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The Water Canalization System of the Petra Southern Temple[1]

Introduction

In Book II Chapter IV, Diodorus Siculus describes the Nabataeans as nomads who "inhabit a tract partly desert, and in other parts without water, and there is very little of it that bears any fruit..."

The Nabataeans, once nomads, became a settled people and as an investment in urban planning, their control of water was vital. They built Petra and it is well-known that one of their great achievements was to develop hydraulic engineering systems to collect water in underground cisterns and reservoirs, to cut out channels in the rock face to divert and direct water into their city, to dam the Wādī Mūsā, and to construct tunnels for water flow. With these irrigation systems, in effect, they redesigned nature and increased their control over their environment. From the Nabataeans' manipulation of the landscape, it appears that water resources were more than sufficient to serve the needs of their great city.

In the very heart of Petra lies the Southern Temple complex (FIG. 1).[2] Under the Temple Forecourt (FIG. 2), in Trench 1, a system of water tunnels was uncovered in 1993-1994 by Brown University archaeologists[3] excavating under the auspices of the Department of Antiquities of Jordan.[4] With the aid of a mining engineer - economic geologist,[5] the tunnels were made safe for entry and study. In 1995, ground penetrating radar [6] was used to plot these tunnels. Excavation during that year also uncovered other areas where the system could be followed.

This canalization system was in continuous use for many years. We assume the Southern Temple was constructed around the time of the city's greatest prosperity, the reign of Aretas IV (9 BCE - 40 CE), and that it was in use throughout the Roman occupation of Petra in 106 CE when the city was annexed by the Roman emperor Trajan, and became part of the Roman Provincia Arabia. Part of the Southern Temple may have survived the 363 earthquake, and the evidence from the 1995 Brown University excavations of the site suggests that the Temple saw reuse in the Byzantine period — thus it may have been in use for some 400 or more years. What is clear so far is that the water supply flowing through these channels must have been plentiful, for the system was carefully planned, in the Nabataean fashion, to maximize a sizable quantity of this most precious resource.

This paper will describe the results of the excavation analysis – the tunnels, their method of construction, the cause of their collapse, their purpose, the objectives for future study – and will conclude with a cursory look at water systems found at other Nabataean sites.

Discovery

On the final day of excavation during the 1993 field season, a small circular patch of loose soil located in the center of the limestone paved Southern Temple forecourt (FIG. 2) was cleared to a depth of 0.5 m, to reveal the main junction area of four subterranean water channels (FIG. 3). Lying obliquely across the top of the junction point, probably serving as a makeshift capstone to the tunnel ceiling, was a dressed ashlar block, which had a mason's mark etched into one side. Removal of this stone

1 I would like to thank the Centro Recerche Archeologique e Scavi di Torino per il Medio Oriente e l'Asia — The Sixth International Conference on the History and Archaeology of Jordan and President Gullini for this conference initiative. The conference title, "Landscape Resources and Human Occupation in Jordan Throughout the Ages," forced me to think about the water resources of the Southern Temple. I would also like to thank the Jordanian Department of Antiquities of Jordan and Dr Ghazi Bisheh, Director–General, for it is with the consent of the Department of Antiquities that our work continues at Petra. A Brown University Faculty Travel Grant made my participation in this conference possible.

2 The Southern Temple represents one of the major archaeological and architectural components of the city, as well as one of the largest temple structures covering some 7000 square meters to be found at Petra. The Southern Temple lies to the south of the Colonnaded Street and southeast of the Temenos Gate. It occupies a position of paramount importance. From north to south the Petra Southern Temple complex is comprised of a Propylaea, which leads to a Sacred Area or Lower Temenos ending in a monumental Grand Stairway which in turn leads to the Upper Temenos, the sacred enclosure for the temple proper.

3 Trench 1 was excavated in 1993 by Erica Schuntz, a Brown University Ph. D. candidate in the Center for Old World Archaeology and Art.

4 Suleiman Farajat was appointed as our on-site Jordanian Department of Antiquities representative 1993-1994. And in 1995, our government representative was Mohammad Abdul-Aziz.

5 Peter B. Nalle has 50 years of mining and construction experience. He was on-site and advised us from 27 June to July 11, 1994. A 1994 excavation and study of these systems was undertaken by Elizabeth Ellen Payne, (now a Ph.D. candidate at Boston University), for a 1995 Senior Honors Thesis at Brown University. Lee Payne was also responsible for the 1995 excavation of the Trench 13 collapse and recovery of the system in Special Project 20.

