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ORIGINAL ARTICLE

A study of phytoliths produced by selected native plant taxa commonly used by Great Basin Native Americans

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Abstract
Reference collections of phytoliths from plant taxa commonly used by the ancient inhabitants of an archaeological site are critical to researchers conducting analyses on these microbotanical remains. Phytoliths recovered from the site are compared to those in reference collections to make inferences about which taxa were being used, as well as where, why and how. This study presents one of the first reference collections of phytoliths from selected taxa likely to have been used by Native American peoples living in the Great Basin area. The results are presented as a list of taxa which we sampled, and that are known to have been used by these tribes, such as the Shoshone and Ute, with illustrations of the range of phytolith morphotypes produced by each taxon. Our hope is that this tool will prove to be a ready and valuable resource for any researchers conducting phytolith analysis at Great Basin Native American sites.

Keywords Phytoliths · Ethnobotany · Great Basin · Reference collections · Taxonomic morphotypes

Introduction

Opal phytoliths are solid inorganic structures which form in many plant taxa as a plant takes up monosilicic acid, $Si(OH_4)$, through its roots and deposits it as silica in and around the plant cells (Pearsall et al. 1995, p. 184). In the plant cell walls and lumens of some taxa, the silica forms a solid deposit that takes the shape of the cell or space in which it formed. In some cases, this shaped silica, or phytolith, can be taxonomically significant (Pearsall et al. 1995, p. 184; Ball et al. 2016).

When a plant's organic components are destroyed through processes such as decay, burning, digestion or grinding, any phytoliths contained there are released into the surrounding environment, thus becoming microfossils of the plant (Ball et al. 1999, p. 1615; Piperno 2006). These microfossils can then be recovered from several different archaeological contexts such as soil, coprolites, dental calculus, stomach contents, residue on artifacts, or lake cores (Berlin et al. 2003, p. 115; Piperno 2006, pp. 81–86). Such phytolith studies have added to both prehistoric and present day environmental and ethnobotanical reconstruction (Ball et al. 2015).

Compared to other plant microremains, opal phytoliths have three characteristics that can make them especially useful for archaeobotanical investigations. First, due to their inorganic nature, phytoliths preserve better in some environments such as highly oxidized soils that typically destroy the organic components of other microbotanical remains (Pearsall 1989, p. 254). Second, unlike plant disseminules such as spores, pollen and seeds that are primarily produced during specific seasons or stages of development, some types of phytoliths, such as those produced in the leaves of many taxa, can be produced in a plant throughout its entire life cycle. Finally, some types of phytoliths can be produced in plant tissues and organs that do not produce other forms of microbotanical remains (Ball et al. 2015, p. 11).

Any analysis of archaeological phytoliths recovered from an excavation relies upon the researcher's ability to distinguish between the different taxa that may have produced them. As a first step towards that end, researchers typically

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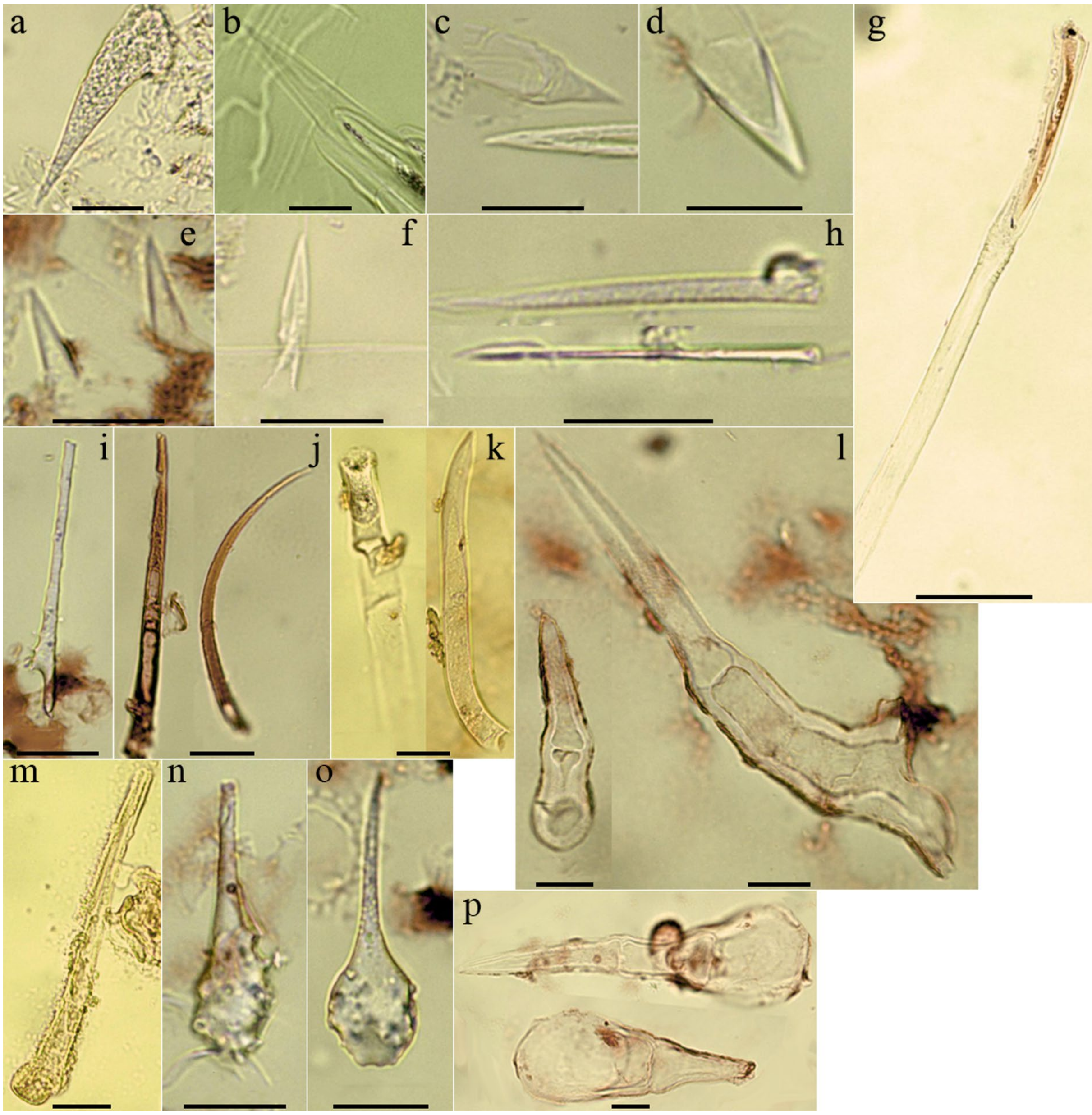

Fig. 1 ACUTE phytoliths—ACUTE crassus granulate: **a** *Poa fendleriana* (Steud.) Vasey; ACUTE crassus psilate: **b** *Achillea millefolium* L.; **c** *Deschampsia cespitosa* (L.) P.Beauv.; **d** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **e** *Elymus glaucus*; **f** *Stipa hymenoides* Roem. & Schult.; ACUTE gracile psilate: **g** *Amelanchier alnifolia* (Nutt.) Nutt. Ex M.Roem.; **h** *Festuca ovina* L.; ACUTE gracile psilate echinate: **i** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; ACUTE gracile psilate/granulate: **j** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller; ACUTE gracile psilate/granulate segmented: **k** *Balsamorhiza sagitta* (Pursh) Nutt.; **l** *Solidago canadensis* L.; ACUTE gracile striate/granulate: **m** *Artemisia dracunculus* L.; ACUTE BULBOSIS echinate: **n** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **o** *Elymus glaucus* Buckley; ACUTE BULBOSIS/psilate segmented: **p** *Heliomeris multiflora* Nutt. Scale bars 20 µm, image g scale bar 50 µm

assemble reference collections of phytoliths produced by the plant taxa that may have been used by the ancient inhabitants of the site, as well as those of the native and non-native vegetation in the area. Archaeological phytoliths recovered from the site are then compared to those in the reference collections to make inferences about which taxa were being used, as well as where, how and why. This study presents an initial or baseline survey of phytolith types produced by selected taxa likely to have been used by Native American peoples, such as the Shoshone, Ute and Southern Paiute who were predominantly in Nevada and Utah, and different tribes in Oregon and western Nevada (ESM 1). The list of taxa which we sampled has illustrations of the phytolith morphotypes that we observed in a single sample from each taxon, with

