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Author(s)	Nakazawa, Yuichi; Maeso, Cristina Vega; Carmona-Ballestero, Eduardo et al.
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Obsidian hydration dating helps understanding pre-Hispanic land use of the volcanic island of Tenerife, Canary Islands, Spain

Yuichi Nakazawa [a*], Cristina Vega Maeso [b], Eduardo Carmona-Ballestero [c], John Rissetto [d], Alberto Berzosa Ordaz [c], Yasuo Naoe [e], Kensho Dohi [f], Mina Araya [f], Hidehiko Nomura [g], Mari Sumita [h], Hans-Ulrich Schmincke [h]

[a] Division of Human Evolutionary Studies, Faculty of Medicine, Hokkaido University, Sapporo, Japan

[b] Servicio de Innovación y Difusión. Junta de Castilla y León, Spain

[c] University of Burgos, Spain

[d] Nebraska Farm Service Agency, US Department of Agriculture, USA

[e] Chitose Board of Education, Chitose, Japan

[f] Hokkaido Archaeological Operations Center, Ebetsu, Japan

[g] Thin Section Laboratory, Group of Technology, Graduate School of Science, Hokkaido University, Sapporo, Japan

[h] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

* Corresponding author.

E-mail address: ynakazawa@med.hokudai.ac.jp (Y. Nakazawa).

Abstract

Critical to the survival of island-based human societies is their resilience and adaptation to volcanic hazards. We here evaluate pre-Hispanic (before 15th century AD) land use patterns on the volcanic island of Tenerife, Canary Islands, Spain using obsidian hydration dating (OHD). The samples studied include archaeological artifacts and natural rock chips from multiple sites of different elevation and micro-climate settings. We systematically collected samples from the southern dry area around Barranco de las Monjas in the Bandas del Sur. These include a total of 28 isolated artifact scatters (here, a scatter is defined as a minimum spatial unit of artifacts distributed spatially limited range on the surveyed surface), one dwelling, and several pyroclastic deposits containing obsidian clasts. We also collected several artifacts adjacent to a large obsidian flow of Tabonal Negro in the Las Cañadas Caldera. Unsystematic surveys in north of Mt. Teide identified large obsidian outcrops located at Tabonal de los Guanches and Charco del Viento. Size differences among surface-derived obsidian artifacts (i.e., Bandas del Sur, Las Cañadas Caldera, Icod Valley) suggest that pre-Hispanic groups utilized obsidian from multiple outcrops over wide areas. Hydration analysis on 136 obsidian flakes collected from both surface and buried contexts showed only minor obsidian hydration rims (5% of total samples) and varied mean rim thicknesses (0.6-3.5μ). The low percentage of hydration rim formation may be caused by environmental factors such as wind erosion, thermal effects from volcanic or natural ground fires, or due to obsidian geochemistry (low SiO_2 and water content of phonolitic obsidian). Surface-collected obsidian flakes from the southern dry area do contain hydration rims along internal fissure. The estimated hydration rates from these samples can provide an approximate age when compared to buried obsidian artifacts with associated radiocarbon dates.

Keywords

Tenerife; Obsidian hydration analysis; Canary Islands; Lithic raw material; Landscape utilization

1. Introduction

Volcanic landscapes often record processes that represent the vulnerabilities and resilience of human societies to volcanic activities (e.g., Sheets and Grayson, 1979; Torry, 1979; Oliver-Smith, 1996; Torrence and Grattan, 2002; Santley, 2003; McConnell et al., 2020). In particular, interactions between volcanic activities and people living in island settings will be reflected in the spatial distribution of the archaeological record. This is reflected most in island environments, immediately surrounded by oceans, where the geography limits the suite of human spatial activities to exploit terrestrial and coastal resources. The Canary Islands, and specifically Tenerife, provide an ideal setting for exploring the question of how humans exploited fundamental resources, namely toolstone, on islands during times of volcanic activity and inactivity.

The island of Tenerife is the largest of the Canary Islands and represents a particularly critical place to investigate this question. The island has a high species diversity in faunal and floral communities that coexist(ed) across landscapes made by volcanisms from Late Miocene to historic eruptions (e.g., Kunkel, 1976; Schmincke and Sumita, 2010). These species inhabited complex ecosystems ranging from sub-desert to endemic laurel forest, to nonindigenous pine forest. Forest in particular existed in different micro-regions influenced by altitude, trade winds, and oceanic currents (e.g., Wildpret de la Torre and Martín Osorio, 1997; Fernández-Palacios and Whittaker, 2008; Morales and Gil, 2014).

While pyroclastic lava flows and pumice deposits can restrict human land use, once these pyroclastic sediments settle they create new landscapes. People will invariably start to explore these new areas for previously unused resources. Obsidian is one of the major byproducts of volcanic activity on Tenerife. Similar to obsidian found on the Island of Gran Canaria (e.g., Del Arco Aguilar 1996; Martín Rodríguez et al. 2004), Tenerife's obsidian is frequently identified in pre-Hispanic (pre-colonial) archaeological sites (before 15th century AD) associated with the indigenous Guanches groups who occupied Tenerife in and around the Teide volcano (e.g., Hodgkin, 1848; Cook, 1900; Mederos Martín and Escribano Cobo, 2002; Carmona Ballestero and Vega Maeso, 2008; Hernández Gómez and Galván Santos, 2008; Arnay-de-la-Rosa et al., 2011, 2019; Tomé et al., 2022).

Building on previous research (e.g., Rodriguez-Gonzalez et al., 2013), this study investigates how pre-Hispanic human resource exploitation varies across multiple

volcanic landscapes and micro-environmental zones. Beginning in 2016, the authors conducted a series of pedestrian surveys to record surface artifact scatters, here, a scatter is defined as a minimum spatial unit of artifacts distributed spatially limited range on the surveyed surface (mainly consisting of obsidian artifacts, potsherds, and marine shells) in dried ravines locally called *barrancos* and laboratory analysis of previously excavated obsidian artifacts from collections curated at the Tenerife Archaeological Museum. Field survey included the collection and analysis of natural obsidian samples from outcrops along the Icod Valley in north of Mt. Teide and in natural barrancos, or ravines, prominent in the Granadilla de Abona and El Desiert districts of southern Tenerife. This incised topography is common on the southern coastal flanks of Tenerife. Known as Bandas del Sur or Bandas del Sur Formation (Bryan et al., 2000), they are often characterized by thick pyroclastic deposits (Bandas del Sur Group [Brown et al., 2010]) (Figure 1).

The three natural obsidian outcrops sampled and analyzed in this study include: Tabonal Negro, Tabonal de los Guanches, and Charco del Viento. These outcrops are visible on the present landscape and have not been modified by human development since the pre-Hispanic period. Post-field laboratory analysis conducted between 2017–2022 focused on organizing basic archaeological data (e.g., spatial locations, material characteristics, artifact measurements) from obsidian samples collected from field identified artifact scatters, natural obsidian outcrops, and museum curated assemblages.

Using these original data sets, this paper describes the application of obsidian hydration dating (OHD) to date and compare pre-Hispanic surface collected obsidian artifacts to natural obsidian samples from various geographic and micro-climatic zones across Tenerife. Together these results serve as a reference point in defining how temporally diverse pre-Hispanic groups organized and managed resource exploitation patterns across ever changing volcanic landscapes.

