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Wādī al-Jarra Dam Rehabilitation Project, Petra

Introduction

The project agency responsible for the Wādī al-Jarra Dam Rehabilitation Project was Petra National Trust. The project funder was the American Ambassador's Fund. The project was directed over all its extension by the author.

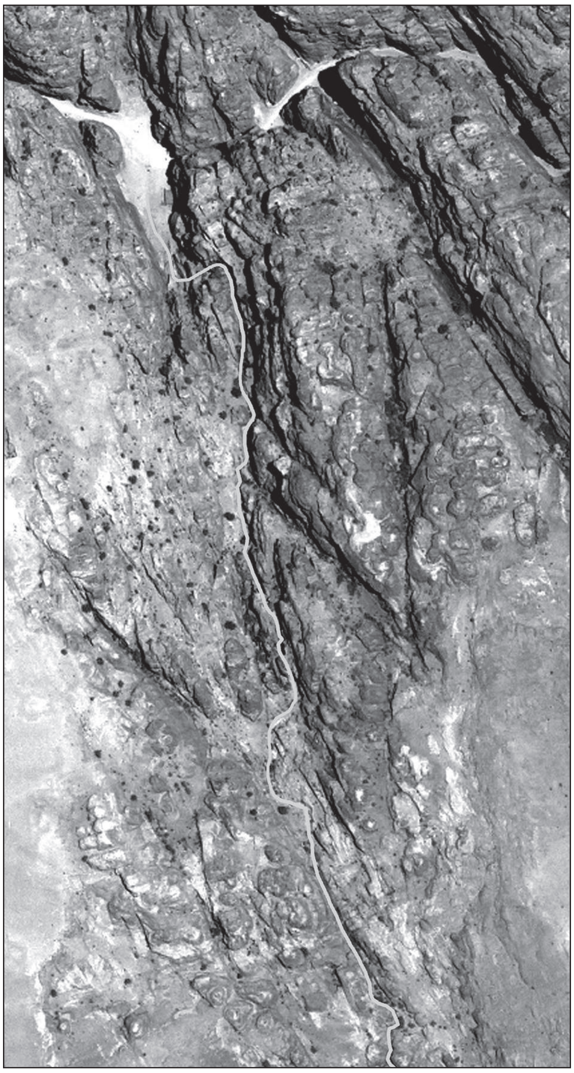
The Results of The Surveys 2005 – 2006

The Water Drainage in Wādī al-Jarra Before the Interventions of the Nabataeans.

Wādī al-Jarra is the longest *wadi* leading from south into the Wādī Mūsā, the main natural drainage channel of the Petra region; hence it is the biggest feeder of runoff water into the Sīq, al-Khaznah Courtyard and the Outer Sīq area during winter storms. Before the construction of the Nabataean flash-flood retention system the runoff water from the southern slopes draining into Wādī al-Jarra was completely channeled along the narrow and steep eastern branch of the *wadi* (FIG. 1). The much wider western branch of the *wadi* had no natural connection with the southern section of the main *wadi* and hence got only the vertical precipitation. Due to the topographical parameters of the eastern branch of Wādī al-Jarra the runoff water from heavy rainfall reached an extremely high level and velocity. Both of these factors resulted in an enormous flood energy, causing serious inundations and bottom scouring in the area of the later al-Khaznah Courtyard. As long as the Sīq and the Outer Sīq were not yet used as one of the main arteries for any traffic to or from Petra and as long as no constructions existed in the area of the later al-Khaznah Courtyard, the runoff water drainage system from Wādī al-Jarra as given by nature didn't have a great impact on the use of the territory by humans and animals. The only precautionary measurement to be taken by passers-by was to avoid the area during flash-floods and to wait for more suitable weather conditions.

