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Extraction of chert boudinage from the Lower-Middle Ordovician Ontelaunee Formation, Wallkill River Valley, Northwestern New Jersey-Southeastern New York

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Abstract

The authors examine the extent to which several episodes of tectonic deformation impact prehistoric chert quarry activity of the chert-bearing Ordovician Ontelaunee Formation. The paper discusses a variety of measureable outcrop and fabric characteristics that impact prospection, extraction and the resulting chain of operation. The results of our analysis indicate that quarrying of bedrock is not an expedient process, but involves considerable planning and orchestration within the seasonal round.

Keywords: bedrock quarries, Ontelaunee Formation, boudinage, tectonic deformation.

Résumé

Dans cet article, les auteurs examinent dans quelle mesure plusieurs épisodes de déformation tectonique affectent l'exploitation minière préhistorique de chert de la Formation ordovicienne d'Ontelaunee. L'article discute d'une grande variété de caractéristiques d'affleurement et de structures mesurables qui ont un impact sur la prospection, l'extraction et la chaîne opératoire qui en résulte. L'étude montre que l'extraction de la roche en place n'est pas une opération opportuniste, mais nécessite une très importante planification et orchestration dans le cadre du cycle saisonnier.

***Mots-clés**: carrières du socle, Formation d'Ontelaunee, boudinage, déformation tectonique.*

1. INTRODUCTION

The Wallkill Valley in Sussex County, New Jersey and Orange County, New York is the home of greater than 800 prehistoric bedrock quarries cropping out within the Cambrian-Ordovician carbonates of the Great Valley Sequence (LAPORTA, 1994, 1996, 2005, 2009; LAPORTA *et al.*, 2017). Previous work has elucidated that the quarries are located in geological terrains determined by the tectonic deformation of the area (LAPORTA, 1994, 1996, 2005, 2009; LAPORTA *et al.*, 2017). The first-order structural features include normal fault, thrust ramp, back thrust, and plunging fold terrains mapped by LAPORTA (2009). Each geological entity displays finer scale tectonic deformation that impacts quarry prospection and extraction, as well as processing of the ore types targeted by prehistoric peoples. Second-order structures include folds accomodation, faults and petrofabric (cleavage, boudinage).

The authors examine the extent to which finer scale deformation impacts the mining experience by focusing on the Ontelaunee Formation and discussing the variety of measurable outcrop and fabric characteristics that impact prospection and extraction. The quarrying of bedrock is not an expedient process, but one that involves considerable planning and orchestration within a complex seasonal round. The more stratigraphically and structurally diverse rocks give rise to more elaborate, and information worthy, discernable prehistoric workings. The more foliated exposures challenge the ingenuity of ancient quarry workers; therefore the imprint of technological achievement is best documented at these quarries. The more complexly developed chert bearing rocks record more technologically sophisticated extraction, and a more elaborate chain of operation. Employing analogies of hand-operated bedrock quarry operations (LAPORTA, 2005), the authors can tentatively flesh out the various tasks and procedures required to prospect and develop a quarry and how this enterprise works in concert with annual subsistence activities.

2. GEOLOGICAL SETTING

The Appalachian Mountains have suffered the amalgamation of at least two supercontinents, only to be torn asunder, creating three ocean basins (HATCHER *et al.*, 1989). The Grenville orogeny (T1) created the supercontinent Rodinia. In the study area, remnants of T1 are found in the Precambrian rocks comprising the Hudson and New Jersey Highlands. Continental rifting fractured Rodinia and created the Iapetos Ocean, which was followed by passive-margin development on the continent of Laurentia (proto-North America) as the ocean basin underwent seafloor spreading. The passive margin sequence is represented by the Cambrian-Ordovician chert-bearing carbonates housing the prehistoric quarries under examination; namely the Leithsville, Limeport, Upper Allentown, Stonehenge, Rickenbach, Epler and Ontelaunee formations (LAPORTA, 1994, 1996, 2009; LAPORTA *et al.*, 2017). Iapetos sea-floor spreading came to a close with attempted subduction of Laurentia beneath the Iapetos ocean floor (HATCHER *et al.*, 1989). Assembly of island arcs and microcontinents from the overriding Iapetos plate marked the Taconic Orogeny (T2). T2 deformation of the Cambrian-Ordovician carbonates in the Wallkill Valley is represented primarily by folds (F2) (LAPORTA, 2009; LAPORTA *et al.*, 2017). In the Wallkill Valley, the Crooked Swamp Synclinorium (F2) is the major Taconic feature (LAPORTA, 2009). F2 deforms and folds the entire Cambrian-Ordovician succession; with the up-plunge termination of the synclinorium exposed in the Rickenbach, Epler and Ontelaunee formations. Smaller scale folds ($F2_1$) within F2 are interpreted as accommodation structures associated with deformation and thrust faulting (LAPORTA, 2009; LAPORTA *et al.*, 2017). Prehistoric quarries discussed in this paper are located in this folded and faulted terrain; this plexus of structures determines the quarries' challenges. The synclinorium (F2), and folds within it ($F2_1$), shifts the trend of the raw material being quarried; rendering prospection of these ore targets exceedingly complicated (LAPORTA *et al.*, 2017). Three types of Taconic petrofabric, in the form of boudinage ($B2_1$, $B2_2$, $B2_3$), increase the number of discontinuities within the raw materials, directly impacting extraction, flaking, chain of operation (LAPORTA *et al.*, 2017).

The Acadian Orogeny (T3) was active for approximately 50 million years, during the Silurian and Early Devonian (HATCHER *et al.*, 1989). T3 involved a number of collisions between proto-North America and off-shore microcontinents, as well as the continent of proto-Africa. T3 resulted in the creation of the Acadian Mountains (HATCHER *et al.*, 1989). The identification of Acadian structures in the Wallkill is uncertain due to erosion of Silurian and Devonian rocks. However, the presence of Middle Devonian Schunemunk Conglomerate to the east of the Wallkill serves as undeniable evidence that the Acadian occurred in this region (LAPORTA, 2009).

The Alleghanian Orogeny (T4) spanned 65 Ma, during the Carboniferous (HATCHER *et al.*, 1989). Unlike T2 and T3, which primarily involved the collision of volcanic arcs and microcontinents, T4 involved continental-continental collision of Africa with North America. This collision formed the supercontinent Pangaea and caused widespread deformation along the eastern seaboard of North America (HATCHER *et al.*, 1989). Folding in the Wallkill Valley is not generally attributed to the Alleghanian. What folds do exist may be thrust-fault related folds in frontal imbricate zones (F4) (KING, 1964; BRYANT & REED, 1970; BUTLER, 1973; HATCHER, 1978). Late crenulation cleavage may be Alleghanian and of two forms; cleavage planes parallel to fold axial surfaces ($C4_1$), or cleavage-kink metamorphic foliation ($C4_2$) (BRYANT & REED, 1970; BUTLER, 1973). What is associated with T4 are southeast dipping thrust faults ($TF4_1$) that are responsible for offsetting of the Crooked

Swamp Synclinorium (F2) (LAPORTA, 2009). Taconic folding and fabric created challenges to extraction of raw materials. This complexity was increased significantly as a result of T4 thrusting and faulting. Additionally, back thrusts ($TF4_2$) in F2 provide yet a third consideration, especially when prospecting for raw materials.

