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RESEARCH

Dibble's Reduction Thesis: Implications for Global Lithic Analysis

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Abstract
Harold Dibble demonstrated the systematic effects of reduction by retouch upon the size and shape of Middle Paleolithic tools. The result was the reduction thesis, with its far-reaching implications for the understanding of Middle Paleolithic assemblage variation that even now are incompletely assimilated. But Dibble's influence extended beyond the European Paleolithic. Others identified additional reduction methods and measures that complement Dibble's reduction thesis, and applied analytical concepts and methods consistent with it to industries and assemblages around the world. These developments facilitated comprehensive reduction analysis of archaeological tools and assemblages and their comparison in the abstract despite the great diversity of their time–space contexts. Dibble argued that many assemblages are time-averaged accumulations. In cases from New Zealand to North America, methods he pioneered and that others extended reveal the complex processes by which behavior, tool use, curation, and time interacted to yield those accumulations. We are coming to understand that the record is no mere collection of ethnographic vignettes, instead a body of data that requires macroarchaeological approaches. Archaeology's pending conceptual revolution in part is a legacy of Dibble's thought.

Keywords Reduction thesis · Lithic · Typology · Curation · Allometry · Macroarchaeology

Around 1980, Harold Dibble began a career that examined sources of variation in Middle Paleolithic industries, mostly in France and southwest Asia. His untimely death in 2018 could not diminish the scale and impact of Dibble's contributions to Paleolithic archaeology. Other contributors can testify to his stature in that field. As an archaeologist who cannot tell a Quina scraper from a *chapeau de gendarme* platform, my task is different: to sketch some of Dibble's broader contributions to lithic analysis beyond Paleolithic studies, and especially to emphasize several current lines of thought and practice that at once derive in part from Dibble's work but extend beyond it. This essay does not pretend to be comprehensive evaluation of Dibble's oeuvre, merely to trace the extent of some of its parts, on the logic that a scholar's work can be gauged partly by surveying how others use and expand it.

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Experimental Controls and Key Variables in Fracture Mechanics

In a series of highly controlled experiments over several decades, Dibble and students demonstrated systematic effects of the fracture mechanics of reduction upon the size and shape of flakes struck from cores. Results synthesized by Li et al. (2023), this experimental program identified variables, mostly continuous, that were independent (e.g., platform dimensions) and dependent (e.g. length, mass or volume) in the fracture mechanics of flake production. The program established a framework for study of variation in flake size and shape. Experiments' designs showed the limited effects of unobservable variables like angle and force of blow, suggesting that observable independent variables could predict original size of flake tools.

Results may seem narrow but these experiments had very broad implications indeed. By itself, inferring flake size and shape has modest value; for the great mass of unretouched flakes, it has none at all, because these dimensions can be measured directly and require no inference. But the results have great value in the study of flake tools that underwent resharpening between first use at larger size and discard at smaller size. In that context, Dibble's experimental program

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identified independent or causal variables, again mostly continuous, like platform area and mathematically expressed their effects upon dependent continuous variables of size and shape. This insight made it possible to predict original flake size from properties like platform area that are retained on many retouched flakes. To the extent that flake tools were smaller at discard than experimental controls predicted, reduction from resharpening or other reasons is implicated. To the further extent that shape changed as size declined, variation in flake-tool shape may be a by-product of reduction, not a reflection of intended original form. Enter the reduction thesis.

The Reduction Thesis

With some ethnographic support (see citations in Dibble et al., 2017:823), Dibble's work showed that many—not all—stone tools varied substantially and systematically between first use and discard. Trivially, they only could become smaller, not larger, but tools and types varied greatly in degree and pattern of reduction experienced and the range of intermediate forms they took between first use and discard. Size and shape at discard are observable directly, but Dibble's contribution was to demonstrate that, for many retouched tools, remnant unchanged segments of the original detached flake (e.g., platform variables) furnished estimates of original size. Thus, arose the reduction thesis (Shott, 2005; Iovita's, 2009:1448 "reversed ontogenies").

Lithic analysts readily appreciate the importance of inferring original size of retouched and therefore reduced archaeological specimens. Again, by itself the knowledge is modest. But it looms larger in the context of Middle Paleolithic studies, where tool types were regarded as Platonic essences based on particular configurations of their form, and placement and extent of retouch *qua* reduction. Alternatively, as Dibble (1987) suggested, the pattern and degree of reduction by retouch allowed large flake tools to transit from what seemed one essential Middle Paleolithic type, often one or another variety of scraper, through a second, possibly to a third, and so on. For example, Middle Paleolithic backed knives experienced "transformations from one morphological *Keilmesser* form to another" (Jöris, 2009:295) as a result of resharpening to maintain functional edges. If so, tool form at discard reflects not original design, least of all size, but "the last stages of a series of metamorphoses" (Jelinek, 1976:27) of original form, as Dibble's mentor put it. In this perspective, the ontological validity of essentialist Middle Paleolithic tool types is in doubt, and to some typology has passed from analytical to descriptive enterprise. Assuming that the form in which a tool was discarded was its intended, unchanging form is Davidson and Noble's (1989) "finished-artefact fallacy," rephrased by Dibble et al. as "the fallacy of the 'desired end product'" (2017:814). In North American practice, it also has been called the "Frison effect" (Frison, 1968).

