Portable XRF Analysis of Obsidian Projectile Points and Debitage from Paipai Territory, Northern Baja California

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Abstract

This study presents the results of an application of Bruker III SD portable x-ray florescence (pXRF) technology to characterize the elemental compositions of a sample of 151 obsidian specimens from an archaeological collection accumulated on Paipai lands, northern Baja California. Chemical signatures derived for every sample specimen are a match to the Tinajas source which is located at the Sierra las Tinajas area within the Paipai orbit. In Baja California previous research demonstrates palpable correspondences between ethnolinguistic boundaries and territories of obsidian conveyance. The sourcing data collected here appears to confirm this pattern. It is proposed that the pattern as it applies to the Paipai reflects obsidian dispersals shaped by seasonal movements to address basic subsistence requirements.

Introduction

The University of California, Los Angeles (UCLA), sponsored an archaeological field survey conducted between October 1958 and September 1959 by Fredric Hicks (Wilken-Robertson and Laylander 2006:71). From his Santa Catarina field camp, Hicks explored a large area between Mexicali and Ensenada, discovering 187 sites throughout the Paipai region, northern Baja California (Figure 1). Lacking topographic maps, Hicks recorded site locations on a sketch map based on Gerhard and Gulick's *Lower California Guidebook* (1956). Artifacts collected during surveys and limited test excavations included stone tools, ceramics, agave quids, and other materials. The Hicks Collection, curated by the Fowler Museum, UCLA, is currently on loan to California State University, Dominguez Hills (CSUDH). It was at CSUDH that the authors accessed the Hicks Collection for the main purpose of pulling an obsidian sample for a sourcing, or provenance, project. The sample was a combination of debitage specimens (n = 100) and projectile points (n = 51) (Figure 2).

The sample's debitage is exclusively from site BC-73, which Hicks described as a "series of small caves worn into conglomerate on bank of dry arroyo" (Hicks 1959). The precise location of BC-73 is not known, but Hicks placed BC-73 southeast of Ensenada, within the core of the Paipai region (Figure 1). BC-73 had a large assemblage of artifacts, perhaps indicating repeated occupations, with one of the caves having "up to 12 feet of fill" (Hicks 1959). Four sample projectile points are from BC-73, with 47 projectile points from 26 additional sites located throughout the Paipai region. Hicks recorded these sites as rock shelters, habitation sites, and food processing sites.

The sample specimens were subjected to an element composition scan using a portable x-ray fluorescence (pXRF) device. Such technology uses properties of x-ray fluorescence to determine with a high level of precision the element compositions (those elements between sodium and uranium on the periodic table) for items that are scanned (Shackley 2010). These determinations can then be compared with known elemental concentrations of previously characterized

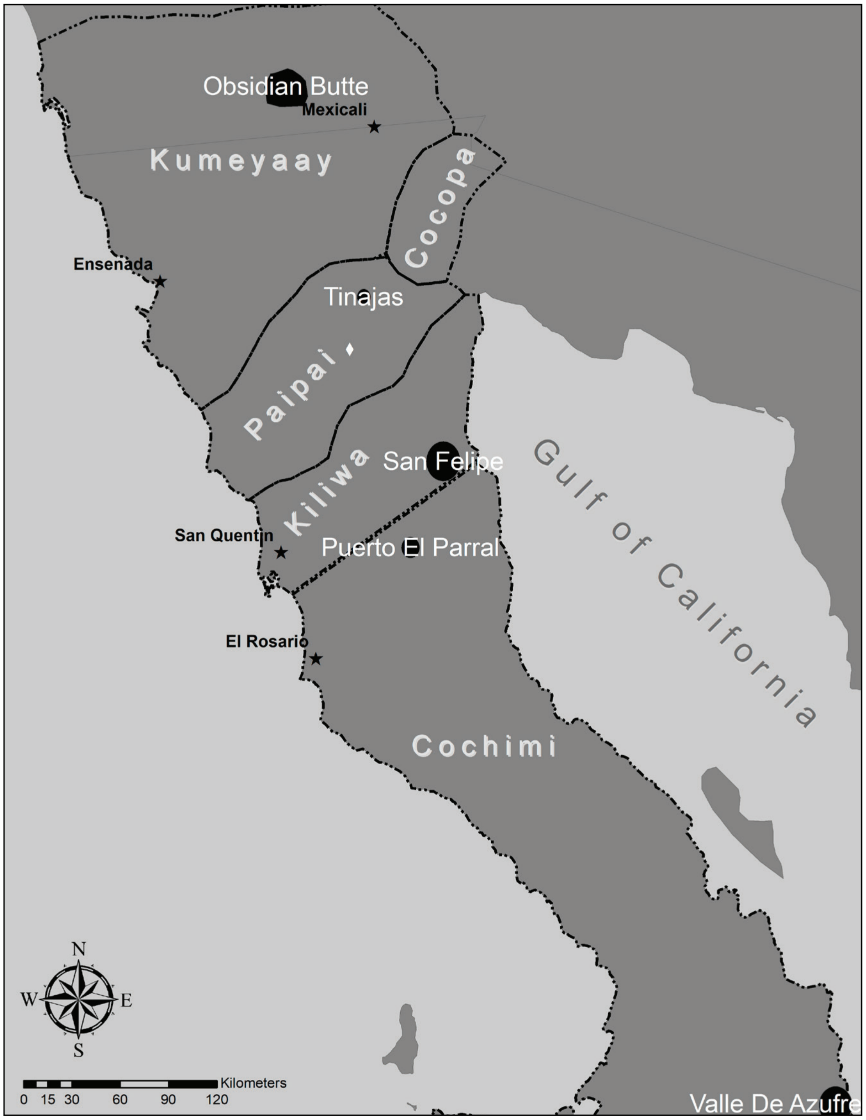

Figure 1. Map of northern Baja California indicating ethnolinguistic boundaries and major sources of obsidian. Tinajas is mapped based on the area proposed by Panich et al. (2017). Obsidian Butte, San Felipe, and Valle del Azufre locations are based on Shackley's geological map found at http://www.swxrflab.net/swobsrcs.htm. The ethnolinguistic boundaries are based on an ethnographic map found in Hinton (1984:6). The White diamond represents the approximate location of site BC-73 based on georeferencing Hick's road map.

obsidian sources. The sample is further described following the section appearing just below, which provides background information regarding obsidian. Following these, there is a section that offers details on methodology and presents the pXRF results. Subsequently, there is discussion of our results in relation to obsidian exchange in northern Baja California. This essay ends with a brief summary of the results and the authors' identification of factors that might best account for Paipai obsidian acquisition patterns.

