

ANTHROPOLOGY

The origins of cannabis smoking: Chemical residue evidence from the first millennium BCE in the Pamirs

Meng Ren^{1,2}, Zihua Tang³, Xinhua Wu⁴, Robert Spengler⁵, Hongen Jiang², Yimin Yang^{2,5*}, Nicole Boivin^{5,6}

Cannabis is one of the oldest cultivated plants in East Asia, grown for grain and fiber as well as for recreational, medical, and ritual purposes. It is one of the most widely used psychoactive drugs in the world today, but little is known about its early psychoactive use or when plants under cultivation evolved the phenotypical trait of increased specialized compound production. The archaeological evidence for ritualized consumption of cannabis is limited and contentious. Here, we present some of the earliest directly dated and scientifically verified evidence for ritual cannabis smoking. This phytochemical analysis indicates that cannabis plants were burned in wooden braziers during mortuary ceremonies at the Jirzankal Cemetery (ca. 500 BCE) in the eastern Pamirs region. This suggests cannabis was smoked as part of ritual and/or religious activities in western China by at least 2500 years ago and that the cannabis plants produced high levels of psychoactive compounds.

INTRODUCTION

Mind-altering plants can produce various altered states of consciousness and have thus played important roles in ritual and/or religious activities in various areas of the world (1–4). In prehistoric and early historic Central Eurasia, many plants were used for their secondary compounds, and several are still in prominent use today, notably the opium poppy (*Papaver somniferum*), ephedra (*Ephedra* spp.), and cannabis (*Cannabis sativa*). Plants in the *Cannabis* genus represent a hybrid complex, with ongoing controversy relating to taxonomy; the lack of taxonomic clarity combined with continual gene flow between wild and domesticated populations has hampered attempts to study the origins and dispersal of this plant (5, 6). Wild cannabis grows across many of the cooler mountain foothills from the Caucasus to western China, especially in the well-watered habitats of Central Asia. However, cannabidiol (CBN) levels in most wild cannabis plant populations are low, and it remains a largely unanswered question as to when, where, and how the plant was first cultivated for higher psychoactive tetrahydrocannabinol (THC) production (6). Little is known about the prehistoric use of cannabis outside eastern China, where it was domesticated as an oil-seed crop (7, 8). While recent well-reported and photographed cannabis macroremains have been recovered from burials in the Turpan Basin (ca. 800 to 400 BCE) in northwest China, suggesting shamanic or medicinal uses (9, 10), these discoveries do not adequately reveal how the cannabis plant was used.

Historically, cannabis plants used for ritual and medicinal purposes involved oral ingestion or inhaling the smoke or vapors produced by burning the dried plant. Smoking is defined as the act of inhaling and exhaling the fumes of burning plant material (11) and is today

often associated with cigarettes, cigars, and pipes. However, smoking pipes were likely introduced to Eurasia from the New World (12), and no clear evidence exists for them in Central Asia before the modern era. The practice of smoking or inhaling cannabis fumes in ritual and recreational activities was documented in Herodotus' fifth-century BCE *The Histories* (13) and was supported by the discovery of carbonized hemp seeds in burials from a handful of sites in Eurasia (1, 14, 15). However, most of the archaeological reports of ancient drug remains were published several decades ago, and re-examination of some of these reports has led to the claims being refuted (discussed below). Modern scientific studies are thus needed to corroborate the remaining reports. Here, we investigated residues from archaeological artifacts recovered in the Pamir Mountains (Fig. 1), a region that served as an important culture communication channel through Eurasia, linking ancient populations in the modern regions of China, Tajikistan, and Afghanistan. The chemical analysis reveals ancient cannabis burning and suggests high levels of psychoactive chemicals, indicating that people may have been cultivating cannabis and possibly actively selecting for stronger specimens or choosing plant populations with naturally high terpenophenolic secondary metabolites (6). Alternatively, a process of domestication through hybridization between wild and cultivated subspecies may have inadvertently led to stronger chemical-producing plants through human dispersal and subsequent selection (7).

Ten wooden braziers, containing stones with obvious burning traces, were recently exhumed from eight tombs at the Jirzankal Cemetery (also known as Quman Cemetery) on the Pamir Plateau (Figs. 2 and 3). These wooden burners were not associated with any macrobotanical remains, and their immediate use was not clear. The Jirzankal Cemetery dates to approximately 2500 years ago (16) and contains material culture that links the occupants to peoples further west in the mountain foothills. The cemetery is characterized by designs on the landscape made of black and white stones arranged in long strips, which mark the tombs' surfaces, and by circular mounds with one or two rings of stones underneath (Fig. 2, B and C) (16). The stone rings and burial mounds find parallels in the mortuary practices of contemporaneous populations in the mountains of Central Asia; however, the rows of stones are unique to this area. Linkages in burial forms between first millennium BCE peoples in

¹Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, P. R. China. ²Department of Archaeology and Anthropology, University of Chinese Academy of Sciences, Beijing 100049, P. R. China. ³Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, P. R. China. ⁴Institute of Archaeology, Chinese Academy of Social Sciences, Beijing 100710, P. R. China. ⁵Department of Archaeology, Max Planck Institute for the Science of Human History, Jena 07745, Germany. ⁶School of Social Science, The University of Queensland, Brisbane, Queensland 4072, Australia.