6 In 1995, GPR was initiated and supervised by Terry Tullis of Brown University's Geology Department.

1. Petra Southern Temple, aerial view, 1995, facing southwest.

2. Petra Southern Temple Forecourt, showing the area of disturbance in the foreground,1994, facing south.

and its surrounding debris revealed narrow tunnels, sealed by stone slab stones at an elevation of 883.7 m, leading to the north, south, east, and west. Due to the potential risk of collapse, and because they were discovered at the close of the season, these passageways were only cursorily investigated, and then covered and sealed for the following season's investigation. Now, after the 1994 and 1995 full seasons of exploration, much more about this impressive water conservation and drainage system is known. Because elements of the same system have been found in different areas of the Petra Southern Temple site, we have designated the various areas as follows:

Channel A. The main north-south channel. We posit that it extends from the Southern Temple interior to the Temple Forecourt and progresses in a northward direction to the Wādī Mūsā where it discharges.

Channels B and C. These are the tunnels located to the east (Channel B) and west (Channel C) off of Channel A located in the Temple Forecourt.

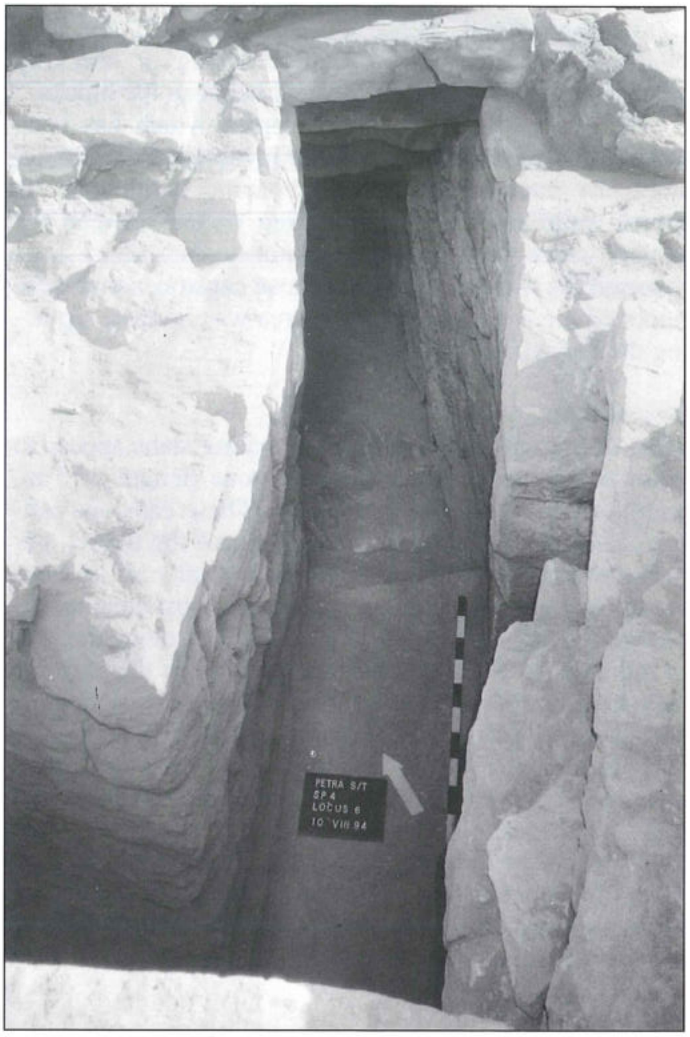
Channels D and E. The tunnels east (Channel D) and west (Channel E) that extend from Channel A in the Lower Temenos (Trench 13, Special Project 20).

Channel F. The artery located in the Temple East (Special Project 30, near Trenches 4 and 19.

Channel G. The continuation and part of Channel A in the Lower Temenos North, located just south of the Propylaea Steps.

The Stratigraphy of Channel A in the Temple Forecourt

Top soil fill, averaging 0.75 m in depth covered the hexagonal pavement which had been disturbed probably by the modern use of the area for growing grain. The white limestone hexagonal paving was uneven but had an average elevation of 884.41 m. Under the hexagonal pavement,[7] there was either a sand and clay fill or a pink



3. Junction of Channels A, B, C in Trench 1, 1994, facing north.

mortar bedding which has the consistency of hard clay. Under this was a pebble-filled yellow mortar which had the consistency of concrete.