Dibble's insight later was expanded in three respects:

1. The reduction thesis applied to cores as well as tools, for instance, in Dibble's (1995) analysis of the Biache St.-Vaast Level IIA reduction sequence that demonstrated how core form and scar-patterning varied with their degree of working. (Throughout this essay, "reduction sequence" indicates the patterned ways that cobbles were reduced in the process of shaping them into tools or detaching flakes from them for use as tools, and subsequent reduction by retouch of core and flake tools, usage consistent with Dibble [e.g., 1995:101]. This is not the place to address the contested issue of how or whether the reduction-sequence concept, originating over a century ago in North America, differs from the more recent and, in Paleolithic studies, more popular "*chaîne opératoire*"; interested readers may consult Shott [2003a].)
2. It explained variation in Paleolithic flake-tool types besides scrapers, e.g., notched flakes (e.g., Bustos Pérez, 2020; Holdaway et al., 1996; Roebroeks et al., 1997). It also was applied to extensively or completely retouched, quasi-formal tools like Acheulean handaxes (McPherron, 1994) in Africa and Europe, European Middle Paleolithic bifaces (Serwatka, 2015) and Upper Paleolithic endscrapers (Morales, 2016), late Paleolithic core tools in Southeast Asia (Nguyen & Clarkson, 2016), Middle Stone Age Aterian points (Iovita, 2011) and Still Bay points (Archer et al., 2015) in Africa and unifacial and bifacial points in northern (Hiscock, 2009:83) and western Australia (Maloney et al., 2017). Such analyses linked in the same tool-use and -reduction sequences what initially were defined as distinct types (e.g., Middle Paleolithic Keilmesser handaxes and leaf points [Serwatka, 2015:19] and late Paleolithic core tools such that "various tool types are viewed as points or stages along a trajectory of continued reduction, rather than as discrete or separate types as in a segmented and discontinuous scheme" [Nguyen & Clarkson, 2016:38]).
3. Largely implicit in Dibble's work, reduction is or at least can be understood as a continuous process.

Expansion of the reduction thesis itself is significant in two further respects. First, it suggested the argument's universal scope, the recognition that stone tools of all times and places can be subject to systematic transformations *during use*. What began, then, as an effort to understand variation in Middle Paleolithic flake tools might apply to stone-tool variation of any age, any industrial character, anywhere. In this perspective, the thesis can "put the analysis of tool's live [sic] histories in a global and standardized framework to interpret the organization of past societies" (Morales, 2016:243). Second, and starting from studies of Acheulean handaxes (McPherron, 1994), the reduction thesis engaged the concept of allometry to explain variation in stone tools. (Crompton and Gowlett introduced allometric analysis to Paleolithic research, defining allometry somewhat broadly, as "size-related variability" [1993:178]. No doubt suitable for their purposes, allometry is best understood as a biological concept—change in shape with change in size—and process that unfolds during growth to maturity. In lithic studies, obviously, the direction of size change is reversed; there, the allometric process unfolds during reduction. In biology where the concept originated and in lithic studies more generally, allometry measures the degree and strength of shape's dependence upon size variation. Although Crompton and Gowlett found allometric variation at Kilombe, they explained it in functional, i.e., design, terms, not as the product of reduction.) Allometry is an inherently continuous process that requires measurement in continuous terms. Allometric variation certainly describes some aspects of the morphological transformations of Middle Paleolithic flake tools wrought by the reduction process. But it is especially pertinent to the analysis of extensively retouched tools, Paleolithic or otherwise, whose distinctive forms and time–space distributions make them markers of industries or cultures. Expansion of the reduction thesis, therefore, is particularly relevant in archaeological contexts that abound in such tools, not least the Americas.

Besides pertaining to many Paleolithic and other defined tool types and besides its invocation of allometry, the reduction thesis bears upon other theoretical and methodological matters. It engages the concept of tool curation and encompasses the methodology of tool failure or survivorship analysis. It has implications for long-term accumulations that help to disentangle the complexities of the formation of stone-tool assemblages. It begs—and can help answer—a deceptively complicated question about stone-tool quantification. Finally, it can contribute to the intellectual transformation that archaeology desperately needs, a "macroarchaeology" (Perreault, 2019) that eschews ethnographic dependency, studies archaeological units in their own terms with their own long durations and applies uniquely archaeological theory to explain their time–space variation. All of this from experiments on the fracture mechanics of flakes and their implications for Middle Paleolithic flake tools. The following sections untangle and address some threads of the reduction thesis.

Typology

The reduction thesis has far-reaching implications, one of course that concerns the integrity of French Middle Paleolithic scraper typology. Tool types from scrapers to notches may not be the Platonic essences sometimes assumed (e.g., like Dibble [1987], Bustos Pérez's [2020:Table 43] and Roebroeks et al.'s [1997:148 and Figs. 17–18] observations that varieties of Middle Paleolithic scraper types transit via reduction to varieties of notch and denticulate types). If so, the reduction thesis reveals Middle Paleolithic Mousterian assemblage variation not as a chronicle of the "acrobatic manoeuvering of…typological tribes" (Clarke, 1973:10) signaling their self-conscious identity by fixed tool form and assemblage composition as they alternate between rockshelters. Instead, variation might be a record of adaptive behavior, when freed of the constraint of subjectively defined "technocomplexes" (Monnier & Missal, 2014; cf. Faivre et al., 2017).

