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Considering Certain Lithic Artifacts of Tiahuanaco (Tiwanaku) and Pumapunku (Bolivia) as Geopolymer Constructs

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Abstract

The studies carried out in 2015-2018 on the monumental stones constituting the Pumapunku site in Bolivia (South America) provide evidence that the stones are ancient artificial geopolymers. The two types of lithics under consideration are large platforms and 'sculptures' exhibiting characteristics that would have been extremely difficult, if not impossible, to achieve with the tools thought to be available to the Tiahuanacans' of 1500-2000 years ago. For examples, big lithics exhibit perforations of unique characteristics. These holes, believed to be boreholes, are found in andesite artifacts. In number, they approach 900 perforations. The holes/perforations of 3 or 4 mm diameter could have been created with wooden dowels forced into the plastic geopolymer, as well as reed or copper tubes forced into the material in the same way cookie cutters remove the cookie from the dough. The paper also discusses other geopolymer lithics .

Keywords: *Tiwanaku, Pumapunku, geopolymer technology, andesite*

1. Introduction

Tiahuanaco, on Lake Titicaca in Bolivia, is a pre-Inca archaeological site known throughout the world for its mysterious Gate of the Sun, ruins of temples and its pyramid (Figure 1). Archaeologists believe that this site was built well before the Incas, around 600 to AD 700. The site of Pumapunku neighbors Tiahuanaco with the ruins of an enigmatic pyramidal temple built at about the same time.

The two types of lithics under consideration are large platforms and 'sculptures' exhibiting characteristics that would have been extremely difficult, if not impossible, to achieve with the tools thought to be available to the Tiahuanacans' of 1500-2000 years ago.

The two types of architectural curiosities are displayed in Figure 2 : four, giant, red-sandstone terraces weighing between 100 and 180 tonnes or metric tons (abb. 't' in the paper according to SI units), numbered (1) to (4) and small blocks of andesite, an extremely hard volcanic stone, whose complex shapes and millimetric precision are incompatible with the technology of the time, arrows (a,b,c) and the andesite platform (d) (Stübel & Uhle, 1892).

Archeology tells us that the Tiwanakans had only stone tools and no metal hard enough to carve the rock, however, they were able to quarry and move these objects, of hundreds-of-tons, to their sites, and then fit them precisely. By what means could they have transported and positioned these gigantic blocks of red-sandstone, which are among the largest in all the American continent ?

Also, they were able to carve other smaller blocks made of volcanic andesite, a very hard and nearly impossible-to-carve stone, with incredible detail and finish. To date, archaeologists have no rational explanations on how this was accomplished. Therefore, the general public often assumes the achievement, was by a lost ancient super civilization or by involvement of aliens. However, this does not comport with our recent research.

2. Lithic Artifacts of Pumapunku (Bolivia) as Geopolymer Constructs

Studies carried out in 2017-2018 by Davidovits *et al.* (Davidovits et al., 2019a,b) on the monumental stones constituting the Puma Punku site have demonstrated that the four megalithic terrasses were made of artificial geopolymer sandstone of the ferro-sialate type. Independently, Gara, T. A., (Gara, 2016) (2015-2018), provides evidence that the stones are ancient artificial geopolymers (concrete) and were not carved with simple hammer-stone nor unknown technology nor by extraterrestrials.

It was human intellect exploiting the resources of its environment, that created these marvels. The most controversial aspect of the Pumapunku site is found in puzzling smaller items, 1 meter high, made of andesitic volcanic stone (Figure 3). They have unprecedented smooth finishes, perfectly flat faces at exact 90° interior and exterior