Under the Temple Forecourt, the Channel A stratigraphy indicates two phases of construction — an original building at the earlier lower phase, and a subsequent later upper phase(s) of repair. The earlier phase walls of the passageways themselves were of a well-planned and well-executed construction, with uniform, well-built corners, which would indicate that the entire system was originally planned and constructed simultaneously. The later upper courses indicate a building up of the system perhaps to allow for a greater water flow. It is possible that this rebuilding may also indicate a repair dating to Phase 2 of the Temple construction.

These main tunnel side walls are vertically constructed with roughly dressed sandstone ashlars, ca. 0.60 -0.70 m in length and 0.30 - 0.40 m in width. The five to seven wall courses are generally dry-laid without mortar and

7 These white limestone pavers measure about 33 cm in diameter. Each side measures 20 cm, and they are 0.12 m in thickness.

were closely-fitted. However, particularly in the later phase, in some instances small chinking or snecking stones were observed to be wedged between the blocks.

The second phase is one of repair, which has been crudely executed. Those who were involved in rebuilding, started by removing the hexagonal paving, building up the tunnel walls and inserting snecking stones between the ashlars when their joins were not sealed. They then reversed the process, replacing those capstones that were removed for entry and, after the area was refilled, replacing the hexagonal pavers.[8]

Description

Most of the tunnels' well-dressed ceiling slabs appear to be of limestone or fine white sandstone (length 0.75 m, width of 0.57 m, thickness 0.18 m). These capstone ashlars were positioned to span the width of the tunnel, but they did not overlap the side walls. Virtually all of these capstones have suffered some damage. Most have multiple breaks, and are stress split in the center, along the axis of the tunnels. This probably occurred when the massive temple columns fell, either from earthquake action or because there was a lack of structural integrity within the Temple structure itself. Sealing these capstones from above was a layer of sterile, densely packed wadi sand, which was clearly distinguishable from the loose, finer layers of fill and topsoil above. To facilitate the excavation of this portion of the Temple forecourt and the canalization system, five capstones, cracked but still *in situ* were recorded and then removed.

Channel A

The major water conduit is the north-south Channel A, which emerges from beneath the temple center, proceeding at a shallow, downward grade below the temple forecourt. The internal dimensions of the tunnel ranges from 0.60 to 0.70 m in width. After the intersection point, it descends at 26° to pass under the steps or wall that demarcates the Upper Temenos from the Lower Temenos. (The differential in elevation between the two areas is approximately six meters.) This main passageway, was lined on the bottom with a fairly thick layer (4 to 6 cm) of mortar, as were the secondary passageways to the east and west. The southern extent of the north-south passage is also uncertain, due to heavy collapse located below the area of the Southern Temple stylobate. But to the south, towards the Temple entrance, the tunnel at an 8.4 m distance ascends up grade to a point where it then pitches sharply upward. This is where collapse can be seen. Shortly before it reaches the northern limit of the Upper Temenos, the main north-south tunnel descends sharply, descending with the slope and passing below the Grand Stairway which leads down to the Lower Temenos area. At this point the channel bottom is stepped, apparently to slow the speed of the water running through it (FIG. 4). The ceiling, which ranges 1.7 m -1.9 m in height, is similarly stepped.[9] The tunnel to the north was found blocked by fine soil and sand at approximately 11 m to the south of the opening in the Temple forecourt. FIG. 5 is the west section of the canalization system.

Careful excavation of the uncapped portion of the north-south channel revealed two distinct layers of soil deposit above the mortar lining. The 0.24 m thick lower layer consisted of fine, silty soil. The fine-grained fill in the tunnels is surprisingly devoid of artifacts — the scant ceramic remains were Nabataean and Roman in date. The one datable lamp fragment was securely first century CE. Presumably this layer was deposited during the system's period of use. Within the tunnels, a second, 0.36 m thick layer of loose, topsoil-like fill and debris then accumulated, apparently after the temple area's abandonment.