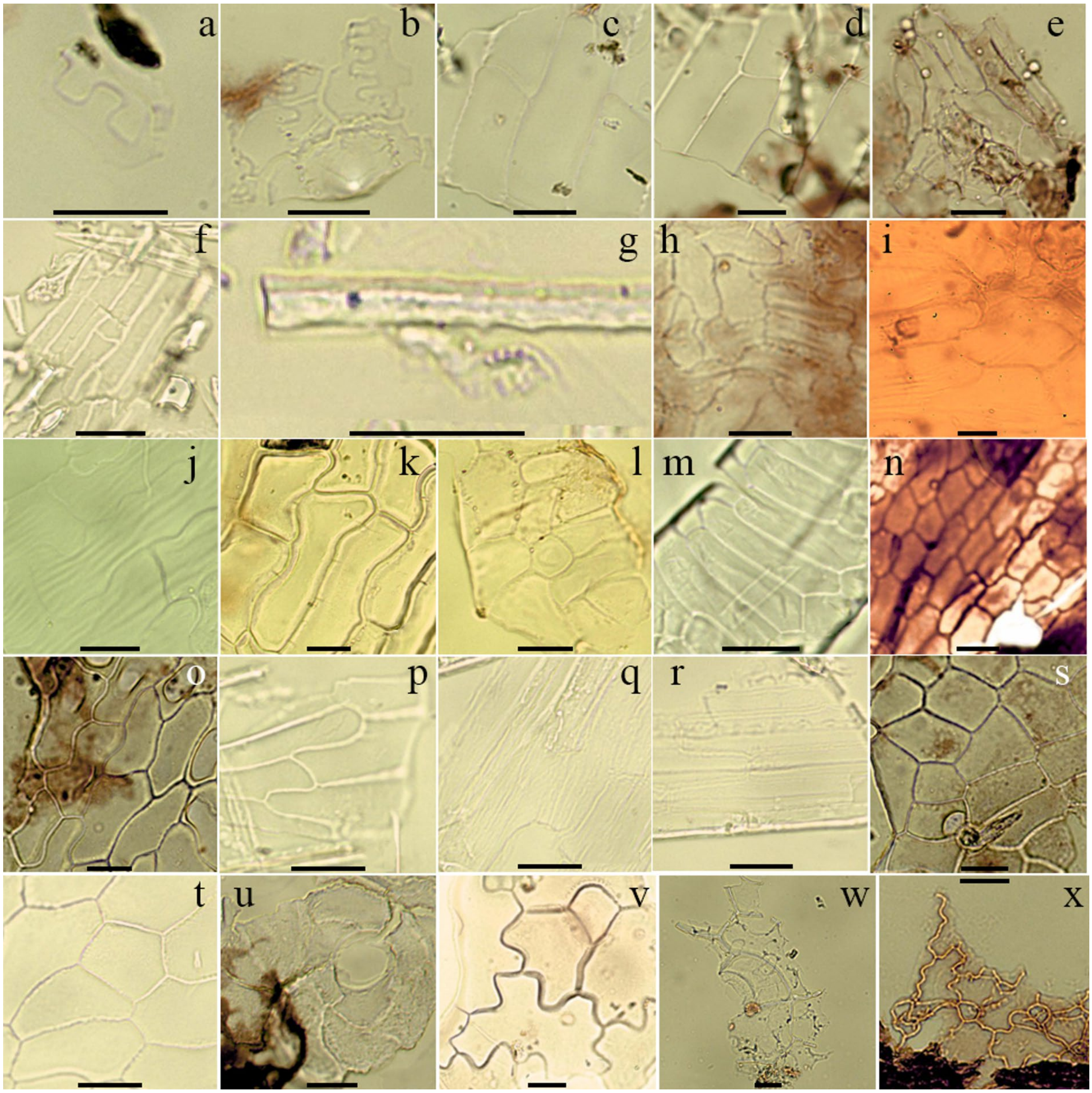

Fig. 2 Articulated epidermal phytoliths—ELONGATE psilate columnar/clavate: **a** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **b** *Elymus glaucus* Buckley; ELONGATE psilate entire/sinuate: **c** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **d** *Elymus glaucus* Buckley; **e** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller; **f** and **g** *Stipa hymenoides* Roem. & Schult.; ELONGATE/irregular psilate/striate entire/sinuate: **h** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller; **i** *Rhus aromatica* Aiton.; ELONGATE/OBLONG/irregular psilate entire/sinuate: **j** *Achillea millefolium* L.; **k** *Artemisia ludoviciana* Nutt; **l** *Artemisia tridentata* Nutt; **m** *Deschampsia cespitosa* (L.) P.Beauv; **n** *Juniperus communis* L; **o** *Rosa woodsii* Lindl.; **p** and **q** *Sporobolus airoides* (Torr.) Torr.; **r** *Stipa hymenoides* Roem. & Schult.; ELONGATE/polygonal psilate entire: **s** *Rosa woodsii* Lindl; **t** *Shepherdia argentea* (Pursh). Nutt. Irregular psilate/granulate sinuate: **u** *Sphaeralcea munroana* (Douglas ex Lindl.) Spach ex A.Gray; Irregular psilate sinuate: **v** *Artemisia dracunculus* L.; **w** *Eriogonum umbellatum* Torr.; **x** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller. Scale bars 20 µm

botanical nomenclature following Welsh et al. (2008) and The Plant List (2019). Our list of morphotypes described should be viewed as illustrative rather than exhaustive or diagnostic for any given taxon, as this is an initial survey. Still, it provides an important first step and baseline that we hope will invite further research and the development of robust reference collections based on replicate analyses of many samples.