2.1. Boudinage Development

Boudinage ($B2_1$, $B2_2$, $B2_3$) within the Ontelaunee Formation is the dominant petrofabric impacting prehistoric quarry extraction (LAPORTA, 2009). Boudinage consists of lenticular segments of a rock layer that have been pulled apart and flattened, in such a way, that the layer is segmented (DAVIS, 1984; HATCHER, 1995). The layer being segmented is stiffer than the enclosing material, and the degree of contrast in competence affects the shapes of the boudins: large contrast in the strength produces boudins with sharp edges; small contrast, boudins with rounded edges (DAVIS, 1984). If boudins exist in chert horizons, then the cherts are rheologically competent (stiff and rigid) materials, while the surrounding dolomite and limestone are incompetent and attenuated and flow between the rigid boudin blocks.

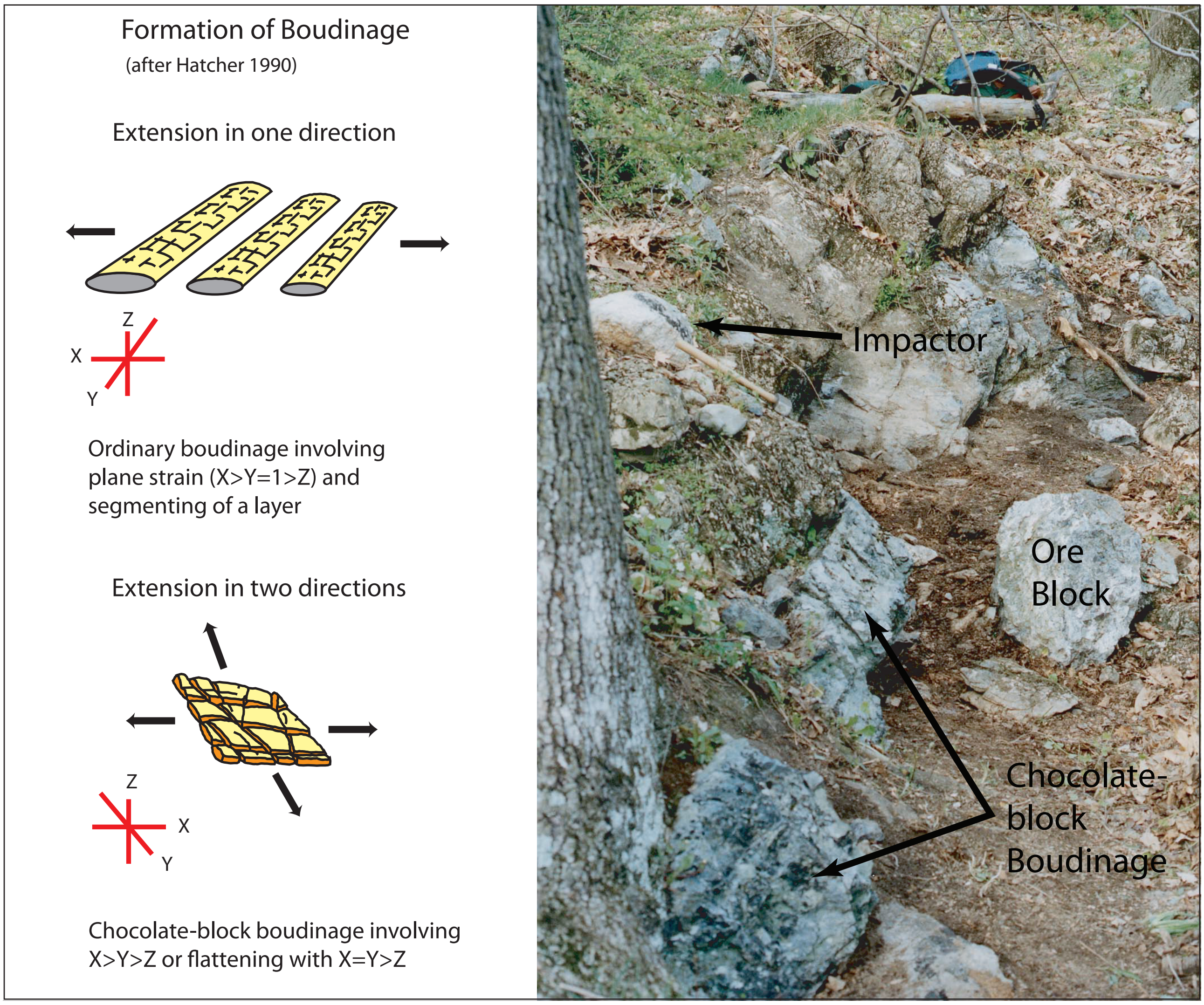

Fig. 1 – The left panel illustrates the effect of extension on one vs. two directions.
The right panel reveals chocolate tablature boudinage in the Beaver Run Member of the Ontelaunee Formation.
Note the quarried 'necks' between the boudins.

There are two general types of boudins (DAVIS, 1984; HATCHER, 1995; Fig. 1). Ordinary boudinage consists of segmented, sausage-shaped pieces of a single layer, in which the lenticular segments are parallel to one another and result from extension in a single direction. Chocolate-block/tablet boudinage has layer-parallel extension in two directions, resulting in boudinage that consists of a series of 3D blocks (Fig. 1).

Boudins may be completely separated from one another along 'boudin lines' or they may be connected by an attenuated neck in the layer (neck lines). Boudin neck lines are the focus of plug-and-feather methods during periods of quarry prospection and development, and are points of access during Zone 1 ore extraction (Fig. 2) (LAPORTA, 1996, 2005; LAPORTA *et al.*, 2017). Rock mechanics experiments have shown that the spacing of the fractures in the competent layer depends on the layer thickness and layer boundary properties (i.e., amount of friction between layers/amount of lubrication) (TWISS & MOORES, 1992). Few, if any, fractures appear if the boundary is well lubricated. Boudins may have a constant width and separation. This is critical for prehistoric mining, because if ore targets are boudinaged, the consistency in width and separation guides quarry development and ore extraction. Boudinage only occurs in strongly compressed areas of isoclinal folds (MARSHAK & MITRA, 1988) (such as $F2_1$ within the Ontelaunee Formation) (LAPORTA, 2009). If prehistoric miners recognized the correlation between isoclinally folded rocks and the presence of boudinage, which is possible as both are observable field characteristics, they may have developed an extraction strategy specifically for the boudinaged cherts of the Ontelaunee Formation (LAPORTA, 1996).