2. The role of obsidian hydration dating in the volcanic landscape of Tenerife

OHD has been widely employed to establish a chronological boundary for collected natural and artifactual obsidian samples. Since its introduction into archaeology by Friedman and Smith (1960), researchers have accepted the empirical statement that hydration rim thickness on obsidian samples is related to time elapsed (e.g., Suzuki, 1971;

114 Friedman and Long, 1976; Leach, 1977; Rogers, 2008a; Liritzis and Laskaris, 2011,
115 2021). For example, the date a flake was removed from an obsidian sample artifact (t)
116 can be calculated using the obsidian hydration equation of $X^2 = kt$, where X = hydration
117 rim thickness (μ) and k = hydration rate (diffusion rate). During the last half century of
118 OHD research, a new diffusion equation has been created that considers the effect of
119 water molecule concentration in a sample's glass matrix as a determinant for a sample's
120 age (e.g., Anovitz et al., 1999; Liritzis, 2006, 2010; Liritzis and Laskaris, 2011, 2021).
121 These diffusion mechanism studies are comparable in accuracy to the empirical
122 measurement of obsidian rim thickness in the hydration equation (e.g., Lanford et al.,
123 1979; Doremus, 2000; Stevenson et al., 2021).
124 Global use of OHD analysis has included other arid regions similar to Tenerife. These
125 comparable regional studies have provided acceptable date ranges for obsidian
126 archaeological materials (e.g., Jones and Beck, 1990; Eerkens and Rosenthal, 2004;
127 Tripcevich et al., 2012). However, it is acknowledged that dating obsidian artifacts from
128 surface artifact scatters without associated chronologically diagnostic artifacts can be a
129 challenge. This is partly because hydration rate represents the effects of ambient
130 temperature on a given sample (e.g., Friedman and Smith, 1960; Friedman et al., 1994;
131 Stevenson et al., 1993; Eerkens et al., 2008; Rogers, 2007; Liritzis, 2010; Liritzis and
132 Laskaris, 2010, 2021). Both theoretical and empirical studies show that the higher the
133 ambient temperature, the faster the diffusion rate (Friedman and Long, 1976; Stevenson
134 et al., 1998; Doremus, 2001; Rogers, 2007; Ambrose and Novak, 2012). Tenerife's
135 present annual temperatures are relatively stable. Based on the 30 years (1981-2010)
136 mean maximum temperature that ranges from 21 to 29 ° C and mean minimum
137 temperature that varies from 15.3 to 21.9 ° C, recorded at Santa Cruz de Tenerife in the
138 northeastern coast of Tenerife (Table 1, data are from World Meteorological Organization,
139 2020), we calculated the effective hydration temperature (EHT) using the equation
140 presented by Rogers (2007, 2012).
141 $$EHT = T_a(1 - 3.8 \times 10^{-5}y) + 0.0096y^{0.95} \quad \text{eq. 1}$$
142 T_a is the annual average temperature, which is given as the mean of monthly averaged
143 temperature. The data of Santa Cruz de Tenerife (Table 1) shows that T_a is 21.5 ° C.

where $y = V_a^2 + V_d^2$ (V_a is the annual average temperature of the location and V_d is the diurnal temperature variation given as a difference of the hottest month and coldest month.)

Having employed the data of Santa Cruz de Tenerife (Table 1), V_d is 13.7 ° C, given as the diurnal variation between the hottest month (29 ° C in August) and the coldest month (15.3 ° C in February). Because monthly averages are not reported, V_a is calculated by (monthly maximum + monthly minimum)/2. For the case of Tenerife, V_a is the difference between August and February, given as 25.45-18.25 = 7.2, and

$y = V_a^2 + V_d^2 = (7.2)^2 \times (13.7)^2 = 51.84 + 187.69 = 239.53$

Given eq.1, $EHT = T_a(1 - 3.8 \times 10^{-5}y) + 0.0096y^{0.95}$

$= 21.5 \times (1 - 3.8 \times 10^{-5} \times 239.53) + 0.0096 \times (239.53)^{0.95} = 23.0523$

Thus, the EHT for Santa Cruz de Tenerife, the northeastern dry coast is 23 ° C.

Critical to applying the OHD temperature-dependent method is tracking the ambient temperatures that surround obsidian artifacts (e.g., Leach and Hamel, 1984; Stevenson et al., 1998; Rogers, 2007). A study of temperature regimes on Tenerife measured at 50 cm below the ground surface showed that soil type variation may be influenced by factors such as elevation, mountain system orientation, and trade wind (Rodríguez et al., 2010). This study focused on survey areas with two distinct soil types. The subtropical southern drylands and the northern coastal area are characterized by hyperthermic soils that have a mean annual temperature above 22° C. Because this temperature is not indifferent from that of northeastern dry coast, EHT of the subtropical southern drylands might be more or less 23 ° C. Contrary, the temperate/semi-arid highland, in and around the central Tabonal Negro (Teide volcano) and Tabonal de los Guanches (Icod Valley) have primarily mesic soils with a mean annual soil temperature of 8-15° C (Buol, 1977; Jonsson et al., 2002, Rodríguez et al., 2010). The meteorological data from the Teide National Park shows that mean maximum temperature that ranges from 17 to 26 ° C and

mean minimum temperature that varies from 10 to 18 ° C (Table 1, data are from Weather-and-climate.com, 2023). Based on this meteorological data set (Table 1),

T_a = 18.9, V_d = 26 - 10 = 16, V_a = (22+13.5)/2 = 17.75, and therefore

$y = V_a^2 + V_d^2 = (16)^2 \times (17.75)^2 = 256 + 315.06 = 571.06$

According to eq. 1, $EHT = T_a(1 - 3.8 \times 10^{-5} y) + 0.0096 y^{0.95}$

$= 18.9 \times (1 - 3.8 \times 10^{-5} \times 571.06) + 0.0096 \times (571.06)^{0.95} = 19.2256$

This result shows that the EHT for Teide is 19 ° C, which is 4 ° C cooler than dry coastal area. Because the diffusion of water into glass is temperature dependent (Rogers, 2007, 2012; Ambrose and Novak, 2012; Liritzis and Laskaris, 2021), the estimated EHTs suggest that obsidian artifacts left in high-elevated central temperate region will hydrate slower than those in coastal area in the island of Tenerife.

To account for micro-climate effects on obsidian hydration rates, this study makes three expectations. First, variation in soil temperatures should produce thicker hydration rims on obsidian samples from the southern dryland and northern coastal area hyperthermic soils (e.g., Bandas del Sur), than those in the mesic soils from the central temperate region (e.g., Teide Volcano, Icod Valley). Second, since there are differences in altitudinal temperatures on Tenerife (e.g., Rodríguez et al., 2010; Martín et al., 2012), it is expected that the hydration rims on obsidian artifacts found at higher elevated sites should be less developed than those at lower elevated coastal sites (e.g., Tripcevich et al., 2012). Third, given the principle of stratigraphic superposition, obsidian samples at lower stratigraphic levels should have thicker hydration rims than those found in the upper levels (Michels, 1969). This relationship is found in other island settings, such as from the open-air site with the Pleistocene and Holocene sediments in southern Kyushu Island (Japan), located 31° N (Nakazawa et al., 2020), and a rockshelter in Manus Island, Papua New Genia located 2° S (Ambrose, 1994).

Based on these expectations, this research used associated artifacts as chronological indicators for all surface identified obsidian artifacts collected during survey. In addition, this research attempted to control for the effects of micro-climatic variation on hydration rim formation by assigning collected obsidian samples to homogenous micro-climate

zones defined by water availability and vegetation density. When possible, hydration rates and rim thickness were correlated to radiocarbon dates from a single occupation level.

3. Materials and Methods

3.1 Archaeological and geological surveys

This project conducted a series of pedestrian surveys for a total of six days on the island of Tenerife. Two types of pedestrian surveys were used, systematic and unsystematic, to obtain samples of natural obsidian from primary geologic outcrops. With permission from Teide National Park a series of systematic surveys were conducted on the obsidian flows of Tabonal Negro in the southern dryland of Tenerife. These outcrops are located at the foot of Mt. Teide (Pico del Teide), in Las Cañadas Caldera. Unsystematic surveys were conducted in the Icod Valley (northern part of Tenerife) where dense vegetation made surface visibility too low to detect surface artifact scatters. Due to this low visibility, the survey strategy focused on evaluating the quantity and quality of obsidian materials from two previously identified outcrops in the area: Tabonal de los Guanches and Charco del Viento.

3.2 Site recording

Pedestrian surveys included 5 – 20 m transects along tributaries, coastlines, and lava flows within the selected locations. Identified obsidian artifacts and natural obsidian outcrops were recorded using a handheld GPS unit (Magellan eXplorist 610). All coordinates assigned as ID numbers were later converted to GPS coordinates visualized through Google Maps.

3.3 Obsidian hydration readings

To evaluate the utility of OHD for chronological dating purposes, the first author used a polarized microscope (MT9300 Meiji Techno Co., LTD.) at 500–1000x magnifications to evaluate thin sections of obsidian samples for the presence of hydration rims. Following established procedures (Origer, 1998; Nakazawa, 2016), whenever a hydration rim was present, its thickness was measured at three points each on the exterior (dorsal)

and interior (ventral) surfaces and recorded at the micron (μ) level using a computer-assisted measuring devise (Art Measure, Artray Inc.).