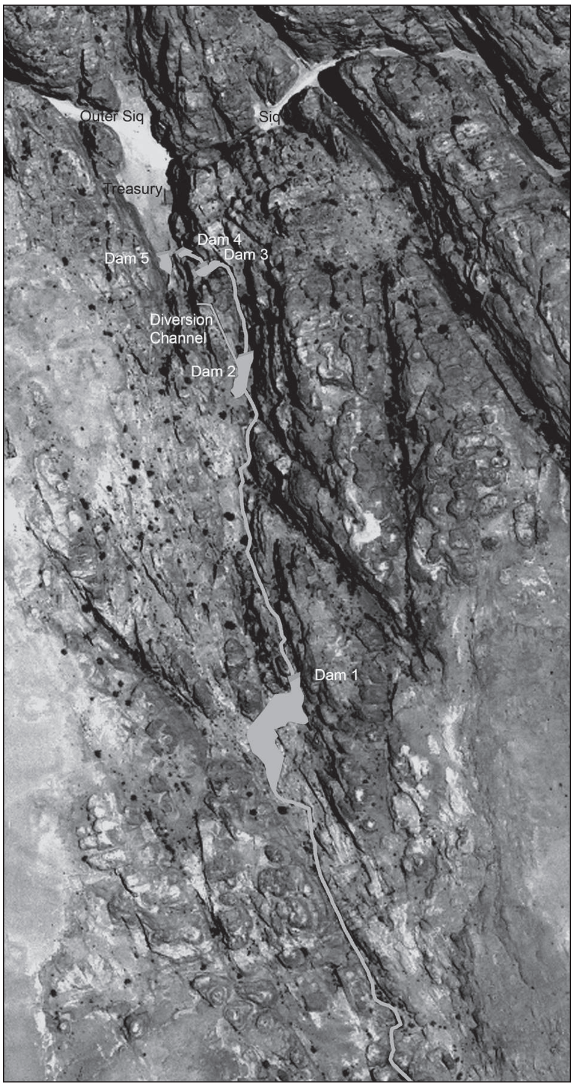
The Water Drainage in Wādī al-Jarra after the Interventions of the Nabataeans

At the beginning of the 1st century BC Petra started to change slowly from a Bedouin encampment into a stone-built city. In the middle of the 1st century BC, under the reign of Malichus I, Petra was completely redesigned as the capital of Nabataea, following plans and models of Hellenistic cities in Asia Minor and in Ptolemaic



1. Satellite view of the lower, northern sections of Wādī al-Jarra, al-Khaznah Courtyard, the Sīq and the Outer Sīq with indication of the natural water drainage stream (Satellite image courtesy of D. Comer, insertion U. Bellwald).

Egypt. In order to protect the inhabitants of the remodeled city and its new buildings from the disastrous impacts of inundations, an ambitious flash-flood retention system was planned, designed and implemented as part of the community's overall infrastructure. This system aimed at retaining, channeling, diverting and stilling down the runoff water from the rainfalls during winter time in order to prevent the city and its inhabitants from any threat caused by flooding. Due to the results of the archaeological research in the Sīq and its adjacent areas from 1996 to 2011 it is known that the flash flood retention system was planned around 50BC and mainly realized between 50BC and 25BC (Bellwald 2003: 75). As al-Khaznah Courtyard became a major key element in the design of Petra as the capital of Nabataea, Wādī al-Jarra had vitally to get into the focus of any efficient flash flood prevention measurements. The intervention realized by the hydraulic engineers of the Nabataeans during the 2nd half of the 1st century BC in Wādī al-Jarra may be considered as the real masterpiece of the entire flash flood retention system of Petra (FIG. 2). As the results of the survey conducted by the author on behalf of Petra National Trust 2005-2006 have shown (Bellwald 2008: 76-86), the layout of the flood retention construction in Wādī al-Jarra consists of a sequence of 5 main dams, followed downstream by stilling basins, auxiliary dams for the complete closure of the retention basins, spillover and diversion channels. Dam Nr. 1 is located approximately 390m to the South of the inlet into al-Khaznah Courtyard and has to be considered as the key element of the entire system, as it has by far the most extended retention capacity. Barrier Nr. 2 was built to dam up the outflowing water from barrier 1 in order to divert it from the narrow eastern branch of the gorge into the wide western section. For that purpose a channel was hewn into the surface of the rock terrace separating the eastern section of the gorge with the western branch. The diversion channel has an overall length of 42m; its width varies from 134cm at its northern to 214cm at its southern mouth. Its depth reaches down to 5.4m at the northern mouth. The dams Nr. 3 and 4 were built for retaining and hence further stilling down the down-flow velocity of the remaining water volume running off along the narrow eastern section of the gorge before reaching al-Khaznah courtyard. Dam Nr. 5 was by far the highest, widest and therefore most imposing construction of the entire system. It was built in shape of a 90^{o} angle wall and closed the inlet of the wide western branch of