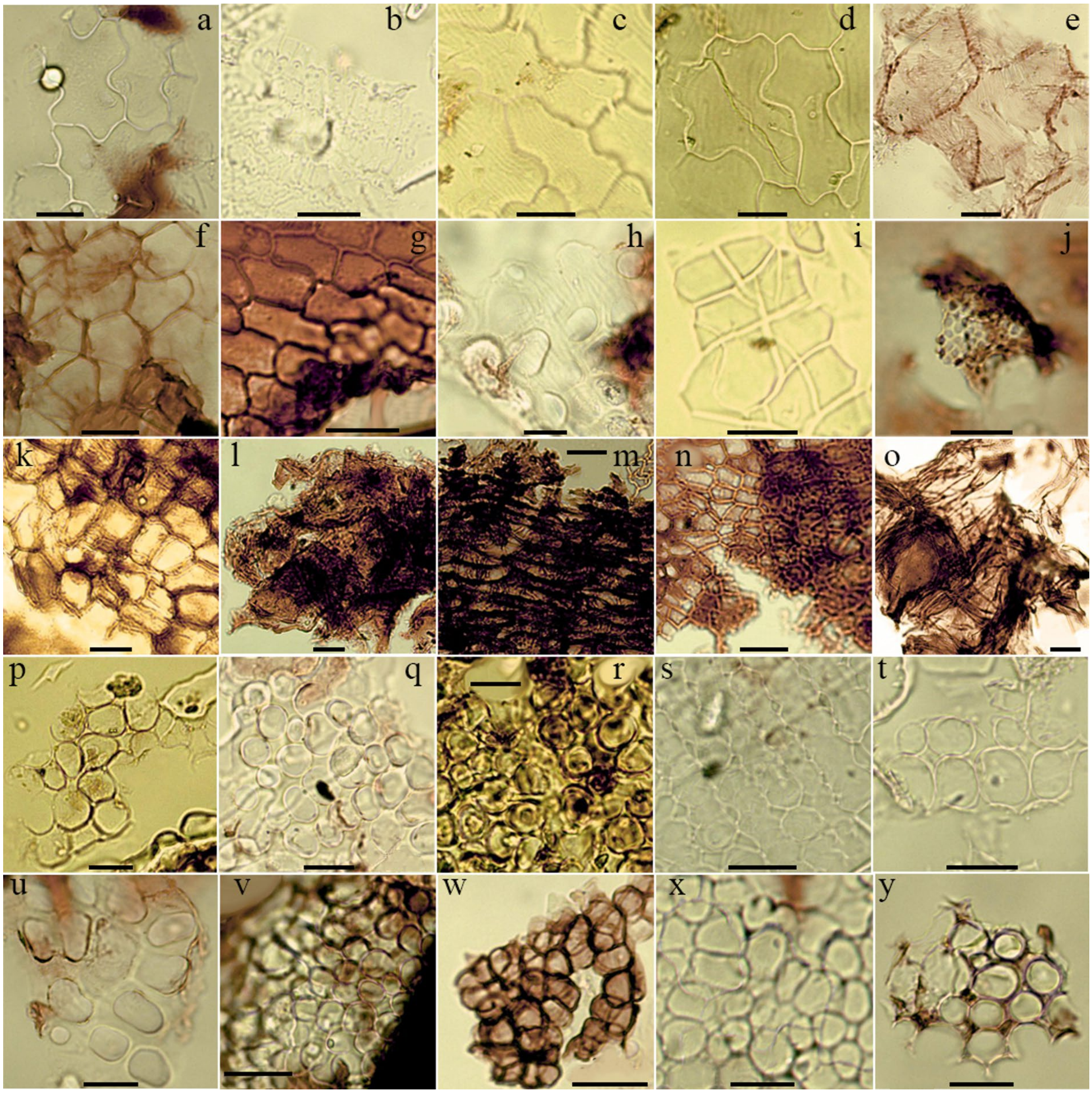

Fig. 3 Articulated epidermal, irregular and circular/ovate phytoliths—Irregular psilate sinuate: **a** *Prunus virginiana* L.; **b** *Sporobolus airoides* (Torr.) Torr.; Irregular striate sinuate: **c** *Artemisia biennis* Willd.; **d** *Artemisia dracunculus* L.; **e** *Hedysarum boreale* Nutt.; Irregular psilate sinuate/velloate/entire: **f** *Amelanchier utahensis* Koehne; **g** *Heliomeris multiflora* Nutt.; Irregular/circular/ovate striate sinuate/entire: **h** *Gutierezia sarothrae* (Pursh) Britton & Rusby.; Polygonal psilate entire: **i** *Artemisia dracunculus* L. Favose; **j** *Eriogonum umbellatum* Torr.; Irregular circular/ovate: **k** *Cercocarpus ledifolius* Nutt. ex Torr. & A.Gray; **l** *Eriogonum ovalifolium* Nutt.; **m** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller; **n** *Rhus aromatica* Aiton; **o** *Solanum jamesii* Torr.; Circular/ovate: **p** *Artemisia ludoviciana* Nutt; **q** *Artemisia tridentata* Nutt; **r** *Balsamhoriza sagittata* (Pursh) Nutt; **s** *Deschampsia cespitosa* (L.) P.Beauv; **t** *Festuca ovina* L.; **u** *Gutierezia sarothrae* (Pursh) Britton & Rusby; **v** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller; **w** *Pinus edulis* Engelm; **x** *Prunus virginiana* L.; **y** *Rhus aromatica* Aiton. Scale bars 20 µm

Methods

We made a list of 160 plant species native to the Great Basin that have documented ethnographic uses by the Shoshone tribe including the Goshute, the Southern Paiute and the Ute tribes (Pearce 2017). We collected various tissue samples from a single example of 52 of these listed taxa from botanical gardens, nurseries, herbariums and wildlife and recreation areas in both Utah and Salt Lake Counties and in the rest of the state of Utah (ESM 2). All non-herbarium samples were collected during the spring and summer of

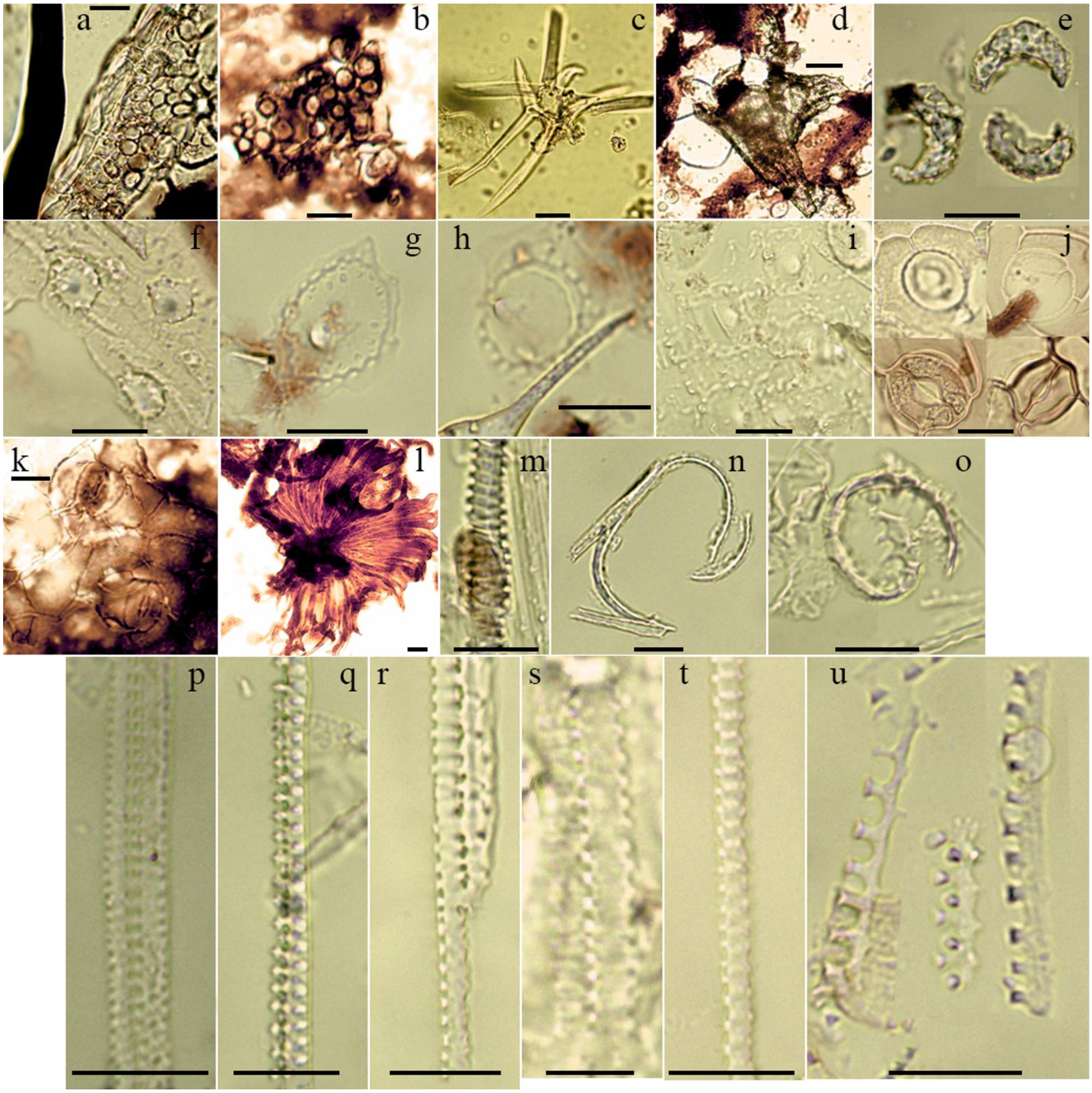

Fig. 4 Circular/ovate, Papillate, stomata, tracheary pitted and other phytoliths—Circular/ovate: **a** *Rosa woodsii* Lindl; **b** *Sphaeralcea munroana* (Douglas ex Lindl.) Spach ex A.Gray. Astrosclerid: **c** *Artemisia biennis* Willd.; **d** *Gutierezia sarothrae* (Pursh) Britton & Rusby.; Lunate granulate: **e** *Pinus edulis* Engelm.; papillate: **f** *Achillea millefolium* L.; **g** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **h** *Elymus glaucus* Buckley; **i** *Poa fendleriana* (Steud.) Vasey. Stomata: **j** *Artemisia dracunculus* L.; **k** *Sphaeralcea munroana* (Douglas ex Lindl.) Spach ex A.Gray.; Umbraculiform striate: **l** *Shepherdia argentea* (Pursh). Nutt.; tracheary pitted/annulate: **m** *Festuca ovina* L.; tracheary pitted curled: **n** *Deschampsia cespitosa* (L.) P.Beauv; **o** *Festuca ovina* L.; tracheary pitted: **p** *Deschampsia cespitosa* (L.) P.Beauv; **q** *Festuca ovina* L.; **r** *Poa fendleriana* (Steud.) Vasey; **s** *Sporobolus airoides* (Torr.) Torr.; **t** *Stipa hymenoides* Roem. & Schult.; tracheary pitted pilate: **u** *Achillea millefolium* L. Scale bars 20 µm, image d scale bar 50 µm

2015; all herbarium samples were collected during the winter of 2014. We failed to record voucher numbers for the specimens, but intend to do so in future studies and recommend this to other researchers. Tissue sample sizes ranged from a few leaves to an entire plant depending on access to the plant and sampling permission limits.