The curated obsidian artifacts analyzed for OHD originate from four, major pre-Hispanic artifact collections stored in the Tenerife Archaeological Museum. These sites include: Estacas 1 (Galván Santos et al., 2000; Mesa Hernández, 2015), Don Gaspar (Del Arco, 1985), Guargacho (Martín, 1976; Cuscoy, 1979), and Cha Silveria (Carmona Ballestero and Vega Maeso, 2008). All four sites were excavated between the 1970s and 2000s. The sites of Estacas 1 and Don Gaspar are cave/rockshleter sites located in Tenerife's northern coastal region. The sites of Guargacho and Cha Silveria are open-air sites situated near the southern coast of Tenerife (Figure 1). Three of the four sites contain multiple pre-Hispanic occupation levels (Estcas-1, Don Gaspar, and Guargacho). With the open-air site of Cha Silveria only containing a single occupation level (Carmona Ballestero and Vega Maeso, 2008). Charcoal and marine shells from all four sites were used to radiocarbon date certain occupation levels. When combined, these dates fall between 1750 –1200 BP. This places these occupations within the Subatlantic chronozone (Mangerud et al., 1974) during the Late Holocene period (2500 BP to the present).

A total of 110 curated obsidian artifact samples were selected for OHD from the four sites. These samples consisted primarily of unretouched small flakes. A summary of the analyzed samples by each stratigraphic component with associated radiocarbon dates is presented in Table 2. The visual characteristics of the analyzed obsidian samples exhibit a considerable range of color variation: black, black opaque, black greasy, brown to green. In addition to the museum curated samples, 26 obsidian specimens were chosen for hydration rim analysis from the 22 artifact scatters identified during the pedestrian survey research. These scatters are located among Tenerife's various micro-climatic zones, including those along the "Barranco de las Monjas" on the southern coast in the Bandas del Sur region (Pittari et al., 2006: 276), Tabonal Negro, and Tabonal de los Guanches from the central and northern portions of the island.

4. Results

4.1 Results of Surveys

4.1.1 Systematic survey of the southern dryland region

The pedestrian survey began along the southern coast of Tenerife at the mouth of the Barranco de las Monjas. The survey area extended west to the present district of Granadilla de Abona which includes the river mouth around the principal coastal highway TF-1 (Figure 2-1). Granadilla de Abona is geologically characterized as primarily pumice and ignimbrite deposits which erupted from the Las Cañadas edifice (Booth, 1973; Bryan et al., 2000). Because of the overall dry environment and sparse vegetation, artifacts on the surface were easily visible. The survey area consisted of 32 localities with 28 archaeological surface artifact scatters, one dwelling, and three geologic localities with natural obsidian clasts (Table 3).

Of the identified artifact scatters, 82% contained obsidian artifacts (23/28). These types of artifacts were mostly small flakes reduced using bipolar percussion. Surface artifact scatters were consistently encountered along dry gully edges and lower terraces within a barranco. Most scatters are geographically isolated and contain only minor artifacts. The rockshelters containing artifacts are natural caves in ignimbrite/pumice deposits along dry gullies. For example, the rockshelter Waypoint (WP) 56 was previously recorded in Tenerife's patrimonial inventory of archaeological sites and labelled "Bco. Las Monjas VIII" (Inventario Patrimonial de Tenerife, 2016). This site contained abundant sea shells and artifacts near its surface and entrance. These remains likely originated from accumulations present in the eroding sediments. This evidence suggests that "Bco. Las Monjas VIII" (WP56) has the potential to contain thick sediments rich in cultural and natural remains.

We also surveyed the barranco around the more elevated (350-370 masl): El Desiert district (Figure 2). This area represents the eastern upstream portion of the same Barranco de las Monjas that continues to the coast. This area is defined by dry conditions and limited vegetation allowing to better scan the surface. This area contains a total of six archaeological sites consisting of one dwelling, one natural obsidian clast, and four artifact scatters (Table 3). The in-situ obsidian clast was encased in a lahar developed above a thick ignimbrite (Figure 3). Of the identified surface artifact scatters, WP71 was the largest and rich in artifacts including flakes and potsherds.

The southwest extension of the survey region included the barrancos directly south of the Tenerife Sur Airport (Figure 2-3). This area was evaluated because of its proximity to the previously excavated site of Cha Silveria (Carmona Ballestero and Vega Maeso

2008). Besides Cha Silveria (WP63), this area contained four (N=4) small surface artifact scatters (WP64, 65, 68, and 69) all situated approximately 20 masl (Table 3). Each of the scatters consisted primarily of obsidian flakes deposited on sand covered by basaltic lava flows.

The survey in the central portion of Tenerife included the Las Cañadas Caldera floor, in and around Tabonal Negro. This area includes an obsidian flow that was erupted as part of Montaña Blanca around 2 ka (Ablay et al., 1995; Ferk et al., 2011). The investigated outcrops are situated approximately 2300 masl at the margin of the extensive lava flow located at the southeastern slope of the Mt. Teide. This flow is best characterized by a large lava clinker. Obsidian from Tabonal Negro is primarily opaque black in color (Figure 4-1) with microlites, and some nodules show an irridescent surface (Exel, 2011). Of the samples evaluated in the field, the obsidian of Tabonal Negro is low to poor quality for making stone tools. During the survey, neither artifacts nor obsidian workshops were identified. However, multiple artifact scatters were identified (WP40-43, 45) along a dried talus slope just west of the obsidian flow (Figure 5). The eruptive history of the Las Cañadas Caldera shows that the talus slope can be assigned to the Arenas Blancas Member which formed prior to Tabonal Negro (Ablay et al., 1995). Artifact scatters from the Las Cañadas Caldera area contained not only obsidian artifacts, but also pottery fragments, including a rim sherd, and a fragment with incised parallel linear lines. This talus slope also included examples of brown obsidian artifacts (WP 43), which differs from the typical dark opaque obsidian normally found in the obsidian flow of Tabonal Negro.

4.1.2 Obsidian outcrops in northern slope of Mt. Teide

Unsystematic surveys were conducted in the high-altitude north-central area of Tabonal de los Guanches. Tabonal de los Guanches located an extensive obsidian lava flow on the northern slope of the Mt. Teide (Hernández Gómez and Galván Santos, 2008). This locality is the part of a phonolitic lava flow from Teide, called Lavas Negras (Figure 6-A). Radiocarbon dating of charcoal recovered beneath the Lavas Negras layer is 660-940 AD (1150 ± 140 cal. BP) (Carracedo et al., 2007: 1032, 2013: 110). This suggests that the pre-Hispanic indigenous groups could have started exploiting obsidian from Tabonal de los Guanches following the 6th century AD. Due to time and location

constraints placed in the survey team by Teide National Park regulations, the survey methodology focused on identifying artifact scatters along the northern slope of the flow at approximately 1500-1550 masl. This methodology proved highly successful based on the numerous obsidian workshops identified across the limited survey area.

The survey area occurred mainly in the pine forests present in and around the extremely thick lava flow (Figure 6-A). On the lava flow, large quantities of visible obsidian artifacts (e.g., flakes, cores, retouched flakes) situated on large piles of worked and unworked obsidian nodules. Flakes and cores representative of workshops contained mostly black opaque materials that predominately exhibited pronounced ripples and fissures on flaked surfaces. The light brown color of many surfaces of the identified obsidian artifacts likely indicates natural weathering processes. The dense distribution of both flakes and cores across the flow support its definition as a "Centro de Producción" (Hernández Gómez and Galván Santos, 2008: 154) (Figure 6-A). Obsidian from Tabonal de los Guanches (Fig. 6-A) is characterized by high quality and of large enough size (> 50 cm^2) for stone tool production (Figure 4-2). This is clearly supported by the abundant number of surface-identified artifacts. These observations are similar to those of the pioneering study of this area by Hernández Gómez and Galván Santos (2008).

An additional unsystematic survey was conducted at the Charco del Viento (WP76) obsidian outcrop located along northern coast (Figure 6-B). The outcrop is located near a sea cliff where the Abejara Alta Lava Flow enters the sea at approximately 67 masl. Abejara Alta Lava Flow dated to 5,911 ± 264 cal. BP (see Table 7.1 in Carracedo et al., 2013: 112) which makes the formation date of obsidian of Charco del Viento roughly younger than ca. 6,000 cal. BP. Compared to the other large obsidian flows (i.e., Tobonal Negro and Tabonal de los Guanches), Charco del Viento is the smallest of the surveyed locality. Identified obsidian lava flow outcrops contained small to medium sized (< 25 cm^2) lava clinkers of varying shapes and vesiculation (e.g., nugget, angular form) that spread across the coast (Figure 4-3). No artifacts were identified on the surface of surveyed locality.

