



Establishing radiogenic strontium isotope signatures for Chavín de Huántar, Peru



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ABSTRACT

The current manuscript reports the first bioavailable radiogenic strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) data for Chavín de Huántar, a U.N.E.S.C.O. World Heritage site long recognized as one of the most important ceremonial centers of the Andean Formative Period. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were measured in local soil, vegetation, and archaeological and modern fauna from in and around the archaeological site. $^{87}\text{Sr}/^{86}\text{Sr}$ signatures from human tooth enamel from five Mariash-Recuay era (1–700 CE) individuals also were generated. Results indicate that $^{87}\text{Sr}/^{86}\text{Sr}$ values among soil, plants, and animals are relatively uniform, although the range of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios within each category is broad. While in the present study, non-migrants and migrants were distinguishable based on their $^{87}\text{Sr}/^{86}\text{Sr}$ values, the wide range of Chavín's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ signature might hinder the differentiation of local and non-local individuals in subsequent analyses. We caution that future $^{87}\text{Sr}/^{86}\text{Sr}$ applications at Chavín should consider both bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ signatures calculated from fauna, plants, and soil along with statistically analyzed human data when investigating evidence for residential mobility in the archaeological record.

1. Introduction

The archaeological site of Chavín de Huántar, Peru represents one of the most important ceremonial centers of the middle to late Andean Formative Period (broadly 1500–200 BCE) (Burger, 1992; Lumbreras, 1989; Kembel and Rick, 2004; Rick, 2005). Located along the eastern slopes of the Cordillera Blanca in the Callejón de Conchucos (Fig. 1), Chavín has been designated a U.N.E.S.C.O. World Heritage site. It comprises a series of elaborately designed monumental platform mounds, terraces, and sunken plazas that overlie a complex network of subterranean, labyrinthine-like galleries. Equally impressive is Chavín's geographic location. Situated 3180 m a.s.l. at the confluence of two rivers—the Mosna and the Wacheqsa—the site rests on the valley floor and is dwarfed to the east and west by a series of extremely steep, geologically dynamic slopes (Contreras and Keefer, 2009).

Archaeological research at Chavín began nearly a century ago (Tello, 1943) and continues through the present day, most recently under the auspices of the Stanford University Chavín de Huántar Research and Conservation Program led by John Rick. The bulk of archaeological investigations have been carried out in the site's monumental core (but see Burger, 1998; Mesia, 2014; Rosenfeld and Sayre, 2016), and have focused in one way or another on Chavín's role as a

ceremonial center during the last two millennia B.C.

Archaeological data from this period suggests heightened levels of ritual activity at Chavín (Lumbreras, 1989; Kembel and Rick, 2004; Rick, 2005; Lumbreras, 1993; Contreras, 2015). Ornate anthropomorphic stone carvings, drug paraphernalia, and caches of ceramics and incised strombus shells have been unearthed in the monumental sector, alongside evidence for restricted access to ritual spaces and increasing sensory experimentation (Rick and Bazán Pérez, 2014). Such evidence has led scholars to speculate on the nature and extent of Chavín's authority, with Chavín variously depicted as the progenitor of Andean culture (Tello, 1943), an important and highly influential pilgrimage center (Burger, 1992; Burger, 1988), and most recently, as a geographic center of emergent authority in the Andes (Kembel and Rick, 2004; Rick, 2005). According to this last perspective, Chavín operated as a cult-like center run by religious elites who offered its participants unique and exclusive transformative experiences in exchange for increased authority, wealth, prestige, and, ultimately, power (Rick, 2005; Rick and Bazán Pérez, 2014).

In this latest model (Rick, 2005; Rick and Bazán Pérez, 2014), Chavín de Huántar can be envisioned as a kind of interregional nexus, drawing together people and objects from various (and often) far-flung locales for participation in strategic and elaborately-staged ritual

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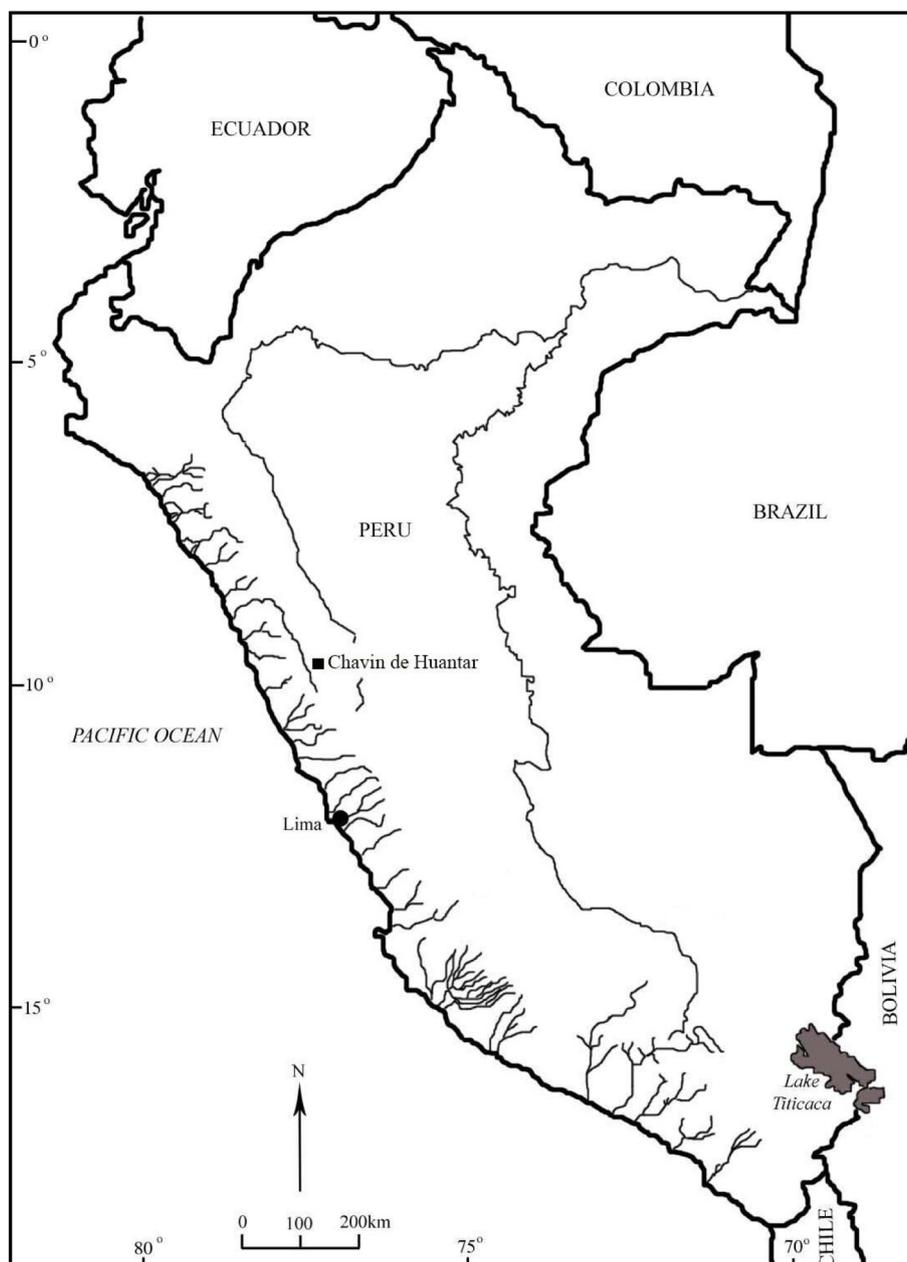