Significantly, Dibble's thesis applies, as above, to more formal Paleolithic tools types and equally to other areas and research contexts. As examples of the reduction thesis's even broader scope, Dibble's argument echoes in the variation exhibited by Hoabinhian and other Southeast Asian industries (Marwick, 2008), in a comprehensive revision of the causes and meaning of variation in Australian flake tools (Hiscock & Attenbrow, 2005), in Hoffman's (1986) concern that a range of Holocene North American point "types" defined using traditional approaches (what Maloney et al., 2017:43 called "ad hoc" classification) capture merely various degrees of reduction of a single original type (reading Fig. 1 from Stages B to E; see Hamsa [2013] for a similar conclusion from a different sample in a different North American region), in New World Paleoindian points (Suárez & Cardillo, 2019; Thulman et al., 2023), and in the need to identify original sizes and shapes of distinct Holocene Patagonian point types whose forms converge in reduction (Charlin & Cardillo, 2018).

Reduction as Continuum

If tools undergo continuous reduction then, *ipso facto*, reduction is a continuum. Increasingly, reduction's continuous nature is assimilated to European Paleolithic practice, with productive results applied to flake tools (e.g., Iovita, 2009; Morales, 2016:236; Serwatka, 2015). What goes for tools goes for debitage; since the reduction thesis arose, lithic analysts have modeled reduction's entire span in continuous terms. Dibble's work on these lines parallels, not presages, research elsewhere, particularly in North America. As there, he questioned typological approaches to flake analysis that involved subjective judgments of selected products and favored detailed measurements of full ranges of flake classes (e.g. Dibble, 1988). (See Shott, 2021:57–70 on the comparative merits of typological and attribute methods in flake analysis.) By engaging the full range of materials in the Biache St.-Vaast Level

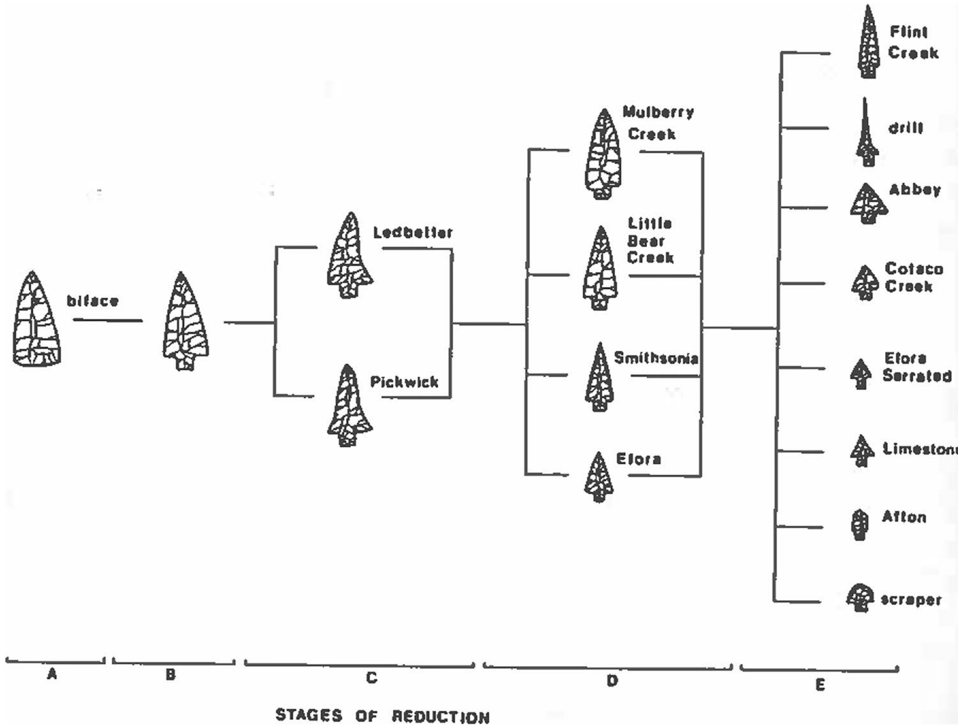

Fig. 1 Reduction's effect upon typology. A single original bifacial tool type (far left) retouched in varying pattern and degree (*x*-axis) yields several apparent "types" (far right) (Source: Hoffman, 1986:Fig. 5)

IIA assemblage and recording dimensions and other continuous measures, for instance, Dibble (1995) showed that cores themselves exhibited systematic, size-related variation according to degree of reduction, and that resulting flakes also patterned by size regardless of the supposedly distinct types to which some of each were assigned. In this way, "Dibble was able to show that relying solely on scar pattern analysis of cores and some Levallois products was not suitable for studying the dynamics of a reduction strategy" (Wojtczak, 2014:26). The continuous nature of this reduction process largely remained implicit in Dibble's treatment, yet is apparent upon close reading.

Reduction sequences, that is, are continuous because the size, shape, and technological properties of cores and even unretouched flakes vary continuously along the reduction continuum from the first to last flake detached from a cobble. Some still question a continuous view of reduction, arguing for instance that "the dichotomy between 'discrete' vs. 'continuous' is difficult to place on neutral grounds – lithic scholars rarely come up with convincing means to evaluate the alternative to their preferred view" (Hussain, 2019:243). This view relates stances—reduction as continuum or successive, discrete stages—to distinct ontological first principles incapable of comparative evaluation. Indeed, to some "Stage-like descriptions of technological choices are the hallmark of" traditional French systematics (Anghelinu et al., 2020:35). If so, the question of reduction as continuous or staged becomes a matter of a priori predilection rather than reasoned inference, metaphysic more than logic.