The results of both systematic and unsystematic surveys yielded the following conclusions. Numerous surface sites consisting of low to high density artifact scatters are present in both low elevation coastal zones and higher elevation montane zones (Figure 7). The montane sites are present at >1000 masl and are frequently on or near large

obsidian outcrops (i.e., Tabonal de los Guanches, Tabonal Negro). The southern sites are located at lower elevations either along the coast or within the deeply incised stream channels (Barranco de las Monjas). Regardless of the spatial extent of scatters, the coastal surface scatters are noticeable with marine shells besides artifacts.

4.2 Obsidian hydration analysis results

The results of polarized microscopic analysis revealed that a limited number of selected obsidian samples both from the curated artifact collections and survey identified surface scatters exhibited measurable obsidian hydration rims (Table 4). Since a large number of samples are appropriate for statistical evaluation (Liritzis and Laskaris, 2011), here we examined a total of 136 samples (Appendices A and B). Of these samples, only 5% (N=7) contained identifiable hydration rims. Rim thicknesses of these seven specimens vary from 0.6 to 3.5μ, and their mean thickness is 1.29μ.

Of the 30 museum-curated obsidian artifacts analyzed from the multi-component site of Guargacho, only four (GU-1-7, GU-2-8, GU-3-2, GU-3-7) contained identifiable hydration rims (Table 4). At this site, very little difference was exhibited between sample rim thickness from Level 1 (GU-1-7) and Level 2 (GU-2-8) (means: 0.6 and 0.7 μm). However, a sample from Level 3 was classified as slightly thicker (mean = 0.89 μm). Even though the sample size is small, this result does support the third expectation that obsidian artifacts from deeper levels are likely to have thicker hydration rims than those from shallower levels. No samples from the curated assemblages of Estacas 1 (N=47), Don Gaspar (N=24) and Cha Silveria (N=9) exhibited hydration rims.

For surface scattered obsidian artifacts, only three out of 26 specimens (12%) exhibited hydration rims (Table 4). Rim thicknesses of these three specimens collected during the pedestrian survey vary from 1.2 to 3.5μ, and mean thickness is 1.98μ. Two specimens from the surface scatters of Granadilla de Abona and one sample from a surface scatter nearby Tabonal Negro have “concealed fissure hydration” rims located along internal fissure (Ambrose, 1994: 139, see also Friedman and Smith, 1960). This type of hydration pattern is present within internal fissures of the sample, which are not susceptible to surface weathering. Figure 8 shows the hydration rims along internal fissures in the flakes collected from Granadilla de Abona (WP50) and Tabonal Negro (WP45-2). Both specimens do not retain hydration rims on their surfaces, but at the

magnifications 1000x under the polarized microscope, measurable hydration rims (HR) are observed along the internal fissures (IF). Table 4 demonstrates that the hydration thicknesses of surface scatter artifacts do not correspond with reported mean annual soil temperatures, which does not support the first expectation (variation in soil temperatures should produce thicker hydration rims on obsidian samples from the southern dryland and northern coastal area hyperthermic soils).

Regarding the second expectation (hydration rims on obsidian artifacts found at higher elevated sites should be less developed than those at lower elevated coastal sites), only one artifact (WP45-2) identified among surface scatters (N=1) in the highly elevated Tabonal Negro (>1500 m) locations do contain hydration rims (Table 4). This suggests that obsidian hydration rim formation on samples deposited at higher elevations with lower temperature regimes than coastal regions. However, this expectation cannot be fully supported due to the small number of overall analyzed samples.

5. Discussion

5.1. On Pre-Hispanic obsidian exploitation

As demonstrated above, there are abundant surface scatters located at lower elevations along the Barranco de las Monjas (Figure 2). This provokes the question as to whether obsidian artifacts recovered along the Barranco de las Monjas in the Bandas del Sur area were procured from the spatially large, higher altitude obsidian outcrops located at Tabonal Negro or Tabonal de los Guanches. Due to the extensive deposits of pyroclastic sediments around Bandas del Sur, the lower altitude areas along the Barranco de las Monjas contain much smaller quantities of obsidian than the higher altitude regions around Mt. Teide and the northern coastal region (e.g., Charco del Viento). However, this expectation may be biased by the sampling strategy utilized in this study that focused on recording only inadvertent discoveries of natural obsidian among the pyroclastic deposits of the barranco instead of deliberate source identifying strategy.

Nonetheless, we identified small obsidian clasts embedded in a lahar along the barrancos in Bandas del Sur (Figure 3). This low presence of natural obsidian is supported by the smaller size (mean maximum length: Bandas del Sur = 26.9 mm) of obsidian artifacts identified among surface scatters in the southern dry lands survey area of Bandas del Sur (e.g., Granadilla de Abona and El Desierto). These artifacts are notably much

smaller than those found in the regions located closer to more central and northern obsidian outcrops (Las Cañadas Caldera floor = 50.9 mm, Tabonal de los Guanches = 66.7 mm). Since the mean lengths are normally distributed, a one-way analysis of variance is applied to see whether there is a difference in mean sizes of artifacts among the regions. The result (ONE-WAY ANOVA: $F=24.395$, $p<0.001$) shows that there is a significant difference in obsidian artifact lengths sampled from Las Cañadas Caldera floor, and Tabonal de los Guanches. Moreover, obsidian artifacts from Bandas del Sur tend to have small flakes and cores struck from pebbles using bipolar percussion. These produced finished flakes that were significantly smaller from ones found at Las Cañadas Caldera and Tabonal de los Guanches ([Tukey's HSD test] Las Cañadas Caldera floor vs. Bandas del Sur: 9.97–38.0, $p<0.001$; Tabonal de los Guanches vs. Bandas del Sur: 25.5–56.2, $p<0.001$).

It is possible that some larger obsidian masses could have been extracted from the central and northern large obsidian outcrops and transported to the southern Bandas del Sur area, but such behavior would require a higher carrying cost relative to energy expended by climbing up and down the elevated landscapes. In addition to the observed difference in artifact size, a behavioral hypothesis can be put forth that argues while pre-Hispanic people in the Bandas del Sur area likely transported/obtained a small percentage of their obsidian from the larger lava domes north of the area, the majority of their procured materials originated from the pyroclastic deposits present on slopes of the Las Cañadas edifice in the southern dryland. This is suggested by geological reports indicating that certain qualities of obsidian nodules are present embedded in the diverse facies of the Arico Ignimbrite Formation across southern Tenerife (e.g., Bandas del Sur, Güimar Valley) (e.g., Brown et al., 2003; Schmincke and Sumita, 2004). While these samples demonstrate the necessary quality, package size, and geographic distribution to serve as tool stone (e.g., Straus 1980; Andrefsky 1994; Kuhn 1995; Rissetto 2009; Prieto et al., 2021), this has yet to be assessed archaeologically.

Regarding a behavioral hypothesis, pre-Hispanic group obsidian procurement and utilization strategies can be tested using evidence from quarries in and around geological outcrops. However, this type of investigation may include additional issues that must be evaluated. Specifically, even though the geochemical composition of analyzed obsidian artifacts can be linked to a specific geological unit, this does not necessarily mean that

