**[Supplementary material]**

# Harvesting and processing wild cereals in the Upper Palaeolithic Yellow River Valley, China

Li Liu[1,2,3,*], Maureece J. Levin[2], Michael F. Bonomo[4], Jiajing Wang[1,2], Jinming Shi[5], Xingcan Chen[6], Jiayi Han[7] & Yanhua Song[7,*]

[1] *Department of East Asian Languages and Cultures, Stanford University, Knight Building, 521 Memorial Way, Stanford, CA 94305, USA*

[2] *Stanford Archaeology Center, Stanford University, Building 500, 488 Escondido Mall, Stanford, CA 94305, USA*

[3] *Henan University, 85 Minglun Street, Shunhe Huizuqu, Kaifeng 475001, China*

[4] *Department of Geological Sciences, Stanford University, Building 320, 450 Serra Mall, Stanford, CA 94305, USA*

[5] *Shanxi Museum, 13 Binhe W Road, Wanbailin Qu, Taiyuan 030024, China*

[6] *Institute of Archaeology, Chinese Academy of Social Sciences, 27 Wangfujing Dajie, Beijing 100710, China*

[7] *Department of Archaeology, Shanxi University, Taiyuan 030006, China*

[*] *Authors for correspondence (Email: liliu@stanford.edu; songyanhuahan@163.com)*

## Experimental study of tool use

*Usewear analysis*

We used sandstone slabs and hand-stones to work on various materials including seeds, tubers, bones, wood, stone and minerals and sandstone and slate knives and sickles, along with chert and quartzite flakes to cut green foxtail, foxtail millet, reeds and cattails, and scrape bones and wood. The results from these experiments provide a database for comparison (e.g. Fullagar *et al.* 2012; Liu *et al.* 2014a; Liu *et al.* 2017). In addition to this, previous research on use-wear patterns on grinding stones and flake tools from other parts of the world  were also consulted (e.g. Anderson 1999; Dubreuil 2004; Fullagar 1991; Unger-Hamilton 1999).

*Residue analysis of tools and stems/leaves*

Residues on experimental cutting tools were extracted following the same protocols used for ancient samples. We also extracted and analysed starches from the stems and leaves of plants collected from the same locations where harvesting experiments were conducted (Liu *et al.* 2017). The starches recovered from the cutting tools are consistent with those extracted from the stems and leaves of corresponding plants. The starch assemblage (n = 219 grains) from green foxtail stems/leaves and those found on the tools used to cut this plant are predominated by the polygonal type (75.3%) with a much lower percentage of the lenticular type (9.1%). In the starches found in stems/leaves of barnyard grass (n=76), these two types account for 44.7% and 27.6%, respectively. Our samples from *Leymus* stems/leaves revealed few starches (n=17), but they included both lenticular (n=3) and polygonal (n=6) types.

**Starch types**

The terminology used to describe starch morphology follows ICSN 2011, The International Code for Starch Nomenclature (http://fossilfarm.org/ICSN/Code.html, accessed in March 3, 2018).

Type I starch grains are mostly large, round or oval in the 2D form and lenticular in the 3D form. The hilum is centric, the extinction cross is '+' or '×' shaped, and lamellae are visible on large grains. In some cases bimodal pattern (containing large A-type and small B-type) is present (size range 2.23–39.5 μm).

Type II starch grains are polygonal or sub-round in form, and often facetted with a size range of 4.32–28.53 μm. The hilum is centric or slightly eccentric; the fissure is 'V', 'Y', or linear in shape, or radiating outward. Extinction crosses are often approximated a '+' shaped, but many are slightly curved or with 'zig-zag' shaped arms. The size range of Type II is much greater than those from the seeds of wild millets, but similar to those of Job's tears. The 'zig-zag' arm on the extinction cross and eccentric hilum have been identified as diagnostic features in the seed starch of Job's tears (Liu *et al.* 2014b). Job's tears are native to China, and their starch has been found on grinding stones from many Neolithic sites in both north and south China (see summary in Liu *et al.* 2014b).

Type III are polygonal or sub-rounded in form, the hilum is centric; the fissure is 'V', 'Y', or linear in shape, or radiating outwards; extinction crosses are often nearly '+' shaped. In several cases Type III grains appear in clusters, showing some consistent characteristics. Type III grains are similar to Type II in terms of their generally polygonal shape, but the former rarely exhibit eccentric hilum or zig-zag arms on extinction cross. The grain sizes of Type III are also considerably smaller (4.26–14.4 µm).

Starch grains classified as Types IV, V, and VI, which are tubers and occurred infrequently in our assemblage, have been identified at other Upper Palaeolithic sites in the region, and their morphologies have been described in previous publications (Guan *et al.* 2014; Liu *et al.* 2013).