*Corresponding author. Email: yiminyang@ucas.ac.cn

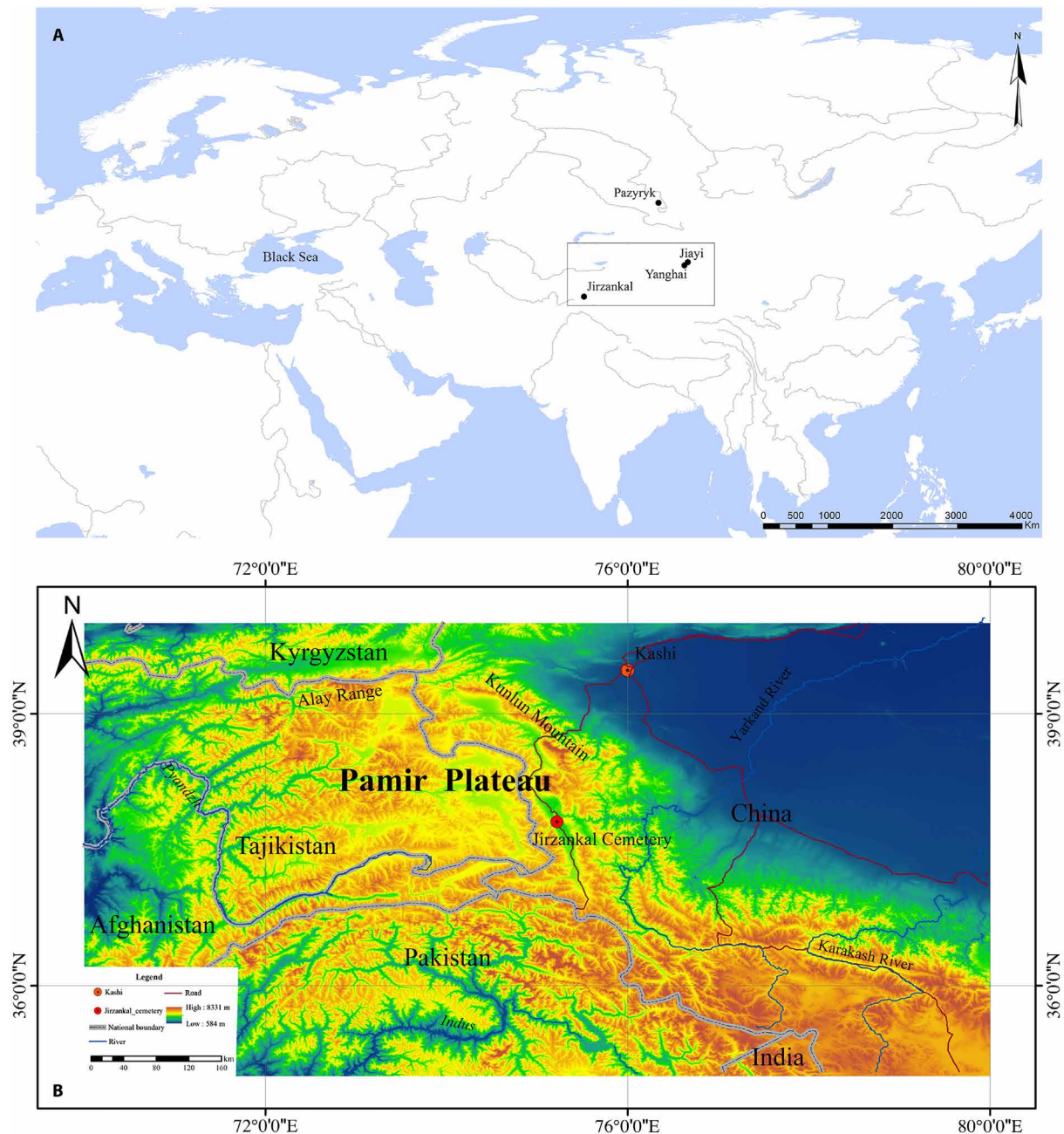


Fig. 1. Location of the Jirzankal Cemetery. (A) Map of Eurasia showing the location of the Pamir Plateau and the sites mentioned in this study. (B) Topographic map of the Pamir Plateau and location of the Jirzankal Cemetery.

Ferghana (present-day Uzbekistan and Kyrgyzstan) and Xinjiang have previously been noted, specifically relating to flagstone cyst burials and the existence of wooded coffin or “boat” burials (17, 18).

RESULTS

We extracted organic material from 10 wooden brazier fragments and 4 burnt stones and analyzed them using gas chromatography–mass spectrometry (GC–MS). In our first test, biomarkers of cannabis (19) were found on the internal charred layer of one wooden vessel (code: M25:2). Subsequently, we analyzed ancient cannabis (dating

to 790–520 BCE; fig. S1) from the Jiayi Cemetery, Turpan to obtain a chemical reference signal (Fig. 4, A and B). This analysis demonstrated that CBN, cannabidiol (CBD), and cannabicyclol (CBL) are all preserved in ancient cannabis. A secondary round of testing, based on the reference signal, identified CBN, which is the oxidative metabolite of THC (20), on the remaining wooden vessels from the Jirzankal Cemetery. We detected the chemical signature of CBN on all of the burnt residues, except for one, from the inside of the wooden braziers and on two of the stones. As a control, no cannabinoids were found on the samples that we collected from the exteriors of the vessels. The experimental results are summarized in Table 1 (see

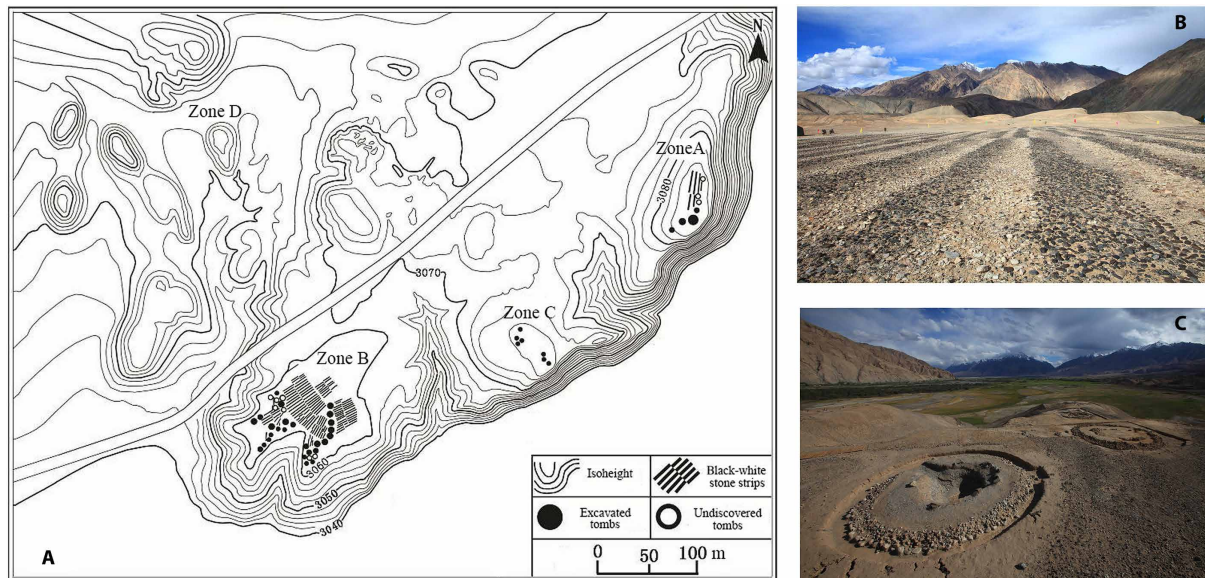


Fig. 2. Typical landscape of the Jirzankal Cemetery. (A) Plan view of the Jirzankal Cemetery; (B) black and white stone strips on the cemetery surface; (C) circular burial mounds with stone rings. Photo credit: X. Wu (Institute of Archaeology, Chinese Academy of Social Sciences).

also figs S2 to S15), and they suggest that cannabis plants were intentionally burned by laying hot stones in the braziers.