Channels B and C

There are east and west tunnel passages to this main system in the Temple Forecourt. The east and west branches are slightly narrower than the north-south conduit, averaging 0.5 m in width. They are constructed 30 cm above the floor of the north-south tunnel, and their side walls are also not as high, Channel B on the west measuring 0.60 m in height, and Channel C on the east 1.1 m in height. The east-west walls are bonded to the north-south tunnel walls, thus again it can be assumed that the system network was constructed at one time. The two tunnels do not join the main passageway at the same point — rather, they are staggered, with the west tunnel joining the north-south 0.75 m further to the south. Our mining engineer observed that this offsetting of the passages was probably intentional, in that one single capstone could not have securely spanned the area of a four-branch join — about 1.5 m from its join to the north-south channel, the east branch curves to the northeast, and at 3.5 m collapse is visible. The west tunnel extends to the west for approximately 1.5 m and then curves to the northwest, and beyond 5.00 m, this passage curves too abruptly to see where it goes. At the end of their observable length, both tunnels are sand-filled up to their roofs. Curiously, these two channels slope slightly north to south, counter to the marked south to north grade of the main channel. Further investigation of these channels is necessary, but it may be that their opposing north to south grade is another method by which water speed was checked, or that the two served as run-off channels for overflow in the system. It may also be that the builders of the later phase just left the Southern Temple access steps, and constructed over them for water

8 In one of the latest phases of repair, crude ceramic pavers served as a substitute for the limestone pavers.

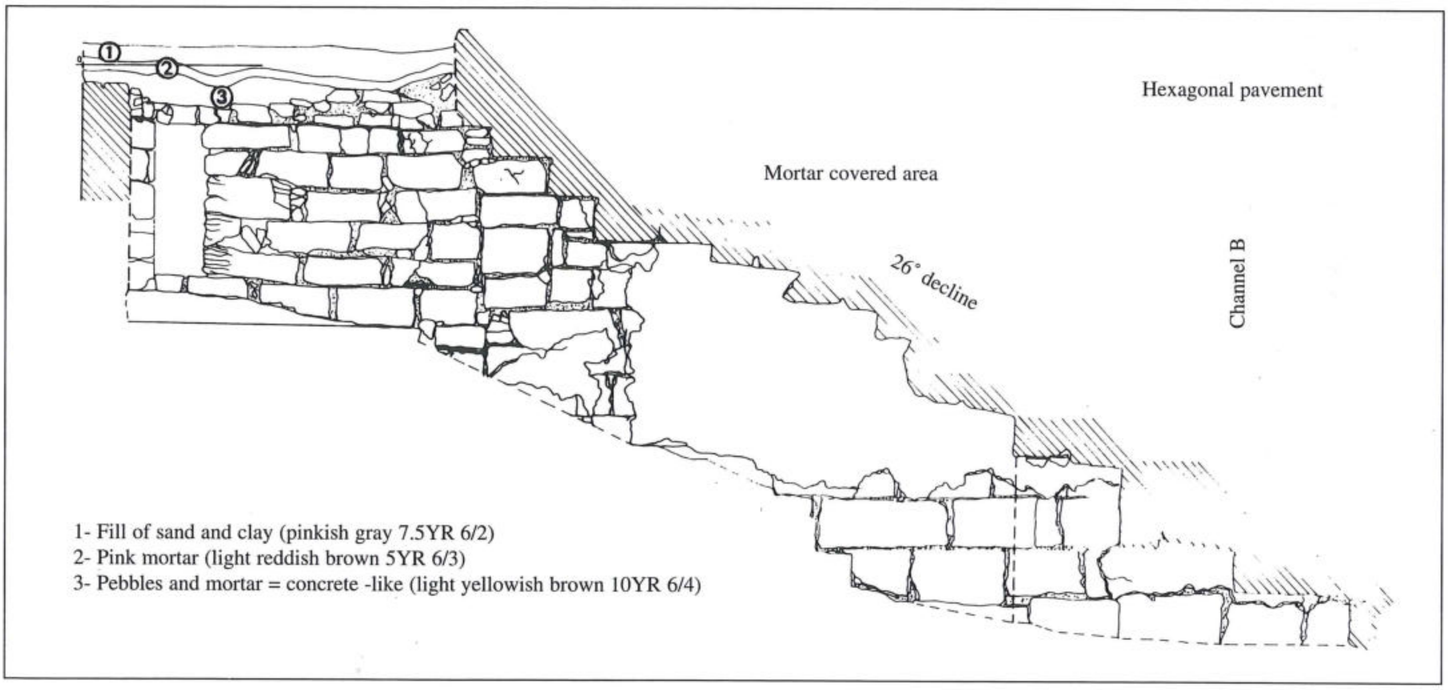
9 The author has questioned if the stepped portion of the tunnel originally may have served as part of the stairway from the Lower Temenos to the Upper Temenos and the Temple Forecourt. At this writing I reject this idea, but it has not been disproved — the elevations of the steps lying to the east of the tunnel in Special Project 4 will have to be aligned with the tunnel stairs for possible connections between them to be drawn.

evacuation. We just do not know.