Yet precisely such evaluations of competing alternatives have been made, testing a priori stances rather than merely choosing between them. Dibble (1988) tested a stage-based thesis of "predetermination" in Levallois reduction. He showed instead that a wide range of reduction products varied continuously among and between themselves, a result inconsistent with stage views. Analyzing experimental flake assemblages, Bradbury and Carr (1999) found no evidence for reduction "stages," and expressed relative order of flake detachment (from 0 to 100% of core reduction) as a joint, continuous, function of faceting measures and flake size. A later study systematically tested key implications of both "stage" and "continuum" views in experimental data, again finding no support for the validity of stages and extensive support for the continuous alternative (Shott, 2017). A complementary approach supplements attribute recording with mass analysis and involves flake-size distributions that, in the same experimental assemblage, vary predictably between successive segments defined arbitrarily or, for instance, by change in hammer. When such assemblage segments hypothetically are "mixed" in various combinations, they model the mixing that characterizes empirical flake assemblages accumulating over long periods. Using suitable methods—in this case, constrained least-squares regression—the approach offers the prospect of disentangling—unmixing—empirical assemblage accumulations. Applied to two large North American Great Basin quarry assemblages, it identified mostly early but also intermediate segments of reduction that varied continuously across contexts and between assemblages (Shott, 2021:98–103), complex mixing and variation that rigid "stage" approaches could neither detect nor characterize. Thus, individual reduction sequences and their products can be understood in continuous terms, as can the complex mixing of many reduction sequences in archaeological accumulations. Again, the continuous nature of the reduction process mostly was implicit in Dibble's work, but clearly his approach paralleled those taken elsewhere and led to similar conclusions.

Allometry and Modularity

Typically, continuous flake-tool reduction produces allometry; some segments—usually distal and/or lateral edges—are reduced while others—usually butts or platforms–remain unchanged. Shape changes as size declines, i.e., allometry. Shape changes because various distinct segments—*modules*—of flakes are retouched to varying degrees or not at all. Hence, the reduction thesis views even humble flakes as composites of modular parts. Because it draws an analytical distinction between segments *qua* modules of flakes, the thesis encompasses allometry and modularity as latent properties, made explicit in recent applications of landmark-based geometric morphometrics (GM) to flake assemblages (Knell, 2022).

Allometry can be analyzed using tool dimensions like length and thickness (e.g., Crompton & Gowlett, 1993). Yet GM methods are particularly suited to analysis of allometry. GM itself is an innovative way to characterize and measure stone tools. GM methods are not "size-free" (cf. Caruana & Herries, 2021:92) in the sense of separating all variation in size from all variation in shape. Rather, they separate shape variation that is independent of size from shape variation that is size-dependent (Shott & Otárola-Castillo, 2022:95). As a result, GM methods can be instrumental to allometric analysis, not obstacles to it.

GM facilitates allometric analysis only by defining modules, segments of larger wholes whose landmarks vary more internally than they do with other modules of the same points. The modularity concept originated in biology, modules there comprising distinct anatomical segments like wings or limbs. As above, though, Dibble's experiments and the reduction thesis arguably preadapted lithic analysis to receive it. Among Paleolithic flake tools, one salient modular distinction is between platforms, which may change little during use and retouch, and distal segments, which may be extensively retouched. Other modules can be defined and their correlations studied depending upon the research focus. In Western Hemisphere bifacial points, an equally salient distinction is between stems and blades as separate modules (e.g., Shott & Otárola-Castillo, 2022; Thulman et al., 2023), again not the only conceivable modular subdivisions. (For instance, Patagonian Bird Type IV-V points support a tip-versus-rest-of-point modularity [González-José & Charlin, 2012], and point margins also can function as modules.) In this perspective, allometry occurs by changing size proportions among modules as functions of overall specimen size. Archaeological GM analysis transforms stone tools from integral wholes to things of complementary parts—modular constructions—in complex interaction. In the process, it invokes a concept of modules implicit in Dibble's experiments.

Curation and Its Distributions

Pattern and especially *degree* of reduction reflect the practice of curation. Originating with Binford (1973), the curation concept was (Hayden, 1976; Nash, 1996; Odell, 1996)—still is, in some quarters—fraught with ambiguity. Yet a consensus has emerged that views curation as a continuous property of individual tools, not a categorical trait of entire assemblages or industries (e.g., Morales et al., 2015b:302). It expresses the ratio between realized and maximum utility (Shott, 1996), calculated in subjects like retouched stone tools as the difference between size at first use and at discard, usually on a 0–1 scale. Thus, curation of retouched flake tools scales as the difference between each tool's size at detachment (or modification in preparation for first use) and at discard. As above, size at discard is a simple matter of observation but Dibble and colleagues' experiments permitted inference to size at detachment. Hence, Dibble's experimental results are key to the measurement of curation.

Again tools, not assemblages or industries, are curated (Shott, 1996), and specimens of a single type can be curated to varying degrees. Of course their original size, shape, and production technology are important properties of tools and their types. But the reduction thesis underscores the equal importance of the characteristic patterns and degrees of reduction that tools of any type experienced. Reduction is inherent in stone-tool curation, so must be measured. Analysts have devised a range of measures, mostly geometric or allometric (e.g., Morale et al., 2015a; Shott, 2005). So many reduction measures demand criteria for their evaluation (Hiscock & Tabrett, 2010) and, considering their diversity and varying statistical properties, may even reward synthesis as pooled or "multifactorial" measures derived from ordination methods (e.g. Shott & Seeman, 2017).