THC is the most potent psychoactive component in cannabis, but it readily decomposes and oxidizes into CBN if exposed to air, light, or heat (20, 21). CBD, another biomarker of cannabis, is not psychotropic, and cannabis with a high THC content often contains a low level of CBD (20, 22). The cannabinoids detected on the wooden braziers are mainly CBN, indicating that the burned cannabis plants expressed higher THC levels than typically found in wild plants. A pattern of relatively equivalent amounts of THC and CBD would be expected for wild cannabis plants (20, 22), but evident peaks corresponding to cannabinoids of CBD and its degradation products (such as cannabielsoin) were not detected in the burning residues. Given that the Jirzankal samples contained higher intensity of CBN than the ancient reference sample, there is no reason to expect that we would not see peaks corresponding to CBD if it had been present in the braziers. These results suggest that the cannabis burned by those using the Jirzankal Cemetery might have been physiologically altered through hybridization (domestication) or a poorly understood expression of genetic plasticity in the plants. Extensive phylogenetic research into the clade has illustrated that a wild/feral ruderal varietal population of the *indica* subspecies (var *kafiristanica*) expresses higher chemical levels (6). The *kafiristanica* clade is today restricted to mountainous areas around Afghanistan; however, scholars have debated whether it is truly a wild population with higher THC levels or a feral or hybrid population (5). Likewise, stress tests illustrate that some plants express a plastic response of higher THC levels when presented with certain stimuli. Lower temperatures, low nutrient availability, strong light intensity, exposure to ultraviolet light, and photoperiod changes have all been suggested as factors that trigger plastic stress responses in this clade (6). All of these stressors are associated with high elevations. It is possible that high-elevation populations of a naturally higher THC-producing variety were recognized and targeted by people in the Pamir region, possibly even explaining the prominence of ritual sites in the high mountains. Moreover, the content of THC also varies across plant parts, decreas-

ing from the bract, flower, leaf, stem, root, and seed in turn (10, 23). The lack of seeds in the burners may suggest that nonfloral plant parts were burned, or it may suggest that seeds were removed from the floral structures because they do not contain the desired secondary compounds.

DISCUSSION

There is a long history of inquiry surrounding early drug use in Central Eurasia, and much of this research started in the 19th and early 20th centuries, with debates over what the mythical soma of the *Rigveda* or haoma of the *Avesta* might have been (1, 24). The soma debates entered Central Asian archaeology with Sarianidi's accounts of the excavations of several large architectural structures of the Bactria-Margiana Archaeological Complex in the southern Karakum Desert of Turkmenistan, which he interpreted as temples (25). Sarianidi claimed to have recovered ancient plant remains used for ritual purposes in ceremonial ceramic vessels from the famous "white room" at the second millennium BCE site of Gonur Temenos and also from a possible temple at the nearby urban center of Togolok 21 (7, 25, 26). Perforated ceramic vessels at the site were further assumed to be associated with preparation of the haoma/soma beverage, although similar strainers are found across Central Asia and often associated with cheese production in other areas (27). The original publications claim that the vessels contained *Ephedra* and *P. somniferum*, and a late second millennium BCE bone tube with supposed poppy pollen was also reported from Togolok 21 (25). However, follow-up studies of the reported cannabis from Gonur have demonstrated that the original identifications were erroneous (28). Despite the fact that these finds are often discussed as if they are actual archaeobotanically preserved remains, the original published photo shows that they are actually impressions of plant parts on a ceramic sherd. In addition, the sherds have been re-examined by specialists, and the round impressions are clearly of broomcorn millet grains (*Panicum miliaceum*), not of *Cannabis* or *Ephedra* (7, 28).