Table S1. Starch counts and ubiquity from all tools, SZT29 and SZT5

| **Starch Type** | **I** | **II** | **III** | **IV** | **V** | **VI** | | |
|---|---|---|---|---|---|---|---|---|
| **Taxa** | **Triti-ceae** | **Pani-ceae** | **Millet** | **Lily** | **Yam** | **Snake-gourd** | **UNID** | **Total** |
| ***Stratum 8*** | | | | | | | | |
| GS1 | 8 | 4 | | | 1 | | 6 | 19 |
| GS2 | 2 | 2 | | | 1 | | 7 | 12 |
| Starch total | 10 | 6 | | | 2 | | 13 | 31 |
| Starch % | 32.3 | 19.4 | | | 6.5 | | 41.9 | 100 |
| Tool no. | 2 | 2 | | | 2 | | 2 | 2 |
| Ubiquity | 100% | 100% | | | 100% | | 100% | 100% |
| ***Stratum 7*** | | | | | | | | |
| GS3 | 8 | 4 | | | 1 | | 1 | 14 |
| GS4 | 1 | 2 | | | | | 1 | 4 |
| GS5 | 3 | 1 | | | 1 | | 8 | 13 |
| GS6 | | 1 | | | | | 2 | 3 |
| GS7 | | 16 | 25 | | | | 5 | 46 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Starch total | 12 | 24 | 25 | | 2 | | 17 | 80 |
| Starch % | 15 | 30 | 31.3 | | 2.5 | | 21.3 | 100 |
| Tool no. | 3 | 5 | 1 | | 2 | | 5 | 5 |
| Ubiquity | 60% | 100% | 20% | | 40% | | 100% | 100% |
| ***Strata 4–6*** | | | | | | | | |
| GS8 | 20 | 55 | 9 | 4 | | 2 | 17 | 107 |
| GS9 | 2 | 26 | 10 | | | | 1 | 44 |
| GS10 | 33 | 6 | | | | | 1 | 44 |
| Starch total | 55 | 94 | 19 | 4 | | 2 | 19 | 195 |
| Starch % | 28.2 % | 48.2 % | 9.7% | 2.1% | | 1.0% | 9.7% | 100% |
| Tool no. | 3 | 3 | | 1 | | 1 | 3 | 3 |
| Ubiquity | 100% | 100% | 75% | 33% | | 33% | 100% | 100% |
| ***Strata 2–3*** | | | | | | | | |
| GS11 | 7 | 3 | 6 | | | | 4 | 20 |
| GS12 | 19 | 9 | 3 | | 1 | 1 | 6 | 39 |
| GS13 | 11 | 2 | 4 | | 1 | 2 | 5 | 25 |
| GS14 | 1 | 2 | 1 | | | 3 | 1 | 7 |
| Starch total | 38 | 16 | 14 | | 2 | 6 | 15 | 91 |
| Starch % | 41.8 | 17.6 | 15.4 | | 2.2 | 6.6 | 16.5 | 100 |
| Tool no. | 4 | 4 | 4 | | 2 | 3 | 3 | 4 |
| Ubiquity | 100% | 100% | 100% | | 50% | 75% | 75% | 100% |
| GS starch total | 115 | 140 | 58 | 4 | 6 | 8 | 64 | 397 |
| GS starch % | 29% | 35.3 % | 14.6% | 1% | 1.5% | 2% | 16.1% | 100% |
| GS tool total | 12 | 14 | 7 | 1 | 6 | 4 | 13 | 14 |
| GS ubiquity | 85.7 % | 100% | 50% | 7.1% | 42.9 % | 28.6 % | 92.9% | 100% |
| **Starch Type** | **I** | **II** | **III** | **IV** | **V** | **VI** | | |

| **Taxa** | **Triti-ceae-type** | **Panicoideae-type** | **millet** | **lily** | **yam** | **snake-gourd** | **UNID** | **total** |
|---|---|---|---|---|---|---|---|---|
| | | | | **Stratum 8** | | | | |
| SF1 | 1 | | | | | | 4 | 5 |
| SF10 | 5 | 3 | | | | | | 8 |
| Starch total | 6 | 3 | | | | | 4 | 13 |
| Starch % | 46.2 | 23.1 | | | | | 30.8 | 100 |
| Tool no. | 2 | 1 | | | | | 1 | 2 |
| Ubiquity | 100% | 50% | | | | | 50% | 100% |
| | | | | **Stratum 7** | | | | |
| SF2 | 7 | 11 | | | | | 1 | 19 |
| SF11 | 12 | 2 | | | | | | 14 |
| SF12 | | 2 | | | | | | 2 |
| MB1 | 4 | | | | | | | 4 |
| MB2 | | | | | 1 | | | 1 |
| MB4 | 2 | | | | | | 2 | 4 |
| MB5 | 2 | 10 | | | | | | 12 |
| Starch total | 27 | 25 | | | 1 | | 3 | 56 |
| Starch % | 48.2 | 44.6 | | | 1.8 | | 5.4 | 100 |
| Tool no. | 5 | 4 | | | 1 | | 2 | 7 |
| Ubiquity | 71% | 57% | | | 14% | | 29% | 100% |
| | | | | **Strata 4–6** | | | | |
| SF3 | 3 | 14 | | | | | 1 | 18 |
| SF4 | 4 | 107 | | | | | 5 | 116 |
| SF5 | 8 | 92 | | | 1 | 1 | 13 | 115 |
| SF6 | 4 | 128 | | | | | 10 | 142 |
| SF14 | 5 | 4 | | | 1 | | 1 | 11 |
| SF15 | 2 | 6 | | | | | 2 | 10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SF16 | 1 | 1 | | | | | 2 | 4 |
| MB8 | 1 | | | | | | 3 | 4 |
| Starch total | 28 | 352 | | | 2 | 1 | 37 | 420 |
| Starch % | 6.7 | 83.8 | | | 0.5 | 0.2 | 8.8 | 100 |
| Tool no. | 8 | 7 | | | 2 | 1 | 8 | 8 |
| Ubiquity | 100% | 88% | | | 25% | 13% | 100% | 100% |
| **Strata 2–3** | | | | | | | | |
| SF7 | 6 | 92 | | | | | 22 | 120 |
| SF8 | 3 | 53 | | | 1 | 1 | | 58 |
| SF18 | 4 | | | | | | 2 | 6 |
| SF19 | 1 | 2 | | | | | 1 | 4 |
| Starch total | 14 | 147 | | | 1 | 1 | 25 | 188 |
| Starch % | 7.4 | 78.2 | | | 0.5 | 0.5 | 13.3 | 100 |
| Tool no. | 4 | 3 | | | 1 | 1 | 3 | 4 |
| Ubiquity | 100% | 75% | | | 25% | 25% | 75% | 100% |
| **Stratum 1** | | | | | | | | |
| SF22 | 2 | | | | | | 1 | 3 |
| SF23 | 4 | 2 | | | | | 1 | 7 |
| ST1 total | 6 | 2 | | | | | 2 | 10 |
| ST1 % | 60 | 20 | | | | | 20 | 100 |
| L1 tool no. | 2 | 1 | | | | | 2 | 2 |
| L1 ubiquity | 100% | 50% | | | | | 100% | 100% |
| ***SZT5*** | | | | | | | | |
| SF24 | 4 | 5 | | | | | 1 | 10 |
| SF25 | 20 | | | | | | | 20 |
| SZT5 counts | 24 | 5 | | | | | 1 | 30 |
| SZT5 % | 80 | 17 | | | | | 3 | 100 |
| SZT5 tool no. | 2 | 1 | | | | | 1 | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SZT5 ubiq. | 100% | 50% | | | | | 50% | 100% |
| ***SZT5&29 flakes and microblades TOTAL*** | | | | | | | | |
| Starch total | 105 | 534 | | | 4 | 2 | 72 | 717 |
| Starch % | 14.6 | 74.5 | | | 0.6 | 0.3 | 10 | 100 |
| Tool total | 23 | 17 | | | 4 | 2 | 17 | 25 |
| total ubiquity | 92% | 68% | | | 16% | 8% | 68% | 100% |
| ***SZT5&29 all tools TOTAL*** | | | | | | | | |
| ST8 total | 16 | 9 | | | 2 | | 17 | 44 |
| ST8 % | 31.8 % | 25% | | | 4.5% | | 38.6% | 100% |
| ST7 total | 39 | 49 | 25 | | 3 | | 20 | 136 |
| ST7 % | 29% | 36% | 18% | | 2% | | 15% | 100% |
| ST4-6 total | 83 | 446 | 19 | 4 | 2 | 3 | 56 | 615 |
| ST4-6 % | 13.5 % | 72.5% | 3.1% | 0.7% | 0.3% | 0.5% | 9.1% | 100% |
| ST2-3 total | 52 | 163 | 14 | | 3 | 7 | 40 | 279 |
| ST2-3 % | 18.6 % | 58.4% | 5% | | 1.1% | 2.5% | 14.3% | 100% |
| ST1 total | 6 | 2 | | | | | 2 | 10 |
| ST1 % | 60% | 20% | | | | | 20% | 100% |
| SZT5 total | 24 | 5 | | | | | 1 | 30 |
| SZT5 % | 80% | 17% | | | | | 3% | 100% |
| **Starch total** | **220** | **674** | **58** | **4** | **10** | **10** | **136** | **1114** |
| **Starch %** | **19.7 %** | **60.5%** | **5.2%** | **0.4 %** | **0.9%** | **0.9%** | **12.2%** | **100 %** |
| **Tool total** | **35** | **31** | **7** | **1** | **10** | **6** | **30** | **39** |
| **Tool ubiquity** | **89.7 %** | **79.5%** | **18%** | **2.6 %** | **25.6 %** | **15.4 %** | **76.9%** | **100 %** |
| Taxa | Triti- | Panico | millet | lily | yam | snake | UNID | total |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ceae-type | ideae-type | | | | -gourd | | |