To prepare the material we used the acid digestion methods described by Portillo et al. (2006) to extract any

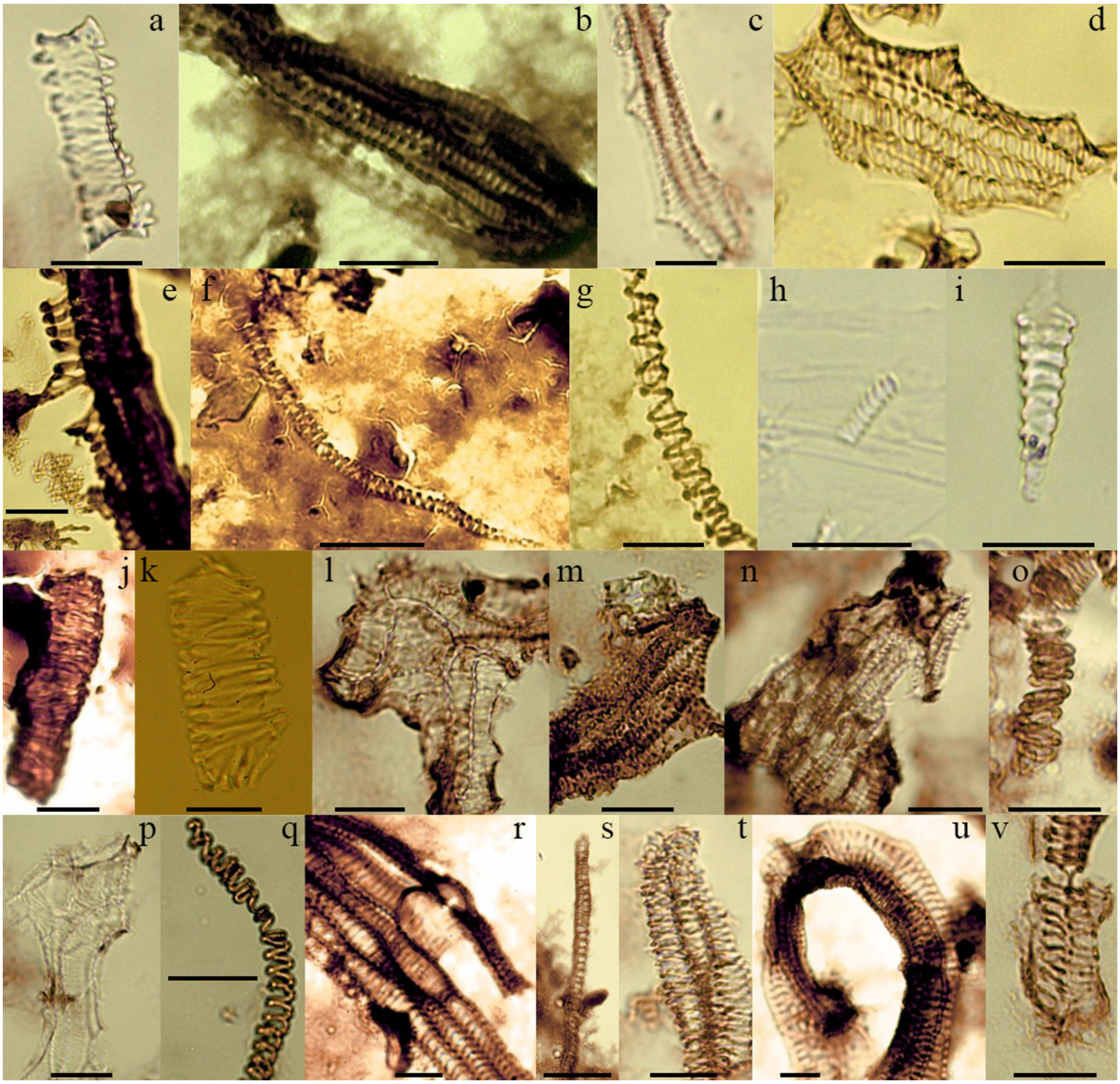

Fig. 5 TRACHEARY ANNULATE/HELICAL phytoliths—TRACHEARY ANNULATE/HELICAL: **a** *Achillea millefolium* L.; **b** *Amelanchier utahensis* Koehne; **c** *Artemisia dracunculus* L.; **d** *Artemisia ludoviciana* Nutt.; **e** *Artemisia tridentata* Nutt.; **f** *Balsamhoriza sagittata* (Pursh) Nutt.; **g** *Ericameria nauseosa* (Pall. ex Pursh) G.I.Nesom & G.I.Baird; **h** *Deschampsia cespitosa* (L.) P.Beauv; **i** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **j** *Ephedra nevadensis* S.Watson; **k** *Ephedra viridis* Coville; **l** *Eriogonum umbellatum* Torr.; **m** *Gutierezia sarothrae* (Pursh) Britton & Rusby; **n** *Holodiscus dumosus* (Nutt. ex Torr. & A.Gray) A.Heller; **o** *Opuntia polycantha* Haw.; **p** *Prunus virginiana* L.; **q** *Rhus aromatica* Aiton; **r** *Rosa woodsii* Lindl; **s** *Sarcobatus vermiculatus* (Hook.) Torr.; **t** *Shepherdia argentea* (Pursh). Nutt.; **u** *Solanum jamesii* Torr.; **v** *Solidago canadensis* L. Scale bars 20 µm

phytoliths from our samples of the 52 taxa. Various plant tissues or organs were processed separately to extract the phytoliths from each. For example, because the berries and leaves of *Shepherdia canadensis* (L.) Nutt. have different documented ethnographic uses, we processed both of them separately for phytoliths.

We found that some plant material was more difficult to digest than usual using the acid digestion method, so occasionally extra grinding and drying of the plant material was required before digestion, followed by repeated acid treatments to remove all the organic content. For example, the inflorescences of *Achillea millefolium* L. required two acid