Fig. 1. Map of Peru, showing the location of Chavín de Huántar.

displays. It is also the case, however, that Chavín and other centers depended on extending their influence outward. Iconic ceramics, textiles, lithics, and metal artifacts have been documented spreading outward from monumental centers across broad geographic distances (Rick, 2005; Contreras, 2017; Contreras, 2011; Druc, 2004; Sayre et al., 2016). Given the proposed movement of people and things in and out of Chavín during the Andean Formative Period, radiogenic strontium isotope analysis, which can be used to track paleomobility, migration, and artifact exchange, holds enormous potential for research at the site.

The current project establishes the first radiogenic strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) values for Chavín de Huántar through the analysis of local soil, plants, fauna and archaeological human tooth enamel. Obtaining $^{87}\text{Sr}/^{86}\text{Sr}$ signatures from multiple sources was purposeful given the complexity of Chavín's local geology. The $^{87}\text{Sr}/^{86}\text{Sr}$ data presented here establishes a foundation for future radiogenic strontium isotope investigations at Chavín and its surrounding environs.

2. Radiogenic strontium isotope analysis ($^{87}\text{Sr}/^{86}\text{Sr}$) in archaeology

Over the last three decades, the use of $^{87}\text{Sr}/^{86}\text{Sr}$ analysis in archaeology has become widespread. $^{87}\text{Sr}/^{86}\text{Sr}$ data derived from the archaeological record have been used to trace the geographic origins, mobility patterns, and trade and exchange networks among ancient people, fauna, and artifacts (see Slovak and Paytan, 2011 for a list of $^{87}\text{Sr}/^{86}\text{Sr}$ applications in archaeology pre-2011). Archaeological applications of radiogenic strontium isotope analysis are rooted in three principles: 1. regional $^{87}\text{Sr}/^{86}\text{Sr}$ values vary geographically; 2. that variation largely is based on the strontium isotopic composition of bedrock; and 3. $^{87}\text{Sr}/^{86}\text{Sr}$ signatures in soil, groundwater, flora, and fauna largely reflect the isotopic signature of the source rock. By comparing $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in humans, animals, and plants to the local geologic signature where they are found, archaeologists can infer movement among people and things in the past.

Strontium (Sr) has four naturally occurring stable isotopes: ^{84}Sr ,

^{86}Sr , ^{87}Sr , and ^{88}Sr . Of these, only ^{87}Sr – which is formed by the long-term radioactive decay of ^{87}Rb – is radiogenic. Old rocks with high levels of ^{87}Rb tend to exhibit higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than younger rocks with low Rb/Sr ratios (Faure, 1977). Modern seawater, whose isotopic composition is derived from young volcanic rocks, old sialic rocks, and marine carbonate rocks (Faure, 1977), is characterized at present as $^{87}\text{Sr}/^{86}\text{Sr} = 0.7092$ (Veizer, 1989).

$^{87}\text{Sr}/^{86}\text{Sr}$ ratios in bedrock pass into groundwater and soil and subsequently to plants and animals through Sr intake (Hurst and Davis, 1981; Beard and Johnson, 2000). Thus, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in local flora and fauna are expected to reflect underlying geologic values (Capo et al., 1998). Humans who consume strontium-rich, locally-grown foods throughout their lifetime also will exhibit $^{87}\text{Sr}/^{86}\text{Sr}$ values that mirror those of the geologic environment (Ericson, 1985; Sealy et al., 1991; Grupe et al., 1997; Price et al., 1998).

Strontium substitutes for calcium in the food web, and is deposited in human tooth enamel and bone (Comar et al., 1957). Tooth enamel mineralizes early in an individual's life and does not undergo further chemical alteration (Hillson, 1996), whereas bone continuously regenerates over the course of an individual's life (Parfitt, 1983). Enamel $^{87}\text{Sr}/^{86}\text{Sr}$ values, therefore, reflect childhood diet and place of residence while $^{87}\text{Sr}/^{86}\text{Sr}$ signatures from bone indicate where a person lived during the last few years of life. Disparities in strontium isotope values between an individual's teeth and bones may indicate that the person moved from one location to a geologically distinct locale over the course of his or her lifetime (Ericson, 1985; Price et al., 1998).

Key to radiogenic strontium isotope analysis in archaeology is the establishment of a site's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ signature. Initially this can be done using local bedrock geology, as the latter often represents the major source of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in soil, plants, and animals (Bern et al., 2005; Bentley, 2006). Currently, no $^{87}\text{Sr}/^{86}\text{Sr}$ data from Chavín bedrock exists; however basic assumptions about expected $^{87}\text{Sr}/^{86}\text{Sr}$ values can be made through an overall consideration of Chavín's geology and through a review of published $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the north-central Andes more generally (see discussion in Section 3.1).