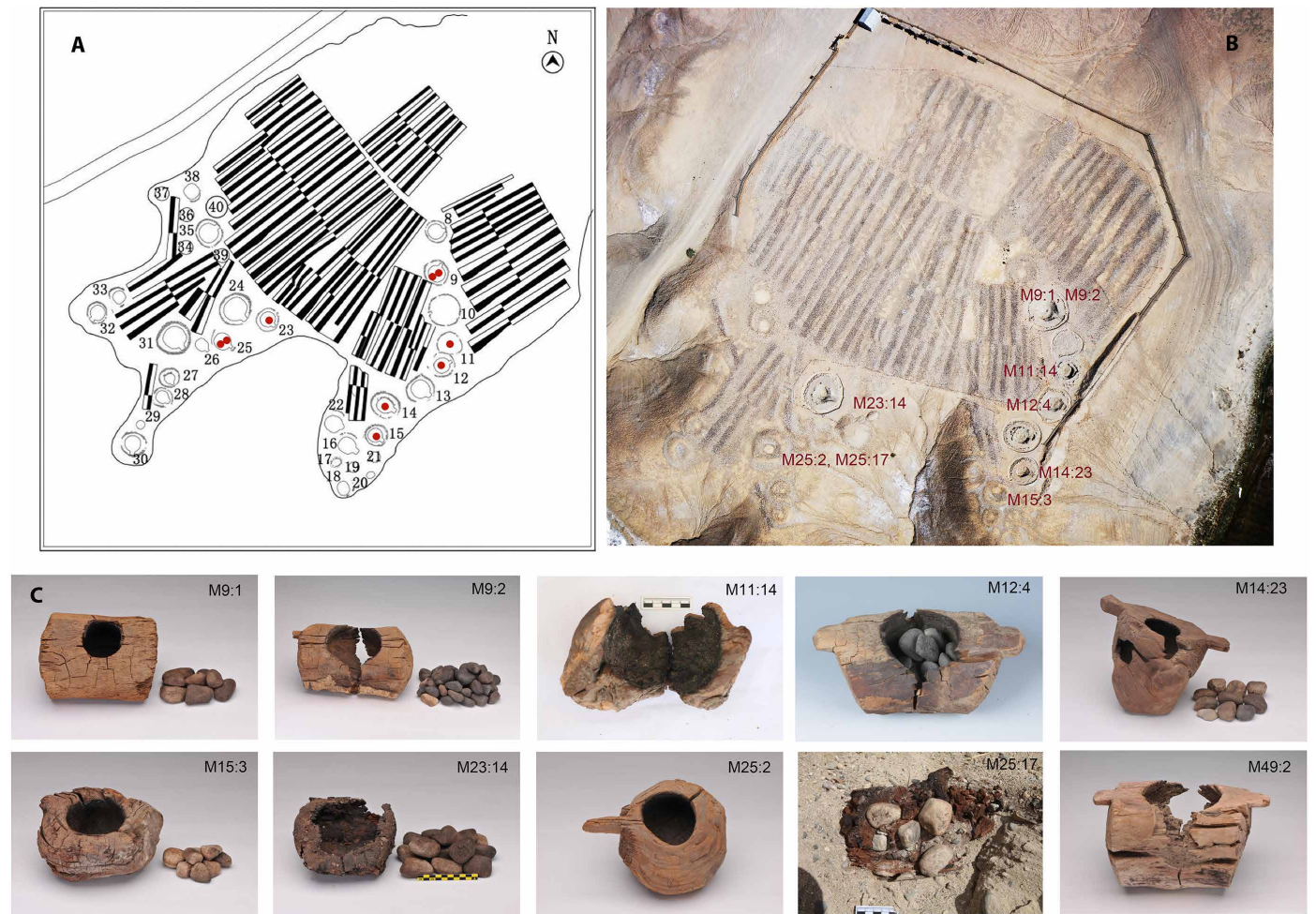


Fig. 3. Archaeological wooden braziers from the Jirzankal cemetery. (A) Plan view of zone B of the Jirzankal Cemetery, (B) aerial view of zone B, and (C) 10 wooden braziers excavated from the cemetery. Red dots in (A) refer to the tombs containing wooden braziers; brazier M49:2 was excavated from zone D. Photo credit: X. Wu (Institute of Archaeology, Chinese Academy of Social Sciences).

Likely due in large part to the single reference in *The Histories*, historians and archaeologists have linked Central Asian people of the first millennium BCE to cannabis. Several scholars have suggested that the crop spread with the mythical “Scythian” warrior nomads (3, 29). The Central Asian origins of cannabis is an argument recently revived and pushed back in time to the poorly defined “Yamnaya” culture group (8, 14). However, it is highly unlikely that the cannabis plants on the steppe before the first millennium BCE were cultivated, and no evidence for wild populations with high THC levels exists for the steppe. Wild cannabis exists across much of Central Eurasia from western China to Eastern Europe and is an abundant component of the vegetation community; hence, claims that the western steppe peoples of the third and second millennia BCE were spreading the plant as a kind of “camp follower” (6, 30) need to be clarified.

In *The Histories*, Herodotus specifically described how people of the mid-first millennium BCE in the Caspian Steppe region smoked cannabis (13). He noted that people would sit in a small tent, and the plants were burned in a bowl with hot stones. Frozen tombs from the Pazyryk culture (ca. 500 BCE) in the southern Altai Mountains of the Tuva Republic, Russia, seem to corroborate the account

of Herodotus, despite being located over 3000 km to the northeast. A small wooden tent frame was recovered with copper containers in one of the Pazyryk kurgans (barrow 2); the copper containers contained stones with evidence of burning and carbonized morphologically wild hemp seeds (7, 15, 31). The original publication also mentions recovery from the kurgan of a leather pouch, which contained cannabis seeds, coriander (*Coriandrum sativum*), and yellow sweet clover (*Melilotus officinalis*) (15). Other finds of seeds in vessels from burials in Eastern Europe and Central Asia have been called hemp or cannabis, but without further verification, they have limited credibility (2). Furthermore, according to *The Histories*, ancient Scythians used the cannabis smoke as a kind of cleaning rite (similar to bathing) after the burial; however, the smoking revealed both in the Pamirs in the present study and in the Altai Mountains was obviously performed during the burial and may represent a different kind of ritual, perhaps, for example, aimed at communicating with the divine or the deceased.

While most of the claims of archaeological cannabis in Central Asia are spurious, as mentioned above (7, 28), new discoveries of ritual cannabis use in western China are well documented and scientifically studied. The recent discovery of a cannabis burial shroud,