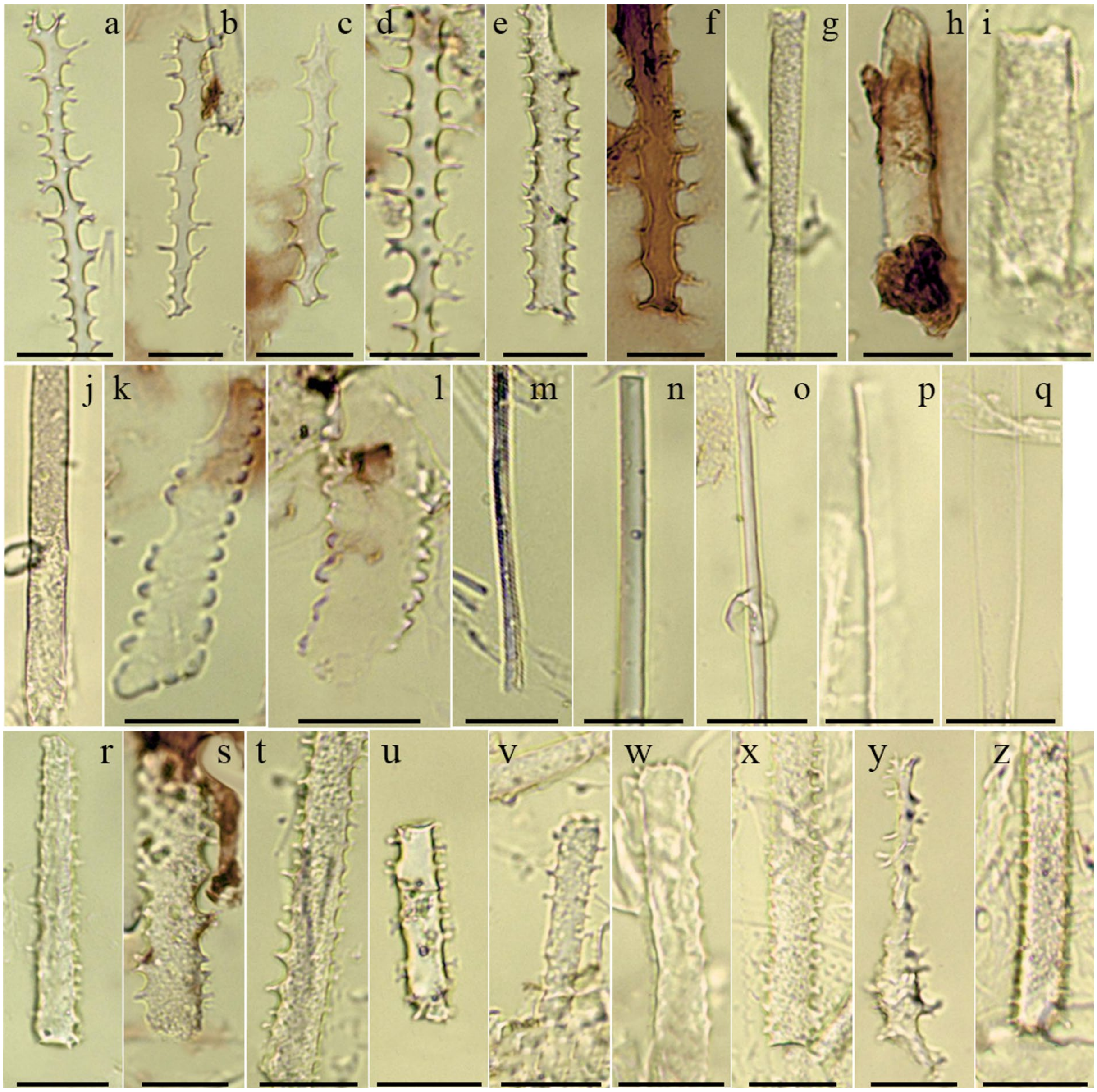

Fig. 6 ELONGATE phytoliths—ELONGATE DENDRITIC/DENTATE: **a**, **b** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **c**, **d** *Elymus glaucus* Buckley; **e** *Festuca ovina* L.; **f** *Pinus monophyla* Torr. & Frém.; ELONGATE entire granulate: **g** *Festuca ovina* L.; **h** *Gutierezia sarothrae* (Pursh) Britton & Rusby; **i** *Sporobolus airoides* (Torr.) Torr.; **j** *Stipa hymenoides* Roem. & Schult.; ELONGATE psilate columnar/clavate/sinuate: **k** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **l** *Elymus glaucus* Buckley; ELONGATE psilate entire: **m** *Deschampsia cespitosa* (L.) P.Beauv; **n** *Festuca ovina* L.; **o** *Poa fendleriana* (Steud.) Vasey; **p** *Sporobolus airoides* (Torr.) Torr.; **q** *Stipa hymenoides* Roem. & Schult.; ELONGATE psilate/granulate echinate/baculate: **r** *Deschampsia cespitosa* (L.) P.Beauv; **s** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **t** *Festuca ovina* L., **u**, **v** *Poa fendleriana* (Steud.) Vasey; **w**, **x** *Sporobolus airoides* (Torr.) Torr.; **y**, **z** *Stipa hymenoides* Roem. & Schult. Scale bars 20 µm

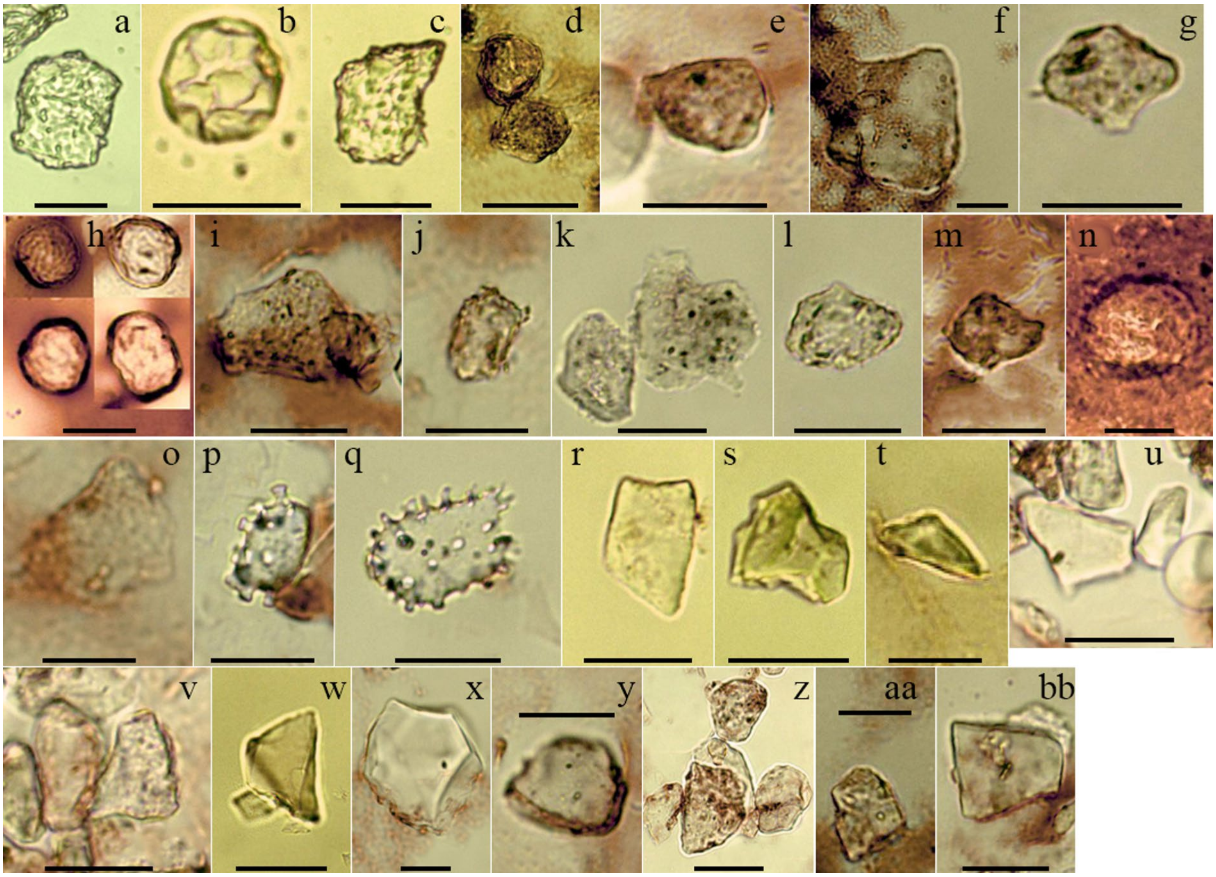

Fig. 7 SPHEROID and BLOCKY phytoliths—SPHEROID ORNATE/ellipsoidal granulate/plicate: **a** *Achillea millefolium* L.; **b** *Artemisia biennis* Willd.: **c** *Artemisia dracunculus* L.; **d** *Balsamhoriza sagittata* (Pursh) Nutt.; **e** *Ericameria nauseosa* (Pall. ex Pursh) G.I.Nesom & G.I.Baird; **f** *Eriogonum ovalifolium* Nutt; **g** *Gutierezia sarothrae* (Pursh) Britton & Rusby; **h** *Juniperus osteosperma* (Torr.) Little; **i** *Prunus virginiana* L.; **j** *Purshia tridentata* (Pursh) DC.; **k** *Rhus aromatica* Aiton; **l** *Ribes aureum* Pursh.; **m** *Shepherdia canadensis* (L.) Nutt; **n** *Solanum jamesii* Torr; **o** *Solidago canadensis* L.; SPHEROID ORNATE/ellipsoidal baculate/pilate: **p** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **q** *Elymus glaucus* Buckley; BLOCKY/tabular/irregular psilate/granulate: **r** *Artemisia ludoviciana* Nutt.; **s** *Artemisia tridentata* Nutt.; **t** *Atriplex truncata* (Torr.) A.Gray; **u**, **v** *Ericameria nauseosa* (Pall. ex Pursh) G.I.Nesom & G.I.Baird; **w** *Crataegus douglasii* Lindl.; **x** *Ephedra nevadensis* S.Watson; **y** *Eriogonum umbellatum* Torr; **z** *Opuntia polycantha* Haw.; **aa** *Purshia mexicana* (D.Don) Henr.; **bb** *Purshia tridentata* (Pursh) DC. Scale bars 20 µm

treatments for complete digestion, while the leaves of *S. canadensis* required three. We assumed that multiple acid treatments would not affect the observed phytolith production index (PI), but further tests should be conducted to confirm this assumption.

We also found it helpful to sonicate the plant material in a mild cleaning solution such as Teepol before acid treatment to remove contaminants such as terrestrial diatoms, dust and other debris that may have adhered to the outer surfaces of the sample, for 5 min using a Mettler Cavitator ultrasonic cleaner. Then the plant material was rinsed by placing it in a clean beaker and sonicating for an additional 5 min in distilled water. Any required grinding or drying followed the sonication before beginning the acid treatment. Sonication did not, we assume, affect the relative abundances of phytoliths observed, but this assumption should be tested in the future.

The phytoliths extracted from the samples were mounted on glass slides under a cover slip using Permount, for light microscope analysis. We used either a Zeiss Axiovert 135 or a Nikon Optiphot 2 light microscope with an attached Infinity 2 camera at magnifications of