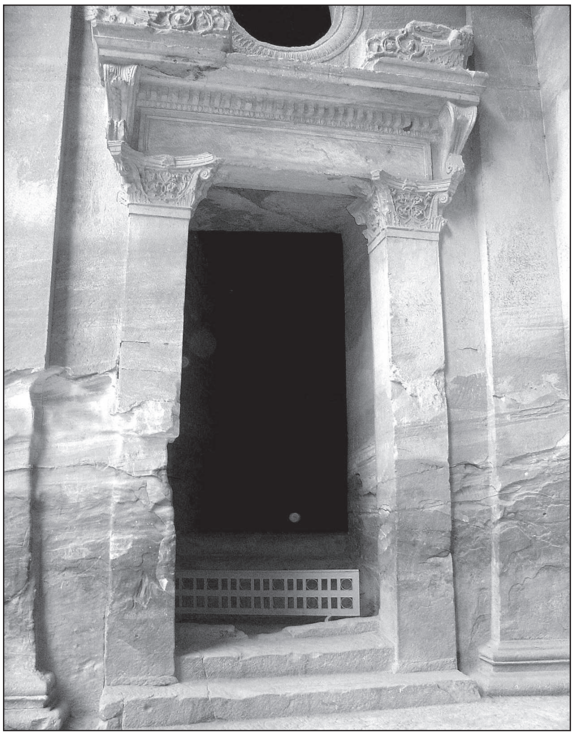


2. Satellite view of the lower, northern sections of Wādī al-Jarra, al-Khaznah Courtyard, the Sīq and the Outer Sīq with indication of the flash flood retention system built by the Nabataeans in the 2nd half of the 1st century BC (Satellite image courtesy of D. Comer, insertions U. Bellwald).

Wādī al-Jarra into al-Khaznah courtyard. Its main function was to retain and to still down the water diverted by the channel besides dam Nr. 2 and to secure its controlled outflow into al-Khaznah courtyard.

The Scope of the Wādī al-Jarra Dam Rehabilitation Project

Since the collapse of the Nabataean flash flood retention system in the earthquake of 363AD, all the ancient constructions in al-Khaznah courtyard have been destroyed and swept away, including the sophisticated drainage channel network assuring a safe and non-destructive outflow of the storm water retained by the lowest dams Nr. 4 and 5. By the centuries the entire courtyard has been backfilled by more than 3m of rubble. This huge backfill works like an enormous sponge, retaining a huge amount of the runoff water sweeping in during the rainy period. In the warm seasons part of this water stored in the underground of the courtyard penetrates into the porosity and capillarity of the sandstone cliffs, rises up and finally evaporates. In the evaporation level the salts dissolved in the water crystallize. As the dimensions of the salt crystals are much bigger than the diameter of the pores and capillaries in the sandstone, the natural voids are bursting and the surface of the cliffs and hence also of the monuments like the treasury are eroding (FIG. 3).



3. View at the doorway in the southern wall of the entrance hall of al-Khaznah, showing the heavy erosion of the sandstone, reaching almost half of its height. This erosion is due to the crystallization of salts during the evaporation of the rising ground humidity in the void of the stone structure in the warm seasons (Photo U. Bellwald).