Obsidian Sources of Baja California: Some Background Information

In the 1960s geochemists discovered that different obsidians have distinctive concentrations of certain elements (e.g., zirconium (Zr), rubidium (Rd), niobium (Nb) (Gordus et al. 1968; Griffin et al. 1969; Key 1969; Shackley 2010). X-ray fluorescence, neutron activation, and electron probe analyses provide researchers with accurate elemental compositions of obsidian (Hall 1970; Shackley 2010). Comparisons between the

Figure 2. Cottonwood Triangular point and four Desert Side-notched projectile points from the Hicks Collection of Paipai artifacts.

chemical signatures of obsidian artifacts and known obsidian sources can reveal the origins of the artifacts' obsidian materials (Peterson et al. 1997; Shackley 2009a; Panich et al. 2015).

Such data might inform on long distance exchange networks. However, Baja California studies have shown that artifact-quality obsidian was typically procured from relatively close sources, more so than received via long distance exchange (Sosa Agular 2014:31–38; Panich et al. 2015:269). Although obsidian studies in Baja California are still few, the present state of knowledge is that the movement of obsidian was associated with seasonal movements determined by subsistence strategies within well-defined ethnolinguistic territories (Shackley et al. 1996:727; Sosa Aguilar 2014:42; Panich et al. 2015:270).

Baja California has several limitations that make obsidian procurement studies difficult. For instance, Baja California has never been subject to a complete geological survey, thus preventing a complete index of obsidian sources, leaving the locations, elemental compositions, and total number of obsidian sources incompletely known (Shackley et al. 1996:720; Panich et al. 2012:184; Panich et al. 2015:262). Further, some of the sources have been chemically characterized but are not associated with a specific location; these are labeled as "unknown" (Shackley et al. 1996:720; Panich et al. 2012:184; Panich et al. 2015:262). Despite these limitations, recent research in Baja California obsidian has presented hypotheses to explain patterns of obsidian procurement and dispersal (Shackley et al. 1996; Sosa Aguilar 2014; Panich et al. 2015; Panich et al. 2017).

Some of the best-known obsidian sources in Baja California include Valle del Azufre, Puerto el Parral, and San Felipe (Figure 1). With the significant exception of Valle del Azufre located in central Baja California, which contains some of the largest nodules and highest quality obsidian in the peninsula (Shackley et al. 1996:724, 726), most sources in Baja California produce relatively small nodules (Laylander 2005). These small nodules precluded the production of large artifacts, but they were adequate for small arrow points (Panich et al. 2015:260). Puerto el Parral is located south of Arroyo Matomi, and that source's obsidian has been found at a few sites along the Pacific coast between San Quentin and El Rosario (Laylander 2005; Moore 2006; Panich et al. 2012:188–189).

The San Felipe source was once considered one of the most widely used obsidian sources; however, recent research disputes its archaeological prominence, and its exact location is not yet precisely known (Panich et al. 2012:190; Panich et al. 2017). Recently, Panich and his colleagues recovered obsidian artifacts from a site near Mission Santa Catalina, where they identified an obsidian chemical group and temporarily classified it as Santa Catalina unknown (SCu). Based on artifact distributions and reconnaissance surveys focusing on obsidian nodules in secondary geological contexts, Panich et al. (2015:262; 2017:54) argued that the SCu source is in the Sierra las Tinajas area, reclassifying it as the Tinajas source. Expanding on their previous findings, Panich and his colleagues reassessed the elemental composition of obsidian artifacts from southern California and northern Baja California, and they now argue that Tinajas obsidian was repeatedly misidentified chemically as San Felipe and that Tinajas, not San Felipe, has the widest dispersal of obsidian (Panich et al. 2017:54).

The Sample

To assemble the sample, Hicks Collection debitage was screened for fragments that exceeded a minimum thickness of 2 mm. The 2 mm thickness provides enough material to effectively pXRF scan the obsidian artifacts, which allows the x-rays to refract, producing reliable results (Speakman 2012). After initial screening, 100 BC-73 primary, secondary, and tertiary flakes remained. Out of the 100 fragments, tertiary flakes accounted for 40 percent, secondary flakes accounted for 30 percent, and primary flakes accounted for 29 percent (one flake was not given a classification) (Table 1). The 51 points were separated into 3 categories: 20 Desert Side-notched points (AD 1300–1800), 5 Cottonwood Triangular points (AD 1300–1800), and 26 unclassified damaged points (Thomas 1981:17, 18) (Table 2).

Methodology and Results

Unlike other analytical techniques such as neutron activation analysis that require samples to be destroyed (Hall 1970), pXRF scans can identify elemental markers without damaging artifacts (De Francesco 2008). This relatively new technology, though portable and nondestructive, has been criticized concerning its accuracy when applied to obsidian (Shackley 2010, 2012; Braswell 2013); however, recent studies using pXRF produced results similar to full laboratory XRF (Milhauser et al. 2011; Speakman 2012; Panich et al. 2015).