At any time, each person has a single value for age, trivially. The populations they comprise do not have discrete ages. But they can be characterized by their age distributions, the number or proportion of individuals at each age or pooled intervals of age from birth to greatest age. Similarly, each retouched tool has a single, individual, curation value. But when numbers of tools of any type are analyzed (types necessarily being defined *before* compiling curation distributions to avoid the mistake of conflating ranges of reduction and curation [e.g., the limited curation of "single scrapers" versus the more extensive curation of "double scrapers"] with distinct types), the resulting range and relative frequency of reduction values are population properties of the type. Ranging from unretouched to extensively reduced specimens, tools' reduction values form curation distributions for the types. Such distributions plot the fate of any number *x* of specimens of a type similar or identical in original size and shape as they undergo varying patterns and degrees of reduction. Fractions of *x* experience discard at progressive intervals along the range of curation from larger original to smaller discarded size and shape. Across a range of specimens of the type, degree of reduction (ascending on the x-axis in Fig. 2) leaves fewer survivals (cumulative survivorship descending on the y-axis there). Figure 2 shows distributions for two variants of reduction indices computed from the same set of North American Paleoindian unifacial scrapers (LT1NP, LT2NP which, for illustration only, are treated here as separate distributions) and one for reduction of a replicate scraper (LTMorrow). (See Sahle & Negash, 2016:Fig. 5 for similar distributions characterizing Ethiopian ethnographic scrapers.) Reduction distributions may indicate high (LT1NP) or comparatively low (LTMorrow) curation. Empirical distributions can reveal differences that certainly are continuous and sometimes are subtle.

Whatever their form, curation distributions are properties of tool types no less integral than their original design (Iovita, 2009). The variation they exhibit itself has analytical value. For instance, reduction distributions correlate degree of utility extracted to varying hunting return rates, making curation a behavioral variable that tracks long-term adaptations (Miller, 2018:55–63). They can be fitted to failure models like Weibull that gauge their scales and shapes and identify causes of discard in experimental assemblages (Lin et al., 2016), and among Upper Paleolithic Iberian endscrapers (Morales, 2016; Morales et al., 2015b:302–303) and late Pleistocene North American scrapers (Shott & Seeman, 2017). Differences between distributions beg explanation, perhaps by industrial variation in Paleolithic assemblages or by changing access to toolstones, varying land-use scales or technological organization, changing population density or sociopolitical organization in assemblages anywhere. In this way, the reduction thesis creates variables by which to explain prehistoric behavior.

Assemblage Formation

Curation rate itself arguably measures *relative* use-life of tools (Shott, 1996). In turn, use-life is a key quantity in assemblage-formation models, along with tool-using activity rates and "mapping relations" (how types "map onto" functions or uses) (Ammerman & Feldman, 1974). Tool-use rates and "mapping relations" establish the functional or activity correlates of tool use. They contribute to assemblage variation, but are irrelevant in the following discussion that holds them constant in order to illustrate how curation and use-life alone can generate assemblage variation. Curation, which can be estimated in stone tools from the reduction thesis, and use-life thereby extend the reduction thesis's scope beyond individual tools to the size and composition of entire assemblages as time-averaged accumulations.

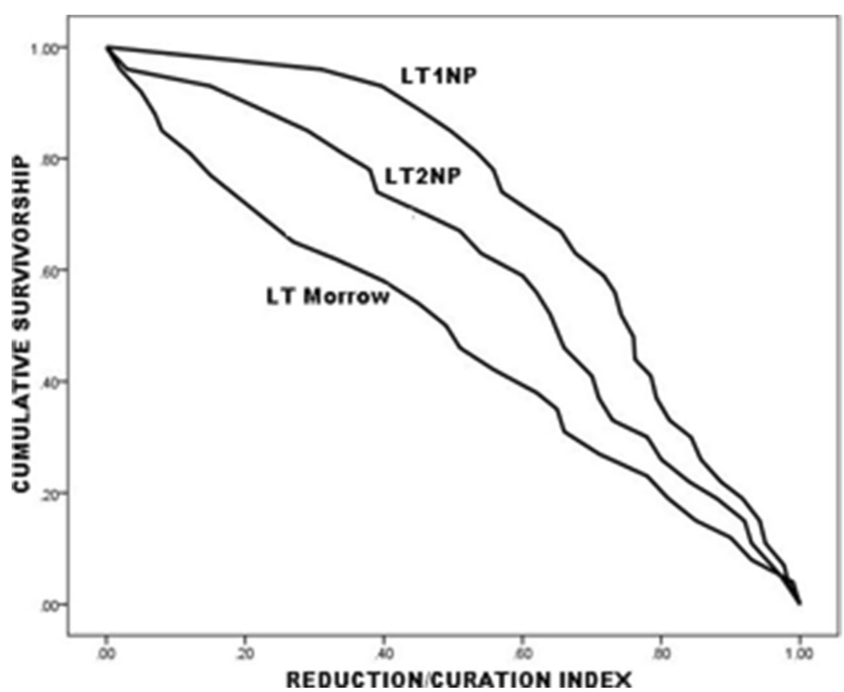

Fig. 2 Reduction distributions plotting cumulative survivorship (descending on *y*-axis) against degree of curation (ascending on *x*-axis). Upper, convex distribution (LT1NP) indicates high curation, most specimens surviving until they experience extensive reduction. Lower, less convex distribution (LT2NP) indicates lower curation by continuous degree, more specimens discarded at low to modest degree of reduction. Distribution of experimental replica (LTMorrow) indicates lowest curation by comparison (Source: Shott & Seeman, 2015: Fig. 5)