In order to stop such a destructive process, al-Khaznah Courtyard has to be excavated in the future to its ancient Nabataean level. Before this excavation may be started, the impact of flash floods on al-Khaznah Courtyard has to be reduced sustainably. Such a drastic reduction may only be achieved by excavating, restoring and reconstructing the original Nabataean flash flood prevention system.

The project started in autumn 2011 is thought to be a first step of a much more extended project aiming at the complete rehabilitation of the full system as built in the 2nd half of the 1st century BC. The area of dam Nr. 3 was chosen as a model project for step 1 because it includes all different aspects of excavation, conservation and restoration work and despite its limited extension may be a first, but remarkable contribution for increasing safety to the monuments around and tourists visiting al-Khaznah Courtyard.

The implementation of step 1 in the area of main dam Nr. 3 was thought to provide the project team with all basic information in regard to the history of the construction, the destruction and the abandonment of the flash flood protection system, to the conservation and restoration methods, to the hydrological parameters for an efficient organization of the work execution and to the integration of the project results into the use and frequentation of al-Khaznah Courtyard site.

The Results of the Excavations 2011-2012 and 2014

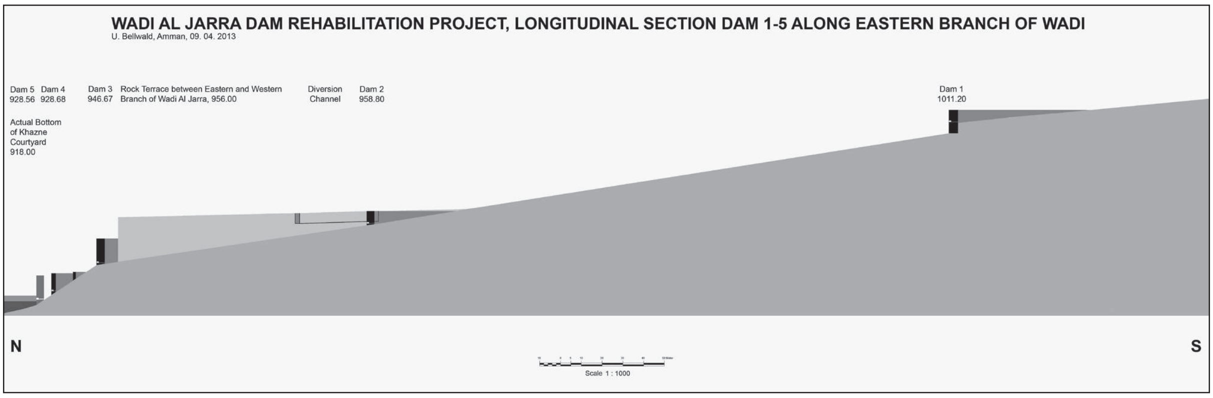
The Elements of the Flash-Flood Retention System

Already the surveys preceding the excavations have clearly shown that dam nr. 3 takes a very distinguished position in the sequence of the flash-flood retention system in Wādī al-Jarra[1]. Its location on a rock terrace directly above the inlet into al-Khaznah Courtyard is at a crucial point in the outflow of water from Wādī al-Jarra: Between dam nr 1 and dam nr 3 the course of the *wadi* has the shape of a narrow, almost straight gorge, extending over a length of 414 m with a difference in height of 65.98 m, which equals a slope of 15.93%. The combination of the straight course, the steep slope and the fact of being wedged in between the cliffs is giving rise to a very high outflow velocity of the runoff water inside the section of Wādī al-Jarra between dams nr 1 and 3. From dam nr 3 down to the original pavement of al-Khaznah Courtyard the distance is only 29.8m and the difference in height 19.74m, which equals an extraordinary slope of 66%. Dam nr 3 was therefore built at a location of a striking escarpment where the slope of the runoff water outflow was suddenly increased by more than four times (FIG. 4).