Channel A and Channels D, E
In 1994, accumulated debris and the threat of collapse prevented northward investigation in the interior of the passage beyond the area below the Grand Stairway. But within an area of disturbance below the white limestone hexagonal pavement[10] in Trench 13 of the Lower Temenos, explored in 1995 (FIG. 6), however, was the continuation of the north-south water channel with east and west branches, in direct line with the principal north-south channel, Channel A, of the Upper Temenos. (This investigatory excavation was labeled Special Project 20 — its opening elevation was at 879.17.) This area, a top priority during the 1995 field season, again confirmed the presence of yet another set of east-west tunnels, (Channels D and E) extending to either side of the main tunnel. Ground penetrating radar indicated that the principal channel, Channel A, then leveled out and extended the length of the Lower Temenos to Channel G.

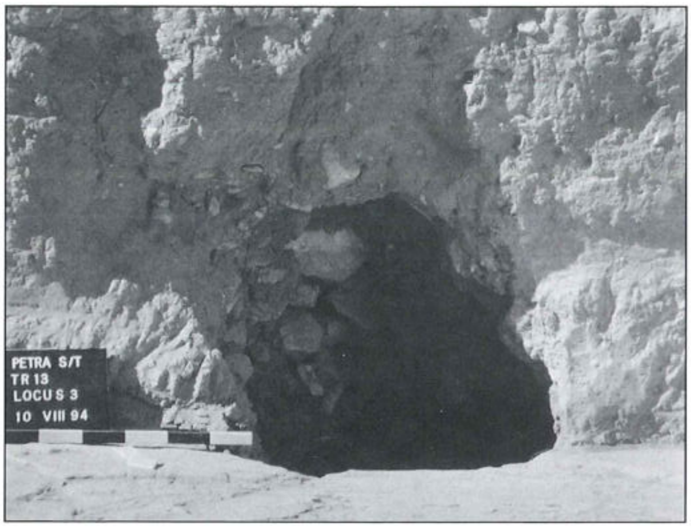
Channel G
Channel G is designated by an area of collapse just south of the Propylaea Steps. Just before the Propylaea Steps, between Channel G and the steps, Channel A took a sharp pitch downwards to a depth of about seven meters. Somewhere in this vicinity there may have been a cistern or a catchment holding system. Additionally the evidence suggests that at least part of the system — perhaps only the overflow — continued to the north, under the Propylaea Steps down and under the Colonnaded Street,

4. Petra Southern Temple, Stepped Channel A, 1995, facing south.



5. West wall of Channel A, Trench 1 and Special Project 4. (Drawn by G. Austin, 1994, Drafted by MSJ).

10 These limestone pavers are among the largest known in Jordan. They are 0.77 to 0.80 m in width.



6. Petra Southern Temple, Trench 13 collapse, 1994, facing south.

7. Petra Southern Temple, East Forecourt, Channel F, 1995, facing west.

to empty into the Wādī Mūsa. We suspect that those great pavement blocks of the Colonnaded Street which are slightly sunken below the street level here have slumped into the fill located above its passage and may even have blocked the water discharge into the wadi. The system has now been charted under the approximate 25 m slope between our datum point 103 and the Colonnaded Street, which extends over an approximate distance of 100 m .

Channel F

Yet another artery of the system was unearthed in 1995 adjacent to the east Temple Crepidoma, just under the hexagonal pavers in the Temple Forecourt, in Special Project 30 in Locus 18 (near Trench 19 on the site plan).[11] The upper elevation is 884.46 and the canalization system was found to extend 12 m from the south to the north with a slight curve to the northeast. This canalization was constructed of three courses of sandstone ashlars which were covered by mortar. A dislodged capstone that brought our attention to a disturbance in the area had been moved in antiquity for repair or cleaning of the tunnels. (FIG. 7) shows the channel extending under the forecourt pavement on the Temple East.