**Table S2. Starch size range from Shizitan and modern plant reference (in μm).**

| Starch types and taxa | Tool types/locations | no. | min | max | mean |
|---|---|---|---|---|---|
| SZT Type I (Triticeae) | SZT GS 1–14 | 116 | 3.69 | 39.5 | 22.12 |
| SZT Type I (lenticular type) | SZT SF-MB | 105 | 2.23 | 38.6 | 19.4 |
| *Agropyron desertortum* (seeds) | Inner Mongolia | 120 | 2.23 | 39.28 | 15.21 |
| *Agropyron cristatum* (seeds) | Inner Mongolia | 162 | 2.9 | 38.25 | 22.15 |
| *Leymus secalinus* seeds | Inner Mongolia | 155 | 3 | 19.37 | 10.76 |
| Lenticular-type from *Leymus* (stems/leaves) | Inner Mongolia | 3 | 26.84 | 34.98 | 29.83 |
| Lenticular-type from green foxtail (stems/leaves) | Henan and Shaanxi | 114 | 10.16 | 38.42 | 21.96 |
| SZT Type II (Panicoideae) | SZT GS 1-14 | 133 | 4.32 | 28.15 | 17.57 |
| SZT Type II (polygonal type) | SZT SF-MB | 534 | 4.75 | 28.53 | 14.82 |
| *Coix lacryma-jobi*, domestic, hard utricle, seeds | Guizhou (RE1244) | 113 | 6.9 | 29.2 | 15.27 |
| *Coix lacryma-jobi*, domestic, hard utricle, seeds | Hebei (REF1287) | 142 | 4.77 | 23.99 | 13.18 |
| *Coix lacryma-jobi*, domestic, soft utricle, seeds | Hebei (REF1250) | 124 | 7.77 | 20.05 | 13 |
| *Coix lacryma-jobi*, wild, seeds | Yunnan (REF1261) | 130 | 7.28 | 20.89 | 14.49 |
| Polygonal-type starch from *Seratia viridis* (stems/leaves) | Henan and Shaanxi | 289 | 5.24 | 25.19 | 14.79 |
| Polygonal-type starch from *Leymus* (stems/leaves) | Inner Mongolia | 6 | 15.85 | 22.74 | 18.84 |

| | | | | | |
|---|---|---|---|---|---|
| SZT Type III (wild millets) | SZT GS 1-14 | 66 | 4.26 | 14.4 | 11.06 |
| *Seratia viridis*, seeds | Henan (REF1637) | 119 | 2.69 | 14.46 | 7.65 |
| *Seratia viridis*, seeds | Inner Mongolia (REF1221) | 137 | 3.45 | 10.41 | 7.62 |
| *Echinochloa colonum*, seeds | China (REF1001) | 239 | 4.62 | 14.43 | 9.01 |
| SZT Type IV (lily) | SZT GS 1-14 | 4 | 31.04 | 52.69 | 41.96 |
| *Lilium pumilum*, wild | Yan'an, Shaanxi (REF1240) | 136 | 5.75 | 57.77 | 25.77 |
| *Lilium tigrinum*, domestic | Hanzhong, Shaanxi (REF1263) | 196 | 4.39 | 61.24 | 22.99 |
| SZT Type V (yam) | SZT all tool types | 10 | 13.72 | 41.27 | 26.19 |
| *Dioscorea polystachya*, wild | Yanshi, Henan (REF1000) | 120 | 12.65 | 63.08 | 33.96 |
| *Dioscorea polystachya*, domestic | Huilou, Henan, (REF1297) | 116 | 17.28 | 46.6 | 29.3 |
| SZT Type VI (snake gourd root) | SZT all tool types | 10 | 11.51 | 32.11 | 19.99 |
| *Trichosanthes kirilowii* | Taiyuan, Shanxi (REF1170) | 125 | 5.37 | 26.34 | 12.91 |
| *Trichosanthes kirilowii* | Yanshi, Henan (REF1129) | 121 | 7.28 | 31.17 | 16.13 |

**Table S3. Phytolith counts from tools where they were present from SZT29 (no phytoliths were present on tools from SZT5).**

| ***Grinding Stones*** | | |
|---|---|---|
| | **Poaceae (grasses)** | |

| Sample | Stratum | Bulliform | Bilobate | Tuberculate | Echinate | Woody sp. | Psilate | Psilate | Tracheid | Total Phytoliths |
|---|---|---|---|---|---|---|---|---|---|---|
| GS1 | 8 | 1 | | | | 1 | | 2 | 1 | 4 |
| GS2 | 8 | 1 | 1 | | | | 2 | | | 4 |
| GS5 | 7 | | 1 | | 300 | | 3 | 1 | 2 | 307 |
| GS6 | 7 | | | | | | | | 1 | 1 |
| GS8 | 4 | | | 1 | | | | | | 1 |
| GS9 | 4 | | | 2 | | | 2 | | | 4 |
| GS10 | 4 | 1 | | | | | 1 | | | 2 |
| GS11 | 2 | | | | | 3 | | | 1 | 4 |
| GS12 | 2 | | | | | 4 | | | 5 | 8 |
| GS13 | 2 | | | 1 | | | | | 1 | 2 |
| GS Total | | 3 | 2 | 4 | 300 | 8 | 8 | 3 | 11 | 337 |