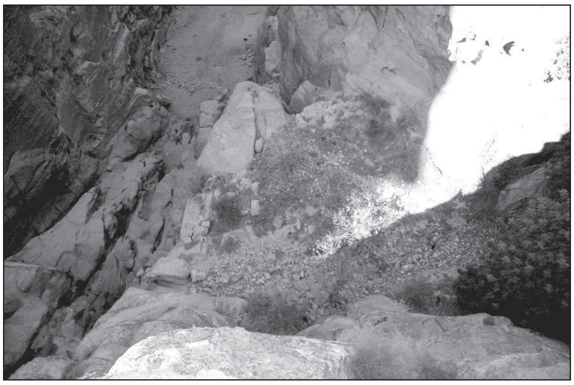
The exact location where dam nr 3 was built benefitted from a very distinguished topographical situation: At the inlet of Wādī al-Jarra into the rock terrace its straight course was broken twice in the shape of a Z before leaving the terrace in the direction of al-Khaznah Courtyard. Flowing straight down from South to North the outflow water bounced against a cliff and was hence diverted to the West, where, after a distance of 30 m it bounced against another cliff and only then it flew out from the terrace down to al-Khaznah Courtyard. Taking advantage from the reduced velocity of the twice diverted outflow water the Nabataean hydraulic engineers closed the exit from the terrace with dam nr 3, intending to reduce further its outflow velocity and hence reducing its destructive energy (FIGS. 5, 6, 7).

Originally the dam had a height of approximately 12.9m. As the uppermost layer of the masonry is nowadays lost by erosion, the actual height of the dam from its crest to its bottom is 12.45m (FIG. 8). The excavations in 2014 have clearly shown that the constructive interventions inside the catchment basin upstream dam nr 3 were minimal and mainly restricted to a narrow outflow channel with a depth of 50cm and a width of 85cm at the bottom of the natu-

1. A short presentation of dams nr 3 and 4 has first be given in: Farajat S. and Falahat H. No date. The Role of the Nabataean Hydraulic System in the Protection of the Monuments at Petra, in Siti e Monumenti della Giordania.

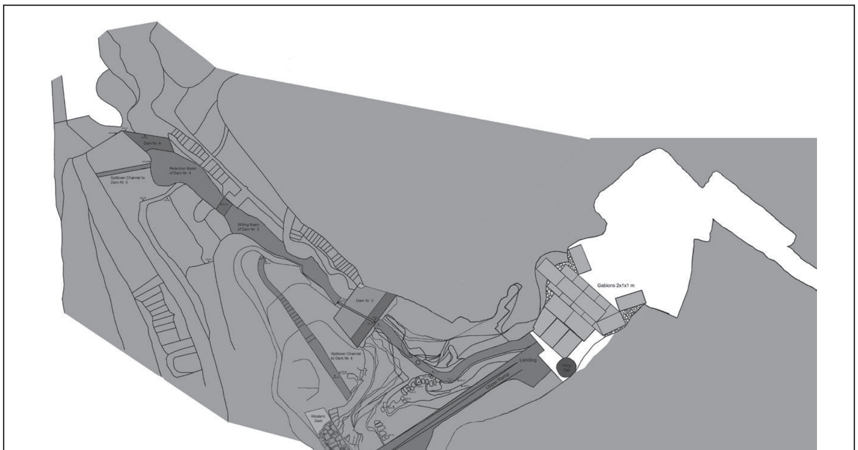


4. Longitudinal section along the main axis of Wādī al-Jarra from dam nr 1 down to the inlet into al-Khaznah Courtyard. The drawing shows perfectly the location of dam nr. 3 on top of the escarpment falling down to the bottom of the Courtyard (Drawing U.Bellwald).