453 the original obsidian nodule was collected from that specific location to produce the final
454 recovered artifact (Glascock, 2020). As suggested in other arid regions, such as the North
455 American Southwest (e.g., Shackley, 1995, 2005), the artifact's parent material could
456 originate from various secondary contexts located within alluvial and pyroclastic deposits
457 in southern Tenerife (e.g., local outcrops and exposures by gully erosion). This
458 uncertainty in procurement origin necessitates additional geoarchaeological surveys to
459 evaluate the size and quality of obsidian in various pyroclastic formations distributed in
460 the Bandas del Sur region and beyond.
461
462 5.2. Dating surface scatters by obsidian hydration
463 5.2.1 Hypotheses to explain low occurrences of hydrated obsidian artifacts
464 Regardless of the microclimatic differences that can influence hydration rate, the
465 present study shows that 95% of obsidian artifacts both from the excavated and surface
466 samples do not retain hydration rims. Three potential hypotheses may explain factors that
467 may cause low occurrences of hydration in obsidian samples.
468 The first hypothesis is that the obsidian hydration rims are erased by heat (e.g.,
469 Friedman and Smith, 1960; Friedman and Trembour, 1983; Trembour, 1990; Benson
470 2002, Loyd, 2002; Solomon, 2002; Steffen, 2005). When an obsidian artifact is exposed
471 to heat > 300° C, hydration rims disappear or become significantly diffuse (Benson 2002;
472 Loyd, 2002; Solomon 2002). Indeed, 88% of a surface collected obsidian (21/24) after
473 the 1993 forest fire in Salt Point State Park in northern California (North American West)
474 does not have hydration rims (Anderson and Origer, 1997). Recent forest fires during the
475 post-colonial period (Nacimiento et al., 2020) could have impacted surface scatters of
476 obsidian artifacts across all parts of Tenerife. Indeed, a study of fire scar record shows
477 that pine forest fires during 1850 and 2007 on the Canary Islands occurred at intervals
478 between 2.5 and 4 years (Molina-Terren et al., 2016). The excessive heat from both
479 prehistoric and modern fires often leave visible thermal damage on obsidian surfaces,
480 notably crazing, vesiculation, and heat fractures (Nakazawa, 2002; Steffen, 2002, 2005).
481 A type of crazing, known as "deep surface cracking" (Steffen 2005: 64) is experimentally
482 reproduced with heated wood ash of more than 500° C (Nakazawa, 2002). However,
483 given the absence of any visible thermal traits on the examined samples, the magnitude
484 of burning from forest fires within the study areas may not have been extensive enough

to alter the heat-exposed glass surface, but would have been enough to erase any evidence of hydration rim development.

The second hypothesis is that hydration rims may have been erased by post-depositional wind erosion. For example, the specimen (WP45-2) collected from the Tabonal Negro implies wind-based surface erosion. This could explain the lack of hydration rim development on the surface of obsidian samples, but also allow for the presence of a thin hydration rim to form along internal fissures (Figure 8). The erosion of obsidian hydration rims has been observed on obsidian samples from the North American West. In these arid landscapes with sparce vegetation surface identified obsidian artifacts are susceptible to wind weathering (Friedman and Smith, 1960; Thomas, 1982). Specimens on Tenerife were identified without hydration rims on their surfaces, but some did have rims along internal fractures. These samples originated from various artifact scatters located at a wide range of elevations (70 to 2286 m) across the island (Table 3). This supports the hypothesis that wind weathering could possibly erase surface hydration rim equally across all Tenerife landscapes.

Hydration rims development may also be affected by endogenous factors such as the chemical composition of the obsidian including its H_2O concentration (e.g., Friedman and Long, 1976; Friedman and Trembour, 1983; Hughes, 1988; Ericson, 1989; Hughes and Smith, 1993; Stevenson et al., 1993; Ambrose and Stevenson, 2004; Steffen, 2005; Rogers, 2008b; Stevenson et al., 2019; Laskaris and Liritzis 2020; Liritzis and Laskaris, 2011, 2021). A slow rate of hydration could be due to the composition of phonolite obsidian on Tenerife with its low concentration of SiO_2 (59-61.5%) and high Na_2O+K_2O concentrations (14.5-16%) (e.g., Gottsmann and Dingwell, 2001; Hernández Gómez and Galván Santos, 2008). While there is minimal definitive evidence for how the quantities of major, minor and trace elements affect obsidian hydration rates, laboratory experiments do suggest that low amounts of CaO and MgO can accelerate hydration rates (Friedman and Long, 1976). Magmas with low SiO_2 concentrations generally contain lower H_2O concentrations (Schmincke, 2006). Thus, the low intrinsic water content of Tenerife obsidians may result in slow hydration rates.

Given the geologic, volcanic, and environmental circumstances on Tenerife coupled with the abbreviated time depth of obsidian artifact deposition, additional research will be necessary to evaluate these hypotheses.

517

518 5.2.2. Dating a surface obsidian artifact using hydration along internal fissure

519 To utilize obsidian hydration dating in instances where no surface rim is present, this
520 research employed measuring the rim thicknesses developed along internal fissures. Rims
521 in these locations are more common since they are less susceptible to the varied
522 mechanical and chemical effects that operate on a sample's surface (Ambrose, 1994). To
523 test the comparison of obsidian hydration rims from both surface scatter artifacts with
524 those from a chronometrically determined archaeological assembles, hydration rims were
525 measured on obsidian artifacts from the site of Guargacho and the WP50 artifact scatter
526 both located along the southern coastal region. These two localities are located
527 approximately 15 km apart.

528 The ^{14}C dates for Level III from Guargacho were calculated using marine shell and
529 range between 1260±60 BP (CSIC-168) and 1288±22 BP (IAAA-162505) (Institute of
530 Accelerator Analysis Ltd., 2017) (Table 2). The hydration rim measurement for the single
531 artifact from the WP50 surface scatter is 1.23μ thick, while the average of the two artifacts
532 (GU-3-2 and GU-3-7) from Level 3 of Guargacho is 0.895 (Table 4). The overall
533 hydration rate for the Guargacho artifacts was then calculated so it could be used to
534 estimate the age of the WP50 artifacts.

535 The hydration rate equation is: $X^2 = kt$, where X = hydration rim thickness (μ), k =
536 hydration rate (diffusion rate), and t = time. In order to determine the hydration rate (k),
537 the above equation is converted to $k = X^2/t$. And so when applied to estimating the
538 hydration rate for specimens from Guargacho Level 3, X = 0.9μ, and t = 1274 (averaged
539 means of two ^{14}C dates from Level 3 of Guargacho, Table 2) are employed.

540 Thus,

541 $k = (0.9)^2 / 1274 = 6.3579 \times 10^{-4}$

542 When this hydration rate (k) is used to WP50 artifact,

543 $t = X^2/k = (1.23)^2 / 6.3579 \times 10^{-4} = 1.5129 / 6.3579 \times 10^{-4} = 2380$

544 where X = 1.23, and $k = 6.3579 \times 10^{-4}$

545 Based on this calculation, the WP50 artifact dates to approximately 2380 years ago,
546 which corresponds to the beginning of the Late Holocene. Because this specimen was
547 thin sectioned and measured in 2018, the age of WP50 is 362 years BC. This places the
548 artifact at a similar age to that of the lowest radiocarbon dated level (XI) from the north

549 coastal site of Estacas 1 (Table 2). Based on this date, it implies that the pre-Hispanic
550 inhabitants of Tenerife settled in the southern dry land as well as northern areas even in
551 the early stages of colonization.
552 To accurately date obsidian samples from the various surface scatters along the
553 southern dryland of Tenerife, it is necessary to account for the various disturbances that
554 have impacted the landscape (e.g., thermal effect, mechanical weathering). Studying the
555 impacts of fire on surface obsidian can help evaluate pre-Hispanic landscape use,
556 procurement, and resource utilization patterns. Since timings of human arrivals to the
557 Canary Islands are unravelling (Nascimento et al., 2020), further evaluation of the dates
558 of surface artifact scatters is critical to evaluate the human resource use in Tenerife (e.g.,
559 Vidal-Mitutano et al., 2019).
560 One way to circumvent these environmental circumstances is to focus analysis on
561 the development of hydration rims on internal fissures within obsidian samples. An
562 additional method may include finding ways to estimate the timing of fire effects on
563 obsidian such as identifying fission tracks on natural or artifact samples that can be erased
564 at 300–400° C (Suzuki, 1971; Leach, 1977). These markers may help identified
565 punctuated fire events caused by volcanic activity or subsequent vegetation fires across
566 Tenerife. In addition, increased recording of artifact scatters located on chronometrically
567 dated lava flows would narrow down timings of human exploitation of obsidian in relation
568 to the times of volcanic activity and inactivity. This becomes more feasible as more flow-
569 specific dates become available (Carracedo et al., 2013), such as at Tabonal de los
570 Guanches.
571
572 **6. Conclusion**
573 Lava flows and pyroclastic deposits can cause cultural and technological disasters
574 (e.g., Torrence and Grattan, 2002). But once these deposits became consolidated, people
575 learned how to exploit these valuable resources, notably shiny and brittle volcanic glass
576 (i.e., obsidian) for their economic and cultural benefit (e.g., Torrence, 1986; Shackley,
577 2005; Hughes, 2018; Kuzmin et al., 2020).
578 Using the ideal geologic and geographic settings of Tenerife (Canary Islands), this
579 study builds on growing research centered on examining human adaptations to volcanic
580 activities. Given post-depositional thermal effects or mechanical weathering to obsidian

artifacts from surface scatter assemblages, we explicitly examined hydration rims along internal fissures. This method proved successful for identifying hydration information since these areas of the specimen are less susceptible to alteration or weathering. Thus, hydration rim thickness could be accurately used to correlate depositional dates between non-chronologically defined surface scatters to chronologically dated archaeological assemblages.