Despite the connection between regional bedrock and bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values, however, there are instances where $^{87}\text{Sr}/^{86}\text{Sr}$ values in the food chain deviate from $^{87}\text{Sr}/^{86}\text{Sr}$ signatures in exposed source rock (Hodell et al., 2004; Sillen et al., 1998; Hedman et al., 2009; Poszwa et al., 2004). Variable strontium isotope concentrations and weathering rates among different minerals, even within the same rock outcrop, can cause some minerals to contribute more substantially to regional bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ levels than others (Bentley, 2006: 141). Atmospheric sources such as sea spray and rainwater (Whipkey et al., 2000; Chadwick et al., 1999), as well as wind-born dust and pollution (Pett-Ridge et al., 2009; Graustein and Armstrong, 1983), can supply significant amounts of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ to soils and plants. Furthermore, the extent to which atmospheric versus bedrock strontium input is reflected in a region's biota can vary depending on a number of factors. Benson et al. (2008), for example, noted that $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from soil-water collected from 2 out of 3 field systems in the Chaco Canyon area varied as a function of depth, with deeper soils yielding lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than near-surface strata. This difference translated to distinct $^{87}\text{Sr}/^{86}\text{Sr}$ ratios among plants and animals in the region. Maize with its deep rooting system tended to yield lower $^{87}\text{Sr}/^{86}\text{Sr}$ values than $^{87}\text{Sr}/^{86}\text{Sr}$ signatures in deer mice – the latter of which depend upon plants and insects that derive their $^{87}\text{Sr}/^{86}\text{Sr}$ from near-surface soils. In a separate study looking at bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ levels in the Golan region of Israel, Hartman and Richards (2014) noted that in volcanic landscapes, bedrock age appears to play a significant role in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of plants. They found that $^{87}\text{Sr}/^{86}\text{Sr}$ values from plants grown on soils overlying young bedrock more closely aligned with bedrock $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than did plants grown on soils formed on older bedrock. Instead, plants grown on older bedrock owed a greater percentage of their $^{87}\text{Sr}/^{86}\text{Sr}$ values to atmospheric sources. Hartman and Richards (2014) also noted that the rate and degree to which

atmospheric sources contributed to plant $^{87}\text{Sr}/^{86}\text{Sr}$ depended on plant type: atmospheric contributions played a more significant role in plant $^{87}\text{Sr}/^{86}\text{Sr}$ among non-ligneous (*i.e.*, herbaceous) plants with shallower roots than ligneous (*i.e.*, woody) plants with deeper root systems.

In addition to the above variables, contemporary cultural practices such as the application of fertilizers to agricultural plots can affect the strontium isotope geochemistry in groundwater and soil (Négrel and Deschamps, 1996; Bohlke and Horan, 2000), which in turn can alter bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in plants and animals. Given the varying degrees to which natural and anthropogenic forces can contribute to regional $^{87}\text{Sr}/^{86}\text{Sr}$ values, it behooves archaeologists to first establish a “local” $^{87}\text{Sr}/^{86}\text{Sr}$ range for a site(s) under study prior to carrying out paleomobility investigations (Knudson et al., 2014).

Multiple lines of data can and have been used to this end, including analysis of $^{87}\text{Sr}/^{86}\text{Sr}$ signatures from partially-dissolved soils (Sillen et al., 1998; Knudson et al., 2014) and plants (Hartman and Richards, 2014; Copeland et al., 2011; Evans et al., 2010). An alternative to these methods, and one of the most commonly employed, is the use of modern and/or archaeological fauna as a proxy for regional bioavailable strontium isotope levels (Price et al., 2002a). $^{87}\text{Sr}/^{86}\text{Sr}$ from small animals with limited feeding territories can help to control for isotopic variability in a geologic locale by averaging together $^{87}\text{Sr}/^{86}\text{Sr}$ signatures from multiple sources of food, and have been shown to be a successful proxy for human diet in particular (Bentley, 2006). Ultimately the method(s) selected for calculating bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ for a region will—and should—depend on what is being investigated. Key to the success of radiogenic strontium isotope analysis is recognizing the dynamic contributions from various sources and proceeding accordingly.

3. Materials and methods

3.1. The study area

Chavín de Huántar is situated in the Callejón de Conchucos, a highland valley located along the southeastern Cordillera Blanca, a northwesterly trending mountain range that is part of Peru's Cordillera Occidental. The Cordillera Blanca contains a number of mountain peaks above 6000 m and is part of South America's continental divide. Geologically, the Cordillera Blanca near to Chavín is composed of young granitic rock that has intruded into the Upper Jurassic Chicama Formation and early Cretaceous Gollarisquizga Group (Turner et al., 1999; Giovanni et al., 2010) (Fig. 2). Published strontium isotope ratios from the Miocene-Pliocene Cordillera Blanca Batholith (9–11°S), which runs along the western edge of the Cordillera Blanca and is composed of a range of quartz diorite to high silica leucogranodiorite, span from $^{87}\text{Sr}/^{86}\text{Sr} = 0.7047$ – 0.7057 (Petford et al., 1996; Petford and Atherton, 1995).

The monumental site of Chavín sits at the confluence of two rivers – the Rio Mosna to the east and the Rio Wacheqsa to the north (Fig. 3). The latter is one of several tributaries to the Rio Mosna, and cuts steeply down the eastern face of the Cordillera Blanca before joining the Rio Mosna immediately north of the monument. Chavín is underlain by bedrock of the Gollarisquizga Group (referred to above), which in turn is divided into four formations: the Chimú, Santa, Carhuaz, and Farrat (Instituto Geográfico Nacional, 1989). Of these, the rocks belonging to the Chimú Formation are most apparent at, and immediately adjacent to, the archaeological site. The rocks of the Chimú Formation include early-Cretaceous sandstone, siltstone, quartzite, limestone, shale, and anthracite coal (Turner et al., 1999; Cobbing et al., 1996).

A thin, intermittent layer of colluvium—a mix of silt, sand, and fragmentary rock—and exposed bedrock characterize the surrounding mid to upper slopes of the Wacheqsa and Mosna River Valleys (Turner et al., 1999), while three large bodies of slow moving rock and soil debris known as earthflows dominate the lower slopes of the Mosna River Valley east and west of the monument (Contreras and Keefer,

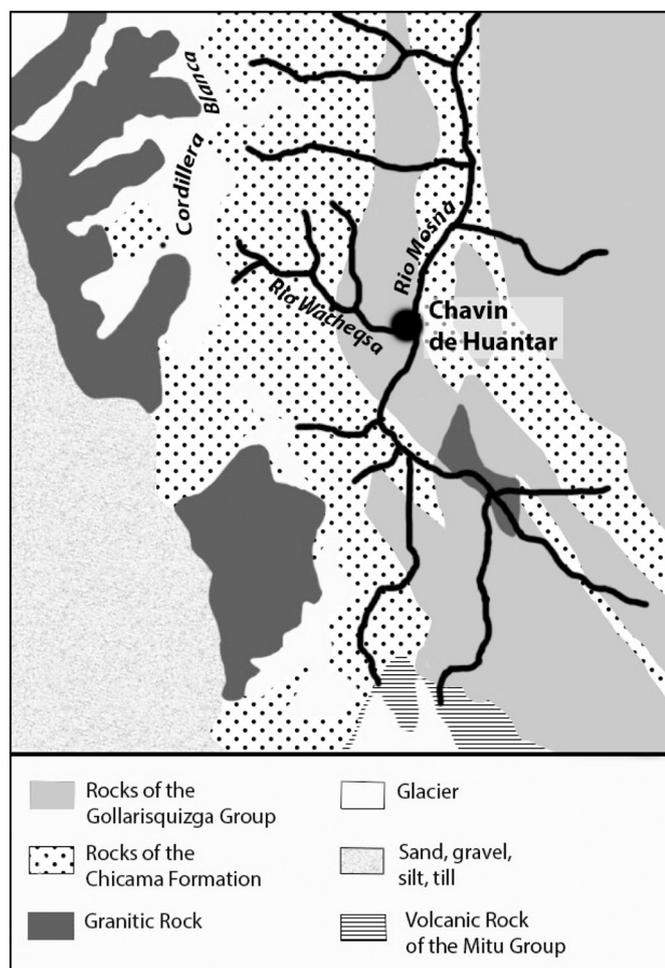


Fig. 2. Geologic map of Chavín de Huántar and the surrounding southeastern Cordillera Blanca. Adapted from Turner, et al. 1999