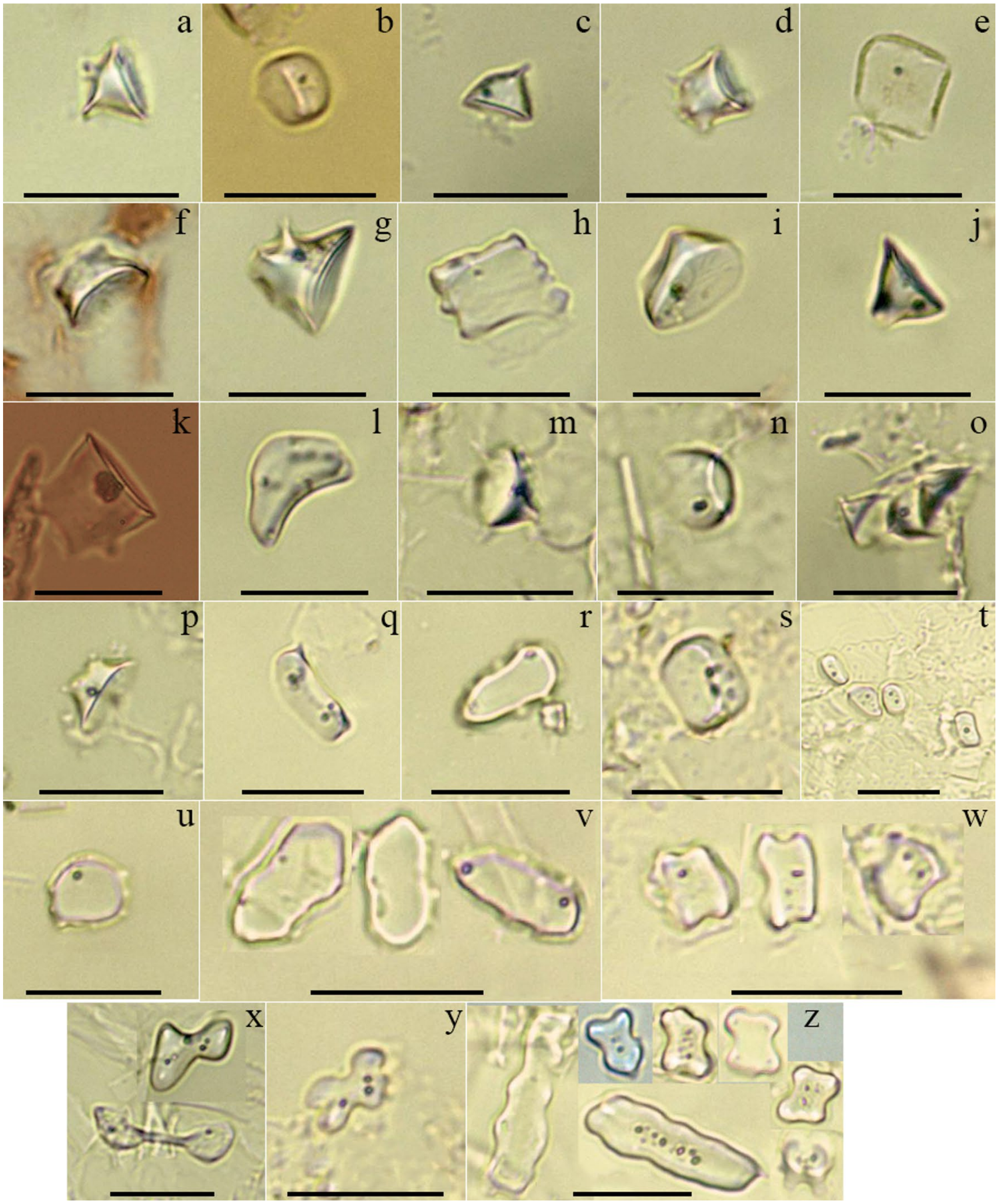

Fig. 8 Grass Silica Short Cell Phytoliths (GSSCP)—RONDEL: **a**–**e** *Deschampsia cespitosa* (L.) P.Beauv; **f**–**h** *Leymus cinereus* (Scribn. & Merr.) Á.Löve; **i**–**l** *Elymus glaucus* Buckley; **m**–**p** *Festuca ovina* L.; **q**–**s** *Poa fendleriana* (Steud.) Vasey; **t** *Sporobolus airoides* (Torr.) Torr.; **u**, **v** *Stipa hymenoides* Roem. & Schult.; SADDLE: **w** *Sporobolus airoides* (Torr.) Torr.; BILOBATE/CROSS/POLYLOBATE/ELONGATE: **x** *Deschampsia cespitosa* (L.) P.Beauv; **y** *Poa fendleriana* (Steud.) Vasey; **z** *Sporobolus airoides* (Torr.) Torr. Scale bars 20 µm

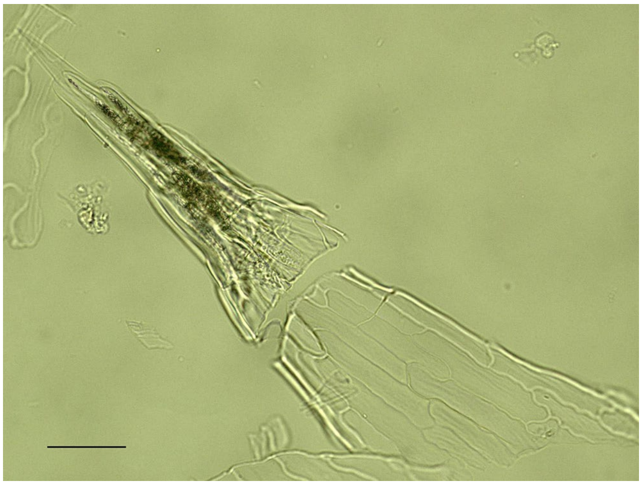

Fig. 9 *Achillea millefolium* L. ACUTE crassus psilate and ELONGATE/OBLONG/irregular psilate entire/sinuate. This figure demonstrates that these two phytoliths, although broken apart, were once connected while on the plant. Scale bar 50 µm

×100, ×200, or ×400 to identify and collect images of the phytolith morphotypes produced by each taxon. All morphotypes are described using the International Code for Phytolith Nomenclature 2.0 (ICPN 2.0) (Neumann et al. 2019) and the International Code for Phytolith Nomenclature 1.0 (ICPN 1.0) (Madella et al. 2005). We primarily relied upon ICPN 2.0, which will be published soon and replaces ICPN 1.0.

Results

Of the 52 plant species that we analysed (ESM 1), we found that 24 contained identifiable phytolith morphotypes, 21 had less distinctive vascular tissue phytolith types and seven had no phytoliths (Figs. 1, 2, 3, 4, 5, 6, 7, 8, and 9). Again, we note that because we sampled only a single specimen of each taxon, our findings should be considered illustrative rather than exhaustive or diagnostic for the types and numbers of phytoliths produced within the taxa. Further detailed studies of each taxon that include quantified samples of many specimens will likely provide a better range of variability, but we assume the most common morphotypes likely to be produced by our selected taxa are included in this study.

Tables 1, 2, and 3 list the results of our analysis of phytolith morphotypes produced by each taxon grouped by plant life form, forbs, trees and shrubs and grasses (Utah State University 2017). Following the ICPN 2.0 format (Neumann et al. 2019), all standard morphotype names currently recognized by the ICPN are written in small capitals. In ICPN 2.0 "phytoliths that exhibit features of two closely related morphotypes may bear combined names with descriptors separated by a slash", so for example, the morphotype ELONGATE DENTATE/DENDRITIC would indicate an elongated phytolith with processes that range from dentate or toothed to dendritic or branched; for a discussion of the factors that determine process shape in ELONGATE, see ICPN 2.0. We also include in each table an initial estimate of the relative abundance or production index (PI) of each phytolith morphotype which was calculated by scanning the sample slides and using a variation of the coding system described by Wallis (2003) and McCune (2013), as follows.

- Non-producer (NP): no phytoliths observed
- Rare (R): one or two examples of the phytolith morphotype observed on an entire slide
- Uncommon (U): 3–30 of the phytolith morphotype per slide
- Common (C): 30–100 per slide
- Abundant (A): more than 100 per slide

In the ESM, we briefly review the range of plant communities in which each taxon in our study is likely to grow, as well as some of the growth habits and ways in which the taxa were historically used by Great Basin Native Americans.

Forbs

We analysed 14 forbs, non-graminoid herbaceous flowering plants (Table 1). Two, *Fragaria vesca* L. and *Typha latifolia* L., were non-producers of phytoliths. The morphotypes we observed most frequently in the other forbs comprising our sample were various epidermal, SPHEROID ORNATE and ACUTE trichome phytoliths. None of the morphotypes observed in the forbs were unique to any taxon.

Trees and shrubs

Thirty-one of the plants sampled for this study were trees and shrubs (Table 2). Five species produced no phytoliths. The phytoliths that were produced most frequently were TRACHEARY ANNULATE/HELICAL and SPHEROID ORNATE types. A lack of silicification in woody plants has been noted by others (Morris 2008).

Grasses

Seven grass species were analysed (Table 3). Grasses typically produce short-cell and long-cell phytoliths. Five of the grass species that we tested are in the Pooideae subfamily.

