FURTHER INQUIRIES INTO THE CASE OF THE ARAPA-THUNDERBOLT STELA

Sergio Jorge Chávez and David Bruce Jorgenson

The present article is a followup of a previous one (Chávez, 1976) which dealt with stylistic and megascopic comparisons of two pieces of a single stone sculpture which were found at opposite ends of Lake Titicaca. The base of this sculpture, known as the Thunderbolt Stela, was found at Tiahuanaco (Bolivia), and the upper portion, or Arapa Stela, was located in Arapa (Peru) (see fig. 1 for all sites mentioned in the text). The importance of this case of stylistic identity lies in the fact that, since a portion of this stela was found in a Tiahuanaco structure known as the "Palacio" in Tiahuanaco itself, it represents one of the strongest pieces of evidence of Pucara presence in the area of Tiahuanaco. One of the most important questions posed dealt with the direction in which one of the pieces had been transported. Based mainly on stylistic grounds, the direction indicated was from northwest to southeast.

It was in this context, then, that the first author felt the need to inquire into further aspects of the Arapa-Thunderbolt case, namely: the location of the possible source of the banded, pinkish quartzite; calculation of the weight of each fragment; and the means by which part of the stela was transported across Lake Titicaca.

Source of Arapa-Thunderbolt Rock

In order to test the hypothesis that the Arapa-Thunderbolt Stela originated in the Arapa area and that, therefore, the Thunderbolt piece was transported from the Arapa area to Tiahuanaco, an attempt was made to locate the source of the Arapa-Thunderbolt rock. If this source could be determined, then the place of origin would be confirmed. While determination of chemical composition by neutron activation analysis was considered one appropriate technique for provenience analysis, the geological technique of petrographic analysis was selected as potentially more productive (see discussion on the use of thin sections below).

The first author collected eight rock samples for petrographic analysis which was carried out by the second author: one sample from the Arapa portion of the stela; one from the Thunderbolt portion of the stela; two samples from different locations on Mumu Hill overlooking Arapa (see fig. 1); two samples from the church in Arapa, one from the façade and one from the steps (this building stone was said to have come from Mumu Hill); one sample from a Pucara-related sculpture found in Arapa which we believed might come from the same quarry because of its location and roughly similar style (Monolith 3; see Chávez, 1976, pl. IX and p. 10); and one sample from the Pucara Plaza Stela found in Pucara, also considered possibly to come from the same quarry because it is of the same substyle as the Arapa-Thunderbolt Stela (Chávez, 1976, pl. V and pp. 7-8).

The use of thin sections for comparative analyses

The rock samples selected for petrographic analysis were prepared in the standard way for examination with a petrographic microscope. The rectangular rock chips were mounted on microscope slides and ground to standard thin section thickness (0.03 mm.) using lapidary wheels and grinding compounds. Petrographic analysis yielded information on mineral types and abundances, porosity, the amount of post-depositional alteration, and the nature of authigenic (post-depositional) mineralization.

Thin section analysis was favored over chemical analysis for this study for the following reasons: (1) Clastic sedimentary rocks (i.e., rock and mineral fragments cemented together to form a rock) generally behave as open or partly open, chemical systems, making chemical correlations unreliable, at best. (2) The variety of source rocks often available for a clastic sediment, and possible changing conditions of deposition, can result in a wide variety of rock types in a single outcrop. However, a factor assumed common to each rock unit in the outcrop or quarry is the physical environment of post-depositional chemical readjustments (diagenesis or metamorphism). These changes are apparent in the nature of the secondary (authigenic or metamorphic) minerals, a property which cannot be detected strictly by chemical means. (3) Rock textures and mineralogy can be readily determined in thin section, adding an important dimension to the correlation of specimens.

Because of these considerations, thin section analysis is recommended as a first step in comparing samples of clastic sedimentary rocks. Furthermore, because of the variety of unique information easily obtained from thin sections, their use should be routinely considered when dealing with rocks and artifacts.

Thin section analysis should not be considered a panacea, however, and the results must be interpreted cautiously. Although the general physical conditions which cause post-depositional changes can be assumed constant on the scale of an outcrop or quarry, it is quite common for a variety of mini-chemical environments to develop at this scale. Variations in clastic mineralogy, proximity to surface oxidizing conditions, the presence of organic material, and so on, can produce a number of different secondary effects in the sandstones. Thin section analyses, therefore, do not always yield definitive correlations by themselves, and they must be interpreted in the context of other evidence.