In the future, additional study of the relationships between obsidian hydration development and obsidian geochemistry will lead to a greater understanding to when pre-Hispanic indigenous peoples settled on Tenerife and neighboring islands, and how they sustained their societies by interacting with available resources during the Late Holocene until European contact.

Author contributions

Yuichi Nakazawa: Field survey, Analysis, Writing, Editing. Cristina Vega Maeso: Obtaining field survey permissions, Field survey, Analysis, Writing, Editing. Eduardo Carmona-Ballestero: Field survey, Analysis, Writing. John Rissetto: Field survey, Analysis, Writing, Editing. Alberto Berzosa Ordaz: Field survey, Analysis. Yasuo Naoe, Kensho Dohi, Mina Araya: Field survey. Hidehiko Nomura: Sample preparation. Mari Sumita and Hans-Ulrich Schmincke: Writing, Editing.

Data availability

All surveyed site coordinates, site dates, and hydration measurements are available from the tables. Original pictures of pedestrian surveys and samples are partly presented in the paper and the rest will be provided upon request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figure captions / Table captions

Figure 1. Surveyed areas in Tenerife of the Canary Islands.

Figure 2. Localities of surface artifact scatters in Bandas del Sur, southern dryland of Tenerife. GPS coordinates are plotted on Google Earth.
1: recorded sites along lower Barranco de las Monjas, 2: a site cluster along the upper valley along Barranco de las Monjas, 3: Coastal sites around Cha Silveria (WP63)

Figure 3. Pyroclastic deposits in Bandas del Sur (southern dryland of Tenerife). 1, 2: Deposits (lahar) along the Barranco de las Monjas, 3: erosionally exposed small obsidian clast (WP75) at Fig 3-1 and 2, 4: a small obsidian clast (maximum length = 34 mm) exposed on the top of surface deposit (lahar) along the southern coast (WP65) near Cha Silveria.

Figure 4. Sampled naturally outcropped obsidians in the surveys. Blocks and nodules from 1: Tabonal Negro, 2: Tabonal de los Guanches, 3: Charco del Viento

Figure 5. Locations of surface artifact scatters near Tabonal Negro, Teide National Park. GPS coordinates are plotted on Google Earth. Artifacts are scattered on the talus slope besides Tabonal Negro, the large obsidian lava flow at the southeastern slope of Mt. Teide. WP 44 is the locality where the natural obsidian sample was obtained.

Figure 6. Locations of surveyed obsidian outcrops and recorded surface scatters on the distributions of lava flows of Tenerife (geological map is adopted from Fig 7.11 in Carracedo et al., 2013: 115) with the area of Figure 4 (dashed frame) that has Tabonal Negro, an extensive obsidian flow. A: Tabonal de los Guanches on Lavas Negras along northern slope of Mt. Teide, and obsidian flakes from surface workshops. B: An outcropped obsidian at the Charco del Viento, northern Tenerife.

Figure 7. Frequencies of surface recorded artifact scatters along the ranges of elevations (m).

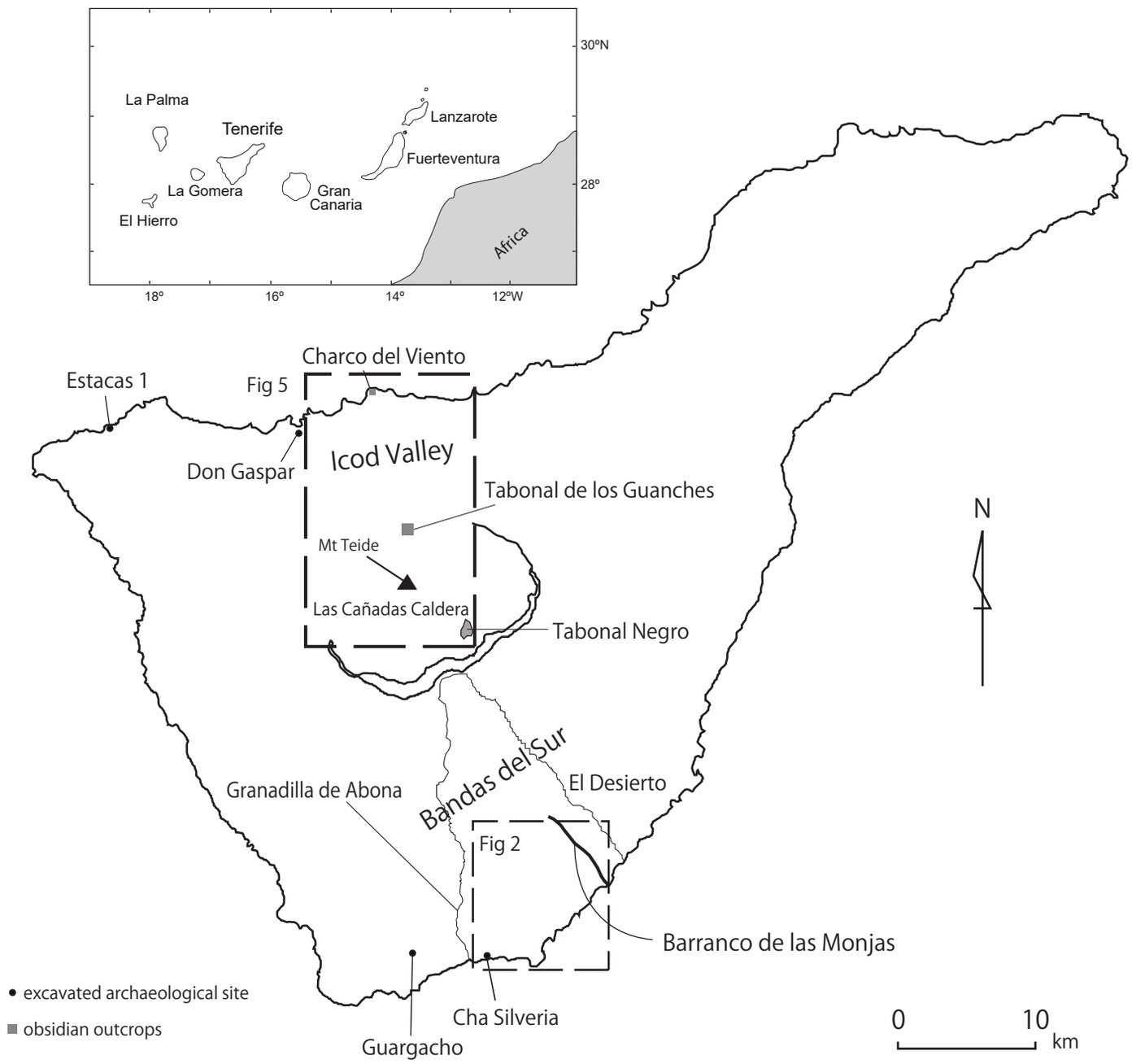
Figure 8. Hydration rims (HR) along internal fissures (IF) observed under the polarized microscope, at the magnifications 1000x, and accompanying diagram illustrates locations of HR and IF in microscopic photograph. Specimen IDs are 1: WP-50, 2: WP-45-2.

Table 1. Monthly meteorological data from the two locations in Tenerife. Data of Santa Cruz de Tenerife are from World Meteorological Organization (2020), and those of Teide National Park are extracted from weather-and-climate.com (2023).

Table 2. Radiocarbon dates from the excavated sites and obsidian samples used for the present study.

Table 3. Recorded points during the systematic and unsystematic surveys in the study area of Tenerife, consisting of surface identified artifact scatters, dwelling, and geological localities of obsidian.

Table 4. Measured hydration rim thicknesses of obsidian specimens from the excavated sites and surface scatters. Measured hydration rim thicknesses of obsidian samples. d, v, int, represent dorsal (exterior), ventral (interior) surfaces, and internal fissures of the flake specimen, respectively, where hydration rims are remained. GU in Sample number signifies Guargacho site.