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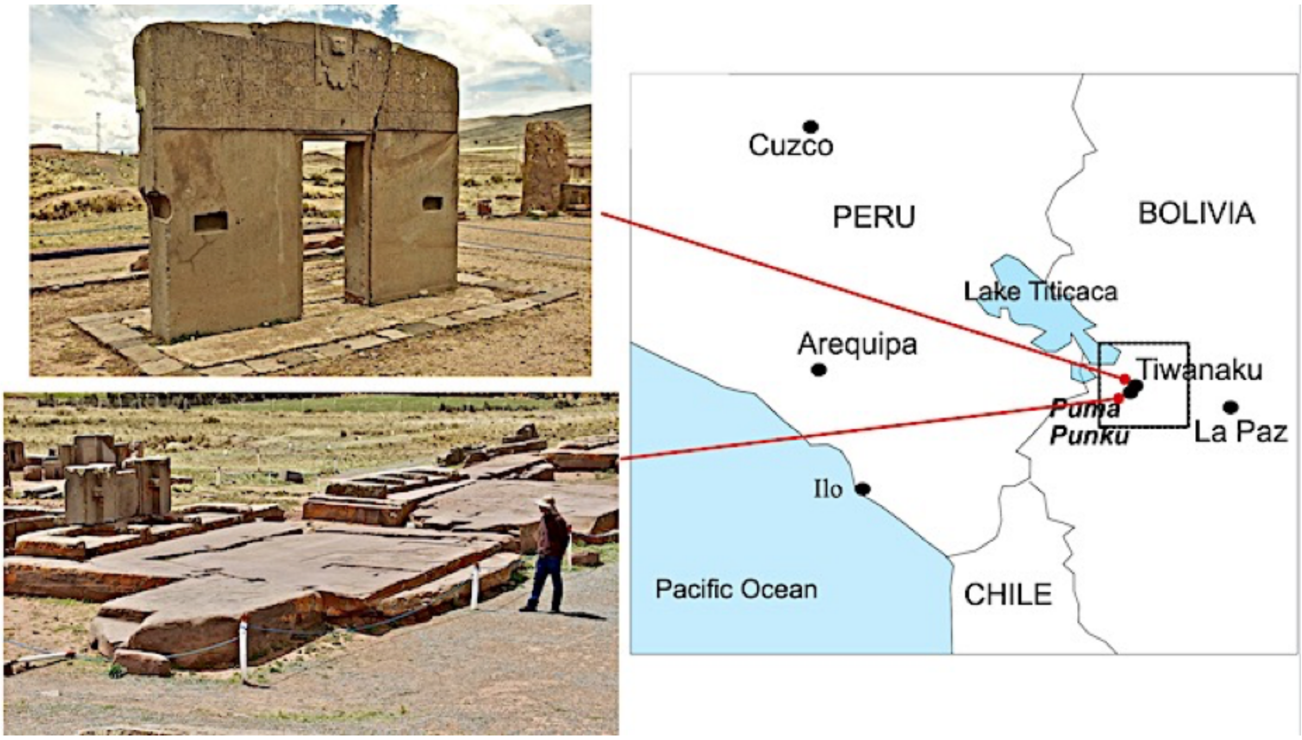

Figure 1: South American Andes Altiplano with Tiahuanaco (Gate of the Sun) / Pumapunku terraces.

Figure 2: General view of Puma Punku; the four, giant, red, geopolymer-sandstone terraces weighing between 100 and 180 tons, numbered 1) to 4); the small blocks in geopolymer andesite, arrows a.b.c.d.

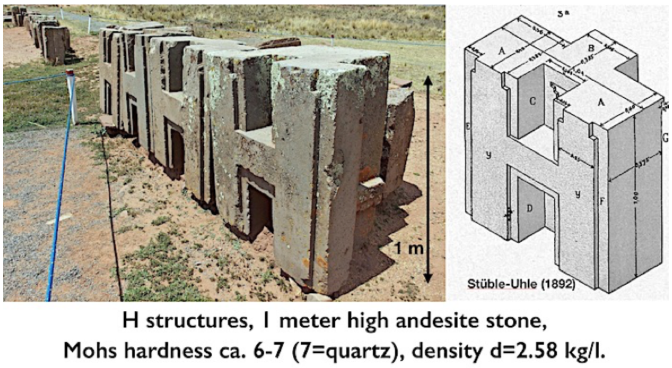

Figure 3: The famous "H" blocks located at point (c) in Figure 2.

right angles. Historian architects wonder how such perfect stonework could have been achieved with only simple stone tools. See location under arrow (c) in Figure 2 (**?**). Davidovits' study (Davidovits et al., 2019b) demonstrates that these architectural components could be fashioned with a wet-sand, geopolymer, molding technique.

There are also other lithics which are perhaps more difficult, such as the rectangular monolith of 85 cm × 40 cm × 40 cm that stands apart from other blocks along the visitor walk way, in front of the red ferro-sialate geopolymer terrace Nr. 1 (Figure 2, arrow (a), and Figure 4 left). Along and within the slot are bore holes of 4 mm diameter that are uniformly 9 mm deep and 3.5 cm apart (Figure 4 right). They are cylindrical, not conical, and with flat bottoms.