Petrography

Thin sections of two samples from the quarry at Mumu Hill, and one sample each of the Arapa and Thunderbolt pieces were examined and compared. The percentages of minerals in each sample were determined by point counting, and are listed in Table 1. In addition, Table 1 includes analyses of two samples of building stone from the church at Arapa and two samples of stone sculpture, one from Arapa (Monolith 3) and one from Pucara (Pucara Plaza Stela). These were included as examples of stone possibly derived from the Mumu Hill quarry.

The most obvious similarities are between the Arapa and Thunderbolt samples. The most apparent dissimilarities are between Mumu 2 and the other samples (see figs. 2-5). The discussion that follows is divided into two parts: a comparison of the Arapa and Thunderbolt samples, and a comparison of the quarry samples with those of the Arapa and Thunderbolt stelae.

Arapa and Thunderbolt samples

The Arapa and Thunderbolt samples have nearly identical compositions and grain size, and are petrographically similar in many other respects. The rocks are sedimentary quartzites, with quartz overgrowths acting as the principal cementing agent. On many quartz grains the original detrital outlines are preserved by a thin coating of a clay mineral which preceded the development of the overgrowths. The original grains apparently developed fairly well-rounded shapes prior to deposition.

Minor amounts of fresh feldspar (microcline and plagioclase) are found in both samples along with rounded grains of clay or claylike material which is probably altered feldspar. Clay also occurs interstitially as a minor constituent, and rims of clay (illite-smectite?) are found in abundance surrounding the detrital grains. The quartz overgrowths and clay rims were likely developed diagenetically in the sediment. Oxidation of the iron-bearing minerals probably occurred as a result of weathering of the sandstone, producing a pale orange-brown color in the rocks. There is no indication of metamorphism in either sample.

The petrographic similarities of the Arapa and Thunderbolt rocks provide strong evidence in support of their common origin. The critical similarities are their essentially identical composition, grain size, post-depositional history, and pre-diagenetic textures.

Mumu Hill quarry samples

The samples Mumu 1 and Mumu 2 were taken from two different stratigraphic positions in the quarry. Both samples can be classified as sedimentary quartzite, but they differ markedly in composition and grain size (Table 1 and figs. 4,5). In addition, the sample labeled Mumu 1 differs from Mumu 2 in having quartz overgrowths on obviously rounded clasts, and rounded grains of altered feldspar. Mumu 2 appears to have a bimodal distribution of grain sizes, with the large grains averaging 0.4-0.6 mm. and the smaller grains averaging less than 0.2 mm. The lack of feldspar, fresh or altered, is also an apparent distinction.

The two samples of building stone from the Arapa church and the two pieces of stone sculpture (Arapa Monolith 3 and the Pucara Plaza Stela) show evidence of iron oxide staining both in hand specimen and in thin section. The major petrographic differences between these rocks and Mumu 1 and 2 are their higher percentages of clay matrix and the poor development of quartz overgrowths. These rocks have a distinct sandstone appearance in thin section and deserve the name quartz sandstone rather than sedimentary quartzite, since their cementing agent is clay rather than quartz. These samples, if they did indeed come from the Mumu Hill quarry, further illustrate the heterogeneity of the rocks in the quarry, making positive correlations with artifacts even more tenuous.

Sample Mumu 1 has some features in common with the Arapa and Thunderbolt rocks, but the correlations are not perfect. Similarities from Table 1 include grain size and percentages of quartz, altered feldspar, and interstitial clay. Other petrographic similarities include quartz overgrowths on well-rounded clastic grains, the presence of sparse, but obvious, clay rims on some of the grains, and the lack of any indication of metamorphism. Differences between Mumu 1 and the Arapa-Thunderbolt samples are principally the total lack of unaltered feldspar and the higher percentage of void space in the Mumu rock.

The petrographic analyses suggest a possible correlation between at least one of the quarry rocks, Mumu 1, and the Arapa and Thunderbolt samples. Although the petrography cannot prove that the stela samples came from this quarry, it does not rule out this possibility, and the similarities mentioned above lend fairly substantial support to the hypothesis presented in this paper.