In the Wallkill Valley, boudinage is well developed within the Beaver Run (Fig. 1) and Harmonyvale members of the Ontelaunee Formation. Chert boudinage in the Ontelaunee are of importance because they are the primary ore target of prehistoric miners and serve as the focus of extraction in Zone 1 of the quarries. The Ontelaunee Formation contains second order isoclinal folds ($F2_1$) within the larger fold of the Crooked Swamp Synclinorium (F2), making it conducive

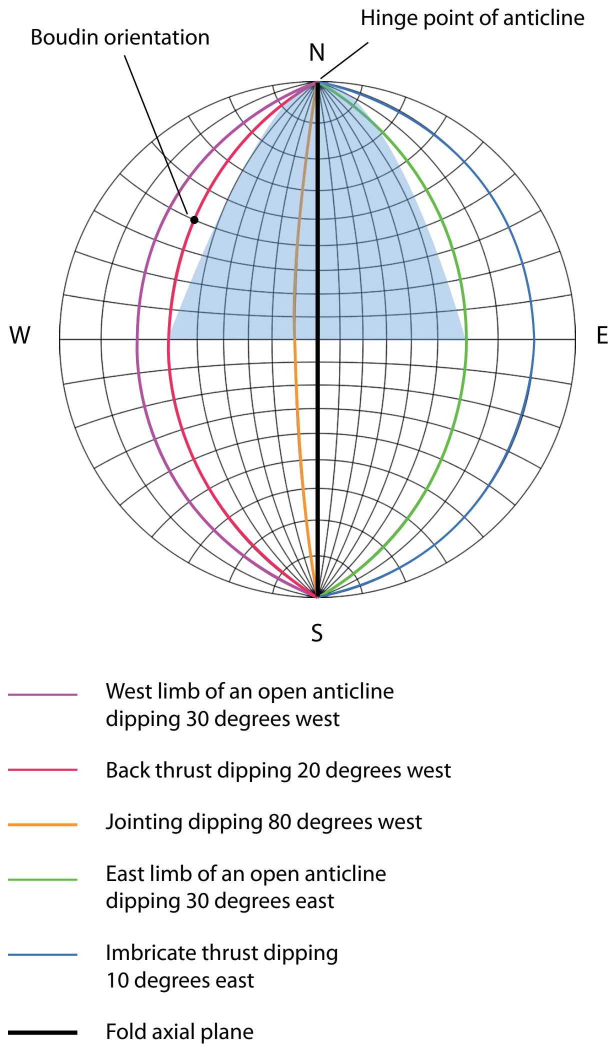

Fig. 2 – Stereographic projection is a tool geologists employ to plot three dimensional structures on two dimensional graphs. The intent is to show accurate angular and areal relationships between intersecting structures in space. On this stereographic projection, we have a generalized plotting of an open anticline with limbs dipping 60 degrees away from the fold axial surface. Also plotted on the stereonet are 3-D planes, represented as 2-D lines, intersecting the fold; such as boudins, back thrusts and imbricate thrusts. hese are representative structures that deform the Ontelaunee Formation of the Wallkill River Valley. While one of each type of structure is shown, it is important to realize that petrofabrics such as cleavage, joints, and boudinage are often penetrative throughout the entire rock. Such penetrative discontinuities in a raw material directly impact how it is mined and processed in the creation of a product.

to the development of a variety of boudinage structures ($B2_1$, $B2_2$, $B2_3$) and general strain fabric (LAPORTA, 2009). Ordinary boudinage is present in the Ontelaunee, but its rheological variation includes elliptical ($B2_1$) (fish eyed, articulate), block ($B2_2$), and elongate lenticular ($B2_3$) in shape.

The $B2_1$ boudins range from 20 to 30 ft in length, and as much as 11 ft in thickness. The boudinage pinch out into dolomites, and the thinnest part of the boudin neck contains reactivated anhydrite replaced by fibrous calcite (LAPORTA, 2009). Stratigraphically higher $B2_2$ bear sharp contacts on opposing sides of the limb, and joint-filling cements are both calcite and quartz (BRUECKNER *et al.*, 1987). The block boudins occur in as many as 40, 60, or 90 beds in succession, each intercalated with a thick dolomite. Individual block boudins are approximately six feet long by two feet thick (LAPORTA, 2009).

$B2_3$ occur within the transitional beds of the Harmonyvale Member. These elongate lenticular boudins are twenty times as wide as they are thick. They pass laterally into dolomitic limestones and limestones (LAPORTA, 2009). Therefore, the boudin dimensions prescribe the parameters of the chert bearing horizon as it crops out within Zone 1 of the quarry.

3. Environmental setting, prevailing conditions for quarry development: The continuance of process and inheritance of conditions (Schultz, 1985)

Geological mapping, archaeological excavation, mapping of prehistoric quarries in the Wallkill Valley has elucidated five zones of quarry development (Fig. 3) (LAPORTA, 1996, 2005; LAPORTA *et al.*, 2017). Zone 1 is the Zone of extraction, where the raw material is actively mined from the outcrop. Zone 2 is where ore milling occurs. Beneficiation of the dressed chert blocks occurs at Zone 3. Ore processing and washing are completed in Zone 4. Finally, refinement of the ore for its intended use occurs at Zone 5 workshops and factories (Fig. 3) (LAPORTA, 1996, 2005).

The parameters and primary tasks present within each Zone have been discussed in previous work (LAPORTA, 1996, 2005). The zones are discussed in this paper with the intent of emphasizing the role petrofabric plays in how extraction, milling, beneficiation, processing and refinement are carried out within a specific formation. Our intent is also to elucidate how labor intensive each process is within the chain of operation. While it has been shown that zones 1 through 5 can be elucidated through excavation at most bedrock quarries in Tectonic Cycle 1 of the Appalachians (LAPORTA *et al.*, 2017), we are introducing examples of intra- and inter-Zone variations in extraction processes resulting from petrofabric variations; or nuances occurring within the structural setting. However, the methods do exist which permit both the measurement, as well as the quantification, of such subtleties (Fig. 2) (MARSHAK & MITRA, 1988). The authors claim intra- and inter-Zone variations are common and predictable, primarily because tectonic deformation varies between geological formations and members within a region; and also within individual formation and member subdivisions. Strain response to tectonic stimuli varies as a result of lateral, and vertical, changes in rock rheology. Therefore within the same member, boudinage may be present in one specific location, but not in another. It is precisely due to this level of geological variability, that the authors have claimed that prehistoric bedrock quarries are initially a geological enterprise. Prehistoric miners possessed the cognitive ability (folk geology) to recognize geological factors that varied from location to location. Furthermore, prehistoric peoples addressed those variations by creating extraction methods and plans to fit the structural and stratigraphic nuances confronted in the rock record (BARKAI *et al.*, 2002, 2006; LAPORTA, 2005, 2009; LAPORTA *et al.*, 2017; SCHNEIDER & LAPORTA, 2008). Traditionally, archaeologists working on quarry-extraction technology do not possess the same level of intimacy with the rock outcrop, as did the indigenous peoples who quarried the rock. Therefore, what level of bias in modeling is precipitated from the repeated application of traditional archaeological field and laboratory methods, where extraction technology is concerned? The apparent cure for this bias is to embrace the quarry with geological reasoning, where necessary; as ultimately, cultural activity results in the modification of a naturally occurring mineral resource (LAPORTA, 2009).