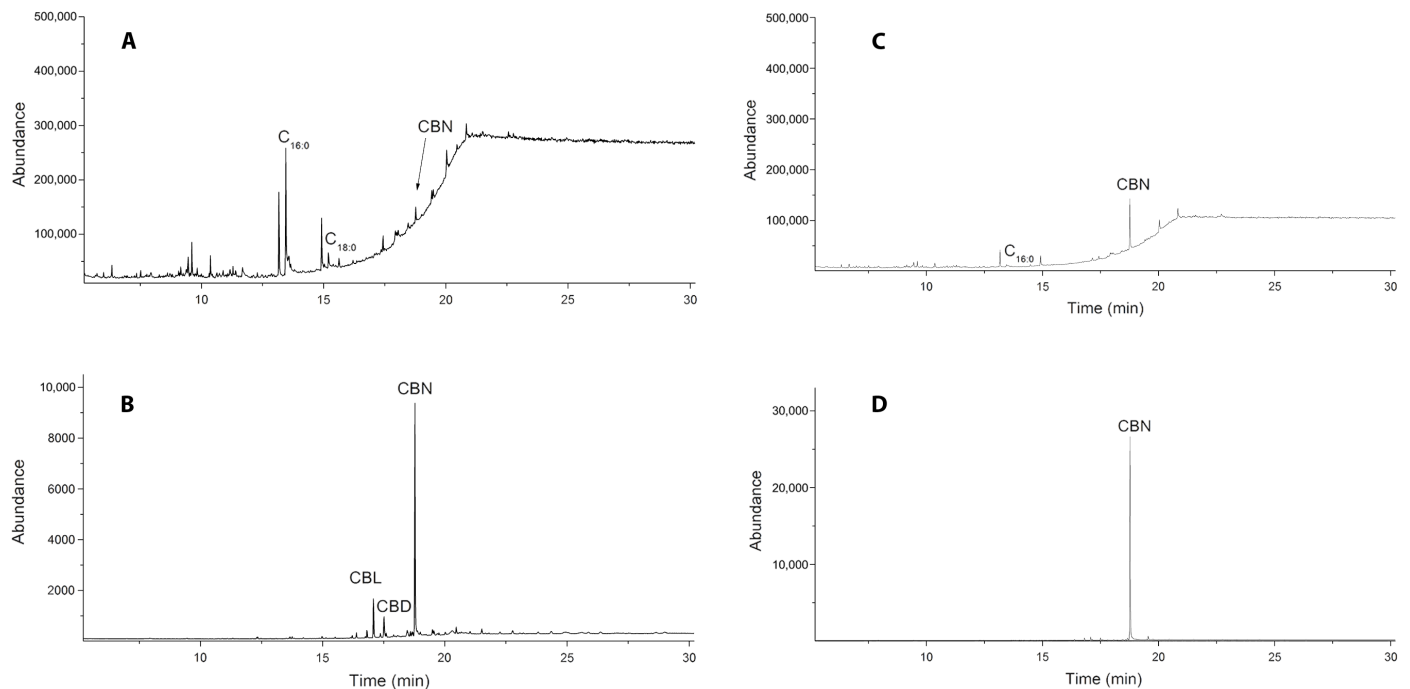


Fig. 4. Chromatograms of the ancient cannabis and the inner charred surface of the wooden brazier M25:2. (A) Total ion current (TIC) chromatogram of the ancient cannabis from the Jiayi Cemetery, Turpan showing the presence of C16:0 (hexadecanoic acid), C18:0 (octadecanoic acid), and CBN. (B) Chromatogram in select ion mode (SIM) of the ancient cannabis showing several cannabinoids: CBN, cannabidiol (CBD) and cannabicyclol (CBL); (C) TIC chromatogram of the internal charred fragment of wooden brazier M25:2 from the Jirzankal Cemetery; and (D) SIM chromatogram of the internal charred fragment of wooden brazier M25:2.

comprising 13 desiccated plants, from the Jiayi Cemetery (ca. 800–400 BCE) in Turpan provides evidence for the ritualistic use of cannabis in prehistoric western China (9). In addition, dried stems, fruits, and branches were preserved in burials in the Yanghai tombs (ca. 500 BCE) (10, 32), where a leather basket and a wooden bowl filled with cannabis seeds, leaves, and shoots was found near the head and feet of the deceased, who may have been a high-ranking male shaman (10). The wooden bowl shows characteristics of prolonged use as a mortar, indicating that cannabis was pulverized before consumption; however, there is nothing in the tomb to indicate that it was burned or smoked, and the psychoactive plant might have been orally consumed. The botanical and chemical analyses further suggest that the ancient cannabis from the Yanghai tomb had elevated levels of secondary compounds (20), corroborating the present study's findings. The lack of evidence for cultivation of hemp plants in this region leaves open the possibility that there were wild varieties with naturally higher phytochemical levels or that the domestication process did not follow conventional models.

The burning of cannabis inside the braziers suggests that fire was an important part of the funerary rites at the Jirzankal Cemetery, as it has been in Central Asia from at least the late third millennium BCE, when human cremations are recorded from Kazakhstan (33, 34) and Xinjiang (35, 36). The ritual use of fire during funerals continued in Xinjiang and eastern Central Asia with the Zoroastrian practices of the Sogdians, and many Sogdian tombs in western China have evidence of burning (37). Some scholars have suggested that cannabis formed part of Zoroastrian religious and mortuary practices during the first millennium CE (38–40), possibly illustrating a long-term continuity in certain cultural practices. In the volume entitled *Vendidad* of the *Zend-Avesta*, *Bangha* (*Bhang* of Zoroaster), cannabis

is referred to as a “good narcotic” (7, 41). Numerous wooden artifacts were preserved inside the tombs at the Jirzankal Cemetery, such as plates, konghou (Chinese harps), and bowls, mostly made from birch trees (*Betula* sp.) (42). Among the 70 wooden objects analyzed, only 4 were made from juniper trees (presumably *Juniperus sabina*), and 3 of those were braziers (42). When burned, juniper releases a rich turpentine perfume, which is important for Tibetan Buddhist ceremonies today. As carbonized fragments of juniper wood have been recovered from archaeological sites across Central Asia at ecotones lower in elevation than those occupied by present-day trees, scholars have suggested that people may have been specifically collecting the wood for its aromatic smoke for millennia (43).

The preliminary results of the human bone analysis at the Jirzankal Cemetery show perforations in some skulls and signs of fatal cuts and breaks in several bones (16); the excavators interpret these as signs of human sacrifice. While further research is needed to verify these claims, it is possible that a complex set of religious practices occurred at these sites in the first millennium BCE. Other artifacts in these tombs suggest ritual practices—for example, the presence of an angular harp, an important musical instrument in ancient funerals and sacrificial ceremonies. In addition, many of the artifacts from these tombs have clear burn marks on them. We can start to piece together an image of funerary rites that included flames, rhythmic music, and hallucinogen smoke, all intended to guide people into an altered state of mind.

At the Jirzankal Cemetery, these cannabis offerings are associated with burials of people of varying social status (16). For instance, eight tombs with wooden braziers were primary or secondary burials, and they consisted of shaft chambers with or without a short passage, which might be related to the size of the tombs and the number of occupants. In general, the large tombs have short passages and were

Table 1. GC-MS results for wooden brazier fragments and burnt stone samples. I and E refer to internal and external surface fragments of the wooden braziers, respectively; S refers to stones inside the wooden braziers. CBN, cannabinoil; CBV, cannabivarin.

Laboratory number*	Sample code	Sample description	Cannabinoids
1I	M9:1	Internal charred surface	CBN
1E	M9:1	External surface	—
2I	M9:2	Internal charred surface	CBN
2E	M9:2	External surface	—
3I	M11:14	Internal charred surface	CBN
3E	M11:14	External surface	—
4I	M12:4	Internal charred surface	CBN
4E	M12:4	External surface	—
5I	M14:23	Internal charred surface	CBN
5E	M14:23	External surface	—
6I	M15:3	Internal charred surface	CBN
6E	M15:3	External surface	—
7I	M23:14	Internal charred surface	—
7E	M23:14	External surface	—
8I	M25:2	Internal charred surface	CBV, CBN
8E	M25:2	External surface	—
9I	M25:17	Internal charred surface	CBN
9E	M25:17	External surface	—
10I	M49:2	Internal charred surface	CBN
10E	M49:2	External surface	—
11S	M11:14	Burnt stone	—
12S	M14:23	Burnt stone	CBN
13S	M23:14	Burnt stone	—
14S	M25:2	Burnt stone	CBN

often held for more than two occupants. Moreover, the $^{87}\text{Sr}/^{86}\text{Sr}$ analysis shows that 10 of the 34 sampled individuals were not local, illustrating that people were moving between communities (44). However, only 1 of the 10 tombs for the immigrant individuals had a mortuary wooden brazier (44), perhaps indicating that cannabis burning was a local burial practice. Although knowledge of psychoactive cannabis use has long been associated with ancient elites, such as shamans, the mind-altering property of cannabis is a powerful tool in ritualistic and recreational activities. The differences in cannabis utilization between the Pazyryk and the Jirzankal Cemeteries might imply that the ritualistic “smoking” of cannabis was gradually popularized from the elite class to the common people in the eastern Pamirs in China at least 2500 years ago.