For this study a Bruker III SD pXRF device equipped with a rhodium x-ray tube was set at 40 KV and 28μA following Speakman (2012). The filter used had the specifications 12 mil Al, 1 mil Ti, and 6 mil CU. The instrument scanned obsidian materials for 200 second assays to compensate for measurement fluctuations during the scanning period (Speakman 2012). After scanning, the Bruker's analytics program, Spectra 5.3, converted raw measurements to elemental data in parts per million (ppm) (Table 3).

The pXRF ppm data from this study were compared to other published obsidian source data sets using the Statistical Package for the Social Sciences (SPSS) program. An agglomerative hierarchical cluster analysis identified three distinct and non-overlapping groups within the sample and the published data (Figures 3, 4, and 5). The cluster analysis indicates that the obsidian of the projectile points and debitage came from a single source. When compared to published values, the analyzed materials all correspond to the Tinajas source (Panich et al. 2017) and are distinct from other known obsidian sources, that is, San Felipe, Puerto el Parral, Obsidian Butte, and Valle del Azufre (Table 4) (Shackley 2009b; Panich et al. 2012; Panich et al 2015).

Discussions

Because the 51 arrow points were recovered from sites throughout Paipai territory, it is probable that the Tinajas source was the principal obsidian source for much of that area. Tinajas material was not used exclusively by the Paipai. For example, the Kumeyaay obtained Tinajas volcanic glass (Panich et al. 2015). Furthermore, Tinajas material can be found as far north as modern-day Orange and Riverside counties (Panich et al. 2017:54, 71). Therefore, clearly Baja California

Table 1. Site Bc-73 Debitage: PPM Trace Element Data.

Pxrf scan object #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73
Code	1 SR2-6	1 SR2-6	2 SR2-3	2 SR1-4	2 SR1-4	2 SR1-3	2 SR1-3	2 SR1-3	2 SR2-2	2 SR2-2	2 SR2-2	2 SR2-2	2 SR2-2	2 SR2-2	2 SR2-2
Date	4/20/1959	4/20/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959
Flake type	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary
Weight (g)	14.93	5.28	6.04	1.31	5.11	2.41	3.31	2.03	7.85	6.49	0.9	4.59	2.28	1.09	2.5
Rb	112.75	126.52	125.03	129.37	120.62	132.29	126.82	120.13	126.01	122.37	126.43	129.62	128.65	132.63	102.57
Sr	23.68	28.41	24.85	29.41	21.59	31.97	28.18	45.8	48.45	27.91	55.19	30.07	28.69	31.42	40.08
Y	27.52	32.53	31.79	32.86	31.44	28.27	31.63	31.22	31.46	29.98	32.31	32.84	31.95	33.89	25.23
Zr	91.98	99.96	92.26	101.51	88.49	100.07	96.06	108.96	112.19	92.48	119.17	99.57	97.69	101.74	98.54
Nb	9.15	8.19	11.18	10.63	9.62	9.52	9.22	10.23	9.97	8.66	10.34	9.01	9.43	9.99	8.91

Pxrf scan object #	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73
Code	2 SR2-2	1 SR2-8	1 SR2-8	1 SR2-8	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-12	1 SR1-12	1 SR1-12	2 SR1-2	2 SR1-2	2 SR1-2	2 SR1-2	1 SR2-6
Date	4/22/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/23/1959	4/23/1959	4/23/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959	4/20/1959
Flake type	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Secondary
Weight (g)	0.44	0.83	0.44	1.59	4.08	0.58	0.42	0.8	1.21	2.26	4.37	3.12	1.93	2.41	3.4
Rb	127.71	138.24	110.15	96.15	89.19	103.57	105.55	114.54	105.33	97.6	91.01	88.21	87.96	89.92	125.9
Sr	54.99	31.32	24.12	18.17	19.08	22.51	24.78	23.76	24.41	22.02	21.3	30.85	34.36	21.62	29.21
Y	32.02	34.48	26.49	24.69	23.27	27.87	26.62	27.25	25.2	24.72	24.31	24.57	23.8	22.73	32.42
Zr	118.49	106.61	79.19	67.44	66.51	80.51	83.43	82.38	78.57	73.89	71.98	77.83	81.25	70.02	98.85
Nb	10.9	9.8	11.8	8.37	7.53	9.61	9.39	10.06	8.25	9.25	8.95	8.92	8.18	7.99	9.45

Table 1. Continued.

Pxrf scan object #	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73
Code	1 SR2-6	2 SR2-3	2 SR2-3	2 SR2-3	2 SR1-4	2 SR1-4	2 SR1-3	2 SR1-3	2 SR1-3	2 SR1-3	2 SR1-3	2 SR1-3	2 SR2-2	2 SR2-2	2 SR2-2
Date	4/20/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/22/1959	4/22/1959	4/22/1959
Flake type	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary
Weight (g)	1.22	2.62	2.29	3.26	1.31	0.71	2.43	1.32	3.9	3.13	4.73	0.33	2.39	2.03	1.92
Rb	120.64	130.31	134.7	129.71	145.01	138.01	125.2	124.33	131.35	125.15	130.96	137.03	123.21	121.67	128.59
Sr	40.22	30.02	30.17	29.87	30.52	30.8	45.58	31.22	29.21	26.61	28.51	55.7	51.36	28.83	28.38
Y	31.29	31.75	33.32	32.47	32.15	35.27	32.59	30.69	30.81	30.25	30.87	35.99	30.55	29.24	30.57
Zr	103.99	99.73	105.13	101.05	106.17	107.92	110.73	99.44	100.84	99.64	97.89	123.36	115.27	97.63	95.13
Nb	9.8	9.56	9.94	10.37	9.68	10.47	8.62	10.03	9.01	10.13	9.59	10.19	9.84	8.66	9.57
Pxrf scan object #	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73
Code	2 SR2-2	1 SR2-8	1 SR2-8	1 SR2-8	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-12	1 SR1-12	2 SR1-2	1 SR2-6	2 SR2-2
Date	4/22/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/23/1959	4/23/1959	4/22/1959	4/20/1959	4/22/1959
Flake type	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Tertiary	Tertiary
Weight (g)	0.72	0.32	1.89	0.29	5.46	2.08	0.7	0.36	0.8	0.77	1.18	1.61	1.61	0.2	0.78
Rb	152.51	108.19	94.25	117.58	98.57	97.53	94.34	108.46	94.68	90.57	107.72	106.88	81.39	150.51	142.01
Sr	33.39	37.05	33.23	47.66	21.63	22.1	38.09	47.41	34.28	36.6	23.45	20.82	30.54	50.28	30.51
Y	36.39	26.61	25.97	28.88	24.16	24.29	25.22	26.92	22.66	26.05	25.94	25.25	21.44	34.83	33.67
Zr	113.28	88.76	81.88	99.81	73.31	75.23	86.93	97.17	80.7	83.02	83.62	75.44	76.82	124.54	108.11
Nb	11.55	11.78	9.17	10.49	9.42	9.69	10.78	11.71	8.6	8.07	10.84	8.93	8.37	12.67	10.77