As complex ore types require a sophisticated prehistoric understanding of the finer scale geology of a region, the need of input from the elders of the group is critical. Past quarry

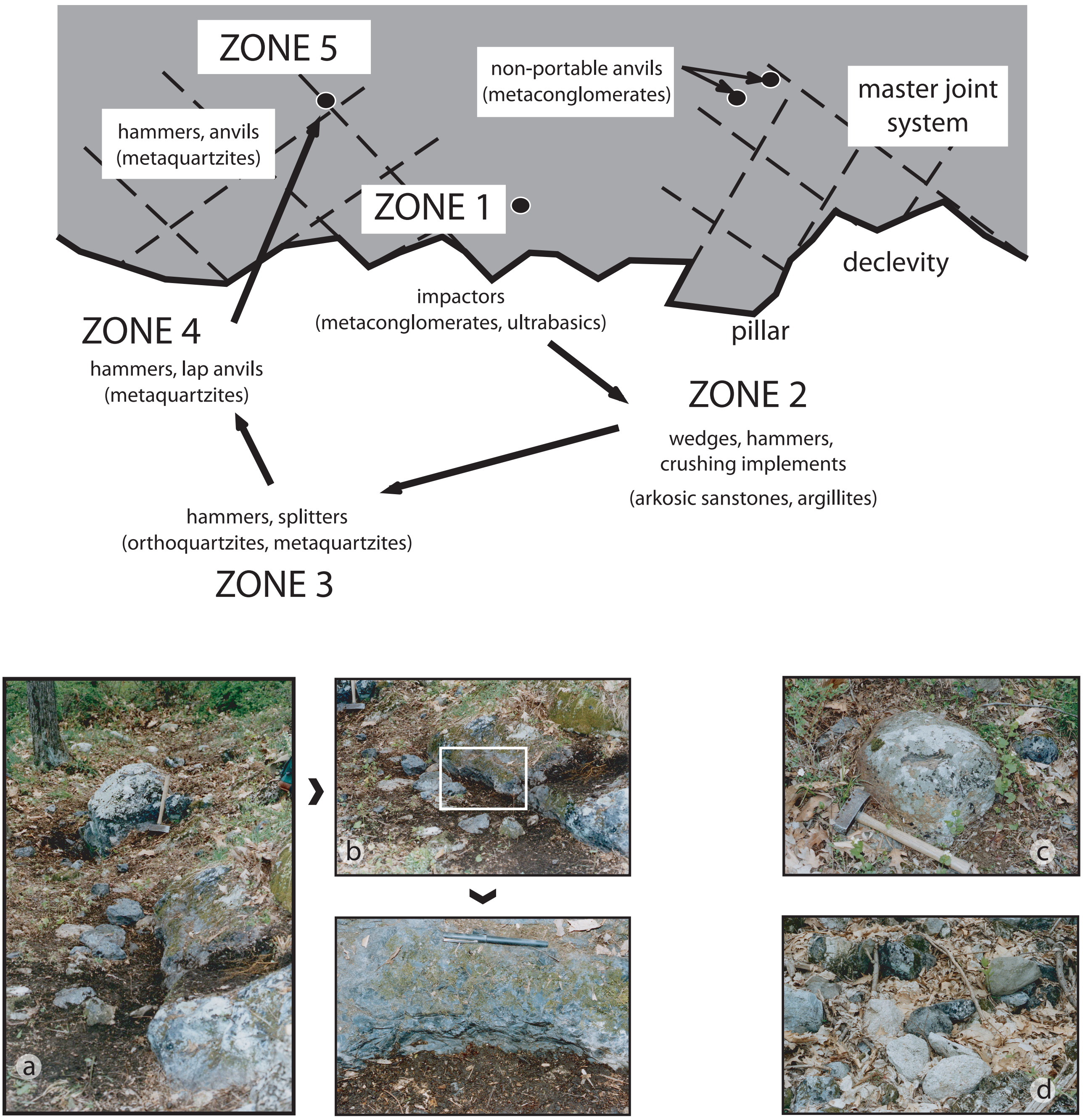

Fig. 3 – Typical First Tectonic Cycle Quarry Plan (LAPORTA, 2005) of the Beaver Run Member, Ontelaunee Formation, at the Beaver Run Standard Section, Sussex County, New Jersey, USA. Images depict: (a) the quarry face, showing excavated neck of block boudinage, along with; (b) castellated surfaces (along with a close-up of cuspate surface overprinted on the castellations) on the block boudins of Zone I, showing limits of quartzite technology; (c) exhumed impactor in front of Zone I; and (d) exhumed instruments and products (ore blocks, middling blocks, and middling cores) of Zones I/II.

experiences, handed down over generations, represents the lexicon of knowledge for the future. The archaeological record suggests that peoples also possessed an empirical understanding of the strength of materials, and were able to select for a specific purpose, the chert types necessary to fulfill a desired need (LAPORTA, 2005; SCHNEIDER & LAPORTA, 2008; LAPORTA *et al.*, 2010, 2017). For example, the Beaver Run Member of the Ontelaunee exhibits specific chert types that are selected for their brittle characteristics, and are useful for the production of single-usage projectile points. Conversely, the Harmonyvale Member of the Ontelaunee Formation possesses a clay-rich chert suitable for manufacture of large bifaces which function as re-utilizable cutting tools. Such empirical knowledge of the strength of raw materials, or an understanding of the rigidity and elastic properties of a rock, require an intimacy with the landscape and is complemented by an accumulated history of experiences, which we have employed as a salient example of the 'folk geology' concept (LAPORTA, 1996, 2009).

Due to the absence of ethnographic data describing the extraction and use of raw material resources along the Atlantic seaboard, data from Australian, Indian, and Canadian aboriginal surveys was carefully employed as a cross cultural comparison (JONES & NEVILLE, 1988; LAPORTA, 2005; unpublished ethnographic notes) to provide flesh to a skeletal record reliant on rock and mineral usage.

The preparation time required for the establishment of the first extraction might be initiated by prospection and evaluation of ore targets, the construction of quarry-support sites, land clearing procedures, complemented with wall or enclosure construction. The collection of raw materials, suitable for the production of a wide variety of extraction implements, is an organized procedure. Time and energy invested in prospection and evaluation of the ore deposit converts the pristine landscape into a multifunction subsistence related site designed for prolonged stays away from stationary base camps. The focused quarry time associated with repeated episodes of extraction render the natural landform into a culturally modified landscape, or standing architecture, in part vitrified (LAPORTA, 1996, 2009; also seen in ethnographic works by HAMPTON, 1999; PATON, 1994). Over time, the quarries are exhausted and transition takes place from an active political reference point on the cultural landscape to a mosaic of memories stored collectively within the minds of those who participated in the extraction of chert and associated activities.

The religious significance of quarries is well-represented in ethnographic literature (GARVAN, 1941; JONES & NEVILLE, 1988; PATON, 1994; HAMPTON, 1999; LAPORTA, 2005). Quarries and stone are said to be guarded by spirits (GARVAN, 1941; BURTON, 1984; PÉTREQUIN & PÉTREQUIN, 1993; HAMPTON, 1999) or are related to specific, or interconnected, myths (PATON, 1994). Even the walk to the quarries, and quarry or non-quarry activities, would have symbolic meaning (SPENCER & GILLEN, 1899, 1904; JONES & NEVILLE, 1988). The detailed mapping and excavation of quarries and analysis of recovered quarry groundstone inventory, suggest that quarry remoteness, and long and enduring activities, may warrant the opportunity for the expression of ritual life and prayer. The most remote quarries, located furthest from navigable waterways, and requiring the greatest energy investment, would also serve as secluded, even mystical, places conducive to activities related to ritual life. The evidence for the presence of possible offerings associated with a giving back process has been documented in excavated contexts, as well as through the detailed analysis of recovered objects (BREWER & LAPORTA, 2005; LAPORTA, 2005; LAPORTA *et al.*, 2010). One must follow the details of the evolution of utilitarian quarry tools, from Zone 1 through Zone 5 (LAPORTA, 1996), in order to elucidate the objects that may serve dual purposes; those with a socio-technical or possibly an ideological function. An understanding of petrology, and petrofabric analysis, is required to tease out the ideological from the vast sea of utilitarian objects (LAPORTA, 2009).