Table 1 Forbs, phytolith morphotypes observed, production indices (PI), and figure references for each species analysed

Species	Tissue type	Phytolith morphotypes observed	PI	Fig.
Achillea millefolium	Inflorescence	PAPILLATE	Uncommon	4f
(see also Fig. 9)		SPHEROID ORNATE/ellipsoidal/granulate/plicate	Uncommon	7a
		TRACHEARY ANNULATE/HELICAL	Uncommon	5a
		TRACHEARY PITTED psilate	Common	4u
	Leaves	ACUTE crassus psilate	Common	1b
		ELONGATE/oblong/irregular psilate entire/sinuate	Common	2j
		SPHEROID ORNATE/ellipsoidal/granulate/plicate	Common	7a
		TRACHEARY ANNULATE/HELICAL	Common	5a
Artemisia biennis	Florets	Astrosclerid	Uncommon	4c
		Irregular clavate/columnar psilate	Uncommon	-
		Irregular striate sinuate	Common	3c
		SPHEROID ORNATE/ellipsoidal/granulate/plicate	Uncommon	7b
		TRACHEARY ANNULATE/HELICAL	Uncommon	-
Artemisia dracunculus	Leaves	ACUTE gracile striate/granulate	Uncommon	1m
		Irregular clavate/columnar psilate	Uncommon	-
		Irregular psilate sinuate	Uncommon	2v
		Irregular striate sinuate	Common	3d
		Polygonal psilate entire	Uncommon	3i
		SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7c
		Stomata	Uncommon	4j
		TRACHEARY ANNULATE/HELICAL	Common	5c
	New growth	Irregular striate sinuate	Uncommon	3d
Artemisia ludoviciana	Inflorescence	TRACHEARY ANNULATE/HELICAL	Common	5d
	Leaves	BLOCKY/tabular/irregular psilate/granulate	Common	7r
		ELONGATE/oblong/irregular psilate entire/sinuate	Common	2k
		Circular/ovate	Uncommon	3p
		TRACHEARY ANNULATE/HELICAL	Common	5d
Balsamorhiza sagittata	Inflorescence	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7d
		TRACHEARY ANNULATE/HELICAL	Uncommon	5f
	Leafy tops	ACUTE gracile psilate/granulate segmented	Common	1k
		Circular/ovate	Uncommon	3r
		SPHEROID ORNATE plicate/facetate	Uncommon	-
Eriogonum ovalifolium	Roots	Irregular circular/ovate	Uncommon	3l
	Leaves	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7f
Eriogonum umbellatum	Leaves	BLOCKY/tabular/irregular psilate/granulate	Common	7y
		Favose	Uncommon	3j
		Irregular psilate sinuate	Uncommon	2w
		TRACHEARY ANNULATE/HELICAL	Uncommon	5l
Fragaria vesca	Berries	None observed		-
Hedysarum boreale	Roots	Irregular striate sinuate	Rare	3e
Heliomeris multiflora	Inflorescence	ACUTE BULBOSIS/psilate segmented	Uncommon	1p
		Irregular psilate sinuate/velloate/entire	Uncommon	3g
		TRACHEARY ANNULATE/HELICAL	Uncommon	-
Solanum jamesii	Leaves	Irregular circular/ovate	Uncommon	3o
		SPHEROID ORNATE plicate/facetate	Uncommon	-
		SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7n
		TRACHEARY ANNULATE/HELICAL	Uncommon	5u
	Tubers	TRACHEARY ANNULATE/HELICAL	Rare	5u
Solidago canadensis	Inflorescence	ACUTE gracile psilate/granulate segmented	Uncommon	1l
		Irregular circular/ovate	Uncommon	-
		SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7o
		TRACHEARY ANNULATE/HELICAL	Uncommon	5v
Sphaeralcea munroana	Leaves	Irregular psilate/granulate sinuate	Uncommon	2u
		Irregular striate entire	Uncommon	-
		Circular/ovate	Uncommon	4b
		Stomata	Uncommon	4k
		TRACHEARY ANNULATE/HELICAL	Uncommon	-
Typha latifolia	Entire stalk	None observed		

Table 2 Shrubs and trees, phytolith morphotypes observed, production indices (PI) and figure references

Species	Form	Tissue	Phytolith	PI	Figures
Abies concolor	Tree	Needles	None	–	–
Amelanchier alnifolia	Shrub/tree	Berries	ACUTE gracile psilate	Uncommon	1g
Amelanchier utahensis	Shrub/tree	Berries	TRACHEARY ANNULATE/HELICAL	Uncommon	5b
		Wood	TRACHEARY ANNULATE/HELICAL	Uncommon	5b
		Wood	Irregular psilate sinuate/velloate/entire	Common	3f
Arctostaphylos patula	Shrub	Leaves	None observed		–
Artemisia tridentata	Shrub	Inflorescence	BLOCKY/tabular/irregular plicate/granulate	Common	7s
		Inflorescence	TRACHEARY ANNULATE/HELICAL	Uncommon	5e
		Leaves	BLOCKY/tabular/irregular plicate/granulate	Uncommon	7s
		Leaves	ELONGATE/oblong/irregular psilate entire/sinuate	Uncommon	2l
		Leaves	Circular/ovate	Rare	3q
		Twigs	Irregular circular/ovate	Common	–
Atriplex truncata	Shrub	Inflorescence	BLOCKY/irregular/tabular psilate	Uncommon	–
		Inflorescence	BLOCKY/tabular/irregular psilate/granulate	Uncommon	7t
		Inflorescence	TRACHEARY ANNULATE/HELICAL	Common	–
Cercocarpus ledifolius	Shrub/tree	Leaves	None observed		–
		Wood	Irregular circular/ovate	Uncommon	3k
Crataegus douglasii	Tree	Berry	BLOCKY/tabular/irregular psilate/granulate	Uncommon	7w
			Irregular vascular	Uncommon	–
Ephedra nevadensis	Shrub	Green stems	BLOCKY/tabular/irregular psilate/granulate	Uncommon	7x
		Green stems	TRACHEARY ANNULATE/HELICAL	Common	5j
		Wood twigs	None observed		–
Ephedra viridis	Shrub	Green stems	TRACHEARY ANNULATE/HELICAL	Common	5k
		Wood twigs	BLOCKY/irregular/tabular psilate	Uncommon	–
		Wood twigs	SPHEROID ORNATE granulate/plicate	Uncommon	–
Ericameria nauseosa	Shrub	Inflorescence and leaves	BLOCKY/tabular/irregular psilate/granulate	Common	7u, v
		Inflorescence and leaves	SPHEROID ORNATE/ellipsoidal granulate/plicate	Common	7e
		Inflorescence and leaves	TRACHEARY ANNULATE/HELICAL	Common	5g
Gutierezia sarothrae	Shrub	Leafy tops	Astrosclerid	Rare	4d
		Leafy tops	ELONGATE entire granulate	Uncommon	6h
		Leafy tops	Irregular/circular/ovate striate sinuate/entire	Uncommon	3h
		Leafy tops	Circular/ovate	Uncommon	3u
		Leafy tops	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7g
		Leafy tops	TRACHEARY ANNULATE/HELICAL	Uncommon	5m
Holodiscus dumosus	Shrub	Inflorescence	ACUTE gracile psilate/granulate	Common	1j
		Inflorescence	Irregular circular/ovate	Uncommon	3m
		Leaves	ACUTE gracile psilate/granulate	Uncommon	1j
		Leaves	ELONGATE psilate entire/sinuate	Uncommon	2e
		Leaves	ELONGATE/irregular psilate/striate entire/sinuate	Uncommon	2h
		Leaves	Irregular psilate sinuate	Uncommon	2x
		Leaves	Circular/ovate	Uncommon	3v
		Leaves	TRACHEARY ANNULATE/HELICAL	Uncommon	5n
Juniperus communis	Shrub/tree	Twigs	None observed		–
		New growth	ELONGATE/oblong/irregular psilate entire/sinuate	Rare	2n
		New growth	TRACHEARY ANNULATE/HELICAL	Rare	–
Juniperus osteosperma	Tree	Berries	TRACHEARY ANNULATE/HELICAL	Uncommon	–
		Leaves	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7h
Juniperus scoporulum	Shrub/tree	Twigs	None observed		–
Opuntia polycantha	Shrub	Bud	TRACHEARY ANNULATE/HELICAL	Common	5o
		Bud	Irregular circular/ovate	Uncommon	–

Table 2 (continued)