Means of Transport

The first author has previously suggested the use of totora rafts for the transportation of the lower portion of the stela across Lake Arapa and Lake Titicaca to Tiahuanaco, a straight-line distance of 220 km. (Chávez, 1976, p. 13). The plausibility of this suggestion can be further supported by historical and ethnographic documentation on the utilization of totora reeds in the manufacture of rafts by the Quechua, Aymara, and Uru groups.

Totora or <u>tutura</u> reed is the single most important plant resource in the altiplano of Peru and Bolivia where it occurs.[1] Totora rafts represent the most economical means of water transport on Lake Titicaca today. They are highly maneuverable and fairly fast (3-5 km/hr, doubling speed with a sail) even in narrow paths and shallow swampways and are extensively used in trade among the islands and shores of the lake and rivers (see, for example, LaBarre, 1948, pp. 105-107 and Romero, 1928, pp. 494-496).

Recently, in an extensive work dealing with the problem of transportation of the huge stones present at Tiahuanaco, the Bolivian archaeologist Ponce Sanginés (Ponce Sanginés and Mogrovejo Terrazas, 1970, pp. 67-188) considered two means of water transport: totora reed and balsa wood rafts. However, both his extensive review of the literature and his experiments were biased in favor of balsa wood rafts (<u>almadías</u>). As perishable totora and balsa wood remains are absent in the archaeological record of the altiplano of Peru and Bolivia, Ponce relied on historical and recent documentation to support his argument. He asserted that the rafts have been utilized at least since Tiahuanaco times, and that balsa wood was obtained from the lower elevations and warmer environments of the eastern slopes (as in Inca and recent times).

Finally, Ponce concluded from an experiment with small models that totora rafts lack rigidity, and that they are "extremely unstable and they tend to overturn quickly dumping the load.... The most adequate and stable watercraft in consequence is the balsa wood raft" (my translation of Ponce Sanginés and Mogrovejo Terrazas, 1970, pp. 109, 147).

While balsa wood rafts might have been used in prehistoric times, more emphasis should be given to the study of totora rafts, as totora is abundant and readily available in the altiplano itself. I disagree with Ponce regarding the stability and rigidity of totora rafts. Several references indicate that totora rafts can transport heavy loads depending on the number and size of reed bundles. For example, during excavations in Taraco (Peru) in 1974 we observed the daily use of totora rafts to transport up to 30 people at a time across the Ramis River. Furthermore, in 1877 Squier reported the use of totora rafts to form a floating bridge in the village of Nasacara (Desaguadero River), and also noted that totora rafts could carry as many as 60 people (Squier, 1877, pp. 264-266,309 with illustrations, and 329). Finally, fig. 6 illustrates a totora raft which is carrying 15 people and a small truck, easily equivalent to the weight of the Thunderbolt piece (about 1000 kg.; see Appendix for calculations).

Since we know the weight of the Thunderbolt stela, we can reconstruct the specific size (by volume) of the raft which would have been necessary to carry the piece. The weight of the stone will displace a corresponding volume of water (based on Archimedes principle) which would be closely equivalent to the volume of the raft itself. For every kilogram of weight, the raft displaces 1000 cubic centimeters of water, or for every 62.42788 lbs. of weight the raft displaces one cubic foot of water. Therefore, since the Thunderbolt Stela weighs 998 kg., the volume of water and hence the volume of the raft, would be about 998,000 cm.^{3}; for example, a raft having hypothetical dimensions of just 300 cm. x 100 cm. x 33.3 cm. thick could support the Thunderbolt Stela (300 cm. x 100 cm. x 33.3 cm. = 999,000 cm.^{3}). However, these dimensions would make the top of the raft level with the surface of the water, so an additional "safety factor" must be added to provide extra thickness to the raft (Clifford F.L. Mohr, personal communication). Other adjustments would be necessary to take into account the water temperature of Lake Titicaca (these calculations are based on a water temperature of 4° C) and how many people might have been on the raft (although the raft could have been towed). Increasing the thickness of the raft to about 50 cm. would probably allow for these variables.

Conclusions

The calculated weights of the Arapa fragment (approximately 1655 kg.) and the Thunderbolt fragment (ca. 998 kg.) are within the limits of the carrying capacity of large totora rafts, which might have been specially constructed for this purpose in prehistoric times. Such rafts, made out of this locally available plant resource, would have been an accessible and effective means for transporting such weighty objects.