Figure 4: Left, author T. G. with andesite block with slot; right, bore holes in the slot.

2.1. Considering 900 Perforations in andesite lithics

Other bigger lithics exhibit perforations of unique characteristics. These holes, believed to be boreholes, are found in other andesite artifacts. These perforations are of extremely regular configurations and placements. Most are 4 mm in diameter, consistent in depth, vertically oriented, flat bottomed and regularly spaced. In number, they approach 900 perforations. To bore so many holes of consistent quality would require drill-bits of hardened materials, the ability to sharpen the bits, and the ability to produce replacement drill-bits of like characteristics. However, we find no such tools in the archaeological record or materials to make them, much less, the tools to drive the bits into hard andesite.

Figure 5: The 3rd gate lying at Pumapunku; dimension: 2.80 meters high, 3.0 meters wide.

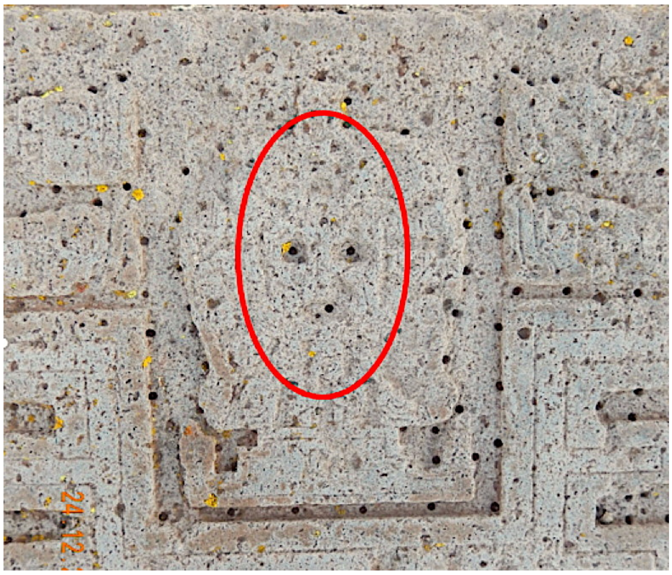

Figure 6: God image and the numerous holes.

The bore holes appear to be vestiges of the original construction and, if drilled, exhibit a surprising technological capability for that epoch. It is generally admitted (Posnansky, 1945) that the bore holes served to secure gold plates which covered the blocks by means of 'nails', also of gold. This may explain why so many of the constructs have been severely damaged and their graphic carvings practically obliterated by looters.

An excellent example is provided by the third Gate of three gates at Pumapunku (Figure 5). It is the only gate of the three to exhibit the characteristics being examined, the cylindrical small holes. Its dimensions (2.80 meters

Figure 7: The meander with hole indicators in red.

high, 3.0 meters wide) are similar to the Gate of the Sun in Tiwanaku (Figure 1) (3.0 meters high, 3.80 wide). The face has similar graphic images (meander), possibly with 11 stations. A twelfth station is assumed to have crowned the center of the gate.

Broken into three parts, the left side (part) is here examined and exhibits 210 holes (Figures 6 and 7). The graphic images have perforations of 3 mm ⌀× 5-7 mm in depth to receive the golden nails that held decorative elements onto the andesite stone face.

2.2. The geopolymer solution

Lithic surfaces were often finished with gold plating and, as earlier mentioned, the plates and other embellishments were attached to the lithics with gold nails.

The holes/perforations of 3 or 4 mm diameter could have been created with wooden dowels forced into the plastic geopolymer, as well as reed or copper tubes forced into the material in the same way cookie cutters remove the cookie from the dough. In Figure 8, the hole profiles are reveled because looters removed the golden decorative plates but needed to break the edges of the lithic off to extract the golden nails. Note the lack of tool marks on the inner cylindrical walls.