Employing the mining literature (OSBORN, 1907; VON BERNEWITZ, 1931; PEELE, 1941) as a baseline, the following is an inventory of necessary activities associated with the establishment of a quarry, as well as an estimate of the length of time required to complete each task.

Task 1. Prospection (Province), two years;
Task 2. Parameterization (District Subdivisions), one year;
Task 3. Evaluation (Sub-District or Trend), six months;
Task 4. Assay (Quarry), one-two weeks;
Task 5. Land clearing (Quarry), three weeks;
Task 6. Quarry support-site construction (Quarry), one-two weeks;
Task 7. Firewood gathering (Quarry), one week;
Task 8. Gathering of glacially derived rocks for the preparation of quarry tools (Trend or Quarry), one week;
Task 9. Wall construction (Quarry Zone 1), one-two weeks;
Task 10. Scaffolding (Quarry Zone), one week;
Task 11. Fire-setting (Quarry Zone 1), one week;
Task 12. Preparation of Quarry Zone 1 (Zone of extraction), plug-and-feather of chert-bearing strata, one-two weeks.

Quarry preparation tasks do not have to be re-initiated each time extraction takes place. The more repeated extractions do not necessitate the revisiting of Tasks 1 to 4. The re-application of Tasks 5 to 11 may only require maintenance and refurbishing of the site and renewal of resources. Conversely, certain tasks require near complete renewal of resources; such as the replenishing of firewood (Task 7), or the gathering of glacial erratics (Task 8) for the manufacture of new quarry tools. Nelson (1987) observed that stone hammers and wooden handles were cached at metate quarries in the highlands of west-central Guatemala. Only metal picks and hammer heads were transported, since they were sometimes rented or were usually owned. The stone-hammer cache served to accommodate the worker with several instruments, so as not to reinvest a large amount of time gathering during each visit (NELSON, 1987). LaPorta (2005) and LaPorta *et al.* (2010) notes that hammers are sacred objects employed only by task masters and delegated workers at living limestone quarries in southern India. Beehive shaped mounds of glacially derived boulders/erratics are seen dotting Ontelaunee quarries where they occur along drainage divides in the Wallkill Valley. They have been interpreted as caches of raw materials whose petrological characteristics render them worthy of manufacture into quarry tools and instruments.

What follows is a more in-depth presentation of the model of Tectonic Cycle 1 Wallkill chert-quarry activities, previously presented by LaPorta (1996, 2005) and LaPorta *et al.* (2017), that illustrate the behavioral zones of extraction and processing of the chert ore after the twelve preparation steps have been completed.

4. ZONE 1: ZONE OF EXTRACTION

Establishment of the first Zone of extraction depends upon the degree to which geomorphological processes have exposed chert bearing units. The precise location of the first extraction may have resulted in part from the conclusions established by elders situated at a distant base camp, based upon the results of Task 4. Re-locating the potential quarry site is accomplished by following the stratigraphically lowest chert marker horizon for several kilometers along stratigraphic strike, until the prospect site (expression) of the potential quarry presents itself on the glaciated landscape. At that time, Tasks 4 to 11 are initiated, and the quarry site area is prepared. Task 12 would have been completed during the late autumn/early winter, prior to early spring visitation of the quarry. Archaeological evidence for the essential application of plug-and-feather methods is visible in the field as outcrops whose exposed joint sets are lined with circular indentations, or perforations, encircled with sub-conchoidal flake scars (LAPORTA, unpublished field notes 1978, 1990-1992; LAPORTA, 2005). On many occasions, recycled instruments and country rock are visible protruding from expanded joint sets.

The results of the assay (Task 4) will determine where, stratigraphically, the first Zone of extraction will occur. Of course, the determination is based in part on human needs, both in terms of volume, as well as for specific functions. Therefore the assay will provide insight into the grade of ore, or its overall tenor, and what products could potentially result from the successful extraction (LAPORTA, 1996). During this time, the rigidity and elastic properties of the chert are considered, as well as the desire for aesthetically appealing materials. Therefore the choices are a feedback response echoed from the base camp to the quarry and back again, until a determination has been made.

Plugs are oriented along accentuated and partially sealed joint surfaces, between bedding planes, as well as within the hinges of folds (i.e. $F2_1$) and close-spaced fracture cleavage (i.e. $C4_1$ and $C4_2$). Plugs may be tips of deer antler, or wetted wood fragments of saplings. Recent findings include broken hammerstone fragments and chert blocks wedged within naturally occurring crevices within the rock. Therefore plug-and-feather techniques, along with the application of heat and a reliance on the mechanics of freeze-thaw, are essential. The process invokes a seasonality to quarry activity and is supported by ethno-archaeological data gathered from disparate sources (LAPORTA, unpublished field notes 1978, 1990-1992; LAPORTA, 2005). The pinned area may be checked seasonally, or left isolated and undisturbed for generations. Entire reserves of chert resources may have been subjected to this behavior in advance of the future need for fresh, hydrated chert. The timing of the movement of hunter-gatherers, and their base camps, may be linked centripetally to the discovery, designation, and preparation of chert deposits as is depicted in Tasks 1 through 4. We theorize that the duration of stay, or existence of the stationary base camp, is in part pre-determined by the longevity of known chert reserves. The extreme organizational energy necessary to achieve the establishment of the province, district, and trend subdivisions (BREWER *et al.*, 2000) is echoed in the systematic organization of the quarry itself.

When the location of the prepared plug-and-feathered area is re-discovered along the trend of the outcrop (Task 12), construction of scaffolding may be necessary to reach outcrop along a vertical cliff face (Task 10). Firewood (Task 7) may be concentrated along the base of the outcrop in an effort to craze, or sear, the surface of the chert bed (Task 11). If a water source is present, and is applied, the outcrop may further rupture along the trace of accentuated joints, or in areas of prior plug-and-feather application.

Once the appropriate accentuated joint surface is rediscovered, the task of gathering the appropriate hammerstone and quarry-tool materials is initiated. Precise petrological groupings, and associated weights and dimensions, are gathered from beehive shaped-mounds (Task 8) of glacial erratics concentrated near the quarry area (LAPORTA, 1996). This activity would occur during the period of wall/enclosure construction (Tasks 8-9). The impact wedge and/or the circular impactor is placed over the join between the two contiguous boudinage ($B2_1$, $B2_2$, or $B2_3$). Here the sediments are thinned structurally and the trace of the necked area forms a line between the two adjacent boudinage structures, occurring on either side of the boudin selected for extraction (Fig. 4). The impact wedge/circular impactor is raised and lowered with its upper rounded surfaces in contact with the join of the two boudinage, following the line generated by the necking process. This procedure is repeated on both sides of the boudin until the join is crushed. If the join occurring between two boudins is 'v' shaped, then a focal chisel is added to the equation. The focal chisel serves to concentrate energy of the impact wedge to the precise location of the weakest part of the join between two boudins. Eventually, crushing along the lines of weakness will intersect the precise location of one of the successful plug-and-feathers. At this juncture, the join may yield to the compressive stress of the impact wedge. The impactor is subsequently turned 180 degrees and the tapered wedge end is oriented over the crushed join and repeatedly impacted. The results serve to separate a boudinage from two contiguous boudinage occurring on either side of the center boudin. The cleaning and further definition of the boudin is accomplished with the application of the spatula shaped wedge which is driven into the open spaces between the boudins. The rounded scaling bar is then employed in order to clean any jagged edges remaining on the boudin surface. The first phase of extraction is now completed and a total of four of the six extraction Zone instrument types have been applied to the rock outcrop. The naked boudin is now ready for detachment from the dolomite outcrop, and struts or chocks are placed under the boudin to orient the loosened ore block on a stable bedrock platform. The chocks or struts are the ruptured remains of an older generation of impact hammers and wedges, recycled in order to buttress the chert bed (LAPORTA, 1996, 2005). The rough edges of the ore block are removed through the application of the scaling bar, and work in Zone 1 is complete.