The direction of transport of the smaller Thunderbolt piece from Arapa to Tiahuanaco in prehistoric times, which was hypothesized earlier on the basis of strong stylistic evidence, seems to be supported by the geologic evidence derived from petrographic analysis made by the second author, on eight samples obtained by the first author. Petrographic comparisons indicate close similarity between the Arapa and Thunderbolt samples, and between these and the Mumu 1 outcrop sample. The samples from the Arapa church, the Arapa Monolith 3, and the Pucara Plaza Stela are quartz sandstone and differ from the other four samples which are sedimentary quartzite. Dissimilarities illustrate the variety/heterogeneity of the rock, even in samples from the same quarry (Mumu 1 and Mumu 2). While similarities between the Arapa and Thunderbolt samples and Mumu 1 are not total, they do not preclude the possibility that the specimens came from the same quarry. In fact, the correlations lend fairly substantial support to the idea that the Mumu quarry was the source of the rock for the Arapa-Thunderbolt Stela. Therefore, the Thunderbolt portion would have originated in the Arapa area and been taken to Tiahuanaco.

Although the petrographic analysis thus far indicates that there is a high probability that the Mumu quarry was the source for the Arapa-Thunderbolt rock material, further systematic sampling of this quarry will be necessary to obtain more precise results.

Additional Notes

Two additional pieces of information regarding the breakage of the Arapa portion and the present condition of the Arapa Stela should be included here. John H. Rowe has informed us that he has a photograph taken by Abraham Guillén which shows the stela (while it was still the church lintel) with the crack running at least part way across the stone at the same place where it subsequently separated (also shown in Kidder's photographs as a break). Consequently, it is possible that neither of the two versions regarding the cause of the breakage of the Arapa portion of the stela (those of Mary B. Kidder and Julián Palacios R. mentioned in Chávez, 1976, pp. 3-4 and note 7) is entirely correct. We have also been informed recently that, regretably, the larger portion of the two Arapa pieces has been moved from the church entrance to the village square of Arapa, where it stands vertically supported by a cement foundation at its base (Alfredo Valencia Zegarra, personal communication).

Acknowledgements

The research upon which this paper is based was partially funded by a Senate Research and Creative Endeavors Grant and a faculty Achievement Award from Central Michigan University, granted to Karen L. Mohr Chávez with Sergio J. Chávez as assistant. Special thanks are due to Clifford F.L. Mohr in appreciation of his mathematical expertise, and to Karen L. Mohr Chávez for her constant support, editing, and for initially obtaining information on the location of the Mumu quarry. I am also grateful to Denise C. Carlevato and Michael D. Affholter who aided in the field. Furthermore, I would like to thank John H. Rowe and Patricia J. Lyon for their editorial assistance and comments.

January 23, 1980
revised October 25, 1980

APPENDIX

Calculation of the Weight of the Arapa and Thunderbolt Pieces[2]

SPECIFIC GRAVITY = 2.596 $\left(= \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}\right)$

DENSITY: Metric = 2,596 gm/cm^3 (= 1* x specific gravity = gm/cm^3)
*gm/cm^3 of water at 4°C.

English = 162.06 lbs/ft^3 (= 62.42788* x specific gravity = lb/ft^3)
*National Bureau of Standards: lb/ft^3 of water at 39.2°F.

VOLUME*: Arapa fragment = 637,458 cm^3
Thunderbolt fragment = 384,480 cm^3
Arapa-Thunderbolt = 1,021,938 cm^3

*Volume = area of one face x thickness (see fig. 7 for dimensions used).

WEIGHT: (= volume x density)

	Metric	English*
Arapa fragment	1,654,840.968 gm	3,648.29 lbs
Thunderbolt fragment	998,110.08 gm	2,200.45 lbs
Arapa-Thunderbolt	2,652,951.048 gm	5,848.75 lbs
	or	or
	2.65 tons (rounded)	2.92 short tons (rounded)

*Using 1 cm^3 = .06102374 in^3, and 1728 in^3 = 1 ft^3.

NOTES

[1]Ethnographic and historical studies undertaken by the first author (still in progress), indicate that this plant resource was and still is used in the manufacture of rafts (<u>yampu</u> or <u>wampu</u>), sails, floor and sleeping mats, roof thatching, fences and doors, coiled and twined baskets, floating bridges, fishweirs, cylindrical containers for grain storage, floating islands, as well as for packing, fuel, and as food for people and animals.