2.2.1. Andesite raw-material source and the transport by boat and land

Research has been done regarding both the sculpting of natural andesite with the soft copper/bronze tools and/or hard volcanic rock available in the area, as well as the transportation of the very large lithics by people without the wheel, winches or 'block and tackle'. Archaeologist and architect J.P. Protzen and Nair (2013) examined the sculpting challenges of andesite (Protzen & Nair, 2013, p. 199). With their team at UC-Berkeley they attempted to replicate the perfect planar surfaces, interior and exterior right angles and exacting measurements of +/- 1 mm, of those early stone-masons with the tools thought to have been available. Their efforts were inconclusive. They wrote:

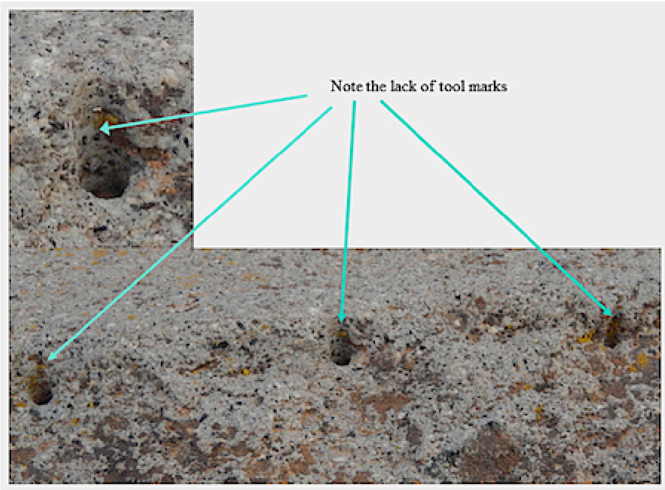

Figure 8: Profiles of the holes created for the golden nails.

> "Normal copper and bronze tools have been shown to be ineffectual in carving andesite as found at Tiahuanaco. . . (. . .) To finish their stones the Tiahuanacans must have had the use of other kinds of tools, for one finds no comparable execution in Inca stonework."

Earlier, Arthur Posnanski's works (Posnansky, 1945), as well as Portugal Ortiz (Portugal Ortiz, 1998) and Escalante Moscoso (Escalante Moscoso, 1994), examined the quarrying, transporting and sculpting of South American lithics. All have assumed that the lithics were naturally formed by understood geological processes and thereafter, quarried, transported, formed and fitted with tools and forces that are not evident in the archaeological record. Metal tools of copper/bronze, the best the pre-Columbian indigenous peoples had, and stone tools of harder materials, would have made the creation of these lithic artifacts very laborious, time consuming and inexact.