5. ZONE 2: ZONE OF ORE MILLING

Zone 2 activities take place both below, and to the right, of the Zone of extraction (Fig. 3). The work in Zone 2 involves the application of five instruments; the rectangular milling instrument, circular impactor, focal chisel, cobbing or ore dressing hammer, and struts (LAPORTA, 1996, 2005). The process which ensues is a cobbing procedure, and the primary tool required is a rectangular hammerstone referred to here as a milling instrument (LAPORTA, 1996, 2005). The instrument contains a higher percentage of clay than tools employed in the Zone of extraction.

Fig. 4 – Prehistorically worked chert beds in Sussex County, New Jersey, USA. The chert outcrop includes: (a-d) Harmonyvale Member of the Ontelaunee Formation showing multiple generations of petrofabric criss-crossing the raw material, from outcrop scale down to individual chert bed; and (e) frozen behavior showing a hammer prying open dolomite beds to access chert (plug-and-feather method).

The variation in clay content, and overall geometry, is a purposeful cognitive choice for the following reasons. The elevated clay content permits the object to adhere to the surface of the ore block for longer than more elastic rocks would. This fact, combined with the rectangular form, allows the force of the hammer to contact a greater portion of the ore block. The result is a flat, dull impact with an associated deadening, but enduring, force. The impact produces broad flat flakes, or splinters, of dolomite and low-grade chert, without initiating micro-cracks into the chert block. The cobbing process is designed to remove all the remaining dolomite and lower grade chert from the boudin without fracturing the homogenous area where future artifacts will be designed. The milling instruments, and smaller classes of cobbing hammers, are almost exclusively designed from clay-rich, arkosic rocks and argillaceous sandstones and siltstones. The ore block, now partially dressed, can be maneuvered along the stable platform where large circular impactors, and a larger class of focal hammers, can be employed to detach large fragments of the ore block (LAPORTA, 1996, 2005). The large chert fragments are middling blocks and possess flat flake scars or joint surfaces along their long axis. The proximal and distal faces may be faceted by flake scars resulting from the initial dressing of the ore block. If the middling block is largely bound by joint surfaces present from the initial extraction, it remains a middling ore block. However, if the middling ore block possesses a greater surface area of flaked surfaces, than it does original flat joint planes of the ore block, it is referred to as a middling core block (LAPORTA, 1996, 2005).

6. ZONE 3: ZONE OF BENEFICIATION

Ore blocks, and middling ore and core blocks, are positioned along the stable platform, now directly below the former work site at Zone 1. The Zone of beneficiation is the transitional phase of the chain of operation, as this Zone represents the comminution of ore blocks, middling blocks, and middling core blocks (Fig. 3), (LAPORTA, 1996, 2005). Work is focused on the orientation perpendicular ($C4_1$ and $C4_2$) to what are the remnants of the long axis of the former boudin block. Finely spaced joint surfaces, and associated intersecting generations of fanning fracture cleavage ($C4_1$ and $C4_2$), are the parameters for the production of more refined chert ore units, which define the product emanating from this Zone of activity.

The work accomplished within Zone 3 is accompanied by large non-portable and portable anvils, smaller classes of impactors, focal chisels, ore dressing hammers, milling instruments, refinement and re-tooling hammers (LAPORTA, 1996, 2005). The range of petrological groupings necessary to complete beneficiation is possibly the greatest in Zone 3. It includes metaconglomerate, ortho- and metaquartzite, arkosic sandstone, metaargillite, sandstone, gneiss, granite, and ultramafic rocks (LAPORTA, 1996, 2005).

The presence of Zone 1 and Zone 2 type instruments in Zone 3 indexes the continuance of cultural process; the steady and systematic comminution of rock along progressively more finely defined planes of weakness. What is inferred here is that the circumscribed work zones, or specific task areas, are part of an integrated continuum of activities which project from the mind of the quarry worker and permeate the quarry site, much as a flow chart of productivity. The five zones of quarry activity are a continuum of thought processes. At every Zone of activity there is an overlap in process (Schultz, 1985), and a need for recycled objects which index the previous work area. Also, the principle of inheritance applies, which states that the earlier events, and resulting effects, set the stage for the later ones (SCHULTZ, 1985). Both principles are at work and are illustrated by the apparent overlap in function and refinement of the prescribed quarry tool and instrument types.

Classes of smaller impact objects are recycled for use where the joint surfaces are tightly sealed. However, the object which best characterizes this Zone is the circular hammer, which is fashioned from ortho- and metaquartzite. The instruments are roughly circular and approximately one third as thick as wide. Many possess flat upper surfaces and assume a wheel shape after prolonged use and recycling. What is salient is the introduction of populations of more elastic quartzite hammers. The size and form of quarry instruments is now smaller and more streamlined.

The chert is subsequently crushed along the lines of close-spaced joint surfaces until the chert block eventually breaks along one of the planes of weakness (Fig. 3). The numerous generations of tectonism in the region present a challenge to the quarry technician; intersecting joints and fracture cleavages influence the Zone 3 product. Additionally, some generations of fabric are resealed with differing cements. Silica cement presents a challenge due to its hardness; while carbonate cement is significantly softer than silica. Additionally, the possibility exists that some generations of fabric are not recemented. The type and degree of cementation of joints and cleavages often occurs in clustered populations reflecting the results of the structural event. Therefore they are definable in their field relations and can be subsequently exploited, or avoided, depending upon human need. The type and degree to which the recementation process is present can be discerned by how the chert block transmits stress. The degree of homogeneity of the chert block can be subjectively appraised by gently tapping the joint-bounded, rhombic block with a small elastic hammerstone; thereby determining its tenor. Eventually, the large middling block yields along the surfaces of a more finely spaced joint planes and a smaller joint bounded block emerges.

Smaller blocks are collected alongside an anvil and each is dressed with a small refinement hammer. Anvils are the by-product of Zone 1/2 activities and represent ruptured fragments of impactors and impact wedges. The application of the smaller class of ortho- and metaquartzite hammers removes all surface irregularities from the now more tapered rectangular piece of ore. The results of this process include the production of elongate, rhombic fragments of dressed ore, bound on two sides by joint faces and crushed free of surface irregularities.

7. ZONE 4: ZONE OF ORE PROCESSING AND WASHING TABLE

Zone 4 activities are indexed by the introduction of another new class of instruments, the anvils. The presence of stationary, portable, lap, and shoe anvils give testimony to the degree of closeness necessary in order to further refine the complex ore (Fig 3).

The fine array of anvils is associated with an even smaller class of metaquartzite focal chisels and sandstone/siltstone abraders. The hammers of choice are highly elastic ortho- and metaquartzite instruments which have evolved into a circular form. Many of these objects possess finely flaked and ground edges, and are approximately 1:4 in terms of width-to-length ratios.