The Pamir Plateau is an essential channel of cultural communication and trade that connected ancient China, Central Asia, and southwest Asia (16). The results of strontium isotope analysis of the human remains from the Jirzankal Cemetery show a high frequency of population movement in this region (44). In addition, glass beads and angular harps, which were typical cultural traits of Western Asia (45), and silk that was unique in eastern China were also unearthed at the site. These finds further highlight the active cultural exchange taking place on the Pamir Plateau before the establishment of Han governmental regulation in the last century BCE, including taxation and military outposts along the northern routes of the Silk Road. The dispersal of cannabis across the mountain barriers may have played a role in driving the higher THC levels of these specific varieties, with the hybridization of disparate and genetically isolated populations resulting in higher chemical-producing offspring. Likewise, ruderal cannabis plants tend to express high levels of phenotypical plasticity (6), a trait associated with many crop progenitors. High elevation-related stressors could have helped drive higher THC levels in wild or maintained populations around the cemetery. Ultimately, this study illustrates that the earliest targeted use of cannabis with higher levels of THC originated in western China or the broader Central Asia region, in contrast to the situation in East Asia where early cultivation of cannabis targeted the oily seeds for food and eventually the long stem cells as durable fibers for clothing and cordage.

MATERIALS AND METHODS

Site and samples

The Jirzankal Cemetery (37°50′54″N, 75°12′11″E) is located on the west bank of the Tashkurgan River, northeast of Qushman Village in the Tashkurgan Tajik Autonomous County of Xinjiang. According to the radiocarbon dating results (table S1) (42, 44) and the characteristics of the unearthed artifacts (16), the use of this cemetery dates between 2400 and 2600 years ago, with material culture traits that parallel those from archaeological sites further west in Central Asia. Large areas of black and white stone strips were created on the landscape using black and white pebbles. From 2013 to 2014, the Xinjiang Archaeological Team of the Chinese Academy of Social Sciences carried out two archaeological excavation seasons at the site, and the entire cemetery was divided into four zones (A, B, C, and D; Fig. 2). Zone A is located in the northeast of the cemetery on the third terrace at an altitude of 3077 meters above sea level (masl) and contains seven tombs, with the black and white stone strips to the north. Zone B is located on the second terrace of the ancient riverbed in the southwest, at an altitude of 3061 masl. This zone is relatively flat and has the highest concentration of tombs ($n = 34$). To one side of the tombs (mainly in the northeast) is a large area of black and white stone strips (Fig. 3, A and B). Zone C has eight tombs and is located between zones A and B. Zone D is located northwest of zones A to C and is on the top of the Yardang platform, at an altitude of 3080 masl, where the archaeological features are not obvious. Most of the tombs at the Jirzankal Cemetery consist of a shaft chamber covered by circular piles of stones. Both primary and secondary burials have been recovered from the site; and the mortuary goods included a large number of pottery items, stone tools, wooden objects, and textiles (mainly wool and no hemp was found), as well as some copper objects, ironware, and glass beads (16).

In this study, samples from nine sets of wooden brazier fragments and four burnt stones from zone B and one set of brazier samples

from zone D were analyzed using GC-MS. Wooden vessel M25:17 from zone B was in a highly degraded state when unearthed. There were two wooden braziers excavated from each of tombs M9 and M25; these tombs contained one male occupant and three individuals (two male and one female), respectively. For the other six tombs, only one brazier was found in each tomb, and the number of the deceased housed within ranged from one to five. The human bones in tomb M12 showed characteristics of secondary burial.

The ancient cannabis plant that we used to obtain the chemical baseline (fig. S1) was from tomb M231 (ca. 790–520 BCE) at the Jiayi Cemetery in Turpan, Xinjiang (9). The ancient cannabis remains were desiccated and well preserved; they included morphologically identifiable seeds and inflorescences of cannabis.

Residue analysis

An approximately 20-mg sample of wood was collected from each fragment of the wooden braziers (internal charred surface and external surface) and was ground into powder. The samples were extracted twice for 20 min by sonication in 3 ml of chloroform/methanol solution [2:1 (v/v)]. The solution was then centrifuged at 2000 rpm for 10 min, and the supernatant was concentrated to 500 to 600 μ l under a gentle stream of nitrogen. After filtration, the sample was subjected to GC-MS. The ancient cannabis reference sample was first cut into small pieces and then placed in a centrifuge tube, also extracted twice for 20 min with sonication. The burnt stones in the wooden braziers were placed in small beakers and extracted with chloroform/methanol [2:1 (v/v)] with sonication three times at 20 min each. All of the extracts were analyzed using the same method.

GC-MS analyses were performed with a 7890A gas chromatograph coupled with a 5975C quadrupole mass spectrometer (Agilent Technologies) and an HP-5MS fused silica capillary column (30 m \times 0.25 mm \times 0.25 μ m). The injection volume was 1 μ l in splitless mode. The oven temperature was held at 70°C for 2 min, ramped to 180°C at a rate of 15°C/min up to 290°C at 10°C/min, and held isothermal at 290°C for 10 min. Helium was used as the carrier gas at a constant flow rate of 1.0 ml/min⁻¹. MS was performed in the electron impact mode at 70 eV. The ion source temperature was set at 230°C, the interface temperature was 280°C, and the MS quadrupole temperature was 150°C. Full-scan acquisition mode within a range of 50 to 650 u and select ion mode (SIM) were performed simultaneously; the mass/charge ratio (*m/z*) values selected for SIM scanning were *m/z* 231 and *m/z* 295. Mass spectra interpretations were primarily derived from searching of the National Institute of Standards and Technology database.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at <http://advances.sciencemag.org/cgi/content/full/5/6/eaaw1391/DC1>

Table S1. Radiocarbon dates from the Jirzankal Cemetery.

Fig. S1. Ancient cannabis plant from tomb M231 (ca. 790–520 BCE) at the Jiayi Cemetery in Turpan, Xinjiang.