Table 1. Continued.

Pxrf scan object #	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73
Code	2 SR2-2	2 SR2-2	2 SR2-2	1 SR2-8	1 SR2-8	1 SR2-8	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-6	1 SR1-12	1 SR1-12
Date	4/22/1959	4/22/1959	4/22/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/20/1959	4/23/1959	4/23/1959
Flake type	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary
Weight (g)	0.85	0.72	0.22	0.71	0.56	1.12	0.82	0.75	0.47	0.27	0.79	0.36	0.33	0.48	0.34
Rb	132.02	144.68	148.94	131.71	140.85	102.9	91.95	103.07	94.8	127.99	92.84	116.52	107.41	102.91	108.7
Sr	31.86	30.73	63.5	27.22	52.3	22.32	42.06	44.51	37.97	27.73	21.11	23.33	26.44	42.17	26.05
Y	31.9	32.84	36.26	32.94	33.49	25.01	26.92	27.98	26.58	27.39	23.39	27.01	27.09	27.41	27.82
Zr	105.15	108.25	130.97	102.23	119.82	76.65	90.13	92.33	87.57	85.55	73.9	84.01	80.53	90.52	81.38
Nb	9.68	10.67	13.25	10.28	11.52	8.91	8.99	9.51	8.5	11.99	7.56	10.86	10.59	10.87	10.07

Pxrf scan object #	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73
Code	1 SR1-12	1 SR1-12	2 SR1-2	2 SR1-2	2 SR1-2	2 SR1-2	2 SR1-2	2 SR2-3	2 SR2-3	2 SR2-3	2 SR2-3	2 SR2-3	2 SR2-3	2 SR1-4	2 SR1-4
Date	4/23/1959	4/23/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959	4/22/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959
Flake type	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary
Weight (g)	0.77	0.14	1.41	0.26	0.49	0.18	1.4	2.3	0.95	1.05	0.93	0.78	1.03	2.04	1.3
Rb	103.93	135.8	104.84	122.69	103.69	130.15	96.62	120.55	147.01	126.17	132.5	132.11	147.73	132.41	139.95
Sr	21.85	28.07	24.57	26.14	21.9	56.96	21.41	27.03	32.59	30.4	28.3	30.66	31.24	29.54	31.3
Y	27.91	29.34	24.73	30.33	26.03	30.95	24.05	30.51	35.01	32.99	33.97	30.07	34.97	31.28	33.05
Zr	76.85	89.9	76.81	87.09	79.93	101.61	72.49	92.88	109.35	98.26	96.82	104.96	108.84	103.06	104.07
Nb	9.62	11.55	8.54	10.54	10.45	12.38	7.2	8.01	11.12	10.21	11.13	10.25	11.65	9.07	10.3

Table 1. Continued.

Pxrf scan object #	91	92	93	94	95	96	97	98	99	100					
Site	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73	BC-73					
Code	2 SR1-3	2 SR1-3	2 SR1-3	2 SR1-3	2 SR1-3	2 SR1-3	2 SR2-2	2 SR2-2	2 SR1-4	1 SR2-6					
Date	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/24/1959	4/22/1959	4/22/1959	4/24/1959	4/20/1959					
Flake type	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary	Tertiary		Secondary					
Weight (g)	0.08	1.01	2.38	2.37	0.54	0.16	2.75	3.23	3.58	0.4					
Rb	183.98		120.16	137.09	134.41	156.22	126.67	131.8	117.14	152.67					
Sr	43.29		51.21	31.55	29.87	63.19	28.97	31.19	26.03	33.37					
Y	38.88		29.95	31.09	32.88	36.32	29.94	30.34	29.49	36.91					
Zr	121.72		110.55	102.28	102.02	133.35	99.06	100.73	91.87	111.52					
Nb	13.19		9.66	9.78	9.94	11.98	8.86	9.02	8.35	11.17					

Note: Debitage flakes (primary, secondary, and tertiary).Weight in grams. Elements (ppm concentrations): rubidium (Rd),strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb).

Table 2. Project Projectile Points: PPM Trace Element Data.