***Microblades***

| Sample | Stratum | m (grasses) | hs |
|---|---|---|---|
| MB 8 | 6 | 1 | 1 |
| MB Total | | | 1 |

***Flakes***

| Sample | Stratum | m (grasses) | sp. | Psilate | Psilate | Ovate | Stellate | Phytoli hs |
|---|---|---|---|---|---|---|---|---|
| SF5 | 5 | 1 | 1 | 1 | | | 1 | 4 |
| SF8 | 2 | | | 2 | | | | 2 |
| SF14 | 5 | | | | 1 | | | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SF23 | 1 | | | | | 1 | | 1 |
| SF Total | | 1 | 1 | 3 | 0 | | 1 | 8 |

**Comparative use-wear data**

In general, plant-cutting tools show high-levels of polish, sometimes with fine striations, but this may vary according to the particular properties of the different lithic raw materials. Stone tools with varying hardness and surface roughness used for harvesting cereals show diverse forms of polish and striations on their edges. For example, soft lithic materials produced more extensive fine striations than hard lithic materials did; the latter, however, produced a higher level of polish.

**Table S4. Use-wear record of SZT29 and SZT5 all tools.**

| Sample no Artefact no | Strata | Polish | Striation | Edge rounding | Pitting | Possible function |
|---|---|---|---|---|---|---|
| GS1, slab (13699) | 8 | low-level polish, very small and isolated polish spots | no | some | unclear | processing soft materials, used infrequently |
| GS2, slab (13805) | 8 | very low-level polish, but slightly reticulated, flat surface | no | | unclear | processing soft materials, used infrequently |
| GS3, slab (13110) | 7 | P1 (top): low level, isolated; P2 (bottom): | P1: no<br>P2: parallel, short on some | rounded or angular | no | processing mostly soft materials, |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | mostly raw crystals, some isolated grains show small polished spots | small polished areas | | | but also hard minerals, both sides used; hematite on P2 |
| GS4, slab (13108) | 7 | Low to medium polish, some reticulate, | mostly no, but some short and wide parallel striations on two spots | some rounde d | prese nt | processing soft and relatively hard materials; probably pounding |
| GS5, slab (collected) | 7 | P1 (top): low level, isolated; P2 (top): medium level, mostly isolated, but some reticulate; P3 (bottom): raw crystals | P1: mostly no, but deep striations and fractures on some crystals; P2: some short and long; | rounde d or angular | no | processing soft materials; haematite on top side; unused on bottom side |
| GS6, slab (66-109) | 7 | P1: medium level, relatively reticulated; P2: medium to high level, reticulated | no | some | uncle ar | processing very soft materials |
| GS7, Hand- | 7 | P1: from the flat end; high-level | no | commo n | prese nt | tool end as polisher or |

| | | | | | | |
|---|---|---|---|---|---|---|
| stone (11959) | | polish, reticulated; P2: a lateral side; high-level polish; very reticulated; P3: an area with a part smooth and a part rough on a lateral side; high-level polish, very reticulated on the flat area; but only raw crystals exposed on the rough area, likely removed by pounding hard material; | | | | grinder; lateral side P2 and P3 as grinder and hammer stone; hematite on P3 |
| GS8.1-4, slab (8396, 8397, 8398, 8399) | 4 | all show medium level polish on isolated spots | 8397: parallel fine striations; others: no | commo n | prese nt | processing mostly soft materials |
| GS9, slab (5744) | 4 | P1: low level, mostly isolated; P2: medium level, more | P1: no P2: occasionally fine and short | unclear | uncle ar | processing mostly soft materials |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | reticulate than P1 | striations | | | |
| GS10, slab (6082) | 4 | low-level very isolated polish spots | no | some | unclear | processing soft materials, used infrequently |
| GS11, elongate slab (3992) | 2 | P1: from one lateral side, low to medium level, isolated; P2: from another lateral side, no clear used traces | no | some | unclear | processing soft materials, used infrequently |
| GS12, slab (3091) | 2 | some very small polished spots, many raw crystals | no | | no | processing soft materials, used infrequently |
| GS13, slab (91-101-2) | 2 | medium level isolated polish areas | no | common | unclear | processing soft materials |
| GS14, slab (2H42_81-103-2) | 2 | very few small polished spots, mostly fresh crystals | no | some | unclear | used infrequently |
| MB1 Chert | 7 | high polish, reticulate on | unclear | unclear | | used |

| | | | | | | |
|---|---|---|---|---|---|---|
| (62-105) | | edge, flat, more extensive on P1 than P2 | | | | |
| MB2 chert (12455) | 7 | high polish, reticulate, flat, on both sides | unclear | unclear | | used |
| MB3 chert (13119) | 7 | high polish, large areas, on both sides | no | unclear | | used |
| MB4 chert (13259) | 7 | high polish, reticulate, flat on P1 | long, parallel, and fine striations nearly horizontal to the edge on several areas on P1 | slightly | | comparable to bone-working traces |
| MB5 chert (11491) | 7 | high polish; less extensive on P2 than P1 | fine striations, horizontally with some diagonal on P1 | present | | cutting plants |
| MB6 chert (60-100-1) | 7 | P1: high polish | P1: long and wide striations, diagonal | present | | used |
| MB7 chert (11703) | 7 | P1: very high polish, but uneven;<br>P2: high polish, reticulate | P1: shallow and wide parallel striations, long and diagonal, P2: long and wide parallel | present | | used |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | striations, multidirectional, | | | |
| MB8 chert (10694) | 6 | a lot of polish, flat surface, on the ventral side | no | no | | hard materials |
| SF1 quartzite scraper (13678) | 8 | no | wide striations, diagonal, on both sides | | | scraping hard material |
| SF2 quartzite scraper (74-97) | 7 | small polished area, rarely seen, on P2 | no | no | | used |
| SF3 quartzite scraper (79-104-3) | 6 | all raw crystals on both sides | no | no | | used |
| SF4 quartzite flake (8776) | 5 | few spots of polish on distal edge | fine striations parallel to the edge | unclear | | cutting plants |
| SF5 quartzite scraper (8829) | 5 | high polish, reticulate | very fine striations, both horizontal and vertical in orientation | present | | cutting plants |
| SF6 quartzite scraper (8367) | 4 | some high polish | no | present | | cutting plants |