30ºN
28º
La Palma
Tenerife
Lanzarote
Fuerteventura
La Gomera
Gran Canaria
El Hierro
Africa
18º
16º
14º
12ºW
Charco del Viento
Estacas 1
Fig 5
Icod Valley
Don Gaspar
Tabonal de los Guanches
Mt Teide
Las Cañadas Caldera
Tabonal Negro
N
Bandas del Sur
El Desierto
Granadilla de Abona
Fig 2
Barranco de las Monjas
Cha Silveria
Guargacho
• excavated archaeological site
obsidian outcrops
0
10
km


El Desierto
WP74
WP73
WP72
2
WP52
WP53
WP50
WP51
WP46
WP47
Granadilla de Abona
WP57
WP56
WP55
Barranco de las Monjas
1
Aeropuerto de Tenerife Sur (TFS)
WP64
Cha Silveria
WP63
WP65
WP69
WP68
3.60 km
3
Image © 2022 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth


1


2


3

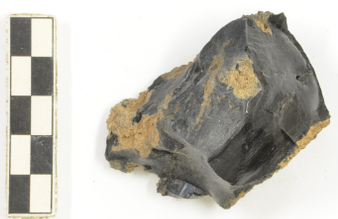

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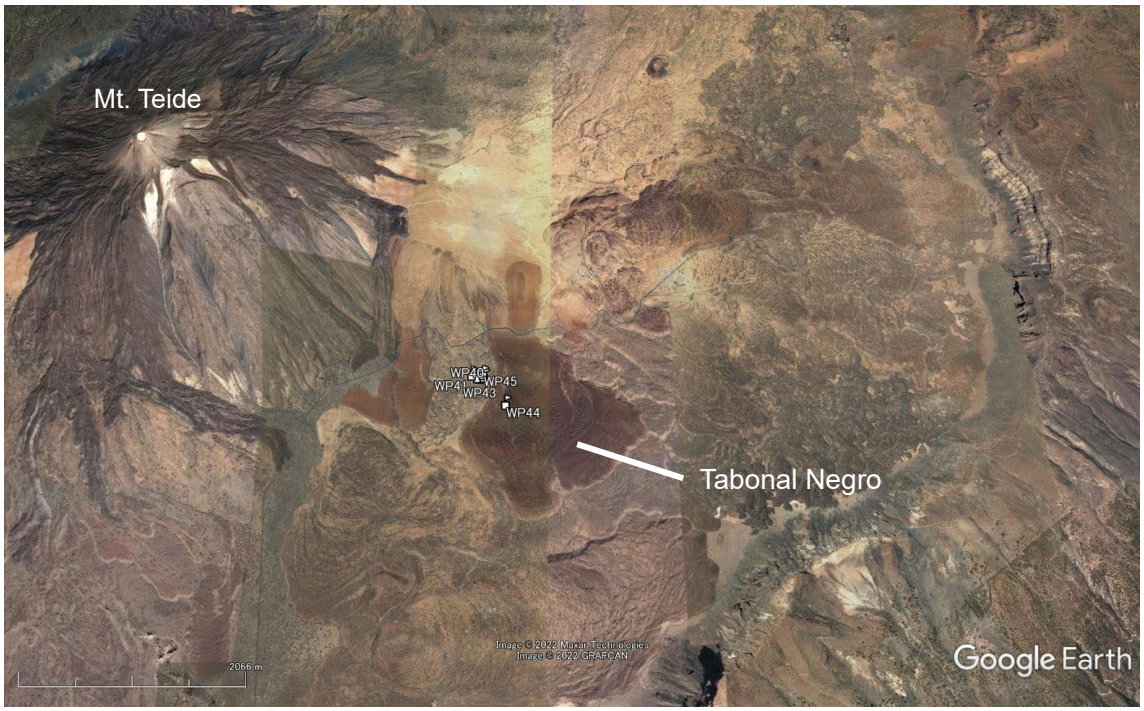
1



2



3


Mt. Teide
WP46
WP41
WP45
WP43
WP44
Tabonal Negro
Image © 2022 Maxar Technologies
Image © 2022 GRAFCAN
2066 m
Google Earth

B

An outcropped obsidian at the Charco del Viento, north coast





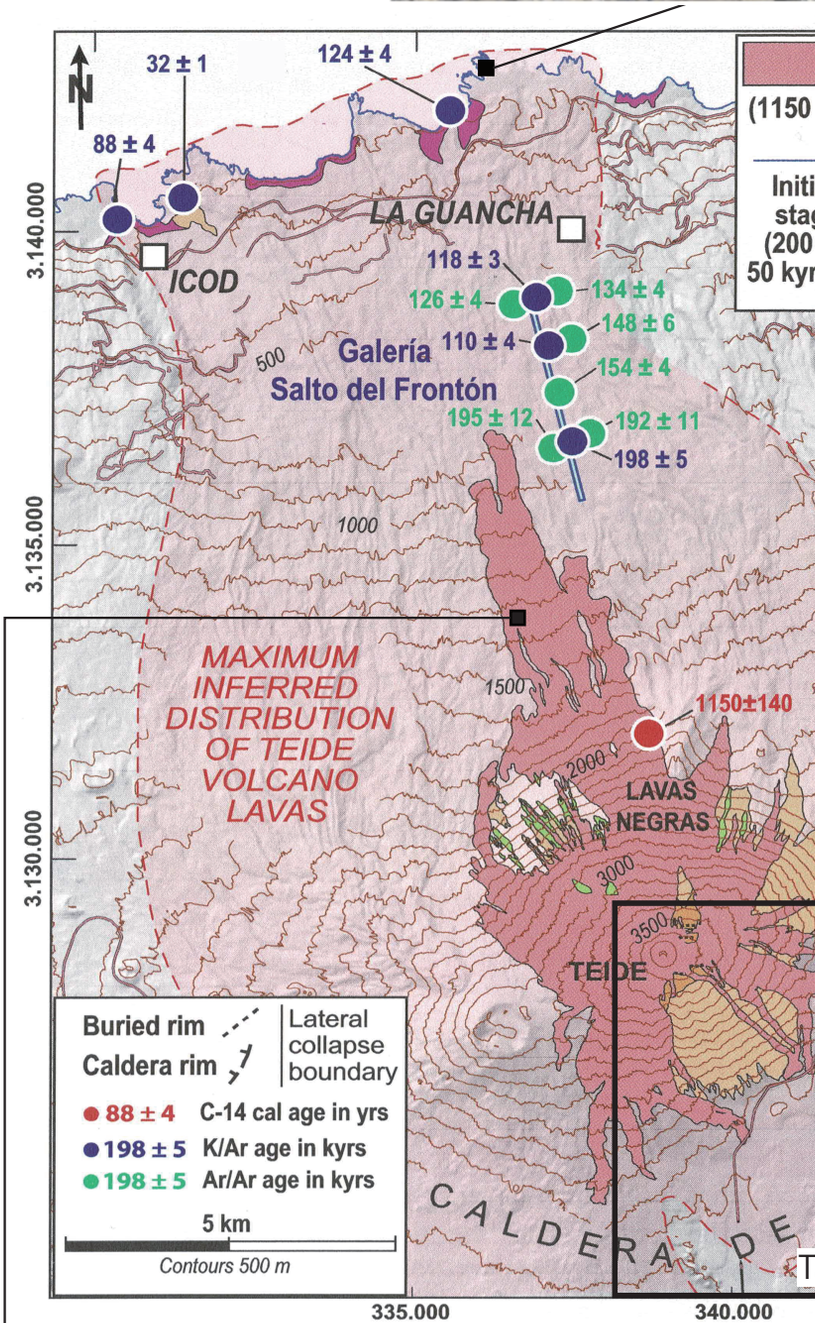
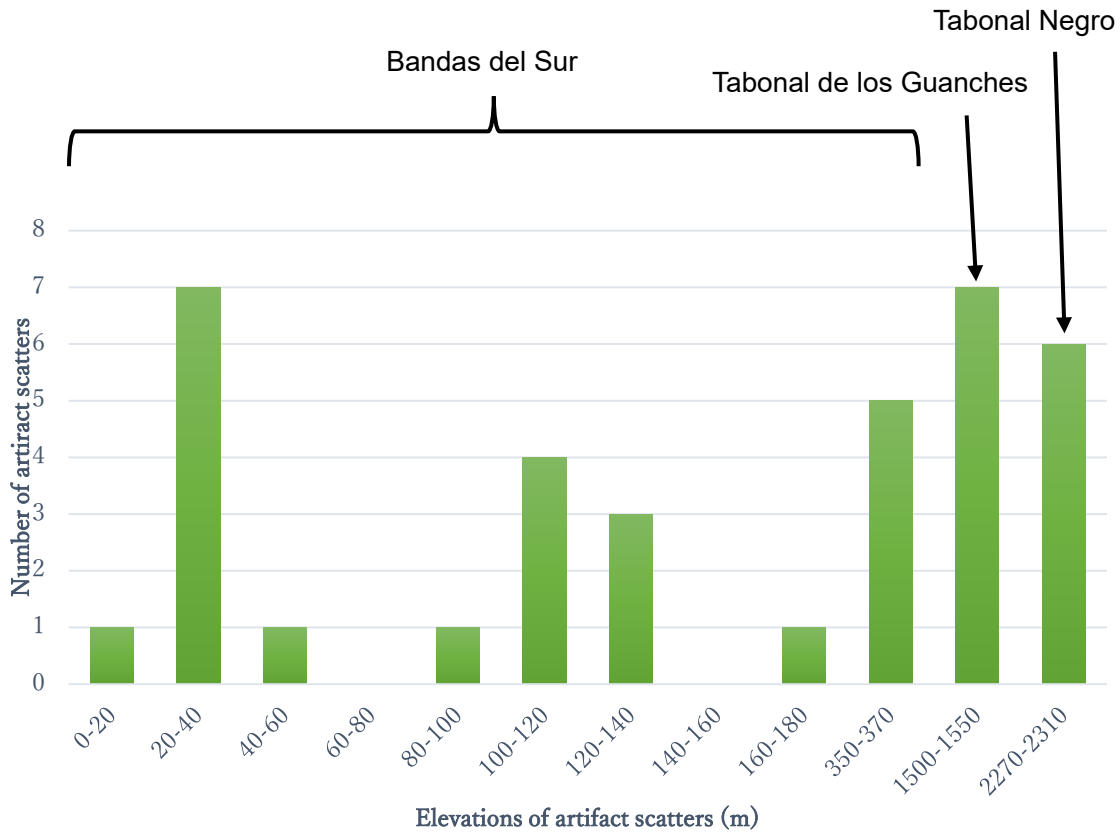