2009; Turner et al., 1999). The monumental center sits directly at the base of one of these earthflows—the Cochás—which is characterized by a matrix of silty sand and rock containing siltstone and sandstone. The remaining two earth flows—the Calvario and the Cancho—lie further to the east and north of the temple complex respectively, and are composed of siltstone, shale, and quartzite (Turner et al., 1999). All three earthflows are organically-rich and have been heavily cultivated in the past, a practice which continues to the present-day (Rick, 2005).

Chavín's valley floor is dominated by considerable amounts of rock and mud debris that were deposited by a massive *aluvión*, or mudslide, in 1945. The *aluvión* began as a result of a breached dam 4600 m above sea level following an avalanche of ice, mud, and rock high in the Cordillera Blanca (Indacochea and Iberico, 1945). The *aluvión*, which was composed of diamicton—a matrix of silty sand interspersed with angular, fragmentary rock, rounded cobbles, and small- to mid-sized boulders (Turner et al., 1999)—funneled down the Rio Wacheqa and spread outward upon reaching the valley floor. Even today, deposits several meters thick can be seen along the stream banks and in parts of the monumental center and modern village.

3.2. The sample

Given the dynamic nature of Chavín's geologic setting, a variety of materials, both modern and archaeological, were collected from the monumental center and surrounding area to determine the site's $^{87}\text{Sr}/^{86}\text{Sr}$ range. Sample collection was carried out during the 2014/2015 archaeological field seasons.

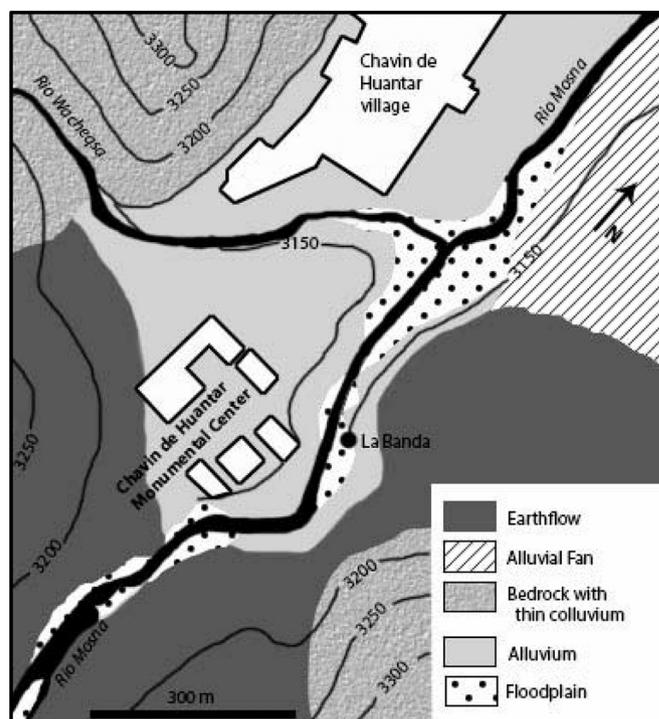


Fig. 3. Map of Chavín de Huántar and surrounding surficial geology. Adapted from Turner et al. 1999 with reference to Contreras and Keefer (2009).

Two soil samples from in and near to the monumental center were taken. The first was gathered during excavations in the monumental core, and represents Chavín-era stratum that clearly predates the 1945 *aluvión*. The second sample was collected from near surface stratum in an agricultural field directly east of the Rio Mosna in an area designated as La Banda (see Fig. 3). Modern plant samples from Chavín ($n = 5$) also were selected for analysis. The plants were collected from the hillsides surrounding the monumental center to the south, east and west, and from the valley floor north of the site and near to the modern village of Chavín de Huántar. Plant samples were air-dried and wrapped in aluminum foil for transport.

In addition to the above materials, archaeological and modern fauna ($n = 3$) were collected for analysis in order to determine Chavín's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ signature. Teeth from an ancient *cuy* (*Cavia porcellus*) uncovered during excavations in Chavín's monumental core and bone from a modern *cuy* raised in the town of Chavín were included for analysis. Teeth from a recently-deceased *llama* (*Lama glama*) who had been born, raised, and buried at the archaeological site also were included in the sample. Typically larger animals like *llamas* would not be reliable indicators of local $^{87}\text{Sr}/^{86}\text{Sr}$ levels because of their broad foraging range; however, given the unique circumstances of this particular *llama's* life history, we anticipate that its $^{87}\text{Sr}/^{86}\text{Sr}$ value will provide an accurate reflection of Chavín's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ signature.

Finally, human tooth enamel from five adult Mariash-Recuay era (1–700 CE) individuals was collected for analysis. The individuals presumably lived at Chavín in the centuries following its role as a ceremonial center, and are here used as a proxy of local human values to compare with $^{87}\text{Sr}/^{86}\text{Sr}$ data determined from soil, plants, and fauna. Although all of the skeletons were found in the Northwest section of the monumental center, they represent distinct burial events. Individuals CdH_36 and CdH_37 were found together in a single mortuary context that had slid, in antiquity, partway down the steep face of a monumental building. As a result of this displacement, the original position of the remains and details of the mortuary practice have been lost. Samples CdH_38 and CdH_39, were found relatively intact as highly

Table 1

Results of radiogenic strontium isotope analysis of plants, fauna (modern and archaeological), soil, and archaeological human tooth enamel from Chavín de Huántar, Peru. Age-at-death and sex estimation data for the human specimens were provided by Lisseth Rojas Pelayo.