Species	Form	Tissue	Phytolith	PI	Figures
		Pad	TRACHEARY ANNULATE/HELICAL	Uncommon	5o
		Spines/hairs	BLOCKY/tabular/irregular psilate/granulate	Uncommon	7z
Pinus edulis	Tree	Needles	None observed		–
		Nuts	Lunate granulate	Uncommon	4e
		Sap	None observed		–
		Twigs	Circular/ovate	Uncommon	3w
Pinus flexilis	Tree	Seeds	TRACHEARY ANNULATE/HELICAL	Uncommon	–
Pinus monophylla	Tree	Resin	None observed		–
		Needles	ELONGATE DENDRITIC/DENTATE	Uncommon	6f
		Needles	TRACHEARY ANNULATE/HELICAL	Uncommon	–
Prunus virginiana	Shrub/tree	Berries	Irregular circular/ovate	Common	–
		Leaves	Irregular psilate sinuate	Common	3a
		Leaves	Irregular circular/ovate	Common	–
		Leaves	Circular/ovate	Common	3x
		Leaves	TRACHEARY ANNULATE/HELICAL	Common	5p
		Roots	SPHEROID ORNATE/ellipsoidal granulate/plicate	Common	7i
		Roots	Irregular circular/ovate	Common	–
Purshia mexicana	Shrub/tree	Inflorescence	None observed		–
		Leaves	BLOCKY/tabular/irregular psilate/granulate	Rare	7aa
		Leaves	Irregular circular/ovate	Uncommon	–
Purshia tridenta	Shrub	Leaves	BLOCKY/tabular/irregular psilate/granulate	Uncommon	7bb
		Leaves	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7j
Rhus aromatica	Shrub/tree	Berries	Irregular circular/ovate	Uncommon	3n
		Berries	Circular/ovate	Uncommon	3y
		Leaves	ELONGATE/irregular psilate/striate entire/sinuate	Uncommon	2i
		Leaves	SPHEROID ORNATE/ellipsoidal/granulate plicate	Uncommon	7k
		Leaves	TRACHEARY ANNULATE/HELICAL	Uncommon	5q
		Leaves	Circular/ovate	Uncommon	3y
Ribes aureum	Shrub	Berries	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7l
Rosa woodsii	Shrub	Berries	SPHEROID ORNATE/irregular plicate/granulate	Uncommon	–
		Leaves	ELONGATE/OBLONG/irregular psilate entire/sinuate	Common	2o
		Leaves	ELONGATE/polygonal psilate entire	Common	2s
		Leaves	TRACHEARY ANNULATE/HELICAL	Common	5r
		Leaves	Circular/ovate	Uncommon	4a
Sambucus cerulea	Shrub	Berries	None observed		–
Sambucus racemosa	Shrub	Berries	None observed		–
Sarcobatus vermiculatus	Shrub	Leaves	BLOCKY/polyhedral psilate	Uncommon	–
		Leaves	TRACHEARY ANNULATE/HELICAL	Uncommon	5s
Shepherdia argentea	Tree	Berries	ELONGATE psilate entire	Rare	–
		Berries	Umbraculiform striate	Common	4l
		Leaves	ELONGATE/polygonal psilate entire	Uncommon	2t
		Leaves	TRACHEARY ANNULATE/HELICAL	Uncommon	5t
		Leaves	Umbraculiform striate	Uncommon	4l
Shepherdia canadensis	Shrub	Berries	BLOCKY/tabular/irregular psilate/granulate	Uncommon	–
		Leaves	SPHEROID ORNATE/ellipsoidal granulate/plicate	Uncommon	7m
		Leaves	TRACHEARY ANNULATE/HELICAL	Uncommon	–

Table 3 Grasses, phytolith morphotypes observed, production indices (PI) and figure references

Species	Sub-fam., tribe	Phytolith	PI	Figures
Deschampsia cespitosa	Pooideae	ACUTE crassus psilate	Uncommon	1c
		BILOBATE/CROSS/POLYLOBATE/ELONGATE	Uncommon	8x
		ELONGATE psilate entire	Common	6m
		ELONGATE psilate/granulate/echinate/baculate	Common	6r
		ELONGATE/oblong psilate sinuate	Uncommon	–
		ELONGATE/oblong/irregular psilate entire/sinuate	Common	2m
		Hair base	Uncommon	–
		Circular/ovate	Uncommon	3s
		RONDEL	Common	8a–e
		TRACHEARY ANNULATE/HELICAL	Uncommon	5h
		TRACHEARY PITTED	Common	4p
		TRACHEARY PITTED curled	Common	4n
Elymus glaucus	Pooideae	ACUTE BULBOSIS echinate	Common	1o
		ACUTE crassus psilate	Common	1e
		ELONGATE DENDRITIC/DENTATE	Abundant	6c
		ELONGATE DENDRITIC/DENTATE	Common	6d
		ELONGATE psilate columnar/clavate	Uncommon	2b
		ELONGATE psilate columnar/clavate/sinuate	Common	6l
		ELONGATE psilate entire/sinuate	Uncommon	2d
		PAPILLATE	Common	4h
		RONDEL	Common	8i–l
		SPHEROID ORNATE/ellipsoidal baculate/pilate	Common	7q
Festuca ovina	Pooideae	ACUTE gracile psilate	Common	1h
		ELONGATE DENDRITIC/DENTATE	Abundant	6e
		ELONGATE entire granulate	Common	6g
		ELONGATE psilate entire	Common	6n
		ELONGATE psilate/granulate echinate/baculate	Common	6t
		hair base	Uncommon	–
		circular/ovate	Uncommon	3t
		RONDEL	Uncommon	8m–p
		TRACHEARY ANNULATE/HELICAL	Uncommon	–
		TRACHEARY PITTED	Uncommon	4q
		TRACHEARY PITTED/ANNULATE	Common	4m
		TRACHEARY PITTED curled	Abundant	4o
Leymus cinereus	Pooideae	ACUTE BULBOSIS echinate	Uncommon	1n
		ACUTE crassus psilate	Uncommon	1d
		ACUTE gracile psilate echinate	Uncommon	1i
		ELONGATE DENDRITIC/DENTATE	Abundant	6a
		ELONGATE DENDRITIC/DENTATE	Common	6b
		ELONGATE psilate columnar/clavate	Common	2a
		ELONGATE psilate columnar/clavate/sinuate	Uncommon	6k
		ELONGATE psilate entire/sinuate	Uncommon	2c
		ELONGATE psilate/granulate echinate/baculate	Uncommon	6s
		Hair base	Uncommon	–
		PAPILLATE	Common	4g
		RONDEL	Common	8h
		SPHEROID ORNATE/ellipsoidal baculate/pilate	Uncommon	7p
		TRACHEARY ANNULATE/HELICAL	Uncommon	5i
Poa fendleriana	Pooideae	ACUTE BULBOSIS echinate	Common	–
		ACUTE crassus granulate	Common	1a

Table 3 (continued)

Species	Sub-fam., tribe	Phytolith	PI	Figures
		BILOBATE/CROSS/POLYLOBATE/ELONGATE	Uncommon	8y
		ELONGATE psilate columnar/clavate/sinuate	Common	–
		ELONGATE psilate entire	Common	6o
		ELONGATE psilate/granulate echinate/baculate	Common	6u–v
		PAPILLATE	Uncommon	4i
		RONDEL	Common	8q–s
		TRACHEARY ANNULATE/HELICAL	Uncommon	–
		TRACHEARY PITTED	Common	4r
Sporobolus airoides	Chloridoideae	BILOBATE/CROSS/POLYLOBATE/ELONGATE	Common	8z
		ELONGATE entire granulate	Abundant	6i
		ELONGATE psilate entire	Abundant	6p
		ELONGATE psilate/granulate echinate/baculate	Abundant	6w, x
		ELONGATE/oblong/irregular psilate entire/sinuate	Common	2p, q
		irregular psilate sinuate	Common	3b
		RONDEL	Common	8t
		SADDLE	Common	8w
		TRACHEARY ANNULATE/HELICAL	Uncommon	–
		TRACHEARY PITTED	Abundant	4s
Stipa hymenoides	Stipeae	ACUTE acicular granulate	Common	–
		ACUTE crassus psilate	Common	1f
		ELONGATE entire granulate	Common	6j
		ELONGATE psilate columnar/clavate/sinuate	Common	–
		ELONGATE psilate entire	Common	6q
		ELONGATE psilate entire/sinuate	Common	2f, g
		ELONGATE psilate/granulate echinate/baculate	Uncommon	6y, z
		ELONGATE/OBLONG/oblong/irregular psilate/entire sinuate	Uncommon	2r
		Hair base	Common	–
		RONDEL	Abundant	8u, v
		TRACHEARY ANNULATE/HELICAL	Uncommon	–
		TRACHEARY PITTED	Common	4t

Discussion and conclusions

Monocots are known to be the most abundant producers of phytoliths, followed by forbs and woody plants (Pearsall 1989, pp. 360–374). Our findings followed this paradigm. Generally, we found that grasses and forbs were the most common and abundant producers of phytoliths, while shrubs and trees were often non-producers or rare and uncommon producers of phytoliths. Moreover, root and woody samples rarely produced any distinctive phytolith morphotypes. These findings were expected. Accordingly, because some taxa, tissue types, or plant life-forms are underrepresented in the phytolith record, researchers using this reference collection should not attempt to use it to compare the usage of any particular plant life-form to another, or to conduct quantitative analysis. But again, we hope this reference collection will provide a good starting point for any researchers conducting analysis of archaeological phytoliths recovered from Great Basin Native American sites. Such analyses should supplement this reference collection with those of other native wild taxa that grow around the site to assure that similar phytolith morphotypes produced by unused native taxa are not confused for those produced by plants that were used.

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