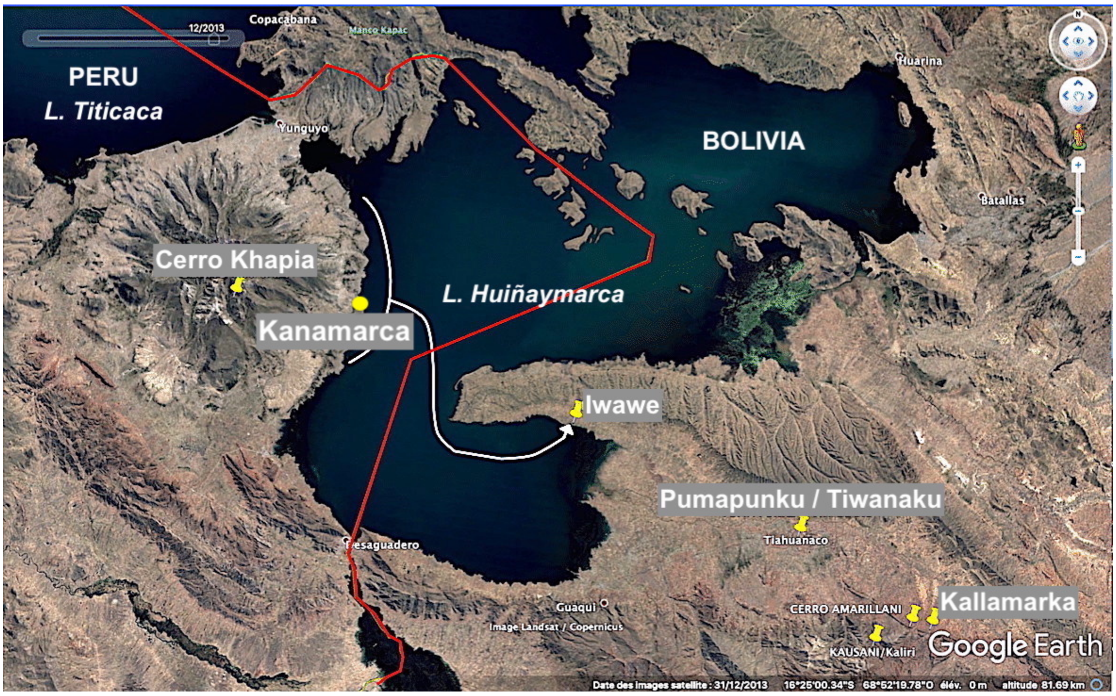

Figure 9: Map showing the border (in red) between Peru and Bolivia, Pumapunku / Tiwanaku and the volcano Cerro Khapia, Largo Huiñaymarca, part of Lake Titicaca. Andesite sand was transported from Kanamarka to the Port of Iwawe. Bottom right, the site of Kallamarka is where sandstone material for the megalithic platforms originated.

It has been determined that the andesite came from a volcanic mountain some 30 km distant across Lake Titicaca (Largo Huiñaymarca) and the sandstone platforms from Quimsashata mountain quarry of Kallamarka, 15 km distant (See in Figure 9).

2.2.2. Considering the Transport by land

Practical logistic concerns regarding the transport of four sandstone terraces weighing over 100 metric tons each (No 1 to No 4) displayed in Figure 2, border on impossible. What kind of rope or cable was used in towing and how, from what was it made and how attached?

According to Protzen & Nair (2013), transporting large lithics overland required "carefully constructed roadbeds". But the ways over which these massive objects were drawn are not evident in the archaeological record. Also, the speed with which the edifices were believed to have been built would be difficult-to-match today. Not to mention, intricate stone masonry that perfectly fitted one stone to many others, would have been very time and labor intensive, even for very skilled stone masons, with only the pre-iron-age tools available. Placing 130 t platforms at the summits of the Pumapunku and Tiahuanacan edifices would have been extremely difficult.

Consider this:

> If 25 kg of lithic can be pulled across flat land by one man, how many men are required to drag a 100 metric ton lithic? We need, at a minimum, 4,000 men to pull this lithic to the site. Add to that the weight of the harnesses used. The physical, organizational and engineering tasks, would be extremely difficult. Imagine an Alaskan dog sled with 4,000 dogs and harnesses. Not a very satisfying solution.

2.2.3. Considering Marine transport

Likewise, marine transport, over Lake Titicaca, of a 9 t lithic, 90 km on a totora reed boat (Vranich et al., 2005; Vranich & Stanish, 2013) has been considered. The process was difficult, dangerous and slow, although successful.

Two pertinent facts: Natural volcanic andesite weights 2.77 t per cubic meter and water weighs 1 t per cubic meter. Therefore, 2.77 m^3 of water would need to be displaced by the vessel for every metric ton of natural volcanic andesite from the volcano Kapia.

At Pumapunku, a single andesite lithic, Figure 1(d), calculates to over 22 t (Gara, 2016) and would have required a vessel of 57 m^3 of displacement to transport it from the quarry's shore at the volcano Kapia, to Tiahuanaco. A vessel of 0.5 m depth by 4 m wide by 11 m long would be needed to displace only the weight of that lithic (excluding the vessel itself). Once again, difficult and dangerous, but, perhaps, doable.

2.2.4. The geopolymer solution

Recent research (Davidovits & Davidovits, 2020) describes how the builders of Pumapunku / Tiwanaku exploited a natural volcanic andesite sand from the volcano Cerro