Lab ID	Alternate field ID	Category	Age	Sex	Specimen description	$^{87}\text{Sr}/^{86}\text{Sr}$	Std Err%
CdH_7		Plant			<i>Lupinus mutabilis</i>	0.71093	0.0002
CdH_14		Plant			<i>Brugmansia arborea</i>	0.70983	0.0002
CdH_19		Plant			<i>Ambrosia arborescens</i>	0.71222	0.0002
CdH_24		Plant			<i>Cortaderia jubata</i>	0.71117	0.0002
CdH_26		Plant			<i>Polylepis</i>	0.71130	0.0002
CdH_31		Fauna			<i>Cavia porcellus</i> mandible (modern)	0.71131	0.0002
CdH_32		Fauna			<i>Cavia porcellus</i> tooth (archaeological)	0.71075	0.0003
CdH_33		Fauna			<i>Lama glama</i> tooth (modern)	0.71014	0.0002
CdH_34		Soil				0.71101	0.0002
CdH_35		Soil				0.71155	0.0002
CdH_36	Muestra 45	Human	Adult	U	PM ₁	0.70788	0.0002
CdH_37	Muestra 42	Human	Adult	U	M ₂	0.70638	0.0002
CdH_38	Muestra 52	Human	Middle adult	M	LPM ₂	0.71120	0.0002
CdH_39	Muestra 51	Human	Middle adult	PM	LM ₂	0.71128	0.0002
CdH_40	Muestra 50	Human	Middle adult	PM	RM ₂	0.71110	0.0002

flexed interments within very simple burial pits, with some degree of stone lining. No clear cultural materials accompanied these burials. CdH_40 also was found in a stone-lined burial pit alongside the disturbed remains of a second individual not included in this study. Excepting Individuals CdH_36 and CdH_37, none of the burials appear to be related to one another beyond their shared stratigraphic placement.

Enamel samples were taken from either an individual's first or second premolar or their second molar. Both types of teeth have similar developmental sequences, with crown formation beginning around two and a half years of age for first premolars and three years for second premolars and second molars (Hillson, 1996). First premolar crowns are completed between five and six years of age, while second premolar and second molar crowns reach completion by the end of the sixth year (Hillson, 1996). $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from the Mariash-Recuay era samples included here, therefore, provide a window into possible residential mobility during the early years of these individuals' lives.

3.3. Laboratory methodology

All samples were transported to the U.S. from Peru for isotopic analysis. Samples initially were readied for isotopic analysis at the Santa Rosa Junior College Physical Anthropology Laboratory. Soil samples were prepared mechanically by first removing rocks and small bits of organic debris. Leaves from desiccated plant samples were cleaned with a nasal aspirator to remove adhering dust and ground to a course powder. Human and faunal remains were cleaned with a Dremel Multipro Drill (Model 395) outfitted with sterile 33 1/2 FG inverted cone tips to remove adhering superficial contamination. Approximately 35 mg of powdered *cuy* bone and 15–20 mg of pristine human and faunal tooth enamel were collected from each specimen.

Samples were transported to the Paytan Lab at the Institute of Marine Sciences and the Keck Isotope Lab, University of California Santa Cruz (UCSC) for further cleaning and analysis. For soil, 2 g of sample were transferred to 50 mL acid-cleaned centrifuge tubes and shaken in 25 mL 0.25 ammonium acetate (ultrapure) for an hour. Samples were dried down to a tan residue overnight, and 4 mL of 2.5 HCl added to each sample. After drying overnight, samples were redissolved in 2 mL of 50% HNO₃. One gram from each powdered plant sample was placed in covered porcelain crucibles and ashed at 500 °C for 4 h. Approximately 20 mg of sample were transferred to acid-cleaned teflon beakers and digested in 2 mL of 65% HNO₃ at 120 °C overnight. Samples were centrifuged 20 min at 13,000 rpm, and liquid samples were dried down at 100 °C and redissolved in 2 mL of 50% HNO₃.

Bone and enamel samples were treated with 1 mL of H₂O₂ (30%)

and left to sit overnight. Samples were rinsed with 1 mL distilled water and centrifuged at 10,000 rpm for 5 min. The latter two steps were repeated twice. Archaeological samples received additional cleaning owing to the increased risk of diagenetic contamination following deposition in the burial environment (Nelson et al., 1986; Sillen, 1986; Price et al., 2002b; Sillen and Sealy, 1995; Hoppe et al., 2003). Fortunately, tooth enamel is largely resistant to post-mortem alteration given its crystalline structure and overall lack of porosity (Koch et al., 1997; Hillson, 2005), and a number of studies have shown that with minimal treatment, biogenic $^{87}\text{Sr}/^{86}\text{Sr}$ values can be obtained (Hoppe et al., 2003; Koch et al., 1997; Quade et al., 1992; Wang and Cerling, 1994; Budd et al., 2000). Accordingly, enamel samples were treated with 0.1 N acetic acid and left overnight. Samples were subjected to a series of rinses with distilled water, and left to dry down at ~50 °C overnight. All bone and enamel samples were redissolved in 1.5 mL 50% HNO₃.

Separation of Sr from the sample matrix was carried out following methods adapted from Horwitz et al. (1992). Briefly, samples in 50% double distilled nitric acid were passed through 1.8 mL Bio-Rad micro bio-spin columns loaded with 600 µL of Eichrom Sr⁻ spec resin (particle sizes 50–100 µ). The resin was then rinsed with 1 mL 50% nitric acid four times to remove other ions (Na, Mg, Ca, Al, Fe), and $^{87}\text{Sr}/^{86}\text{Sr}$ fractions were eluted with 4 mL Milli-Q water in 1 ml increments into a Teflon beaker. This eluent was dried down and heated with concentrated nitric acid with the lid closed for at least 5 h to get rid of organic matter. Dried samples were brought up with 20 µL of 6% nitric acid.

Samples were loaded on Rhenium filaments and analyzed by thermal ionization mass spectrometry (Phoenix62, Isotopx) in the W.M. Keck Isotope Laboratory. We measured the NIST987 standard along with each batch of samples and adjusted the $^{87}\text{Sr}/^{86}\text{Sr}$ of the samples to make the standards values match the NIST987 of 0.710248 (McArthur et al., 2001). The uncertainty of the data is 4 ppm based on repeat analyses of standards.

4. Results and discussion

4.1. $^{87}\text{Sr}/^{86}\text{Sr}$ results

$^{87}\text{Sr}/^{86}\text{Sr}$ results for the Chavín soil, plant, faunal, and human tooth enamel samples are reported in Table 1. $^{87}\text{Sr}/^{86}\text{Sr}$ values for soil range from 0.7110 in the monumental center to 0.7116 in La Banda, with a mean exchangeable soil $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7113.

Plant $^{87}\text{Sr}/^{86}\text{Sr}$ ratios vary more widely than soil values, and range from 0.7098 to 0.7122. The average $^{87}\text{Sr}/^{86}\text{Sr}$ value for plants is 0.7111.