[2]The specific gravity was determined from a small (ca. 2") fragment of the Arapa stela by the second author who is a faculty member of the Department of Geology, Central Michigan University. Mathematical calculations included in this section were made by Clifford F.L. Mohr, chemical engineer.

BIBLIOGRAPHY

Chávez, Sergio Jorge
1976 The Arapa and Thunderbolt stelae: A case of stylistic identity with implications for Pucara influences in the area of Tiahuanaco. Ñawpa Pacha 13, 1975, pp. 3-25. Berkeley.

LaBarre, Weston
1948 The Aymara Indians of the Lake Titicaca Plateau, Bolivia. American Anthropologist, vol. 50, no. 1, pt. 2, January. Memoir no. 68. Menasha.

Ponce Sanginés, Carlos, and Mogrovejo Terrazas, Gerardo
1970 Acerca de la procedencia del material lítico de los monumentos de Tiwanaku. Academia Nacional de Ciencias de Bolivia, Publicación no. 21. La Paz.

Romero, Emilio
1928 Monografía del Departamento de Puno. Imprenta Torres Aguirre, Lima.

Squier, Ephraim George
1877 Peru; incidents of travel and exploration in the land of the Incas. Harper & Brothers, Publishers, New York.

TABLE 1

Mineral Percentages and Average Grain Sizes Determined from Thin Section

	Quartz	Unaltered Feldspar	Altered Feldspar	Interstitial Clay	Opaque	Void	Other*	Average Grain Size
Arapa	85	3	2	7	1	1	1	0.1-0.2 mm.
Thunderbolt	89	2	2	5	tr	2	tr	0.1-0.2 mm.
Mumu 1	80	none	2	8	1	9	tr	0.1-0.2 mm.
Mumu 2	91	none	none	7	tr	2	tr	0.4-0.6 mm.
Church Façade	84	none	1	15	tr			0.22 mm.
Church Steps	81	none	none	17	2			0.20 mm.
Monolith 3	79	none	3	12	2		1	0.20 mm.
Pucara Plaza Stela	84	none	none	16	none			0.18 mm.

*Includes principally amphibole, pyroxene, and zircon.