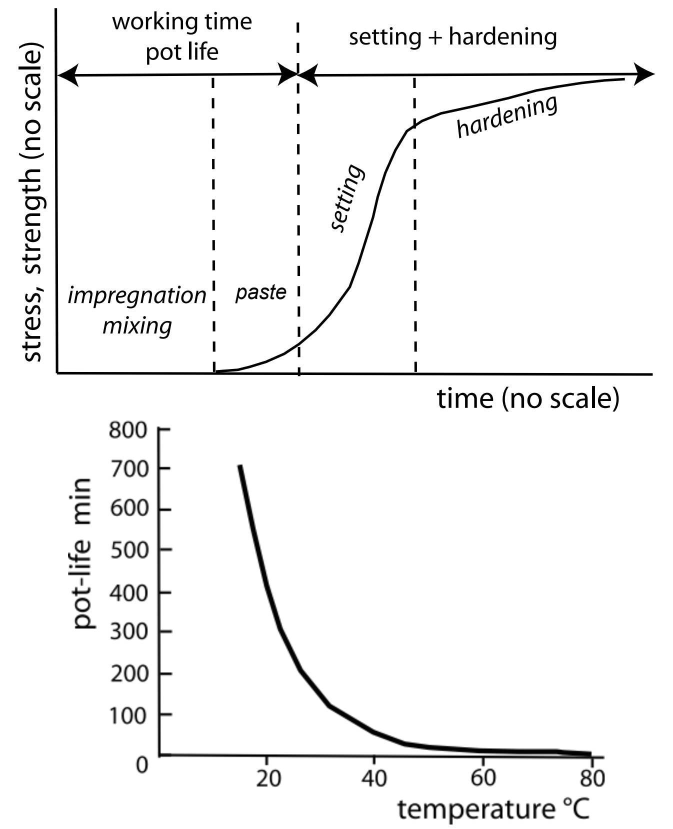

Figure 10: Top, the four phases of geopolymerization: working time / pot life / setting / hardening; bottom, pot life for K-poly(sialate-disiloxo) resin and storage temperature (Davidovits, 2008-2020).

Khapia, transported it to the shores of Kanamarka in Peru. Then it would have crossed the lake on rafts and been stockpiled in the port of Iwawe, Bolivia (see map in Figure 9) and up the Tiahuanaco River and along the canal that encircled the Tiahuanaco / Pumapunku sites.

For the making of their andesite geopolymer monuments, they did not need to crush andesite rock. This andesite sand is similar to one of the pozzolana sands found in the best ancient Roman mortars and coined in Latin “carbunculus”, 2000 years ago.

To make geopolymer andesite stone, the builders could have transported an andesite stony material, having the consistency of sand, from the Cerro Khapia volcano site, and added an organo-mineral geopolymer binder manufactured with local biomass ingredients. They did not use the many quadrangular volcanic blocks, the famous "piedras cansadas”, the tired stones, which are still lying on both sides of the lake Titicaca and which are possible evidence of failed attempts by later civilizations, to transport whole lithics.

In the same way, research already found the geological material used in the manufacture of Pumapunku megalithic geopolymer sandstone terraces of the ferro-sialate type. It is a red sandstone that has been disintegrated by climatic erosion and transformed into geopolymer sandstone sand (Davidovits et al., 2019c; Davidovits & Davidovits, 2020). It is associated with Kallamarka (Bolivia), a historical village that is part of the UNESCO World Heritage (see map in Figure 9).

2.3. Considering Handling and Hoisting: the geopolymer solution

The fitting and refitting of lithics to exacting shapes and tolerances would require repetitive hoisting and manoeuvring, tools of which are not in evidence in the archaeological record of the site. Additionally, there is little information regarding the composition of the labor force, how they were recruited, trained, equipped and organized. Consequently: although we have the evidence (the lithics and their origins), we have not yet understood the means, by way of tools, materials, skills and labor force that were used to accomplish the task.

The hoisting and fitting are eliminated by pouring the lithic in place or by forming smaller, manipulable units that, in their plastic stage, were easily cut and formed with simple tools. Geopolymers also allow for easy distribution of the required quantities of materials and/or mixes to their needed locations.

Considering Known Tools and Techniques: Forming geopolymer objects required some specialized tools for shaping and finishing. The hand tools listed below are those needed only to work with semi-set geopolymer mixes. The time it takes a geopolymer to harden is the hardening time (see in Figure 10, (Davidovits, 2008-2020)).

- **Hand tools** Shovels, picks, construction of carriage containers for men and llamas
- **Cutting and shaping of unhardened geopolymers** Saws for cutting, scrapers, trowels, forms
- **Quarry tools** Stone ‘hammers’, basalt and obsidian cutters

The time during which the material is fluid is called the working time or pot life-time. This is when the raw materials are mixed and placed into molds. The Setting Time is an intermediary period in which the geopolymer is in a plastic form, moldable, carve-able, attachable to other lithics. During the Setting Time a geopolymer can be shaped, repaired and embellished. The hardening, or curing time, is when the lithic obtains its strength and hardness.