$^{87}\text{Sr}/^{86}\text{Sr}$ signatures from archaeological and modern fauna span from $^{87}\text{Sr}/^{86}\text{Sr} = 0.7101$ to 0.7113 , which falls within the $^{87}\text{Sr}/^{86}\text{Sr}$ ranges for both soil and vegetation. The mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratio for all three faunal samples is 0.7107 . Following Price et al.'s (2002b) method for determining bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ levels (i.e., mean $^{87}\text{Sr}/^{86}\text{Sr}_{\text{fauna}} \pm 2$ standard deviations), Chavín de Huántar's biologically available $^{87}\text{Sr}/^{86}\text{Sr}$ signature is 0.7096 to 0.7119 .

$^{87}\text{Sr}/^{86}\text{Sr}$ values from human tooth enamel are more variable than those of the soil, plant, or faunal $^{87}\text{Sr}/^{86}\text{Sr}$ values, and range from 0.7064 to 0.7113 . Three individuals—CdH_38, CdH_39, and CdH_40—exhibit $^{87}\text{Sr}/^{86}\text{Sr}$ values that cluster tightly together ($^{87}\text{Sr}/^{86}\text{Sr}$ range = 0.7111 – 0.7113). These values fall well within the range of biologically available $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the site as determined by fauna, and are similar to values reported for Chavín soil and plants. On the other hand, individuals CdH_36 ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7079$) and CdH_37 ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7064$) had $^{87}\text{Sr}/^{86}\text{Sr}$ signatures well outside of Chavín's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range.

4.2. Homogeneity and variability within the Chavín sample

Overall, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from Chavín soil, plants, and fauna are consistent in two ways: First, individual $^{87}\text{Sr}/^{86}\text{Sr}$ values across the three data sets overlap; and second, all three data sets exhibit a wide range of intragroup variation. Regarding the first observation, mean values among Chavín soil, plant, and fauna are not notably different from one another. Chavín's bioavailable range as established by fauna ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7096$ to 0.7119) encompasses mean $^{87}\text{Sr}/^{86}\text{Sr}$ values for both soil and plants reported here, as well as all but one individual $^{87}\text{Sr}/^{86}\text{Sr}$ ratio from soil and plants. This suggests an overall uniformity across data sets, and indicates that the bioavailable range reported here is a reasonably reliable representation of Chavín's $^{87}\text{Sr}/^{86}\text{Sr}$ signature.

A review of the human $^{87}\text{Sr}/^{86}\text{Sr}$ data presented here demonstrates this point clearly. Fig. 4 shows human $^{87}\text{Sr}/^{86}\text{Sr}$ values alongside the $^{87}\text{Sr}/^{86}\text{Sr}$ ranges for Chavín's soil, plants and fauna. In all instances, the same pattern emerges regardless of whether one compares human

Table 2

Radiogenic strontium isotope data for fauna from various sites in the Andes, including Chavín de Huántar (in bold). The range of $^{87}\text{Sr}/^{86}\text{Sr}$ signatures among fauna from a single site varies considerably among the sites listed above.

Site	Material	Number of individuals	$^{87}\text{Sr}/^{86}\text{Sr}$ range	$^{87}\text{Sr}/^{86}\text{Sr}_{\text{difference}}$
Ilo	Fauna	2	0.70668–0.70671 ^a	0.00003
Kanamarca	Fauna	2	0.70653–0.70665 ^b	0.00012
Upper Tierras Blancas Valley	Fauna	3	0.70578–0.70593 ^c	0.00015
Tipón	Fauna	4	0.70821–0.70840 ^b	0.00019
San Pedro de Atacama (Quitor)	Fauna	3	0.70751–0.70776 ^a	0.00025
Ancón	Fauna	5	0.70638–0.70668 ^d	0.00030
Chokepukio	Fauna	4	0.70782–0.70812 ^b	0.00030
Moquegua	Fauna	3	0.70612–0.70645 ^e	0.00033
Khonko	Fauna	5	0.70872–0.70918 ^f	0.00046
Wankane	Fauna	2	0.70594–0.70669 ^c	0.00075
Pajonal Alto	Fauna	3	0.70610–0.70703 ^c	0.00093
Middle Nasca Valley	Fauna	3	0.70610–0.70703 ^c	0.00093
Chavín de Huántar	Fauna	3	0.71014–0.71131	0.00117
Chiribaya Baja	Fauna	2	0.70672–0.70789 ^a	0.00117
La Tiza	Fauna	7	0.70590–0.70725 ^c	0.00135
Ayacucho*	Fauna	5	0.70567–0.70720 ^g	0.00153
Machu Picchu*	Fauna	3	0.71246–0.71524 ^h	0.00279

* = Outliers excluded.

^a (Knudson and Price, 2007).

^b (Andrushko et al., 2009).

^c (Conlee et al., 2009).

^d (Slovak et al., 2009).

^e (Knudson et al., 2004).

^f (Knudson and Torres-Rouff, 2009).

^g (Tung and Knudson, 2008).

^h (Turner et al., 2009).

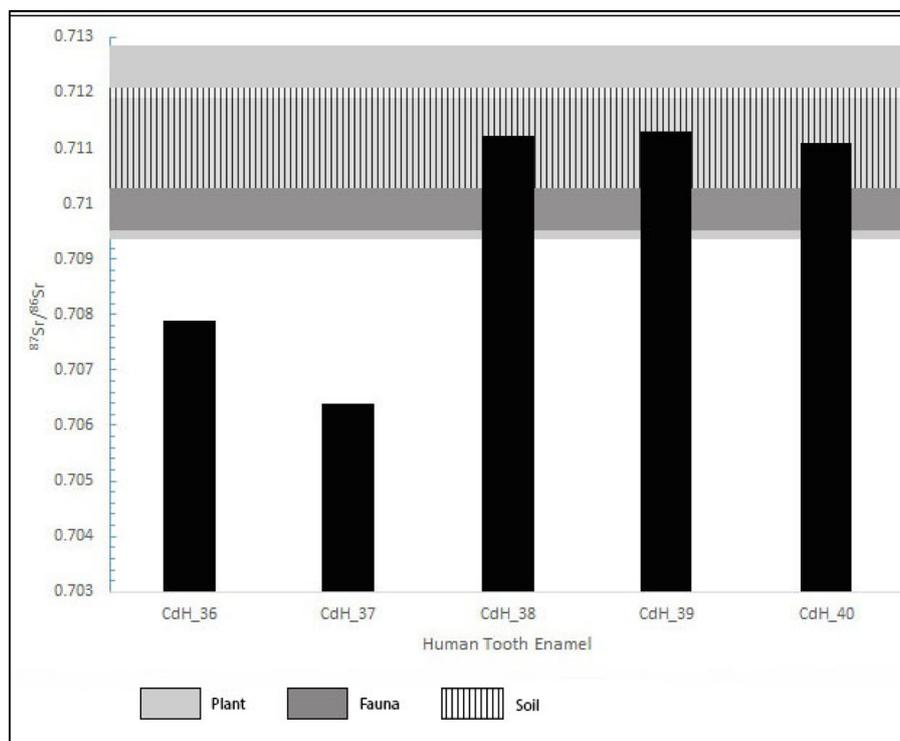


Fig. 4. Human $^{87}\text{Sr}/^{86}\text{Sr}$ values from tooth enamel from individuals buried in a Mariash-Recuay era (0–700 AD) tomb at Chavín de Huántar plotted against $^{87}\text{Sr}/^{86}\text{Sr}$ ranges for Chavín plants, fauna, and soil, where the range represents the mean $^{87}\text{Sr}/^{86}\text{Sr}$ value for each category $\pm 2\sigma$.