The joint-bounded, dressed ore is finely crushed along the surfaces of the partially, and completely sealed, finely spaced joints and fracture cleavage (C_1, $C4_2$). The results of this process include five different types of refined ore; the five or greater microlithon bounded unit, the four microlithon unit, the three and two microlithon unit (LAPORTA, 1996, 2005). Refined ore pieces have low weights (ounces to grams) and are bounded by two flat planes ($C4_1$, $C4_2$), which are referred to as domains. The volume of chert occurring between two domains is the microlithon (LAPORTA, 1996, 2005). The ore processing area also serves to sort the domain-bounded microlithons by degree to which diagenesis has taken place and to what degree silica replacement of the host rock is complete (LAPORTA, 2009).

The Ontelaunee Formation preserves a vast quantity of punky and porous stromatactis bearing chert. The outer portions of individual boudins are clay rich. The intermediate parts of the boudin less so, and the centers of many boudins are relatively clay free. This concentric 'layering'of the boudins permits prehistoric workers to grade ore types, establishing the tenor of the ore. Taken a step further, the clay-rich, outer portions of the boudin are more elastic and occur in greater volumes. Conversely, the clay-deficient areas are more brittle ores and occur in much smaller volumes. The intermediate chert Zone contains both an appreciable volume of clay-rich chert, as well as elevated silica. In general, the three zones are characterized as high, intermediate and low grade ore (LAPORTA, 2005), and these important qualifications of the ore determine the desired tool type, and potential function.

The overall tenor of ore is calculated during Task 4 (assay), prior to the development of the Zone of extraction. Such fine-scale work may require the application of water, in order to highlight the various grades of ore, to better define the domains of joints and cleavage ($C4_1$, $C4_2$), and to highlight the effects of diagenesis. It is inferred that Zone 4, and possibly Zone 5, activities may require the application of water, or the presence of a 'washing table', for detailed analysis of the ore (LAPORTA, 1996, 2005).

8. Zone 5: Zone of raw material refinement

Zone 5 includes the greatest bi-modality occurring within the quarry-tool assemblage. At this locale, situated strategically above Zone 1, the focused ore processing occurs centripetally around non-portable anvils weighing over 100 kg each (Fig. 3), (LAPORTA,1996, 2005). At such locations, the results of ore processing of Zone 4 are cached and made ready for the final phase of refinement. The hand-held hammers are the most elastic of the metaconglomerate and metaquartzite instruments, surviving the prior four phases of lithic refinement. Some anvils are associated with struts and occasionally, the full complement of smaller anvils is revealed through excavation as being stacked in the near vicinity of non-portable anvils. This would include large lap anvils, smaller portable anvils and shoe anvils. Entire caches of smaller hammerstones are present, some perfectly circular and spherical. Abraders of sandstone and siltstone, as well as bi-pitted stones designed for fire-making activities, have been discovered.

The non-portable anvils are surrounded by an apron of fine flaking debris and it is here that the first taxonomic flake scars are discernible upon close inspection. Zone 5, domain-bounded chert microlithons are sorted and thinned within the parameters defined by the opposing parallel sets of domains ($C4_1$, $C4_2$). The interplay between intersecting domains and diagenesis is revisited at Zone 5 and the ore units are separated one final time; this time thinning along edges, and basal and lateral edge grinding, is accomplished. The results of the refinement include both large and small classes of block cores, bifacial cores, thick hand-held bifaces, thin bifaces for notching, and flakes for utilization.

In general, four to five, or greater, microlithon ore units evolve into block cores; while those microlithon packages comprised of three to four units are generally serviceable as hand-held bifacial cores and bifaces (LAPORTA, 2005). The outcome will partially depend upon the thickness of the microlithon and its overall dimensions. Thinned bifaces comprised of two or less microlithons may progress on to become notched and hafted depending upon the degree of welding of the domain surfaces period.

Detailed analysis of petrofabric is critical, as the different generations of fabric ($B2_1$, $B2_2$, $B2_3$, $C4_1$, $C4_2$) resulting from multiple episodes of tectonism (T1, T2, T3, and T4) can align themselves parallel or sub-parallel to each other, or intersect at measurable angles. This being the case, further refinement must include a detailed analysis of the fabric on the finest sale. The interplay between fabric, and diagenesis, represents the equation for final refinement and designation for function of the chert as an ore. Detailed analysis is necessary because further refinement of the chert, without careful assessment of intersecting domains of many generations of petrofabric, may result in failure or rupture of the artifact at the workshop, or during use or re-sharpening.

9. Conclusion

Greater than 800 prehistoric bedrock quarries have been discovered in the Wallkill River Valley. The prehistoric chert resources of the Wallkill Valley provide the optimal challenge to the quarry technician, as well as the stone-tool manufacturer. No less than five episodes of tectonic deformation have deformed the chert, which imposes the most challenging task offered to the stone tool worker. Geological field mapping, and laboratory analyses, indicates that the prospection for chert quarries, as well as the preparation of the quarry faces and extraction, is highly dependent upon stratigraphic and structural variables at several scales. The comminution of chert towards the production of refined, utilizable, objects is controlled by fabric at the meso- and micro-scale. Close examination of archived collections, and objects provenancing from Ordovician chert quarries, reveal that the objects are manufactured along lines of petrofabric, with few exceptions. This being the case, the argument for long and enduring stays at prehistoric chert quarries is proposed, coupled with shorter-term revisitations to the quarry outcrop.

The prospection of provinces, districts, and trends requires years of reconnaissance; while the preparation of the quarry itself requires months, and the extraction and refinement processes require weeks of activity. Archaeological evidence suggests that the quarries may be prepared for extraction in the late autumn, with quarry activity ensuing in early spring. Short visitations to quarries may take place again in the early autumn of the following year, for the purpose of recycling objects from previous zones of extraction.

All evidence suggests that there is no expedient process involved in quarry activity in the Wallkill River Valley and conversely, as many as three rigidly timed visits to quarries may take place each year, all orchestrated within the seasonal round of hunter gatherer bands foraging outward from stationary base camps. The elucidation of the elaborate chain of operation, and the associated complex array of quarry instruments, is testimony to the long and enduring stays at the quarries.

The 800 quarries represent only a percentage of the actual number of quarries that exists in the valley. Yet, recovered from the estuaries to the east and south are disproportionate numbers of objects fashioned from Ordovician chert. The close spatial proximity to the estuaries (approximately 30 to 50 miles) of the lower Hudson River, and the presence of abundant aquatic resources occurring within the vicinity of the quarries, may have fueled much of the need for such a tectonized ore type. Certainly, it is important to note that the Wallkill River Valley is also a natural corridor for the migration of peoples and migratory herd animals, and serves to connect the Delaware River Valley with the Hudson River Drainage. The Wallkill River Valley may also have served as portion of the flyway for migratory avian populations.

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Bibliography

BARKAI R., GOPHER A. & LAPORTA P., 2002. *Paleozoic landscape of extraction: Flint Surface Quarries and Workshops at Mt. Pua, Israel,* Antiquity, **76**, p. 672-680.

BARKAI R., GOPHER A., & LAPORTA P., 2006. *Middle Pleistocene Landscape of Extraction: Quarry and Workshop Complexes in Northern Israel. In*: GORING-INGBAR N. & SHARON G. (eds), *Axe Age-Acheulian Toolmaking- From Quarry to Discard,* Equinox Publishers, p. 7-44.