Total fabrication times can be quite long, ranging from 3 days to 3 months, depending on the formula and the ambient or curing temperature. At Tiahuanaco, the average summer temperature is 8 °C (ranging from 3 °C in the night to 15 °C during the day) and the average winter temperature is 5 °C (ranging from -2 °C in the night to 12 °C during the day). As shown in Figure 10, at this low temperature, even modern geopolymer resin would need several days to set and harden. We assume that the formula used by those who built Tiwanaku / Pumapunku monuments were reacting more slowly, leaving plenty time for mixing, pouring,

Figure 11: Examples of repairs made on already hardened andesite geopolymer stone.

cutting, sculpting, and finishing of any geopolymers lithic constructs.

2.4. Errors and Omissions, Repair techniques

Occasionally, repairs to the lithics were necessary. These are evident on the Akapana Gate that rests at the top of the Akapana pyramid at Tiwanaku. Damage to the gate was repaired with mixes of geopolymers that did not match in color or composition because of ingredients that differed from the original mix, were used. See examples in Figure 11.

3. Discussion

We could continue our description of other lithics which should be considered as geopolymer constructs. Yet, there are too many. Let us now discuss a few questionable sculpting and building techniques that illustrate our hypothesis.

1. The central figure of the Gate of the Sun in Figure 12 offers an example of irrational sculpting of large lithic surfaces. Here we have the Staff-God and frieze in high relief. The face and nose project from the surface of the Gate some 2 cm. If the sculptors wanted the face to project from the surface, they must have removed 2 cm from the entire surface of the gate in order to bring the frieze and the face into such high relief.

Figure 12: Staff-God in high relief and frieze of the Gate of the Sun at Tiwanaku.

2. On many wall uprights and foundation (floor) lithics are shallow recesses into which the ashlars were fitted (Figure 13). These recesses, of only a few millimeters in depth, are thought to have been carved into the stone to fit the various ashlars to the uprights and secure them to the floor. Why one would expend the time and energy to sculpt these shallow recesses with the crude tools available is not clear, particularly when other, simpler, methods of securing lithics were used by the Tiahuanacan builders.
   The images in Figure 13 reveal an ancient building technique that is still used around the world today.

The trouble with long stone walls is that they tend to quickly crumble and fall into disrepair if they are not stabilized in some way. The technique, still used by the locals in the pueblo of Tiahuanaco, is to place the ashlars over a prepared foundation of lithics or pounded soil, leaving gaps in the wall at regular or convenient distances. Once the wall is to the desired height and length, the stabilizing upright is 'poured' between the ashlars creating a securing 'fence post' that maintains the integrity of the construction. This technique creates the recesses formed by the ashlars in both uprights and foundation pours.

3. The Tiahuanaco Lithic Museum exhibits strange and complicated sculptures displayed in Figure 14.

4. Conclusion

These questions have confounded archaeologists for over 150 years. Ancient and extraterrestrial societies have been proposed, unconvincingly. Levitation and unknown mystic powers have been suggested, also unconvincingly. Massive labor forces, elite builders/stone-masons and powerful religious polities deemed necessary, but none are in evidence. However, through the use of geopolymers we have a reasonable and doable methodology for these constructs that only required basic human intelligence and will. The journey from the quarry Kallamarca or volcano Cerra Khapia to Tiahuanaco / Pumapunku could have been achieved by walking overland with loads of disaggregated stone on the backs of men and llamas. It would have been relatively easy to bring the materials to the required site over existing paths and ways. These amazing constructs, of such large and difficult-to-sculpt materials, have been created by many peoples, around the world, with only the most basic techniques and tools described herein.

Obviously, we know of other archaeological sites that present the same architectural characteristics and that seem too complicated or impossible to achieve with traditional methods of construction. We should mention, for example, the murals and walls in Cusco, Sacsayhuaman, Ollantaytambo, in Peru, and others across the world. Each one of these sites would deserve a specific and exhaustive study like the one we carried out in Pumapunku (JD's team). These studies require the involvement of geopolymer specialists and also geologists ready to consider the scientific contribution of geopolymerization techniques. The confusion between hard monolithic volcanic rock and volcanic sand is still all too widespread and is an example of what is found in other archaeological sites.