Construction

Excavation from the surface of a 2.5 x 3.0 m trench located over one corner revealed repeated layers of large rock and rubble fill behind the tunnel walls, which clearly served as packing for support and stability. P. Nalle offers the following comment regarding the construction of the system:

> From the manner in which the tunnels are put together, they must have either been built in an open ditch or on a lower surface as free standing walls with the capstones placed on top. The ditch was then filled in or the entire area built up with fill to bury the structure. With the small amount of cover and the short cap stones at right angles to the center line of the tunnel, it would be virtually impossible to drive the tunnels underground. Further excavation will show if the ditch were used or if the whole area were filled. The small amount of excavation done to the NE of Trench 1 hints that the whole area was fill. Clay stabilized sand alternating with random stone paving in 15 to 20 cm layers was used to stabilize the area of fill. At the time of writing this report, [1994], the excavation had not gone deep enough to determine the depth of fill. Since the whole temple complex is built on a side-hill slope, this type of construction makes sense.

Other Studies and Conclusions

Pollen sample analysis [12] has proven the presence of non - arboreal field plants and suggests large open areas with few trees, and further opening of the tunnels this season will provide more material for study. The water that flowed through here must have had a high calcium content for there are heavy lime deposits coating the walls. Again, P. Nalle (1994:4) states:

> Gypsum ($CaSO_4$. $2H_2O$) forms under rather specific conditions of moisture and temperature. Too little moisture an anhydrite ($CaSO_4$) forms. With too much water the gypsum will dissolve and wash away. Gypsum will form under water but it must be in a saturated solution which would not be

[11] This area was excavated by Laurent Tholbecq, a Ph. D. candidate at the University of Paris I - Sorbonne.

[12] The Petra Southern Temple pollen analysis was researched by Peter Warnock of the University of Missouri, Columbia, Missouri.

> possible in the Petra tunnels. The appearance of the coating in the North tunnel indicates that moisture slowly evaporated on the wall allowing gypsum to crystallize over time...It is postulated that the coating started to form after the collapse and after the last major earthquake.

Much work still needs to be done on the water management system of the Southern Temple Complex. Ongoing investigations below the Upper Temenos courtyard area should reveal whether this system was itself set into bedrock or rather, as we suspect, into the artificial al-Katuta slope which was graded for the temple's construction. Continued exploration with ground penetrating radar may help to define the route of the east and west passages in both the Upper Temenos and the Lower Temenos. When we find the source intake of the system and find out how it served the Temple interior, how the water may have been stored and how it served the so-called "baths" located adjacent to the Temple northwest and the discharge under the Colonnaded Street, we will be on surer ground. Many questions remain to be answered: What was the character of the system intake? Was there a water diversion system at the back of the Temple? And where is the cistern? We suspect there is a cistern, perhaps even a great cistern located in the Lower Temenos precinct. The Lower Temenos area should reveal the further northern extent of the main channel, and perhaps even a cistern or catchment area for final water conservation.

Purpose of the Southern Temple Canalization

We may question the purpose of the Southern Temple canalization system.[13] This writer will argue that it principally served to evacuate a massive water flow away from the Southern Temple, possibly into a cistern or catchment area which has not yet been located. Logically, this is where the water would have been conserved. Not only is the Southern Temple vulnerable to flash floods, but its construction, on artificially filled sloping ground would leave the structure vulnerable and exposed to the elements.

Although the excavation of the Temple cannot confirm the roofing pattern of the cella, it might be suggested that the cella was unroofed and open to the sky, in which case flash floods would be considered an element to be reckoned with. The distance between the interior colonnade of the Temple is approximately 20 m in width and, to date, few roof tiles have been found in the excavation of this area, thus it is not unreasonable to theorize that the center of the structure was unroofed, and that its builders foresaw the necessity of having water channeled away from the structure. But this idea can only be tested by further excavation in the Temple cella, which up to this time has been unexplored. Thus its major purpose would have been to drain and thereby protect the Southern Temple, as well as to harness and conserve its precious water resources. (FIG. 8) shows a 1995 plan of the Southern Temple with the subterranean water system imposed on it.