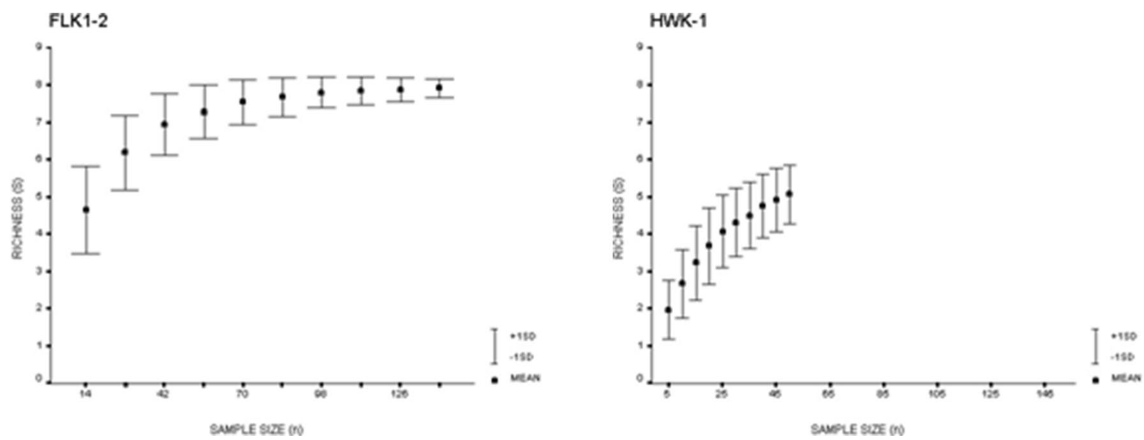

Fig. 3 Examples of bootstrap gauging of richness adequacy and standard deviation in Oldowan assemblages. **a** FLK1-2, adequate because empirical size is sufficient to stabilize richness and narrow standard deviation; **b** HWK-1, inadequate because richness fails to stabilize and standard deviation to narrow before reaching empirical size (Data source: Leakey, 1971)

Use-life is measured in time, and assemblages accumulate in time, a truism but one with important implications. Assemblage size increases, *ceteris paribus*, with time, therefore with accumulation span. But assemblage composition also changes as size increases, even holding tool-use activity rate and mapping relations constant, if tool types vary among themselves in use-life. How and why this occurs is explained elsewhere (e.g., Schiffer, 1975; Shott, 2010). Relevant here is that the composition of assemblages—presence or absence of and, if present, proportions of, various tool types—can vary strictly as a function of time and the accumulation of discarded specimens; assemblage size and composition are not always, possibly not often, independent quantities, composition instead changing with size up to an equilibrium point determined by the relationship between accumulation span and tool-type use-lives. When assemblage composition (as richness—number of types present—or other measures like heterogeneity) is plotted against assemblage size, either between assemblages or in bootstrap sampling within an assemblage, a positive linear relationship can result, up to the equilibrium point beyond which composition changes little. Before that point, assemblage composition has not stabilized for use-life and assemblage-size effects; beyond it, composition is stabilized with respect to those effects.

The reduction thesis bears directly upon assemblage formation only in helping to reveal types' relative use-lives. But because the thesis demonstrates that some Paleolithic "types" like single scrapers are not types at all but merely modestly reduced versions of the legitimate type "flake tool," indirectly it also helps explain some patterns of assemblage variation. For instance, assemblage size-composition correlations are documented in contexts as diverse as the French Middle Paleolithic (Shott, 2003b), the North American Paleoindian (Shott, 2010) and late prehistoric New Zealand (Phillipps et al., 2022). As one example, Olduvai Paleolithic flake-tool "types" can, like Middle Paleolithic ones, be linked as segments of cobble reduction sequences (Potts, 1991); they are not legitimate types. Bootstrapped plots of richness, a composition measure, against number or size distinguish assemblages there whose size-composition relationships had stabilized (Fig. 3a, FLK1-2) from those that had not (Fig. 3b, HWK-1)(see Shott, 2003b:142–143 for similar treatment of French Middle Paleolithic assemblages).

Similarly, Dibble argued that a Middle Paleolithic scraper's "type" registers not its Platonic essence—single, double and convergent scrapers are not legitimate, distinct types but merely segments of the reduction continuum of the legitimate type "flake tool"–but its curation rate and, *ceteris paribus*, relative use-life (Lin, 2018:1791). Dibble and Rolland (1992:11) defined "intensity of occupations" in part as the ratio of Bordean scrapers to notches. In size-stabilized assemblages, Bordean single scrapers correlated inversely with the intensity ratio, double scrapers positively at high slope or rate, convergent ones positively at lower rate. The reduction thesis explains this size-composition pattern; single scrapers first must become double scrapers before they might become convergent ones. Both double and convergent scrapers can be transformed single scrapers, but double scrapers are transformed sooner because they form directly from single scrapers. As a joint probability of transformation-by-reduction first to double scraper and only later, possibly, to convergent scraper, a lower proportion of convergent scrapers is a highly probable arithmetic consequence of the reduction thesis. Scraper "types" considered as successive segments of a reduction continuum of a single flake-tool type increase proportionally in size-stabilized assemblages as measured by Dibble and Rolland's scraper:notch ratio of occupational intensity because the ratio measures increasing scraper use and discard (Shott, 2003b:145 and Fig. 11.9). Recognition of such size-composition correlations also

Fig. 4 Reduction sequence of North American Early Side-notched points, a–e representing progressive intervals of reduction (Source: Randall, 2002:Fig. 4.2)

contributed to one of Dibble's and colleagues' later arguments (e.g., Dibble et al., 2017) that surface assemblages may be time-averaged palimpsests revisited as.