Name	Site	Artifact #	Rb	Sr	Y	Zr	Nb
Pai Pai Point 1	BC-39-S	469-315	142.5025778	30.82370267	32.83463089	103.132504	11.09995445
Pai Pai Point 2	BC-161	469-217	130.6207977	27.12734593	31.27782675	98.79239138	9.85445538
Pai Pai Point 3	BC-175	469-419	122.7397586	27.20551179	29.95293956	95.17464533	9.134191703
Pai Pai Point 4	BC-40	469-216	145.237182	32.1490474	31.13910873	105.9063149	11.33746608
Pai Pai Point 5	BC-?	469-999	130.3031251	31.16181728	30.78434062	98.69841685	10.76573682
Pai Pai Point 6	BC-132	469-331	118.5169567	46.37818254	29.85619342	109.3806216	9.898651488
Pai Pai Point 7	BC-74	469-323	111.6177187	45.24310521	30.25081017	105.964491	8.097413146
Pai Pai Point 8	BC-179	469-327	122.8333428	49.51480443	30.5675723	111.3336508	9.775554324
Pai Pai Point 9	BC-161	469-218	127.2548934	27.46649285	31.71868986	95.38641746	9.904370566
Pai Pai Point 10	BC-144	469-326	135.7147571	31.23371806	34.08333439	101.7900683	11.19124125
Pai Pai Point 11	BC-40	469-219	142.9177787	31.33046169	33.50114342	108.2595444	11.54814589
Pai Pai Point 12	BC-136	469-432	129.6140732	52.805382	32.82592642	116.3014711	10.96986773
Pai Pai Point 13	BC-161	469-214	131.4704285	30.00628829	32.02416053	100.0156652	9.855896659
Pai Pai Point 14	BC-47	469-330	133.2955946	48.76259988	30.82711107	112.5931158	9.926206127
Pai Pai Point 15	BC-11-S	469-322	125.8553473	28.2318469	31.19645854	97.44173585	9.070587102
Pai Pai Point 16	BC-73-S	469-314	116.9665424	41.86217339	29.90417181	102.0933115	9.457615278
Pai Pai Point 17	BC-186	469-221	126.5547809	27.32216446	31.68270796	95.27010328	10.01509354
Pai Pai Point 18	BC-99	469-324	117.5204267	42.95620439	30.10060955	104.5485561	8.633257505
Pai Pai Point 19	BC-26	469-215	140.3848799	27.00984512	36.00210917	100.8382689	10.78007355
Pai Pai Point 20	BC-136	469-433	128.0245834	29.10244851	32.35091328	101.5070398	10.54703376
Pai Pai Point 21	BC-12-S	469-317	134.0484691	29.90848787	31.16420589	101.3428883	10.20906164
Pai Pai Point 22	BC-147	469-454	126.29795	27.19617315	30.53416453	98.22995174	10.11220829
Pai Pai Point 23	BC-73	469-224	133.1290711	30.81189078	30.83253872	100.6719135	10.04855561
Pai Pai Point 24	BC-131	469-313	130.1702514	28.16471279	31.90696179	98.49060111	9.192695364
Pai Pai Point 25	BC-14	469-222	123.3952432	47.87138956	30.26604019	111.9927484	10.52336661
Pai Pai Point 26	BC-12	469-370	125.9216996	51.54622005	32.69272536	113.6565821	10.21190679
Pai Pai Point 27	BC-19	469-441	126.28032	28.08908679	30.70506561	96.29735283	9.241179539
Pai Pai Point 28	BC-?	469-329	130.517233	48.61047811	29.95961999	113.9277508	10.97814071
Pai Pai Point 29	BC-?	469-824	120.5434816	43.75105199	30.56047066	105.1928969	10.09554563
Pai Pai Point 30	BC-96	469-434	113.6687154	40.18361831	28.75579615	99.43596334	8.813769234
Pai Pai Point 31	BC-163A	469-391	117.4835825	26.23528437	30.18045545	93.44946742	8.619268816
Pai Pai Point 32	BC-32-S	469-827	122.3454433	26.71573003	28.58053944	91.90839905	9.530866185
Pai Pai Point 33	BC-39-S	469-XXX	128.6368257	28.17748022	28.92557019	96.46539297	11.09286441
Pai Pai Point 34	BC-14	469-223	131.4498268	30.03009152	30.42630794	98.12589041	10.2554091
Pai Pai Point 35	BC-14	469-856	118.9224293	48.44115334	32.1093377	114.0062906	10.29126917

Table 2. Continued.

Name	Site	Artifact #	Rb	Sr	Y	Zr	Nb
Pai Pai Point 36	BC-73	469-1281	143.2804793	32.60995401	32.69713273	105.5903751	10.9996646
Pai Pai Point 37	BC-73	469-1303	131.0284839	30.97949961	31.08704228	100.2126492	10.58529826
Pai Pai Point 38	BC-1A	469-858	160.7327773	34.7161852	36.25794986	110.1156869	13.17412543
Pai Pai Point 39	BC-41-S	469-316	114.1111799	48.10863521	30.12618891	105.1970878	9.175781746
Pai Pai Point 40	BC-77-S	469-308	103.1714085	37.62512912	27.21252319	92.83232341	8.892216045
Pai Pai Point 41	BC-46-S	469-311	116.960092	41.51592107	31.23299587	101.7774376	8.206133937
Pai Pai Point 42	BC-74-S	469-851	127.320618	27.22392385	32.67112734	96.76794798	9.241684294
Pai Pai Point 43	BC-172	469-453	119.1169722	48.55342227	30.41256248	107.1918053	9.101350021
Pai Pai Point 44	BC-96	469-436	125.4142316	28.7906394	31.88941701	97.73278044	9.397450317
Pai Pai Point 45	BC-39-S	469-319	126.8749955	28.40321939	31.36118696	98.45391306	10.17053742
Pai Pai Point 46	BC-186	469-328	139.5890618	30.89949756	30.58599094	101.9488131	11.01118161
Pai Pai Point 47	BC-12-S	469-826	122.0240195	27.47780271	29.73554531	94.00458514	8.731620952
Pai Pai Point 48	BC-14-S	469-854	118.5477247	44.68466269	28.85996055	102.1862384	8.90115322
Pai Pai Point 49	BC-14-S	469-855	118.7398469	26.83174144	31.06539572	91.66875184	9.010244684
Pai Pai Point 50	BC-46	469-312	122.0767418	26.79723838	30.91174693	94.59364765	9.46413022
Pai Pai Point 51	BC-12-S	469-320	113.7326759	40.57358884	28.67654324	100.1526933	8.969815763

Note: Elements (ppm concentrations): rubidium (Rd),strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb).