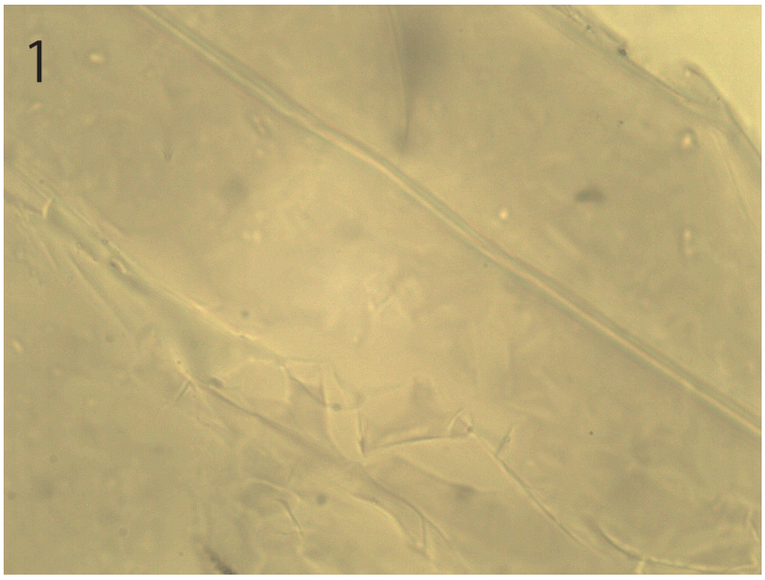
Figure 5

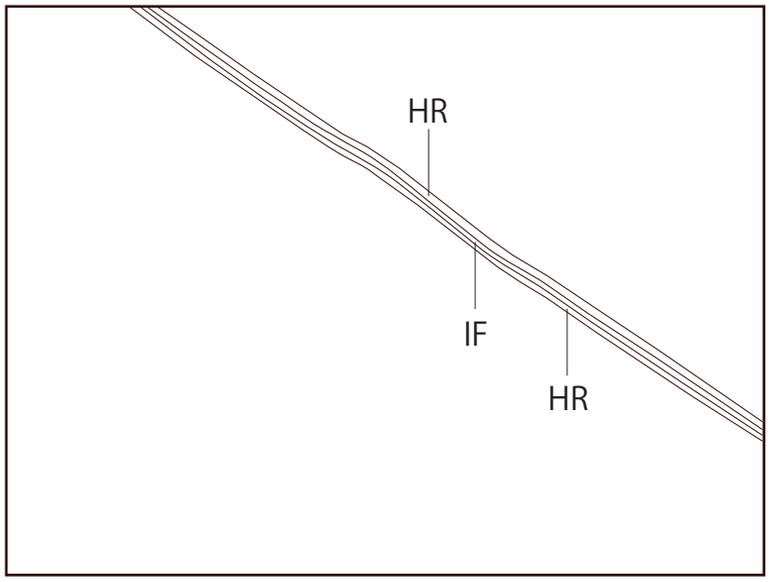


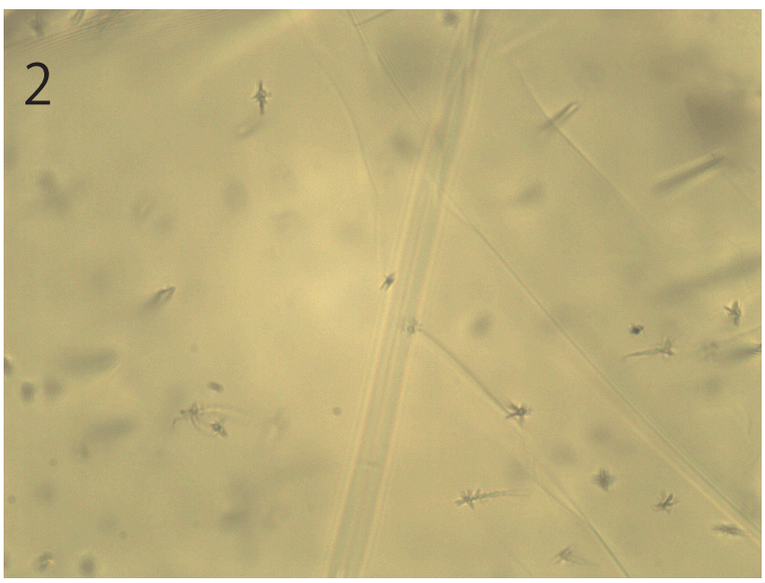
A

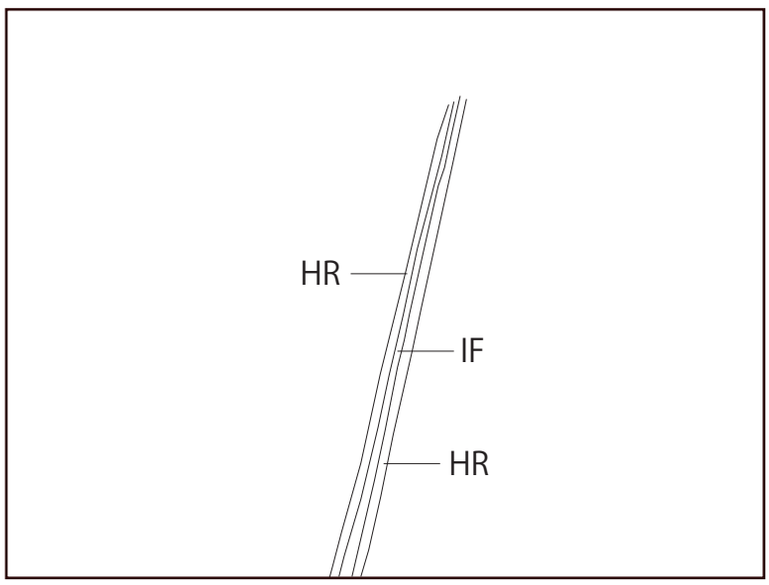
Tabonal de los Guanches on LavasNegras along northern slope of Las Cañadas Caldera, and obsidian flakes from surface workshops


Tabonal Negro
Bandas del Sur
Tabonal de los Guanches
Number of artiract scatters
8
7
6
5
4
3
2
1
0
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
350-370
1500-1550
2270-2310
Elevations of artifact scatters (m)


1


HR
IF
HR


2


HR
IF
HR