Quantification

Assimilating several components of the reduction thesis—its prevalence, resulting allometric variation, curation rates and their connection to use-life, and assemblage size-composition correlations—begs a question that appears trivial at first glance: how much is a tool? In limited respects, this question was broached years ago (e.g., Hiscock, 2002; Shott, 2000), chiefly to improve and standardize assemblage characterization for comparative analysis. Applied to a Syrian Middle Paleolithic assemblage, for instance, several measures of original number of specimens yielded generally concordant results, best among them considered total length of all intact and broken specimens combined divided by mean length of intact tools at discard ("TLV 1") (Wojtczak, 2014:63–72).

We regard tools as integral wholes not only for purposes of typological assignment and various analytical approaches, but also for counting. Leaving aside the fragmentation that further complicates quantification, for counting purposes one Quina scraper or one Early Side-notched (ESN) point, to use a North American example, is as much as another, no more or less: it's one. But recognizing that many tools are subject to reduction of varying degree and pattern, whether or not they transit between types in any taxonomic system, we might change our perspective. A newly minted, large ESN point (Fig. 4a) is, trivially an ESN point. But is it as much of an ESN point as a heavily resharpened stub (Fig. 4e)? More? Less? Is the large, new point "one," the reduced stub much less than one? Alternatively, is the latter, owing to its extensive use, more than one mint-condition ESN point? Questions so abstruse may seem unworthy of consideration. Yet if assemblages reflect, at least in part, patterns and frequencies of past activities, then not all ESN points register the same amount, or necessarily kind, of activity. For the study of original design, the specimen shown in Fig. 4a is more than that shown in Fig. 4e; as registers of use, Fig. 4e is much more of a tool than is Fig. 4a. The reduction thesis is essential to the calibration of tool occurrence to past design and behavior, in part by linking amount of use to degree or pattern of reduction.

Macroarchaeology

Fitfully, archaeology is evolving as a scholarly discipline. In the mid-twentieth century, essentially it was culture history. Later, American archaeology became a functional or ecological anthropology, later still a postmodern critique of whatever postmodernists disliked, latterly a forum for identity construction and defense. Archaeology can be all of those things; it also can be a science of the human past, a possibility that encompasses at least part of all such approaches save postmodernism.

Dibble practiced a scientific archaeology, although not exactly as conceived by Perreault's (2019) "macroarchaeology" that extensively revises the field's ontology. Yet despite macroarchaeology's breadth, even the limited domain of the reduction thesis and the study of stone tools bear upon it. For instance, objects like stone tools and their attributes are directly observable. But so trivial a statement obscures important implications. In macroarchaeological perspective, objects and the attributes they possess are "primary historical events" or units (Kitts, 1992:136), of a time–space scale commensurate with individual observation and experience. Anyone can observe an object in production or use today, and lithic analysts can directly examine a prehistoric stone tool. The theory required to explain objects and their attributes, be it technological, functional, symbolic or social, and how they serve their broader cultural context, be it material (e.g., behavioral ecology), symbolic, structural, or social (e.g., agency, Marxism), is suitable to primary historical units, i.e., of a time–space scale commensurate with individual experience. Such theory explains the actions of individuals or social groups at moments or short intervals in time; it is historical (e.g., the movement of populations, the rise or decline of complex societies), material (e.g., environmental change, adaptation), or ethnographic. Little or none is unique to archaeology or its customary time–space scales.

Tool types are defined by repetitive patterning in attributes across specimens. Industries or assemblages of specimens of various types are defined by joint patterns of use and deposition. Types and industries or assemblages, and the cultures constructed from them, are bounded empirically by their time–space distributions. Types may occur over broad areas and persist for generations or longer, and their distribution at any moment surpasses the scale of individual experience. Pompeiis excepted, industries or assemblages are time-averaged over at least years, usually much longer. Neither types, assemblages, and cultures, or their time–space boundaries, are primary historical units. Types persist, and assemblages and industries accumulate, at time scales orders of magnitude greater than ethnographic or historical contexts. They are secondary historical events or units that "have no counterpart in the present…[and] are composed of primary events related in a spatial and temporal nexus" (Kitts, 1992:137). As secondary units, types and assemblages possess properties that are emergent at the lower level of primary events—not deducible from the properties of units at that level—and that require "explanatory principles emergent with respect to" (Kitts, 1992:142) them. Secondary units' salient properties must be constructed from the material record. Units' origins—how and why types or other secondary units arise, according to what causes–and behavior—their duration, changing incidence or distribution over that span, how and why they end, either by termination, transformation or branching—can be explained only by theory that pertains to their nature and time–space scales as secondary historical units. No other discipline has or needs such theory; archaeology has yet to develop it for its own purposes. Here lies its greatest challenge: conceiving the method and theory to define and explain the character and behavior of secondary historical units.