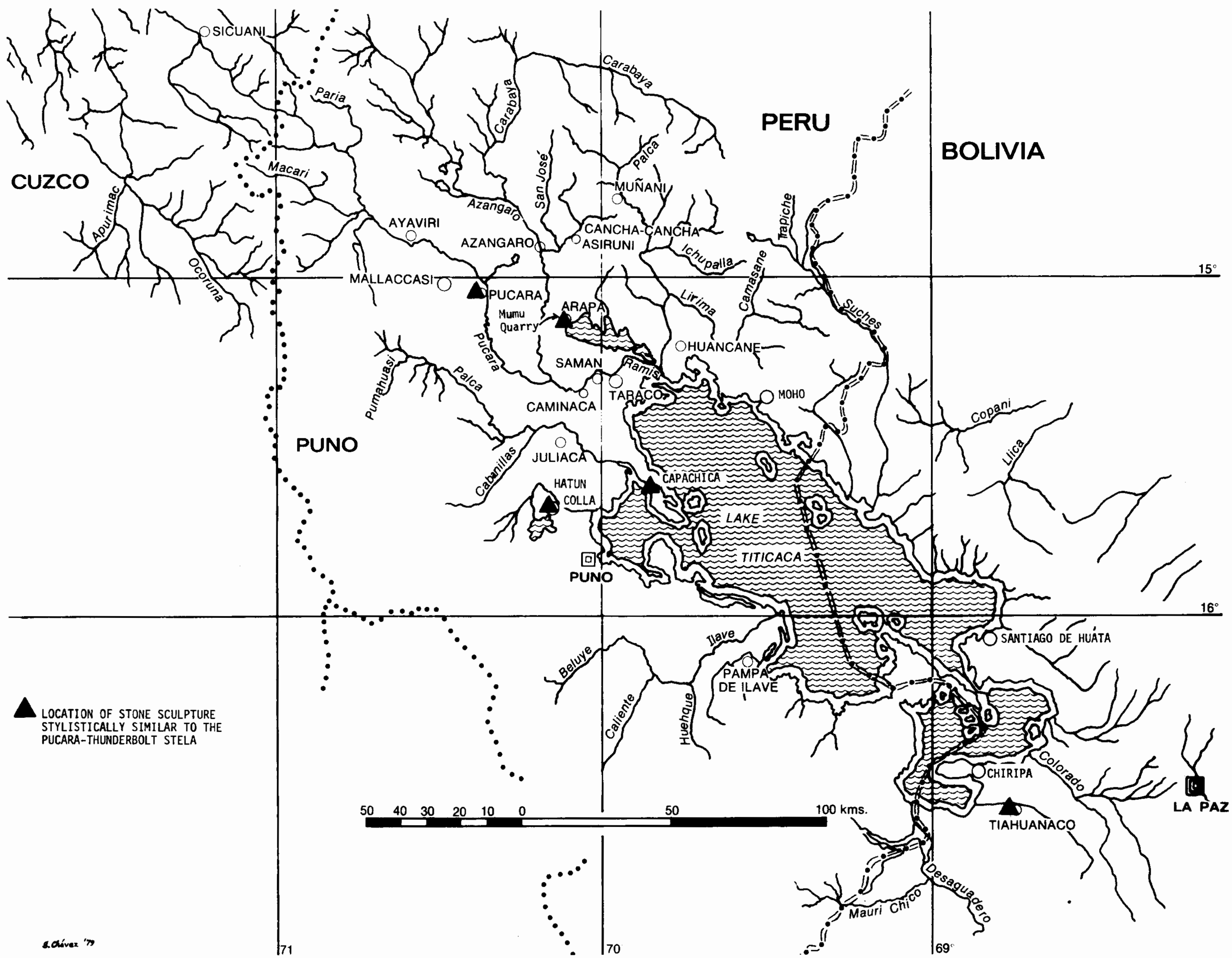

Plate XV. Fig. 1, map of Lake Titicaca Basin with major sites indicated.