Table 3. Minimum, Maximum, and Mean Trace Element Values for Primary, Secondary, and Tertiary Flakes.

	BC-73 Obsidian Debitage								
	Primary (N = 29)			**Secondary (N = 30)**			**Tertiary (N = 40)**		
	MIN	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**
RB	87.96	138.24	114.03	81.39	152.67	119.23	91.95	183.98	125.8
SR	18.17	55.19	29.96	20.82	55.7	33.52	21.11	63.19	33.88
Y	22.73	34.48	28.72	21.44	36.91	29.56	23.39	38.88	30.43
ZR	66.51	119.17	90.99	73.31	123.36	96.34	72.49	133.35	97.8
NB	7.53	11.8	9.41	8.07	11.78	9.84	7.2	13.19	10.28

Note: Values in ppm concentrations.

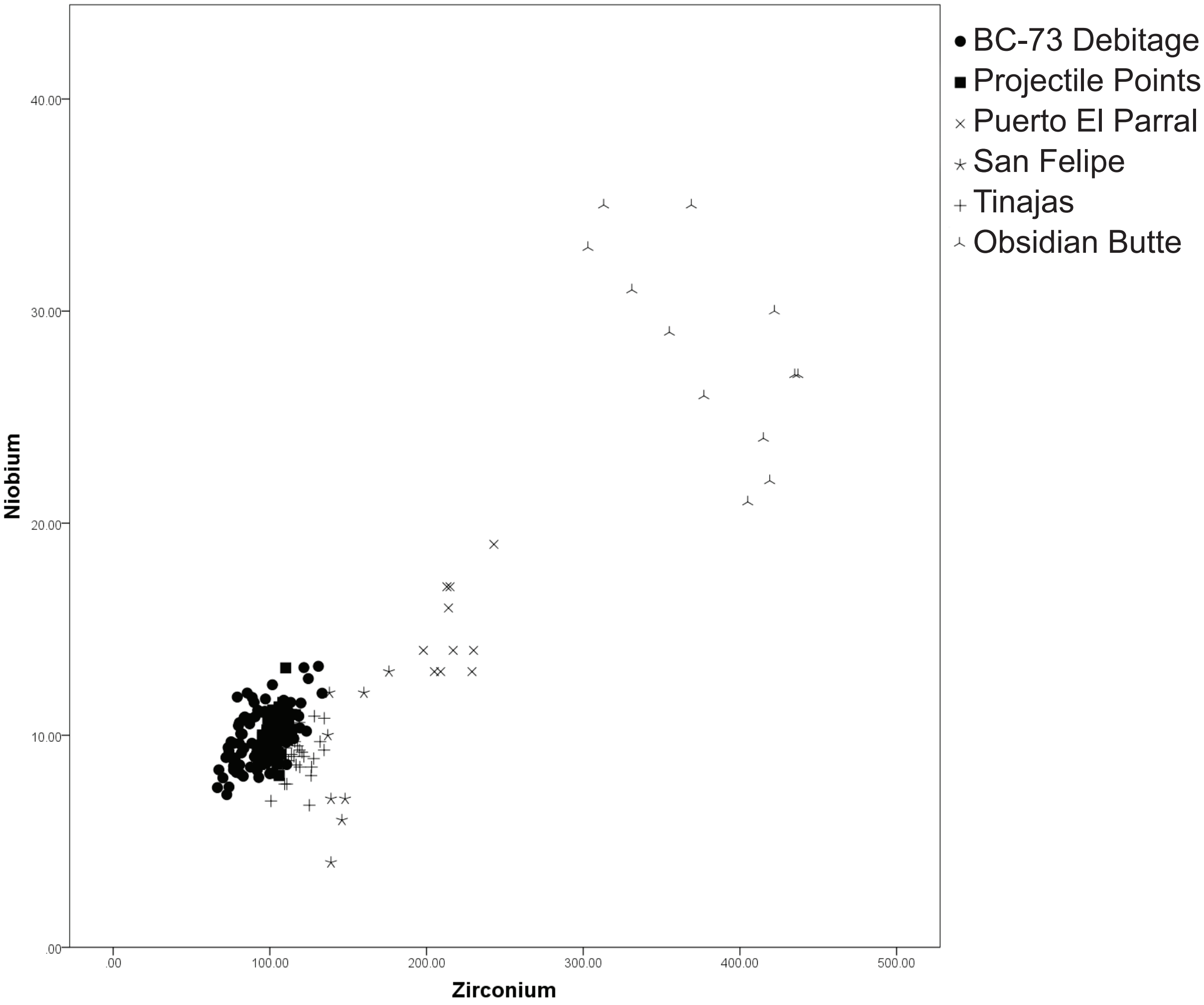

Figure 3. Concentrations (in ppm) of niobium and zirconium for this project's sample debitage and projectile points compared with independently derived chemical signatures for the Tinajas source and chemical characterizations for the Puerto el Parral, San Felipe, and Obsidian Butte sources.

obsidian transport was not limited to the ethnolinguistic territory in which a particular kind of volcanic glass was located (Panich et al. 2015:269; Shackley et al. 1996:727; Sosa Aguilar 2014:42). Nonetheless, there remains a robust correlation between a territory of obsidian conveyance and an ethnolinguistic boundary. The data from this study's sample are not at odds with this correlation.