values to soil, plants, or fauna: Three individuals demonstrate $^{87}\text{Sr}/^{86}\text{Sr}$ values that mirror Chavín's environmental range, while two clearly do not. The significance of these outliers will be discussed in Section 4.3.

In terms of the second observation dealing with intragroup variation among the Chavín sample, the breadth of strontium isotope values within each data set is broad, particularly when compared to $^{87}\text{Sr}/^{86}\text{Sr}$ data from sites elsewhere in the Andes (Table 2). At the coastal site of Ancón, Peru, for example, intragroup $^{87}\text{Sr}/^{86}\text{Sr}$ variation for both soil ($n = 2$) and fauna ($n = 5$) was narrow, with soil samples differing from one another by 0.0002 and fauna at most by 0.0003 (Slovak et al., 2009). Similarly, Andrushko et al. (2009) reported similarly limited $^{87}\text{Sr}/^{86}\text{Sr}$ ranges for fauna from the sites of Kanamarca ($n = 2$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{difference}} = 0.0001$), Tipón ($n = 4$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{difference}} = 0.0002$), and Chokepukio ($n = 4$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{difference}} = 0.0003$), while Conlee et al. (2009) noted close $^{87}\text{Sr}/^{86}\text{Sr}$ values among rodents from the Upper Tierras Blancas Valley ($n = 3$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{difference}} = 0.0002$). At San Pedro de Atacama, Chile, $^{87}\text{Sr}/^{86}\text{Sr}$ values among local fauna ($n = 3$) varied by 0.00025 (Knudson and Price, 2007), and by as little as 0.00003 at the site of Ilo ($n = 2$) (Knudson and Price, 2007). In contrast, Chavín soil values vary from each other by 0.0006 and Chavín fauna by 0.0017. The intragroup $^{87}\text{Sr}/^{86}\text{Sr}$ variation for plants is even higher, with $^{87}\text{Sr}/^{86}\text{Sr}$ values differing by as much as 0.0024.

Though admittedly broad, Chavín's values are not unprecedented in the Andes. At Pajonal Alto, the Middle Nasca Valley, and La Tiza, for example, intra-site faunal values varied by 0.0008 ($n = 2$), 0.0009 ($n = 3$), and 0.0014 ($n = 7$) respectively (Conlee et al., 2009). At Chiribaya Baja (Knudson and Price, 2007), $^{87}\text{Sr}/^{86}\text{Sr}$ values among local fauna ($n = 2$) differed from each other by 0.0012, while at Machu Picchu (Turner et al., 2009), $^{87}\text{Sr}/^{86}\text{Sr}$ values varied by as much as 0.0028 among the 3 fauna reported.

The relatively wide range of values among Chavín's soil, animals, and plants likely reflects the geologic and environmental complexity that characterizes Chavín's geographic location. As discussed previously (see Section 3.1), the landscape surrounding the monumental center is incredibly dynamic. Shifting earthflows, seasonal flooding from the Mosna and Wacheqsa Rivers, and periodic, catastrophic *aluviones* all can be expected to have contributed in varying, yet significant, degrees to Chavín's $^{87}\text{Sr}/^{86}\text{Sr}$ signature. When viewed in this light, then, it is not surprising that Chavín's $^{87}\text{Sr}/^{86}\text{Sr}$ range is broader than what might be expected either from its underlying bedrock composition or when compared to $^{87}\text{Sr}/^{86}\text{Sr}$ values reported at other sites.

4.3. Human $^{87}\text{Sr}/^{86}\text{Sr}$ values from Chavín

Despite Chavín's relatively broad $^{87}\text{Sr}/^{86}\text{Sr}$ range, it is possible to detect local from non-local individuals within the present human sample. As discussed above, 2 of the 5 individuals (CdH_36, $^{87}\text{Sr}/^{86}\text{Sr} = 0.7078$; CdH_37, $^{87}\text{Sr}/^{86}\text{Sr} = 0.7063$) yielded $^{87}\text{Sr}/^{86}\text{Sr}$ signatures below Chavín de Huántar's bioavailable range (Fig. 4). Two possibilities can account for these outlying values. The first hypothesis is dietary in nature. $^{87}\text{Sr}/^{86}\text{Sr}$ analysis serves as an effective marker of migration in archaeological populations if the consumption of imported foods can be ruled out (Ericson, 1985). The incorporation of foods from regions with geologically distinct compositions have been shown to have potentially profound effects on human $^{87}\text{Sr}/^{86}\text{Sr}$ signatures (see most notably Wright, 2005).

The notion that Chavín's ancient residents relied at least partially on imported foods is not out of the question. Miller and Burger (1995), for example, analyzed Formative-period faunal assemblages from Chavín and argued that the site's inhabitants relied heavily on *ch'arki* (dried camelid meat) imported from the high-altitude *puna* environment. Stahl (1999) argued against Miller and Burger's consumption-heavy model, and suggested instead that Chavín was more likely a site of *ch'arki* production and distribution, relying on llamas raised either at Chavín or in the immediate vicinity. Stahl (1999), however, allowed for the slim possibility that live camelids may have been imported to Chavín from

elsewhere and subsequently made into *ch'arki*. More recently, Rosenfeld and Sayre (2016) weighed in on the *ch'arki* debate. According to their analysis of more than 2000 camelid remains from the *La Banda* sector of Chavín, the site's Formative-period residents likely consumed fresh llama meat from locally-raised camelids rather than imported *ch'arki*. Thus, the latest evidence from Rosenfeld and Sayre (2016) points toward reliance on local foods rather than imported resources during the Formative—a trend that may or may not have continued into the subsequent Mariash-Recuay era at Chavín.