| | | | | | | |
|---|---|---|---|---|---|---|
| SF7 quartzite scraper (91-95-3) | 3 | smooth surface, high polish on P1 | no | some | | soft materials incl. plants |
| SF8 chert scraper (4230) | 2 | high polish, reticulate on both sides | fine striations multidirectional on both sides | present | | cutting plants |
| SF9 (13834) | 8 | | | | | non-tool |
| SF10 quartzite flake (13819) | 8 | many polished areas on both sides, Side A shows less polish than Side B | striations multi-directional to the edge | present | | cutting and scraping plants |
| SF11 quartzite flake (13207) | 7 | mostly fractures, only one spot of polish on Side B | no | unclear | | unclear |
| SF12 chert flake (13246) | 7 | high polish on the edge | no | present | | soft materials incl. plants |
| SF13 chert flake (10731) | 6 | | | | | non-tool |
| SF14 quartzite flake (8777) | 5 | very little visible polish | no | no | | soft materials incl. plants |
| SF15 | 5 | few medium | no | no | | soft |

| | | | | | | |
|---|---|---|---|---|---|---|
| chert flake (8825) | | level polished areas | | | | materials incl. plants |
| SF16 quartzite flake (86-109-3) | 4 | medium level polish, more on the dorsal side than on the ventral side | no | present | | soft materials incl. plants |
| SF17 quartzite flake (8134) | 4 | | | | | non-tool |
| SF18 chert flake (4487) | 3 | few medium level polished areas | | unclear | | soft materials incl. plants |
| SF19 chert flake (92-93-4) | 3 | high polish on both sides and the edge | horizontal striations parallel to the edge on Side A | present | | soft and hard materials incl. plants |
| SF20 quartzite flake (4273) | 2 | | | | | non-tool |
| SF21 quartzite flake (4267) | 2 | | | | | non-tool |
| SF22 quartzite scraper (811) | 1 | no clear use-wear found | | | | unclear |
| SF23 | 1 | very high polish | no | present | | siliceous |

| | | | | | | |
|---|---|---|---|---|---|---|
| chert scraper (890) | | on one side | | | | plants |
| SF24 quartzite scraper (SZT5: 5121) | 1 | few small spots of polish near the edge on both sides, | fine striations parallel to the edge on one spot | unclear | | soft material including plants |
| SF25 chert flake (SZT5) | 1 | very high polish near the edge | some long furrow along the edge | present | | siliceous plants |

**Shizitan pigment analysis**

Analyses of the red mineral powders extracted from grinding stone GS5 and reference mudstone samples were performed using a Bruker Tracer III-SD handheld pXRF spectrometer. Operational settings of 15 kV and 25 μA were used in conjunction with the instrument's vacuum pump attachment for the analysis of major elements shown in Figure S3a–b, while settings of 40 kV and 30 μA were used with a layered aluminum (304.8 μm) and titanium (25.4 μm) filter, without vacuum, for the analysis of trace elements shown in Figure S3c; an analytical duration of 120 seconds was used for all analyses. Mineral grains were analysed while embedded in the PVS substrate (Figure S3a, S29[t]GS5P2) and compared to a 'blank' PVS peel collected on the same sample (although lacking macroscopically visible grains; Figure S3a, S29[t]GS5P1) to isolate elements present in the grains. Mineral grains are shown to contain predominantly iron and calcium components (Figure S3a), possibly suggesting a mixture of iron-bearing haematite and post-depositional carbonate grains. Minor aluminum, potassium and titanium peaks are also observed in the pXRF spectra. Although silicon is a significant component of the PVS substrate, it is probably present in the mineral grain spectra as well. Chromium may have been used in trace quantities as a green colourant in the PVS peel and is probably not a component of the mineral grains.

A reddish-brown mudstone sample collected at the modern surface of the Shizitan site was analysed as a potential local source rock for the GS5 mineral powders (Figure S3b, analysis nos. 1–2). Crushed red shales and mudstones often contain suitable concentrations of haematite or other iron oxide/hydroxide minerals for use as pigment sources (Dayet *et al*. 2013; Eiselt *et al*. 2011; Rifkin 2012). The analysed Shizitan mudstone sample is likely haematitic, displaying localised bright red colouration and prominent iron spectral peaks, although it contains less total iron relative to the haematitic red shale sample analysed for comparative reference (Figure S3b, Passaic Fm. shale). Silicon, aluminum and potassium are identifiable in both the Shizitan mudstone and mineral powder pXRF spectra, suggesting a crushed mudstone/shale source for the pigments; alumino-silicate minerals, e.g. clay minerals and potassium-bearing micas and feldspars, tend to dominate the non-quartz fraction of mudstones and shales (Boggs 2009; Shaw & Weaver 1965).

Direct comparison of pXRF trace element signatures in the Shizitan mineral grains with those in the Shizitan mudstone sample (Figure S3c) offers little insight, however, due to the differences in bulk matrix composition and sample thickness between a thin PVS matrix containing sparse, sub-millimetre mineral grains and a thick, dense rock (both sample thickness and sample diameter in relation to the pXRF analyzer window have significant effects on the intensity and shape of a spectral profile; Davis *et al*. 2011). The mudstone sample appears to contain trace elements not conclusively observed in the mineral powder analysis (e.g., gallium, lead, and rubidium), though it is possible that such peaks are masked by the background signal in relation to sample thickness concerns and analyzer "field of view" effects. Trace amounts of platinum identified in the GS5 mineral powder spectrum (Figure 3c) are likely a component of the PVS material.

**Control samples**

Four control sediment samples were analyzed for starch residues, including three from the surrounding sediments (top, side, and back) of GS8 and one from the soil adhering to the bottom of GS5, weighting around 2.4 g, 2.0 g, 2.0 g, and 2.0 g respectively. Each soil sample was transferred to a 15-mL tube, and mixed with four microliters of 0.1% EDTA

($Na_2EDTA{\bullet}2H_2O$) solution. Then the capped tubes were placed in an automatic shaker for 2 h to disperse the sediments. After being removed from the shaker, the tubes were filled to 15 mL with distilled water and centrifuged (Eppendorf 5804, Hamburg, Germany) for 5 min at 1,500 rpm, and the supernatant was decanted. The samples were then extracted using heavy liquid sodium polytungstate at a specific gravity 1.8. No starch grains were present in the control samples.