We hypothesize that the dispersal of Baja California obsidian was shaped specifically by an exploiting ethnolinguistic group's proximity to the resources in the annual round of subsistence activities. Precontact inhabitants of Baja California adapted to the environment through a hunter-gatherer subsistence strategy that relied on local vegetation, small terrestrial and coastal animals, and most importantly, water sources (Massey 1966:38–40; Aschmann 1967; Gamble and Wilken-Robertson 2008:131). Sources of water and food varied throughout the year, and humans adapted to those variations through seasonal migrations between the Pacific coast, the interior, and the Gulf

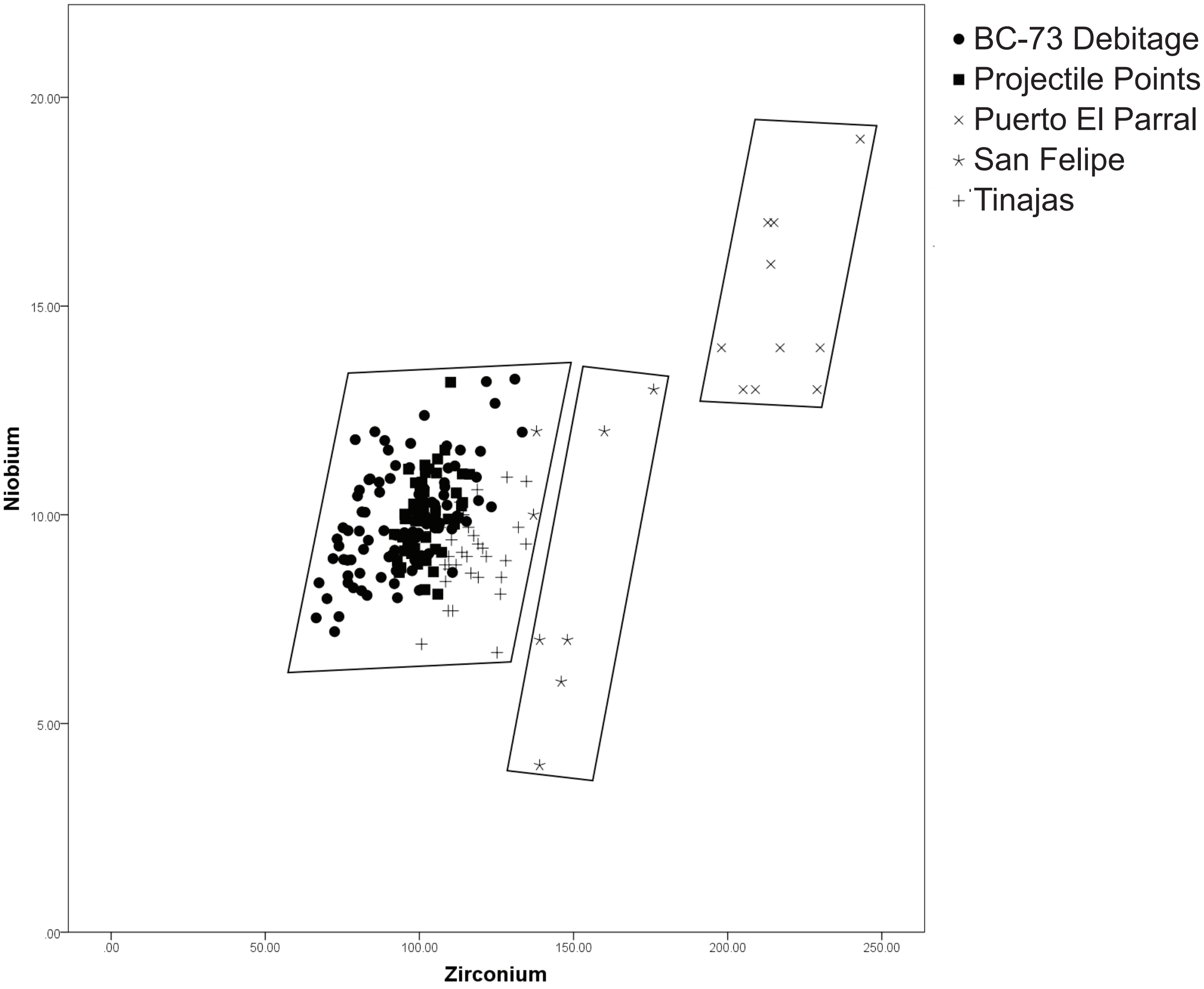

Figure 4. Concentrations (in ppm) of niobium and zirconium for this project's sample debitage and projectile points compared with independently derived chemical signatures for the Tinajas source and chemical characterizations for the Puerto el Parral and San Felipe sources.

of California (Aschmann 1967; Laylander 2006:9; Wilken-Robertson and Laylander 2006:75). It is interesting that all types of obsidian artifacts (primary, secondary, and tertiary flakes, and finished projectile points) at BC-73 are from the same source. Site BC-73 may have been a manufacturing area where the entire toolmaking process was done. Either way, the Paipai transported obsidian from Tinajas and processed it at BC-73.

The character and quantity of obsidian in Baja California may have inhibited the development of long distance trade. As discussed above, most obsidian sources throughout northern Baja California, including the Tinajas source, yield small nodules of obsidian. The small nodules of obsidian, though useless for large bifaces, were ideal for the production of projectile points, and many Native groups could easily access them. This ease of access in northern Baja California would reduce any potential trade value of obsidian and undermine the need for the type of long distance trade networks documented elsewhere in North America (Cannon and Hughes 1993; Laylander 2005). These hypotheses, however, require additional