While it is possible that individuals CdH_36 and CdH_37 consumed a diet of primarily non-local foods with distinct (and in this case, lower) $^{87}\text{Sr}/^{86}\text{Sr}$ values than those found at Chavín, it is unlikely. Were the variability in these individuals' $^{87}\text{Sr}/^{86}\text{Sr}$ signatures primarily due to unique diets, we might expect that these individuals would appear to be outliers in other aspects of their personhood as well. While analysis of the Mariash-Recuay tomb in which these individual were interred is in its nascent stages, it was clear at the time of excavation that CdH-36 and CdH-37 were not treated differentially in regards to their interment, and instead received similar burial treatment to the remaining three individuals in the sample.

The second and more likely hypothesis surrounding the outlying $^{87}\text{Sr}/^{86}\text{Sr}$ values for CdH_36 and CdH_37 is that these individuals were born elsewhere. They may have either migrated to Chavín following childhoods spent somewhere else or were brought to Chavín specifically for burial. Future $^{87}\text{Sr}/^{86}\text{Sr}$ analysis from the skeletal tissue of both individuals potentially could resolve the issue. If $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the individuals' bones reflect Chavín's local signature, then it would seem likely that CdH_36 and CdH_37 relocated to Chavín permanently, living at the site for many years prior to their death. Conversely, $^{87}\text{Sr}/^{86}\text{Sr}$ bone values that fall outside of Chavín's bioavailable range would suggest that the individuals did not live at the site for any considerable length of time prior to their interment, or were brought to Chavín for the purposes of burial.

Assuming that CdH_36 and CdH_37 were non-local, it is possible to suggest potential regions from which each may have originated based on published $^{87}\text{Sr}/^{86}\text{Sr}$ from elsewhere in the Andes. CdH_36's signature ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7078$), for example, parallels the mean $^{87}\text{Sr}/^{86}\text{Sr}$ values reported for humans living at the Central Coast site of Ancón during the Middle Horizon (600 CE–1000 CE) (Slovak et al., 2009), and falls within the bioavailable ranges reported for San Pedro de Atacama ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7074$ to 0.7079) (Knudson and Price, 2007), the Ilo Valley ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7058$ to 0.7082) (Knudson and Price, 2007), and the site of Chokepukio near to Cuzco ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7072$ to 0.7091) (Andrushko et al., 2009). The possible locations where Individual CdH_37 ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7063$) may have spent his or her childhood are even more numerous. CdH_37's $^{87}\text{Sr}/^{86}\text{Sr}$ ratio overlaps with Ayacucho's bioavailable signature ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7051$ to 0.7065) (Tung and Knudson, 2008) as well as the bioavailable ranges established for Moquegua ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7059$ to 0.7066) (Knudson and Price, 2007), La Tiza ($^{87}\text{Sr}/^{86}\text{Sr} = 0.70559$ to 0.70727) (Conlee et al., 2009), and the Ilo Valley ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7058$ to 0.7082) (Knudson and Price, 2007). It is also possible that neither individual grew up in one of the above region(s), but instead originated from a region whose $^{87}\text{Sr}/^{86}\text{Sr}$ values remain unknown.

One other aspect of the human $^{87}\text{Sr}/^{86}\text{Sr}$ data reported here is worthy of brief discussion. $^{87}\text{Sr}/^{86}\text{Sr}$ values among the three local individuals cluster tightly ($^{87}\text{Sr}/^{86}\text{Sr} = 0.71110$ to 0.71128) and the range of intragroup variation among them differs by only 0.00018. This is notably smaller than the intragroup variability reported for Chavín's soil, vegetation, or fauna (see Section 4.2). While we acknowledge that a sample of three individuals is inadequate to project an overall $^{87}\text{Sr}/^{86}\text{Sr}$ range for Chavín's human population, it does raise the possibility that human $^{87}\text{Sr}/^{86}\text{Sr}$ values may be considerably narrower than the site's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ signature as determined by fauna. At the south-central site of Conchopata, for example, Tung and Knudson (2008) noted that human enamel and bone $^{87}\text{Sr}/^{86}\text{Sr}$ values were more

homogeneous than $^{87}\text{Sr}/^{86}\text{Sr}$ ratios among local fauna, and opted to define Conchopata's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range according to human $^{87}\text{Sr}/^{86}\text{Sr}$ values, rather than faunal. It may be the case that at Chavín, as at Conchopata, the best way to distinguish between locals and non-locals is by reference to human $^{87}\text{Sr}/^{86}\text{Sr}$ data from the site. While this suggestion would have had little effect on the interpretation posited here for the identities of individuals CdH_36 and CdH_37, it might have important implications for a scenario in which the range of $^{87}\text{Sr}/^{86}\text{Sr}$ values among human samples is less obvious. In such an instance, adopting a method like the one proposed by Tung and Knudson (2008) or by Wright (2005), in which both biologically available $^{87}\text{Sr}/^{86}\text{Sr}$ data and statistically analyzed human data are used to establish a local range, may provide the most meaningful results.

5. Conclusion

This paper reported the first $^{87}\text{Sr}/^{86}\text{Sr}$ data for Chavín de Huántar, Peru using soil, vegetation, fauna, and archaeological human remains from in and around the monumental site. $^{87}\text{Sr}/^{86}\text{Sr}$ data across categories largely overlapped, suggesting that Chavín's bioavailable range ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7096\text{--}0.7119$)—as calculated by fauna—is an accurate representation of the site's local $^{87}\text{Sr}/^{86}\text{Sr}$ signature. Using Chavín's $^{87}\text{Sr}/^{86}\text{Sr}$ range, it was possible to distinguish between individuals of local and non-local origin among a small sample ($n = 5$) of Mariash-Recuay era individuals buried at the site. Based on their $^{87}\text{Sr}/^{86}\text{Sr}$ signatures, two of the five individuals likely spent their childhoods and possibly some of their adult life elsewhere.

Despite this initial success, we stress that future archaeological applications of $^{87}\text{Sr}/^{86}\text{Sr}$ analysis at Chavín should proceed cautiously. First, while there is consistency in $^{87}\text{Sr}/^{86}\text{Sr}$ values across data sets, the number of samples within each category is small. Second, the range of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios among Chavín soil, plants, and fauna analyzed in the present sample is relatively broad compared to local human $^{87}\text{Sr}/^{86}\text{Sr}$ values from the site. Assuming this pattern is accurate and not an artifact of small sample size, it may be that the breadth of Chavín's bioavailable signature could result in an overestimation of locally-born individuals and an underestimation of the number of migrants in a sample. We suggest that future $^{87}\text{Sr}/^{86}\text{Sr}$ applications at Chavín include either additional pre-Hispanic human samples or faunal data to further refine the site's bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range.

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