 2013). This also goes someway to explain the high frequency of deposits within rivers or river valleys. The idea of palstave ingots is reinforced by the narrative of PR-1884.119.113, a palstave axe that is shoddily cast, crooked, and still retains flashing; if this object was meant to be a functional axe it could have been easily re-melted and re-poured. On the other hand, some palstaves may have been cast purely for deposition as token axeheads (Knight 2022, p. 136); RCM-1919.9.5, for example, presents an interesting case. This unfinished palstave axe is also a crooked casting, which was deliberately broken and placed within a multi-period hoard (Late Bronze Age socketed axes were present). It could be possible that this object was cast after the cessation of the MBA to complete this specialist '*in memoriam*' hoard (see Knight et al., 2019, p. 33).

In general, there appears to be a slight tendency for palstave axes with evidence for deliberate damage to exhibit as-cast or partially manufactured microstructures. RCM-9.1919.5, which has already been mentioned in the above text, RAMM-A1952, and WBM-1968.63.Y3, are all as-cast, while WBM-1968.68.Y2 was only partially annealed, and RAMM-50/1971 was not finished with a final hammering. This could suggest that these axes were not intended for use, but rather created with the intention to be destroyed, for which it is probably advantageous if they are less mechanically robust.

On the other hand, the evidence points to the functional application of palstave axes with as-cast microstructures on several occasions. For instance, the cutting-edge of RAMM-593/2005 was not properly processed by the smith; however, the axe was subjected to use anyway, causing the blade to deform, which was then tidied up by sharpening prior to deposition. While it is likely that this palstave axe was accidentally used whilst in a completely unfinished condition, it is also a possibility that the object was subjected to use specifically to imbue it with a use-history before deposition.

The deformations observed on the cutting-edge of a small number of palstave axes (WBM-OA351, PR-1892.67.86, MoS-41B, and MoS-14A) resembled 'nicks' and, therefore, did not fit within the rubric presented by the experimental data (Andrews 2021). These could represent marks that were produced when the tool was used for a purpose other than tree-felling. The formation of 'nicks' under these conditions has also been suggested by Roberts and Ottaway in their study of leaded tin-bronze socketed axes (1998, p. 126). WBM-OA351 and MoS-41B also present very pronounced use-striations alongside the nicks, which suggests periods of sliding contact between the surface of the axe and a material with a greater hardness than wood. It is interesting that these axes have been included within deposition practice, given the severe blemishing of the cutting-edge, which seems to generally preclude palstave axes from deposition (for whatever reason). While little is known about the deposition circumstances of WBM-OA351 and PR-1892.67.86, palstave axe MoS-41B was found within a substantial hoard, which included ornaments, and Mos-14A is said to have been discovered with a human skeleton (now lost).

The results of this project have revealed that it is common for palstave axes with very different lives to end up in the same assemblage, a trend that has also been observed by Crellin (2017; 2020) in her studies of Early Bronze Age axes. The hoard uncovered on Dewlish Hill, Dorset, consisted of a number of palstave axes (DCM-1902.1.1, DCM-1902.1.2, DCM-1902.1.3, and DCM-1902.1.5) with as-cast microstructures and symmetrical blades that suggest they were never used or sharpened. However, DCM-1902.1.4 (another axe within this assemblage) was fully manufactured, had a significant use-history, and an area of bending at the cutting-edge. Similarly, the narratives of palstave axes MoS-81C and MoS-81D, both uncovered together at Old Cleeve, Somerset, are completely contrasting; MoS-81D was an as-cast, unfinished, unused axe, on the other hand, MoS-81C was well manufactured and had obviously been used quite intensely. If this was a result of deliberate selection for ceremonial purposes, it may be that it was important for communities in Bronze Age Britain to present objects with varying narratives within the same deposits.

6. Conclusions

In this paper we have sought to establish the common life trajectory for MBA palstave axes in the British Isles by combining data produced from chemical characterisation, metallography, metalwork wear-analysis, and damage assessment with other types of available biographical data. The results presented here-in indicate that many palstave axes were prepared for use and subsequently used prior to deposition. A clear pattern towards palstaves finding their way into metalwork deposits when they appear unused or where there is little visible evidence of use or damage is apparent. This could suggest a high turnover of palstave axes, with only those with optimum function remaining in circulation and use, or the purposeful selection of objects with specific morphology and/or use-histories for deposition. Moreover, this paper has identified palstave axes with life trajectories that deviated from the typical, demonstrating inconspicuous trends in behaviour, like the potential production of as-cast axes for the sole purpose of deposition, and axes that were used in an unusual way, or against a different opposition material. While we may never comprehend the true motive for the marrying together of palstave axes with either similar or differing narratives to one another in metalwork assemblages, the present study has provided fascinating insight into the consumption of palstave axes and traits commonly associated with deposition practices.

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CRediT authorship contribution statement

Miriam Andrews: Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Tomas Polcar:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Jo Sofaer:** Writing – review & editing, Supervision, Conceptualization. **Alistair W.G. Pike:** Writing – review & editing, Supervision, Methodology.

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