Nevertheless, in the context of this paper, we wanted to show how we now perceive the Ollantaytambo structure (Figure 15). Materials are thought to have come from a quarry 3 km distant on an opposing mountain top. The journey, moving materials down the mountain side, across a river and up to the other mountain's side, is 3 km (as the crow flies). These lithics reveal shaping and molding

Figure 13: a) recesses formed by the ashlars in uprights pours; b) foundation lithics with wall recesses likely formed when the wall was constructed on top of unhardened geopolymer; c) Kalasasaya (Tiwanaku), North wall with stabilizing columns.

characteristics. On Figure 15, note the molding design on (a) and horizontal troweling or scraping marks (b, c, d). The author (TAG) suspects that the nubs (e, in blue) were used to hold the lithics in place as the 'mortar' in-between

Figure 14: Tiahuanaco Lithic Museum: lithic sculpture made easily with geopolymers, interior and exterior right angles, flat surfaces.

hardened (f, in yellow) . The nubs are also characteristic of Sacsayhuaman and Machu Picchu.

The traditionalist explanations are based on the presence of the famous "piedras cansadas", the isolated blocks distributed along the routes to the Tiahuanaco/Pumapunku archaeological site. We have shown (Davidovits & Davidovits, 2020) and partly in this article, how this explanation was not valid for Tiwanaku / Pumapunku. It could be the same for the architecture of Ollantaytambo.

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Photo Credits

T. A. Gara : Figures 4, 5, 6, 7, 8, 11, 13, 14, 15
Ralph Davidovits : Figures 2, 3, 12

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Figure 15: next page

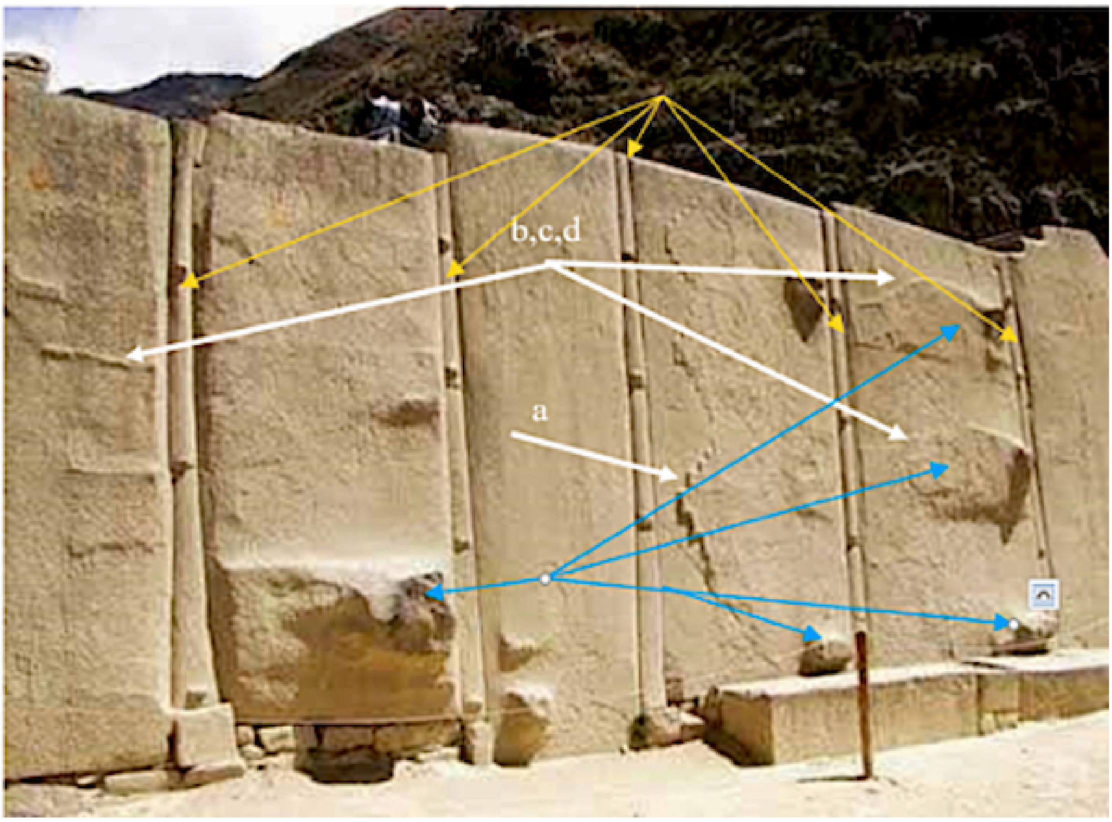

Figure 15: Ollantaytambo structure and possible shaping and molding characteristics.