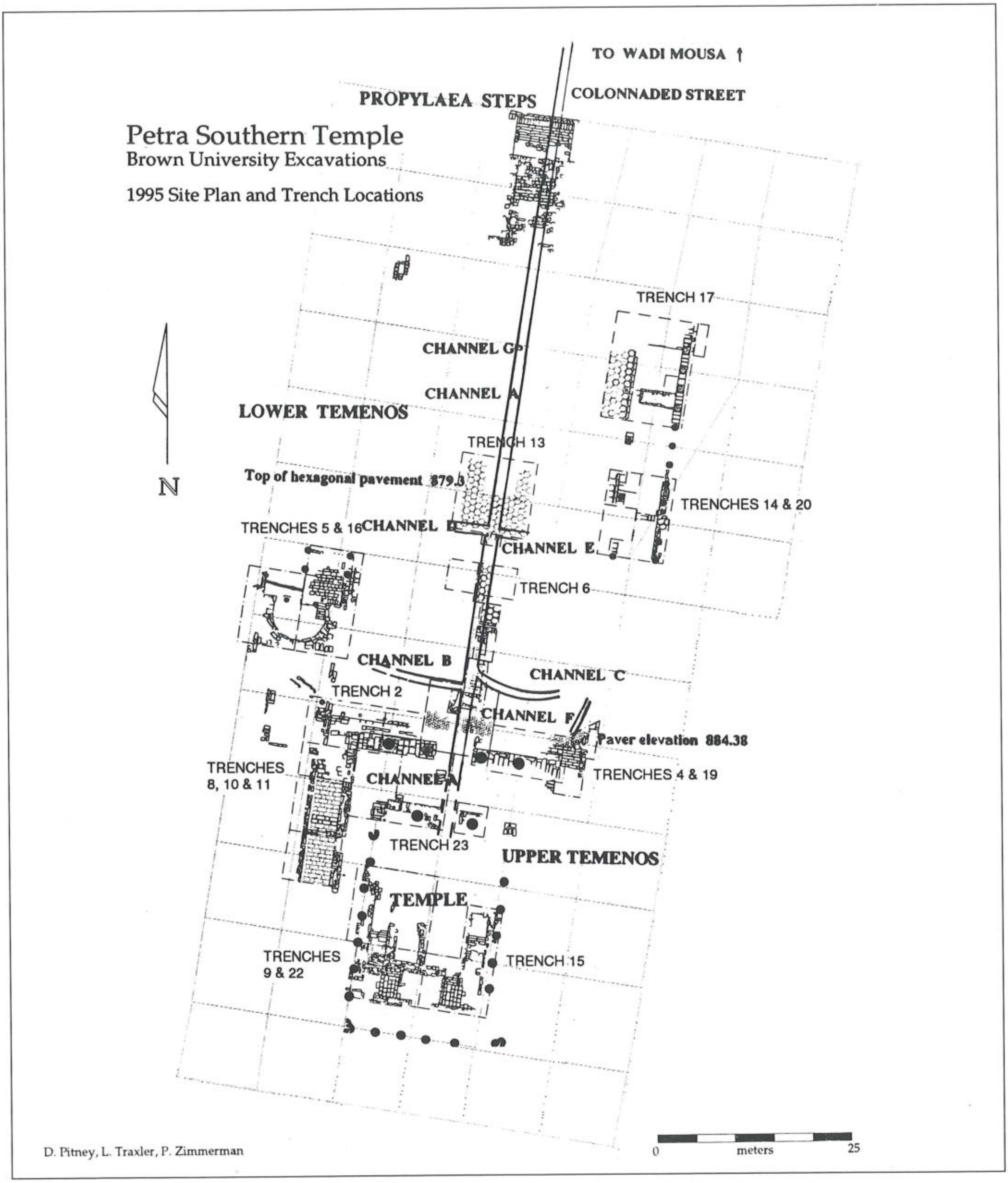
Other Nabataean Sites

The Nabataeans left extraordinary examples of the ingenuity and creativity to provide for water storage and conservation. Such water systems, including channels, cisterns, and dams are characteristic of Petra. The cisterns found at Umm al-Biyārā (which means, "the mother of cisterns") may date from the Edomite period. There is also the complex water system in the Sīq described by Judith McKenzie (1990:38) which is dated to 50 CE. Peter Parr (1967:49) suggested that the Sīq had to be dammed before al- Khaznah could be constructed, so that the building would not suffer damage from flash floods. The al-Khubtha water system carries water by aqueduct from the spring at 'Ayūn Mūsā over a six kilometer distance into Petra, where it is conserved in cisterns with a holding capacity of 1.5 million liters. This system has been studied by Manfred Lindner (1978) and E. Gunsam (1980). The subterranean Wādī Mūsā reservoir with its Dushārā niche and cistern has been restored by Sulieman Farajat — it serves as an excellent example of Nabataean water systems for their capital city.