Five control sediment samples were analyzed for phytolith remains, also collected from cultural layers and near a grinding stone (GS10), weighting 1.1-1.8 g. The samples were processed using a 10% HCl solution, followed by 30% $H_20_2$. They were deflocculated with sodium hexametaphosphate, and finally extracted using heavy liquid sodium polytungstate of specific gravity 2.35. They were viewed using a technique identical to that for residue analysis. Phytolith concentrations were extremely low in three of the four samples, with only six phytoliths totally recovered from each. One exception was sample 4H61 (from the center of an activity feature), which contained 21 phytoliths, all either grasses or indeterminate types. This is still a low concentration for sediments.

Five non-tool flakes were analyzed for residues, and no starch or a single unidentifiable starch was found on each specimen.

**Materials and methods**

Use-wear analysis: Polyvinyl siloxane (PVS) impressions or ‘peels’ were taken from different parts of the tools that were analysed to document used and unused surfaces (Fullagar 2006). The PVS peels were examined under a compound (reflected light) Zeiss microscope at magnifications of 50 ×, 100 ×, 200 ×, and 500 ×. Residue samples were extracted from tools using an ultrasonic bath or an ultrasonic toothbrush, and processed for starch and phytolith extraction using the heavy liquid sodium polytungstate (in a gravity of 2.35). Extractions obtained from residue samples were mounted in 50% (vol/vol) glycerol and 50% (vol/vol) distilled water on glass slides, scanned under a Zeiss Axio Scope A1 fitted with polarising filters and differential interference contrast (DIC) optics. Images were taken using Zeiss Axiocam HRc digital cameras and Zeiss Axiovision software Version 4.8.

Starch identification was conducted through residue analysis and based on our modern reference collection, which comprises over 1500 specimens. We specifically analysed those starch-rich and economically important samples relevant to the research area, including more than 250 samples belonging to 129 species in 56 genera of 23 families. Phytoliths were described using the International Code for Phytolith Nomenclature 1.0 (Madella *et al*. 2005) and identified taxonomically wherever possible. 300–350 individual phytoliths were counted where possible; where there were fewer than 300, the entire slide was counted.

**References**


ANDERSON, P.C. 1999. Experimental cultivation, harvest, and threshing of wild cereals, in Anderson, P. C. (ed.), *Prehistory of Agriculture: New Experimental and Ethnographic Approaches*: 118-144. The Institute of Archaeology, University of California, Los Angeles, Los Angeles.

BOGGS, S., JR 2009. *Petrology of Sedimentary Rocks* Cambridge University Press, New York.

DAVIS, M., T. JACKSON, M.S. SHACKLEY, T. TEAGUE, and J.H. HAMPEL. 2011. Factors affecting the energy-dispersive X-ray fluorescence (EDXRF) analysis of archaeological obsidian, in Shackley, M. (ed.), *X-ray Fluorescence Spectrometry (XRF) in Geoarchaeology*: 45-63. Springer, New York.

DAYET, L., P. TEXIER, F. DANIEL, and G. PORRAZ. 2013. Ochre resources from the Middle Stone Age sequence of Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science* 40: 3492-350. https://doi.org/10.1016/j.jas.2013.01.025

DUBREUIL, L. 2004. Long-term trends in Natufian subsistence: a use-wear analysis of ground stone tools. *Journal of Archaeological Sceince* 31 (11): 1613-1629. https://doi.org/10.1016/j.jas.2004.04.003

EISELT, B., R. POPELKA-FILCOFF, J. DARLING, and M. GLASCOCK. 2011. Hematite sources and archaeological ochres from Hohokam and O’odham sites in central Arizona: an experiment in type identification and characterization. *Journal* *of Archaeological Science* 38: 3019-3028. https://doi.org/10.1016/j.jas.2011.06.030

FULLAGAR, R. 1991. The role of silica in polish formation. *Journal of Archaeological Science* 18 (1): 1-25. https://doi.org/10.1016/0305-4403(91)90076-2

– 2006. Residues and usewear, in Balme, J. & A. Paterson (ed.), *Archaeology in Practice: A Student Guide to Archaeological Analyses*: 207-234. Blackwell Publishing, Malden.

FULLAGAR, R., L. LIU, S. BESTEL, D. JONES, W. GE, A. WILSON, and S. ZHAI. 2012. Stone tool-use experiments to determine the function of grinding stones and denticulate sickles. *Bulletin of the Indo-Pacific Prehistory Association* 32: 29-44.

GUAN, Y., D.M. PEARSALL, X. GAO, F. CHEN, S. PEI, and Z. ZHOU. 2014. Plant use activities during the Upper Paleolithic in East Eurasia: Evidence from the Shuidonggou Site, Northwest China. *Quaternary International* 347: 74-83. https://doi.org/10.1016/j.quaint.2014.04.007

LIU, L., S. BESTEL, J. SHI, Y. SONG, and X. CHEN. 2013. Paleolithic human exploitation of plant foods during the last glacial maximum in North China. *Proceedings of the National Academy of Sciences* 110 (14): 5380-5385. https://doi.org/10.1073/pnas.1217864110

LIU, L., L. KEALHOFER, X. CHEN, and P. JI. 2014a. A broad-spectrum subsistence economy in Neolithic Inner Mongolia, China: Evidence from grinding stones. *The Holocene* 24 (6): 724-740. https://doi.org/10.1177/0959683614526938

LIU, L., S. MA, and J. CUI. 2014b. Identification of starch granules using a two-step identification method. *Journal of Archaeological Science* 52: 421-427. https://doi.org/10.1016/j.jas.2014.09.008

LIU, L., J. WANG, and M.J. LEVIN. 2017. Usewear and residue analyses of experimental harvesting stone tools for archaeological research. *Journal of Archaeological Science: Reports* 14: 439-453. https://doi.org/10.1016/j.jasrep.2017.06.018

MADELLA, M., A. ALEXANDRE, and T. BALL. 2005. International Code for Phytolith Nomenclature 1.0. *Annals of Botany* 96 (2): 253-260. https://doi.org/10.1093/aob/mci172

RIFKIN, R. 2012. Processing ochre in the Middle Stone Age: Testing the inference of prehistoric behaviours from actualistically derived experimental data. *Journal of Anthropological Archaeology* 31: 174-195. https://doi.org/10.1016/j.jaa.2011.11.004

SHAW, D., and C. WEAVER. 1965. The mineralogical composition of shales. *Journal of Sedimentary Petrology* 35 (1): 213-222.

UNGER-HAMILTON, R. 1999. Experiments in harvesting wild cereals and other plants, in Anderson, P. C. (ed.), *Prehistory of Agriculture*: 145-152. Institute of Archaeology, University of California, Los Angeles.