Fig. S2. Chromatograms of the wooden brazier M9:1 from the Jirzankal Cemetery.

Fig. S3. Chromatograms of the wooden brazier M9:2 from the Jirzankal Cemetery.

Fig. S4. Chromatograms of the wooden brazier M11:14 from the Jirzankal Cemetery.

Fig. S5. Chromatograms of the wooden brazier M12:4 from the Jirzankal Cemetery.

Fig. S6. Chromatograms of the wooden brazier M14:23 from the Jirzankal Cemetery.

Fig. S7. Chromatograms of the wooden brazier M15:3 from the Jirzankal Cemetery.

Fig. S8. Chromatograms of the wooden brazier M23:14 from the Jirzankal Cemetery.

Fig. S9. Chromatograms of the wooden brazier M25:2 from the Jirzankal Cemetery.

Fig. S10. Chromatograms of the wooden brazier M25:17 from the Jirzankal Cemetery.

Fig. S11. Chromatograms of the wooden brazier M49:2 from the Jirzankal Cemetery.

Fig. S12. Chromatograms of the burnt stone in the wooden brazier M11:14 from the Jirzankal Cemetery.

Fig. S13. Chromatograms of the burnt stone in the wooden brazier M14:23 from the Jirzankal Cemetery.

Fig. S14. Chromatograms of the burnt stone in the wooden brazier M23:14 from the Jirzankal Cemetery.

Fig. S15. Chromatograms of the burnt stone in the wooden brazier M25:2 from the Jirzankal Cemetery.

REFERENCES AND NOTES

- M. D. Merlin, Archaeological evidence for the tradition of psychoactive plant use in the Old World. *Econ. Bot.* **57**, 295–323 (2003).
- A. Sherratt, *Sacred and Profane: Proceedings of a Conference on Archaeology, Ritual and Religion*, P. Garwood, D. Jennings, R. Skeates, J. Toms, Eds. (Oxford Univ. Committee for Archaeology Monograph, Oxford, 1991), pp. 50–64.
- R. E. Schultes, Hallucinogens of plant origin. *Science* **163**, 245–254 (1969).
- R. E. Schultes, Antiquity of the use of New World hallucinogens. *Heffer Rev. Psychodelic Res.* **1**, 1–7 (1998).
- R. C. Clarke, M. D. Merlin, Letter to the Editor Re. Small, Ernest. 2015. Evolution and classification of *Cannabis sativa* (marijuana, hemp) in relation to human utilization. *Bot. Rev.* **81**, 295–305 (2015).
- E. Small, Evolution and classification of *Cannabis sativa* (marijuana, hemp) in relation to human utilization. *Bot. Rev.* **81**, 189–294 (2015).
- R. C. Clarke, M. D. Merlin, *Cannabis: Evolution and Ethnobotany* (University of California Press, 2013).
- T. Long, M. Wagner, D. Demske, C. Leipe, P. E. Tarasov, Cannabis in Eurasia: origin of human use and Bronze Age trans-continental connections. *Veg. Hist. Archaeobot.* **26**, 245–258 (2017).
- H.-E. Jiang, L. Wang, M. D. Merlin, R. C. Clarke, Y. Pan, Y. Zhang, G. Xiao, X. Ding, Ancient *Cannabis* burial shroud in a central Eurasian cemetery. *Econ. Bot.* **70**, 213–221 (2016).
- H.-E. Jiang, X. Li, Y.-X. Zhao, D. K. Ferguson, F. Hueber, S. Bera, Y.-F. Wang, L.-C. Zhao, C.-J. Liu, C.-S. Li, A new insight into *Cannabis sativa* (Cannabaceae) utilization from 2500-year-old Yanghai Tombs, Xinjiang, China. *J. Ethnopharmacol.* **108**, 414–422 (2006).
- C. A. Rose, M. J. Hilton, J. Henningfield, D. T. Sweanor (Encyclopædia Britannica Inc., 2018); www.britannica.com/topic/smoking-tobacco.
- B. Warf, High points: An historical geography of *Cannabis*. *Geogr. Rev.* **104**, 414–438 (2014).
- Herodotus, A. D. Godley. *Trans. The Histories* (Harvard Univ. Press, 1920).
- D. W. Anthony, *The Horse, the Wheel, and Language: How Bronze-Age Riders from the Eurasian Steppes Shaped the Modern World* (Princeton Univ. Press, 2007).
- S. I. Rudenko, *Frozen Tombs of Siberia—The Tazryk Burials of Iron Age Horsemen* (University of California Press, Berkeley and Los Angeles, 1970).
- Xinjiang Archaeological Team, Institute of Archaeology, Chinese Academy of Social Sciences, The excavation of the Jirzankal Cemetery in Taxkorgan county, Xinjiang. *Acta Archaeol. Sin.* **2**, 229–252 (2015).
- K.-t. Chen, F. T. Hiebert, The late prehistory of Xinjiang in relation to its neighbors. *J. World Prehist.* **9**, 243–300 (1995).
- J. H. Yang, M. Zhang, A study of Early Iron Age in Tian Shan Mountain and Semirechiye, Ferghana Valley and Pamir Mountains—Interaction with Xinjiang area. *Res. China's Front. Archaeol.* **2010**, 85–104 (2010).
- M. A. ElSohly, D. Slade, Chemical constituents of marijuana: The complex mixture of natural cannabinoids. *Life Sci.* **78**, 539–548 (2005).
- E. B. Russo, H.-E. Jiang, X. Li, A. Sutton, A. Carboni, F. del Bianco, G. Mandolino, D. J. Potter, Y.-X. Zhao, S. Bera, Y.-B. Zhang, E.-G. Lü, D. K. Ferguson, F. Hueber, L.-C. Zhao, C.-J. Liu, Y.-F. Wang, C.-S. Li, Phytochemical and genetic analyses of ancient cannabis from Central Asia. *J. Exp. Bot.* **59**, 4171–4182 (2008).
- O. Aizpurua-Olaizola, U. Soydaner, E. Öztürk, D. Schibano, Y. Simsir, P. Navarro, N. Etxebarria, A. Usobiaga, Evolution of the cannabinoid and terpene content during the growth of *Cannabis sativa* plants from different chemotypes. *J. Nat. Prod.* **79**, 324–331 (2016).
- E. P. M. de Meijer, M. Bagatta, A. Carboni, P. Crucitti, V. M. C. Moliterni, P. Ranalli, G. Mandolino, The inheritance of chemical phenotype in *Cannabis sativa* L. *Genetics* **163**, 335–346 (2003).
- P. S. Fetterman, E. S. Keith, C. W. Waller, O. Guerrero, N. J. Doorenbos, M. W. Quimby, Mississippi-grown *Cannabis sativa* L.: Preliminary observation on chemical definition of phenotype and variations in tetrahydrocannabinol content versus age, sex, and plant part. *J. Pharm. Sci.* **60**, 1246–1249 (1971).
- R. G. Wasson, *Soma: Divine Mushroom of Immortality (Ethno-mycological Studies)* (Harcourt, Brace & World, 1968).
- V. Sarianidi, Temples of Bronze Age Margiana: Traditions of ritual architecture. *Antiquity* **68**, 388–397 (1994).
- V. Sarianidi, Margiana and Some-Hoama. *Electron. J. Vedic Stud.* **9**, (2003).