Among other sites where such systems have been recovered are Ṣabra (M. Lindner 1982a) , Ḥumayma (J. Oleson (1984, 1990, 1991, 1992a, 1992b) and Mampsis (A. Negev 1988). Rediscovered for the west by Leon de Laborde, is the system at Ṣabra which was surveyed and reported on by Manfred Lindner (1982a). Here at Ṣabra, the system is associated with the theater, which Lindner suggests was flooded for sea battles (Lindner 1982b. 232). Well up behind the theater is a series of four terraces and pools which flow into a reservoir with a dam. From the dam there are channels leading down into the theater. In the mountains surrounding Ṣabra, there is also an enormous Nabataean dam and reservoir complex that Lindner (1986:6) has estimated to hold 3.6 million liters of water. A water channel system was used to evacuate water from here to its settlement as well. For years the site of Ḥumayma, 80 kilometers north of 'Aqaba has been excavated by John Peter Oleson (1984, 1990, 1991, 1992a, 1992b). This city which was founded by Aretas III Philhellen (87 - 62 BCE) boasts 51 cisterns, four springs, an aqueduct some 27 kilometers in length (Oleson 1991:59), a dam, wadi barriers, and terraces. These systems exemplify remarkable Nabataean engineering know-how.

Located in an area of only 80 mm of rainfall per annum is the site of Mampsis (in Arabic, Kurnub), situated inland from the Dead Sea, in the Central Negev desert, 40 km southeast of Beersheba. Avraham Negev (1988) excavated here from 1965-1967. This site has long been recognized as having important water systems that were

13 It was proposed that the tunnels were used by people, but the east and west are far too cramped and narrow and their height precludes standing in them. The N-S tunnel was not intended as a passage way — the steps are too irregular.



8. Petra Southern Temple Water System, hypothetical Plan 1995.

planned for public use — Sir Leonard Woolley and T. E. Lawrence surveyed the area in 1914, and P.L.O. Guy in 1937-1938 (Negev 1988:21). In the Wādī as-Sidd, west of Mampsis, are a series of dams, reservoirs, and cisterns. Of interest to us is one rock cut cistern in particular. Like the Southern Temple system, one system with a massive cistern is located under the paved courtyard of Building Va (Negev 1988: Fig. 32), which Negev dates to the Middle Nabataean period (end of the first century BCE through the first century CE). In the Late Nabataean period (second and third centuries CE) there is an arched public reservoir, Building VII, with steps leading to the water. Apart from these structures, Negev located cisterns throughout the site, including two outside the 'Palace' Building I (Negev *op. cit.* Fig. 32), Buildings IX, XII, and the Bath House, and Building V, which the excavator dates to the Late Nabataean period (Negev, *ibid.*179-181).

In conclusion, I think what is most interesting about the archaeological examination of the relationships and interactions between the Nabataeans and their environment is that it dramatically illustrates humanity's total dependence on the surrounding world. While we may presume that science and technology (whether represented by lamp fragment, a temple or a canalization system) are unlimited in their ability to sustain and insulate humanity from the constraints of the environment, it is painfully clear that there are environmental limitations for human civilization in general, as there were in antiquity for the Nabataeans. As humanity increasingly lives in urban settings, people begin to think that food comes from the supermarket, and they forget that its origins are in the ground, and from the animals that walk on the ground.

As we look at the archaeological record, we can see ebbs and flows of settlement into different areas – the Bedouin still move their herds into the desert during moist years and retreat during wet ones. Modern scholars are finding more clues that civilizations abandoned sites because of environmental collapse — such as dessication of the land or devastating earthquake action, as we find at Petra — and the inability to provide food and water. All resources hinge on water supplies. Humanity has experienced periods of collapse when it ignored the environment and focused too closely on human ingenuity and science: the Romans were unable to sufficiently provide grain for their large civilization, and the Babylonians fell victim to over-irrigation of their soil which caused salinization and water logging, turning their wheat and barley fields into desert. The archaeological evidence provided by this conference in Torino should demonstrate the ancient as well as modern needs and alterations of the Jordanian landscape. We must thoughtfully examine our current interactions with the Jordanian environment so that our own society does not experience similar collapses and problems. For these reasons, the Petra Southern Temple water system warrants further detailed archaeological study.

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