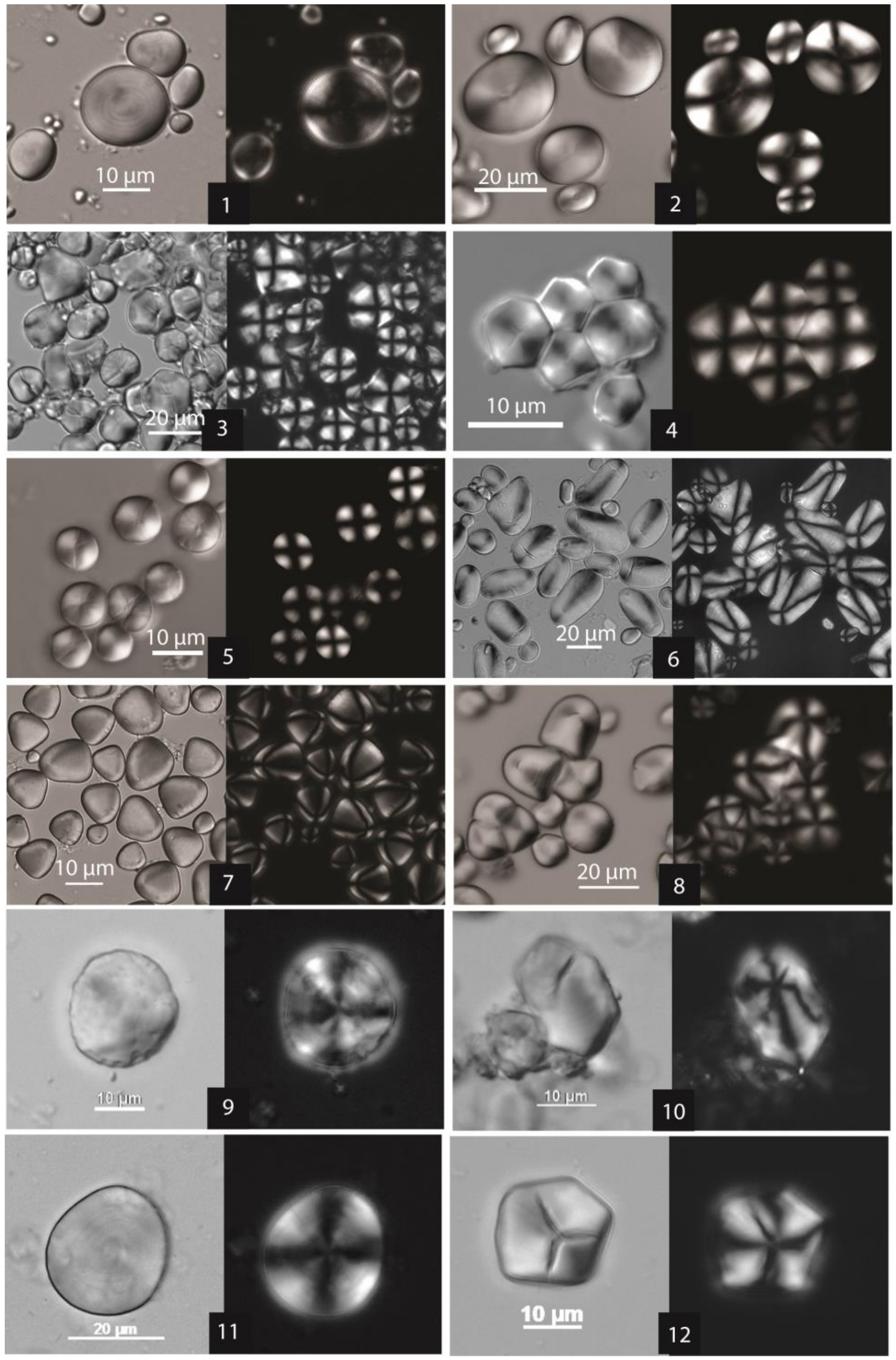


*Figure S1. Modern starch reference. 1: Leymus secalinus; 2: Agropyron cristatum; 3: Coix lacryma-jobi; 4: Setaria viridis; 5: Echinochloa colonum; 6: Lilium pumilum; 7: Dioscorea polystachya; 8: Trichosanthes kirilowii; 9 & 10: lenticular-type and polygonal-type starches from green foxtail stems/leaves; 11 & 12: lenticular-type and polygonal-type starches from Leymus stems/leaves.*