Perreault argued that the time–space scale that defined secondary historical units compromise the application of explanatory theory based on primary units, that the archaeological record was underdetermined by such theory (2019:29–32). Then he posed questions that limn the macroarchaeological challenge, some pertinent to lithic studies and the reduction thesis (2019:169–173). Merely as examples relevant in this context, macroarchaeological questions include the following examples. Do tool types or the industries they form and the reduction sequences that produced them trend in complexity over archaeological time? If so, why? Are types' or industries' rates of change related to that complexity, to population size, even to curation rate if, like biological taxa whose evolutionary rates are proportional to individual lifespan, higher curation implies fewer instances of replication? What explains why and how tool types, industries or other constructs originate and, crucially, why and how they end? No current theory–from behavioral ecology to evolutionary archaeology to any prehistoric equivalent of *Annales* to archaeology of the long term–approximates the macroarchaeological approach that Perreault advocates.

Of course macroarchaeology far surpasses the scope of the reduction thesis, which nevertheless has relevant implications for its development. The thesis promotes typological hygiene and thereby the definition of valid types *qua* secondary units. It distinguishes resharpening allometry and the modularity on which allometry rests from typological variation. Degree and pattern of allometry measure curation rate; the latter then becomes, as above, a continuous attribute of types as secondary units. Through its effect upon assemblage formation and accumulation (e.g., the size-composition effects noted above), the thesis links the composition of assemblages or industries as secondary units to the composition of tool inventories at the level of primary units.

Even if most of Dibble's work did not attempt the shift in scale and focus that Perreault's macroarchaeology entails—no one has, to this point—he helped establish knowable, replicable—positivist—foundations for scientific inference from the material record. And Dibble et al.'s (2017) accumulations view takes a limited macroarchaeological perspective on the formation and transformation of assemblages. Until macroarchaeology prevails, we will continue to define the wrong units at the wrong scales whose nature and behavior we try to explain using the wrong theory. The reduction thesis has a role, admittedly modest, in this necessary transformation.

Reception of the Reduction Thesis

The reduction thesis rejects the view of Paleolithic tool types as Platonic essences. Being a powerful explanation for considerable variation in lithic industries and assemblages, as sketched above, it has earned broad if uneven acceptance, particularly in New World and Australian archaeology. Ironically, that reception is conspicuously uneven in European Paleolithic archaeology, where the thesis originated. If to some there the reduction thesis is "reasonably demonstrated" (Anghelinu et al., 2020:37), others dismiss or ignore it. Despite noteworthy exceptions, my outsider's impression is that many, possibly most, European Paleolithic scholars remain unpersuaded by, or indifferent to, the reduction thesis and its far-reaching implications for our understanding of the past.

No doubt the number of such scholars and the breadth of their practice surpass any simplistic opposition between views of Paleolithic tool types as Platonic essences or mere domains of nominal variation (Marwick, 2008:109), of French versus American paradigms (Clark, 2002), of Bordes's facies *qua* cultures versus Binford's toolkits. Nor can an outsider like me command the relevant literature or be attuned to possibly subtle changes in approach or ontology in Paleolithic studies. But even recent efforts to reconcile or synthesize approaches betray a strong predisposition toward essentialism (e.g., Hussain, 2019; Reynolds, 2020:193; cf. Anghelinu et al., 2020, whose attempt at synthesis deserves close study). Even if, then, Dibble's reduction thesis is a figurative prophet with highly uneven honor in its field of origin, it has transformed the analysis of stone tools in other contexts.

One Recent Example of Dibble's Influence

Many Dibble students and colleagues are recognizable by the nature and quality of their work, itself one of his greatest legacies; you know who you are, Holdaway, Iovita, Li, Lin, McPherron, Monnier, Olszewski, Rezek and others. But Dibble influenced many more.

As one example among many, my current collaborative project involves GM allometric analysis of a fairly large sample—over 5000—midcontinental North American points catalogued from private collections that form a time sequence that spans more than 10,000 years of prehistory (Nolan et al., 2022). The reduction thesis and its implications, sketched above, are integral to our analytical approach. We can chart time trends in curation rates, allometric trajectories and degrees of modularity and integration in our dataset (e.g., Shott et al., 2023), and relate these properties of secondary historical types to environmental, demographic, or sociopolitical trends at suitable time–space scales. Certainly in its current form, this project would be inconceivable without Dibble's work. In prehistoric archaeology, Dibble's influence extends well beyond the Old World Paleolithic. In theoretical terms, it extends well beyond the fracture mechanics of brittle solids.

Conclusion

This essay began with flakes and ended at some of the greatest ontological challenges confronting archaeology today. In the process, it discussed other archaeologists' practice as much as Dibble's. That is at once deliberate and meant as praise. Dibble's own interests lay in important details of fracture mechanics and in Middle Paleolithic archaeology, as well as field-recording and database management. Yet implications of his work were explored and elaborated in time–space contexts that far surpass the Middle Paleolithic. Today, we can devise reduction measures suitable to a range of tool types and practice typological hygiene by distinguishing continuous or categorical variation between types from continuous allometric reduction variation within them. We can gauge that allometric variation in the context of varying integration of modular segments of stone tools. We can derive curation distributions, measure their properties in detail and compare variation among types or periods. We can begin to probe the complexities of assemblage formation, the persistent correlation between assemblage size and composition. We can pose and begin to address deceptively profound questions like "How much is a tool?". We even can contemplate needed, macroarchaeological, revisions to the field's ontology. We can do these things and more in part because of Dibble's work with his students and colleagues. Not a bad legacy, that.

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