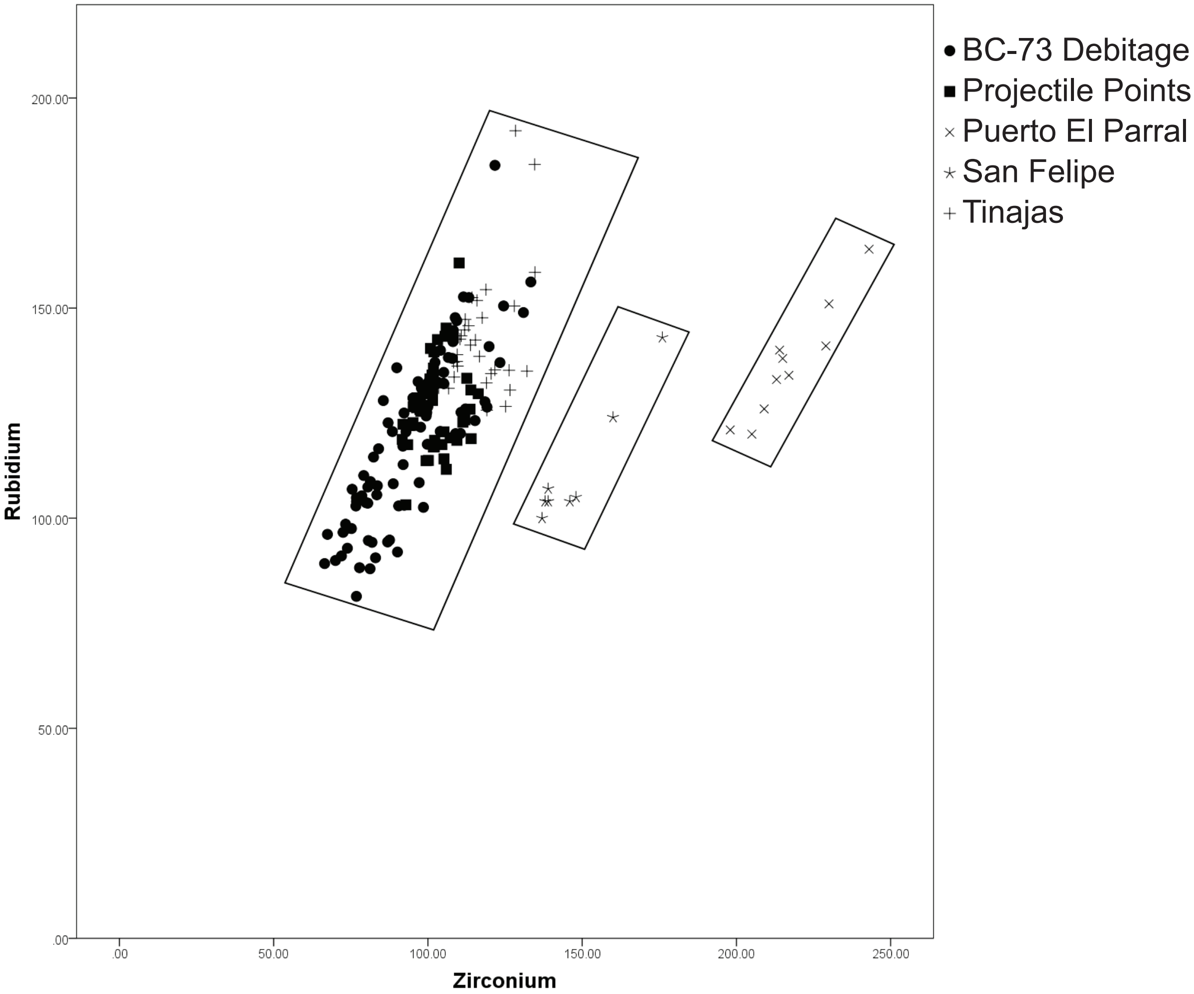

Figure 5. Concentrations (in ppm) of rubidium and zirconium for this project's sample debitage and projectile points compared with independently derived chemical signature for the Tinajas source and chemical characterizations for the Puerto el Parral and San Felipe sources.

Table 4. Minimum, Maximum, and Mean Trace Element Values for BC-73 Debitage, Sample Projectile Points, and the Tinajas, San Felipe, and Puerto El Parral Obsidian Sources.

	BC-73			**Pai-Pai Projectile Points**			**Tinajas**			**San Felipe**			**Puerto El Parral**		
	MIN	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**
RB	81.39	183.98	120.27	103.17	160.73	126.77	125.7	192.2	142.7	100	143	111.37	120	164	136.8
SR	18.7	63.5	32.54	26.23	52.8	35.27	27.4	66.6	39	35	64	41.62	57	72	62.6
Y	21.44	38.88	29.66	27.21	36.25	31.08	28.3	38.9	33.9	30	36	32.75	33	39	34.8
ZR	66.51	133.35	95.3	91.66	116.3	101.92	100.7	134.7	117	137	176	147.87	198	243	217.3
NB	7.2	13.25	9.87	8.09	13.17	9.92	6.7	10.9	9.1	4	13	8.87	13	19	15

Note: Values in ppm concentrations.

research to explore the possible cultural, ecological, and geological forces that affected obsidian acquisition in northern Baja California.

Summary

This study suggests that a single source of obsidian—the Tinajas source—provided most of the raw material for the Paipai ethnolinguistic region. The Paipai used the same obsidian that Panich et al. (2015) identified as used by the Kumeyaay. The Paipai acquisition pattern suggests that the Paipai gathered obsidian opportunistically while traveling along an east-west pattern of seasonal movements.

The data presented in this study is a fit to the hypothesized patterns of obsidian acquisition for Baja California, where obsidian was transported mostly within a single ethnolinguistic boundary. No single factor can fully account for this pattern of obsidian acquisition in northern Baja California. This study points to two factors that apparently shaped exchange networks. First, obsidian sources are plentiful in the region and yielded nodule sizes that with one exception were particularly small and useless for the production of large tools. Second, the Paipai could procure these small nodules of obsidian during seasonal rounds while following natural resources. Both of these factors would diminish the regional economic value of obsidian and inhibit its use as a commodity in long distance exchange.

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