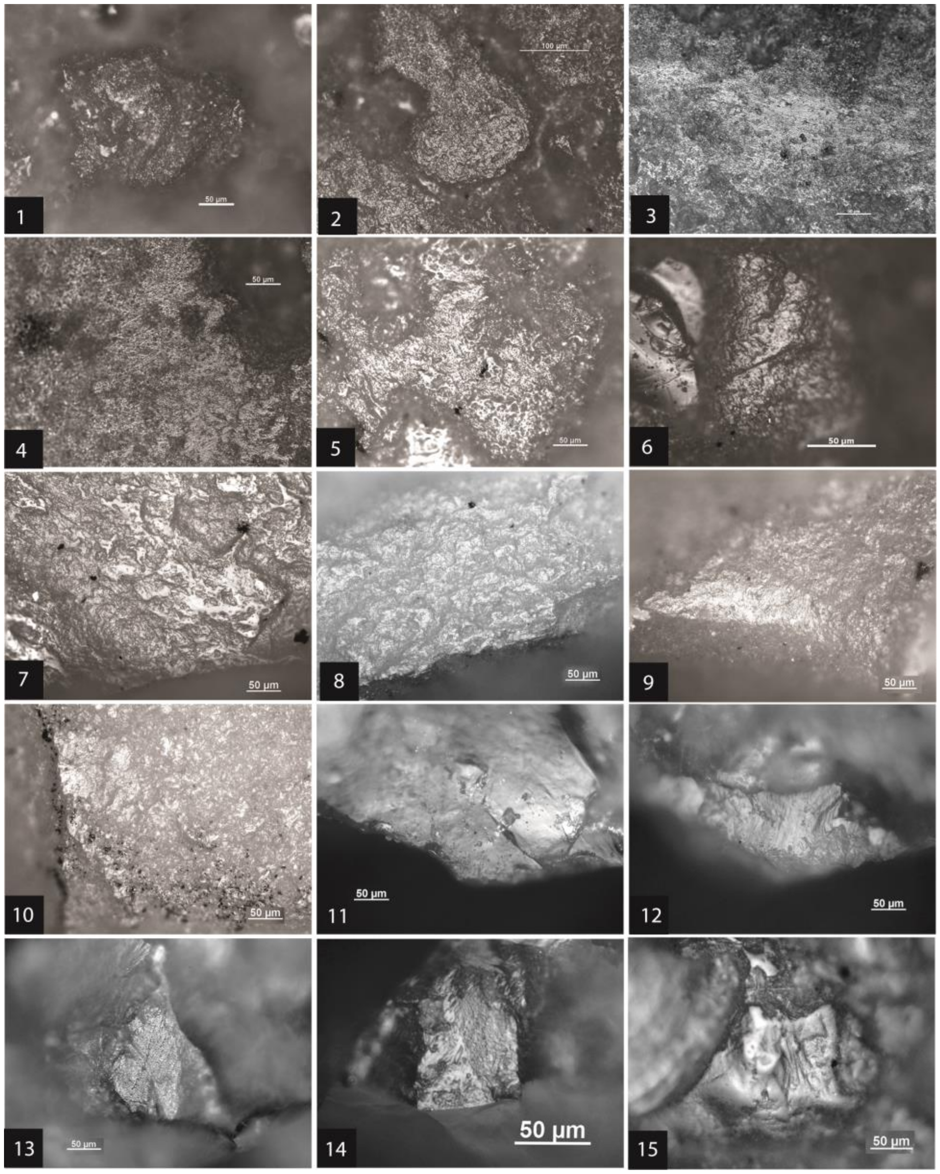


*Figure S2. Experimental Use-wear reference based on our experimental study.*
*1: sandstone slab, grinding millet, 1.5 hrs; 2: sandstone slab, grinding wheat, 1.5 hrs; 3: sandstone hand-stone, grinding root of snake gourd, 2 hrs; 4: sandstone hand-stone, grinding yam, 2 hrs; 5: sandstone slab, grinding Job's tears, 2 hrs; 6: sandstone pestle, pounding haematite, 20 min; 7: chert flake, cutting reeds, 1 hr; 8: chert flake, cutting green foxtail, 1 hr; 9: chert flake, scraping tree branches, 1 hr; 10: chert flake, scraping fresh bone, 1 hr; 11,12: quartz flake, cutting half-green foxtail, 1 hr; 13: quartz flake, cutting dry green foxtail, 1hr; 14: quartz flake, cutting green cattail, 1hr; 15: quartz flake, cutting green reeds, 1 hr.*

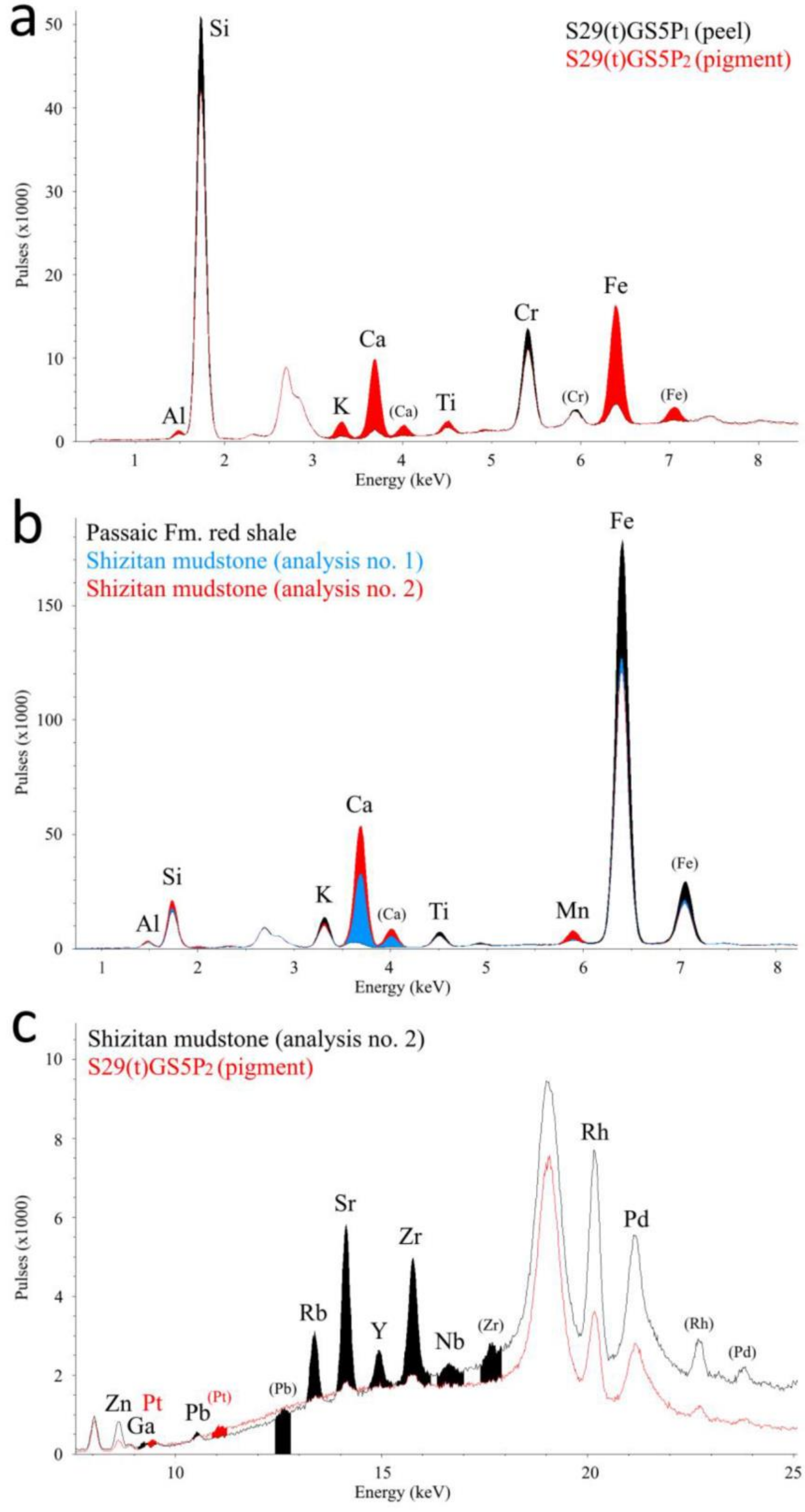


*Figure S3. Energy-dispersive pXRF spectral overlays among (a) Shizitan pigments and blank PVS, (b) Shizitan mudstones and reference shale, and (c) Shizitan pigments and*

*Shizitan mudstone. Solid colours corresponding to given samples represent differences in peak intensity across spectra for given elements.*