27. D. W. Anthony, D. Brown, E. Brown, A. Goodman, A. Kochlov, P. Kosincev, P. Kuznetsov, O. Mochalov, E. Murphy, D. Peterson, The Samara valley project. Late Bronze Age economy and ritual in the Russian steppes. *Eurasia Antiq.* **11**, 395–417 (2005).
28. C. C. Bakels, The contents of ceramic vessels in the Bactria-Margiana Archaeological Complex, Turkmenistan. *Electron. J. Vedic Stud.* **9**, (2003).
29. A. d. Candolle, *Origin of Cultivated Plants* International Scientific Series (D. Appleton and Company, 1885).
30. E. Anderson, *Plants, Life, and Man* (Melrose, 1954).
31. The British Museum, *The BP Exhibition: Scythians: Warriors of Ancient Siberia* (Thames & Hudson, 2017).
32. M. Zhao, H. Jiang, C. J. Grassa, Archaeobotanical studies of the Yanghai cemetery in Turpan, Xinjiang, China. *Archaeol. Anthropol. Sci.* **11**, 1143–1153 (2018).
33. M. D. Frachetti, R. N. Spengler, G. J. Fritz, A. N. Mar'yashev, Earliest direct evidence for broomcorn millet and wheat in the central Eurasian steppe region. *Antiquity* **84**, 993–1010 (2010).
34. P. N. Doumani, M. D. Frachetti, R. Beardmore, T. M. Schmaus, R. N. Spengler III, A. N. Mar'yashev, Bronze Age mountain agriculture, funerary ritual, and mobile pastoralism at Tasbas, southeastern Kazakhstan. *Archaeol. Res. Asia* **1**, 17–32 (2015).
35. X. Liu, Cremation tombs in prehistoric Xinjiang. *NW. J. Ethnology* **2**, 120–127 (1997).
36. X. Xiao, Funeral fire usage in prehistoric Xinjiang. *W. Reg. Stud.* **1**, 56–65 (2016).
37. P. Wertmann, *Sogdians in China. Archaeological and Art Historical Analyses of Tombs and Texts from the 3rd to the 10th Century* (Philipp von Zabern, 2015).
38. C. Bennett, *Cannabis and the Soma Solution* (Trine Day, 2010).
39. M. Eliade, C. J. Adams, *The Encyclopedia of Religion*. (Macmillan, 1987).
40. M. Eliade, *A History of Religious Ideas*, vol. 2 (University of Chicago Press, 1982).
41. J. Darmesteter Trans., *The Zend-Avesta, Part I: Vendidad* (Clarendon Press, Oxford, ed. 2, 1883 [3rd-7th CE]).
42. H. Shen, X. Wu, Z. Tang, X. Zhou, N. Sun, X. Li, Wood usage and fire veneration in the Pamir, Xinjiang, 2500 yr BP. *PLOS ONE* **10**, e0134847 (2015).
43. R. N. Spengler, G. Willcox, Archaeobotanical results from Sarazm, Tajikistan, an Early Bronze Age Settlement on the edge: Agriculture and exchange. *Environ. Archaeol.* **18**, 211–221 (2013).
44. X. Wang, Z. Tang, J. Wu, X. Wu, Y. Wu, X. Zhou, Strontium isotope evidence for a highly mobile population on the Pamir Plateau 2500 years ago. *Sci. Rep.* **6**, 35162 (2016).
45. M. Lin, *Fifteen Lectures on Archaeology of the Silk Roads* (Peking Univ. Press, 2006).

Acknowledgments: We thank H. Rao for helpful advice and X. Jiang for sampling assistance. We also thank M. Merlin and an anonymous reviewer for their valuable suggestions to improve the quality of this work. **Funding:** This study was supported by National Young Top-Notch Talent Support Program and Youth Innovation Promotion Association of CAS. Contributions from Y.Y., R.S., and N.B. are supported by funding provided by the Max Planck Society. Y.Y. is also supported by the University of Chinese Academy of Sciences. **Author contributions:** Y.Y. and X.W. planned the project. M.R., R.S., Y.Y., and N.B. wrote the paper. M.R. performed experimental work and data analysis. X.W. directed the field excavations, Z.T. contributed to excavations and field sampling, and H.J. collected the reference sample. All authors participated in the discussions of the results and commented on the manuscript. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials. Additional data related to this paper may be requested from the authors.

Submitted 21 November 2018

Accepted 2 May 2019

Published 12 June 2019

10.1126/sciadv.aaw1391

Citation: M. Ren, Z. Tang, X. Wu, R. Spengler, H. Jiang, Y. Yang, N. Boivin, The origins of cannabis smoking: Chemical residue evidence from the first millennium BCE in the Pamirs. *Sci. Adv.* **5**, eaaw1391 (2019).

The origins of cannabis smoking: Chemical residue evidence from the first millennium BCE in the Pamirs

Meng Ren, Zihua Tang, Xinhua Wu, Robert Spengler, Hongen Jiang, Yimin Yang and Nicole Boivin

Sci Adv 5 (6), eaaw1391.
DOI: 10.1126/sciadv.aaw1391

ARTICLE TOOLS	http://advances.sciencemag.org/content/5/6/eaaw1391
SUPPLEMENTARY MATERIALS	http://advances.sciencemag.org/content/suppl/2019/06/10/5.6.eaaw1391.DC1
RELATED CONTENT	http://science.sciencemag.org/content/sci/364/6445/1018.full
REFERENCES	This article cites 27 articles, 2 of which you can access for free http://advances.sciencemag.org/content/5/6/eaaw1391#BIBL
PERMISSIONS	http://www.sciencemag.org/help/reprints-and-permissions

Use of this article is subject to the [Terms of Service](#)