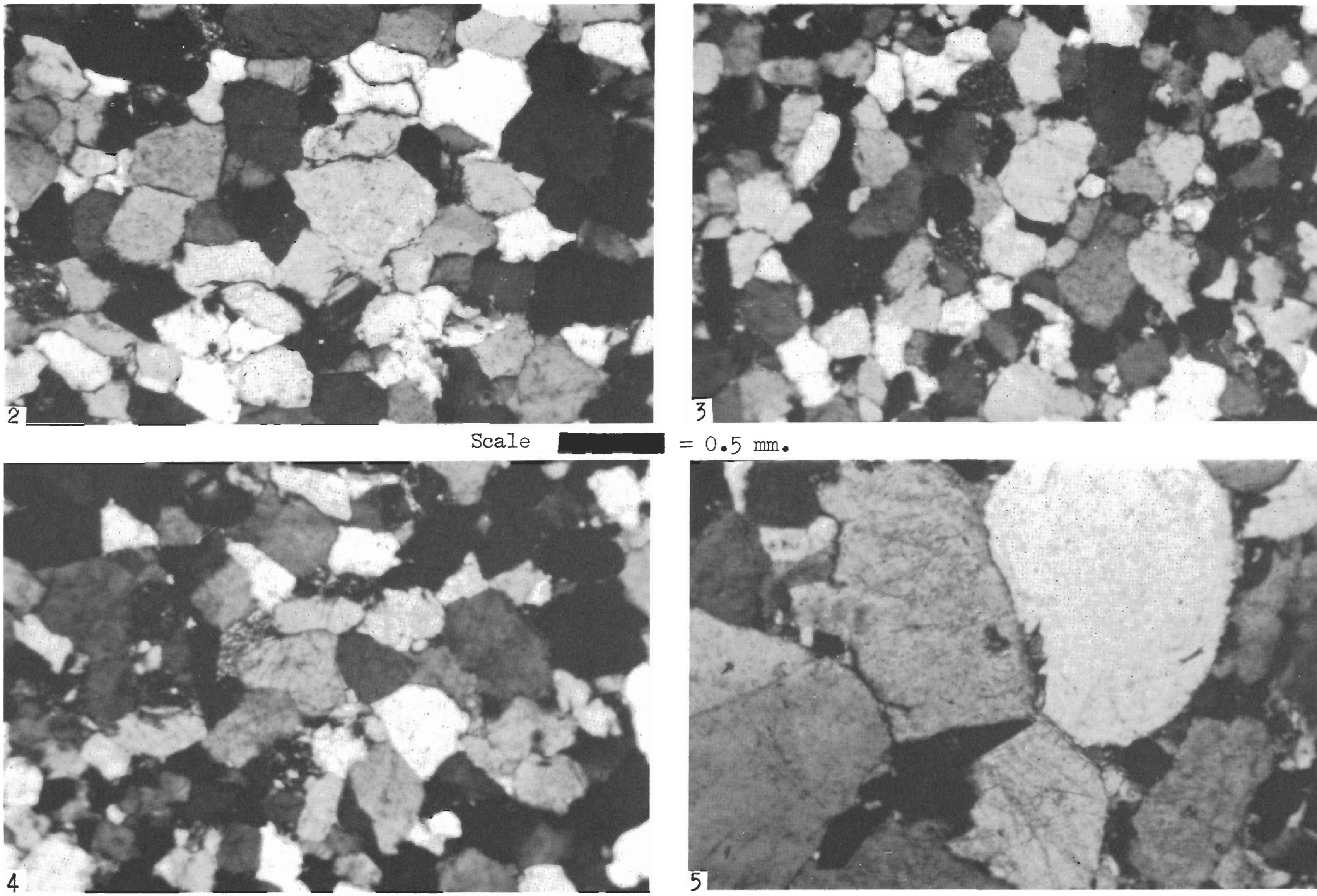

Plate XVI. Photomicrographs of thin sections of samples. Fig. 2, Arapa Stela; fig. 3, Thunderbolt Stela; fig. 4, Mumu 1; fig. 5, Mumu 2.

Plate XVII. Fig. 6, a 1927 photograph taken on the Ramis River, Puno, documenting the feasibility of water transport of heavy loads. Photograph courtesy of Manuel Chávez Ballón.

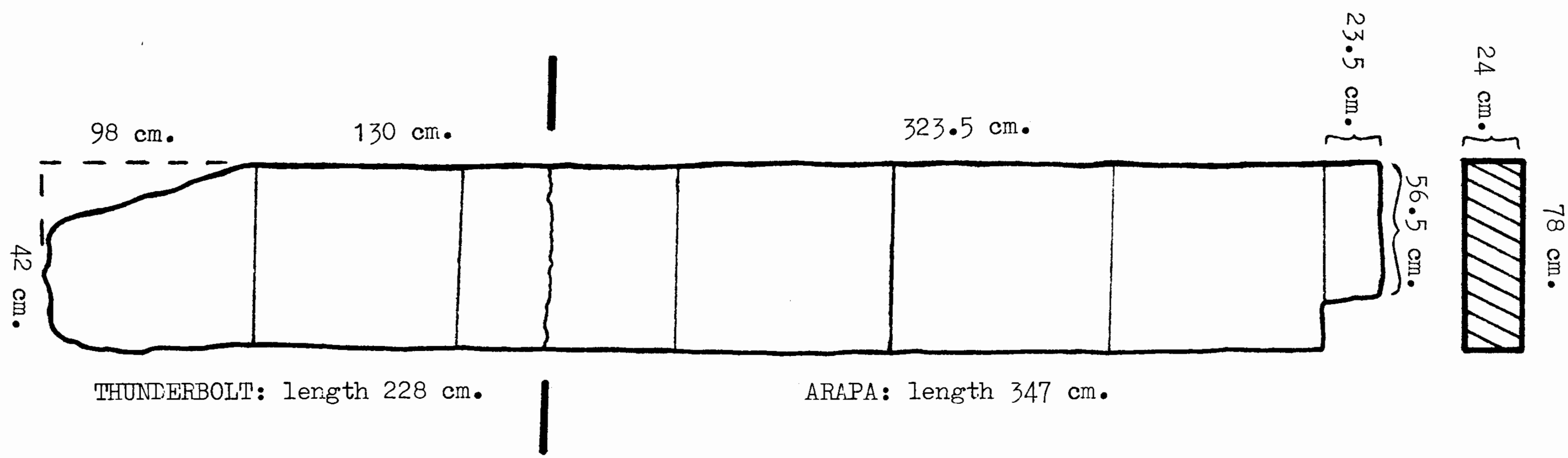

Plate XVIII. Fig. 7, dimensions of the Arapa-Thunderbolt Stela. Total length 5.75 m. The maximum thickness of 24 cm. includes the relief carving (1 cm. on each face), but thickness without carving is 22 cm., and to calculate density 23 cm. was used as an average thickness in determining volume. Measurements of the combined length were made on the pieces themselves and compared to their corresponding rubbings.