BREWER M., MINCHAK S.A. & LAPORTA P., 2000. *A mineral resource approach to raw material analysis and quarry investigations: Examples from the Central Appalachians* [abs], Society for American Archaeology, Annual Meeting Abstracts, **65**, p. 64.

BREWER M. & LAPORTA P., 2005. *Direct Procurement Quartz Quarries of the Lower Hudson River Estuary* [abs], Society for American Archaeology, Annual Meeting Abstracts, **70**, p. 56.

BRUECKNER H., SNYDER W.S. & BOUDREAU M., 1987. Diagenetic Controls on the Structural and Tectonic Evolution of Siliceous Sediments, Golconda Allochthon, Nevada*, Journal of Structural Geology,* **9**, p. 403-417.

BRYANT B. & REED J., 1970. Structural and Metamorphic History of the Southern Blue Ridge. *In*: FISHER G. *et al.* (eds), *Studies of Appalachian Geology: Central and Southern*, New York, Wiley-Interscience, p. 213-225.

BURTON J., 1984. Quarrying in a Tribal Society, *World Archaeology*, **16**, p. 234-247.

BUTLER J., 1973. Paleozoic Deformation and Metamorphism in Part of the Blue Ridge Thrust Sheet, North Carolina, *American Journal of Science*, **273-A**, p. 72-88.

DAVIS G., 1984. *Structural Geology of Rocks and Regions*, New York, John Wiley & Sons, 492 p.

GARVAN J., 1941. *The Manóbos of Mindanáo*, Washington D.C., Government Printing Office (Memoirs of the National Academy of Sciences, **23**, First Memoir).

HAMPTON O., 1999. *Culture of Stone: Sacred and Profane Uses of Stone Among the Dani,* Texas, A & M University Press, College Station.

HATCHER R., 1978. Tectonics of the Western Piedmont and Blue Ridge: Review and Speculation, *American Journal of Science*, **278**, p. 276-304.

HATCHER R., 1995. *Structural Geology: Principles, Concepts and Problems,* Macmillan Publishing Company, U.K.

HATCHER R., THOMAS W.A. & VIELE G. W., 1989. *The Appalachian-Ouachita Orogen in the United States*, Decade of North American Geology Series, F2, Geological Society of America, Boulder, Colorado.

JONES R. & NEVILLE W., 1988. Point Blank: Stone Tool Manufacture at the Ngilipitji Quarry, Arnhem Land, 1981. *In*: MEEHAN B. & JONES R. (eds), *Archaeology with Ethnography: An Australian Perspective* (Occasional Papers in Prehistory, **15**), Canberra, Department of Prehistory, Research School of Pacific Studies, Australian National University, Canberra, Australia), p. 51-87.

KING P., 1964. *Geology of the Central Great Smoky Mountains, Tennessee*, U.S. Geological Survey Professional Paper **349-C**, 148 p.

LAPORTA P., 1994. *Lithostratigraphic models and the geographic distribution of prehistoric chert quarries within the Cambro-Ordovician lithologies of the Great Valley Sequence, Sussex County, New Jersey*. *In*: BERGMAN C. & DOERSHUK J. (eds), Recent Research into the Prehistory of the Delaware Valley, *Journal of Middle Atlantic Archaeology*, **10**, p. 47-66.

LAPORTA P., 1996. *Lithostratigraphy as a Predictive Tool for Prehistoric Quarry Investigations: Examples from the Dutchess Quarry Site, Orange County, New York*. *In*: LINDER C. (ed.), *A Golden Chronograph for Robert E. Funk*, Bethlehem, Connecticut, Archaeological Services (Occasional Papers in Northeastern Anthropology, **15**), p. 73-84.

LAPORTA P., 2005. A Geological Model for the Development of Bedrock Quarries, with an Ethnoarchaeological Application. *In*: TOPPING P. & LYNOTT M. (eds), *The Cultural Landscape of Prehistoric Mines*, Oxford, Oxbow Books, p. 123-139.

LAPORTA P., 2009. *The Stratigraphy and Structure of the Cambrian and Ordovician Carbonates of the Wallkill River Valley: The Nature of the Diagenesis of Chert and Its Archaeological Potential,* unpublished Ph.D. thesis, New York, City University of New York.

LAPORTA P., MINCHAK S.A. & BREWER-LAPORTA M., 2010. The Life and History of Quarry Extraction Tools Excavated from the Skene Motion and Workshop, Hartford Basin, Champlain Valley, New York, USA. *In*: BREWER-LAPORTA M., BURKE A. & FIELD D. (eds), *Ancient Quarries and Mines: A Transatlantic Perspective*, Oxford, Oxbow Press, p. 109-119.

LAPORTA P., MINCHAK S.A. & BREWER-LAPORTA M.C., 2017. The Prehistoric Bedrock Quarries Occurring within the Chert Bearing Carbonates of the Cambrian-Ordovician Kittatinny Supergroup, Wallkill River Valley, Northwest New Jersey-Southeastern New York. *In*: WERRA D. and WOŹNY M. (eds), *Between History and Archaeology, Papers in honor of Jacek Lech*, Oxford, Archaeopress Publishing Ltd., p. 133-145.

MARSHAK S. & MITRA G., 1988. *Basic Methods of Structural Geology*, Prentice Hall, New Jersey, 446 p.

NELSON M., 1987. Site Content and Structure: Quarries and Workshops in the Maya Highlands. *In*: HAYDEN B. (ed.), *Lithic Studies Among the Contemporary Highland Maya*, Tucson, Arizona, The University of Arizona Press, p. 120-147.

OSBORN H., 1907. *Field-book and Guide: In the Search for and the Easy Determination of Ores and Other Useful Minerals*, **7**, Philadelphia, Pennsylvania, Henry Carey Baird & Co.

PATON R., 1994. Speaking through Stones: A Study from Northern Australia, *World Archaeology,* **26**, p. 172-184.

SCHNEIDER J. & LAPORTA P**.,** 2008. Geological Constraints on Ground Stone Production and Consumption in the Southern Levant. *In*: ROWAN Y. & EBELING J. (eds), *New Approaches to Old Stones: Recent Studies of Ground Stone Artifacts*, Sheffield, Equinox Publishing Ltd., 386 p.

PEELE R., 1941. *The Mining Engineer's Handbook*, New York, John Wiley & Sons.

PÉTREQUIN P. & PÉTREQUIN A.-M., 1993. *From polished stone tool to sacred axe: The axes of the Danis of Irian Jaya, Indonesia*. *In*: BARTHELET A. & CHAVAILLON J. (eds), *The Use of Tools by Human and Non-Human Primates*, Oxford, Oxford University Press, p. 360-377.

SCHULTZ A., 1985. *The Geology of Pennsylvania, Part VI: Geologic History*, Pennsylvania Geological Survey and Pittsburgh Geological Society, p. 413.

SPENCER B. & GILLEN F., 1899. *The Native Tribes of Central Australia*, London, Macmillan and Co.

SPENCER B. & GILLEN F., 1904. *The Native Tribes of Central Australia*, London, Macmillan and Co.

TWISS R. & MOORES E., 1992. *Structural Geology*, Macmillan Publishers, U.K., 532 p.

VON BERNEWITZ M., 1931. *Handbook for Prospectors*, New York, McGraw-Hill.

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