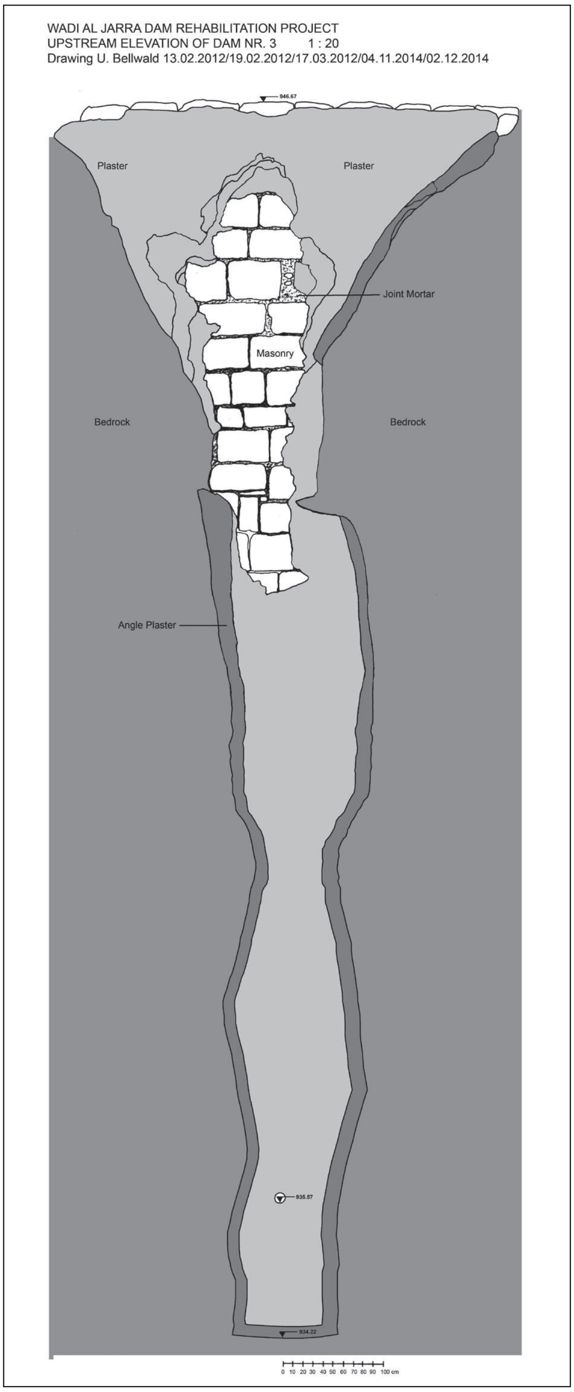


5. View from the rock terrace of the diversion channel below the second dam onto the catchment basin of the third dam. Photo taken in June 2005 during the first survey study. It shows the area before excavation started (Photo U. Bellwald).

6. View from the rock terrace of the diversion channel below the second dam onto the catchment basin of the third dam photograph taken on December 11th, 2014 upon completion of the excavation (Photo U. Bellwald).



7. Site plan covering the area of dam nr 3 and dam nr 4 upon completion of the excavation, showing the outflow of the runoff water along the channel at the bottom of the retention basin upstream dam nr 3, through the outflow valve in dam nr 3, along the stilling basin downstream dam nr 3 into the retention basin of dam nr 4 and finally through the spillover channel from dam nr 4 to the wide western branch of Wādī al-Jarra. The plan reproduced here is not to scale (Drawing U.Bellwald).



8. Elevation of the upstream face of dam nr 3 upon completion of the excavation of the retention basin. The plan reproduced here is not to scale (Drawing U. Bellwald).

ral *wadi* bed (FIGS. 7, 11). Besides this outflow channel and a stone collection tank with a depth of 1.5m and a length of 3.5m in front of the upstream bottom of the dam no other features for increasing the storage capacity of the catchment basin could be verified. The only contribution for increasing the retention capacity of the catchment basin upstream dam nr 3 was the construction of the small auxiliary dam on top of the western cliff. As the surface of the bedrock flanking dam nr 3 was approximately 2 m higher than the top of the western cliff, the western delimitation of the catchment basin had to be elevated by a dam to the same level in order to prevent the runoff water from spilling over to the western branch of the *wadi* (FIG. 16).

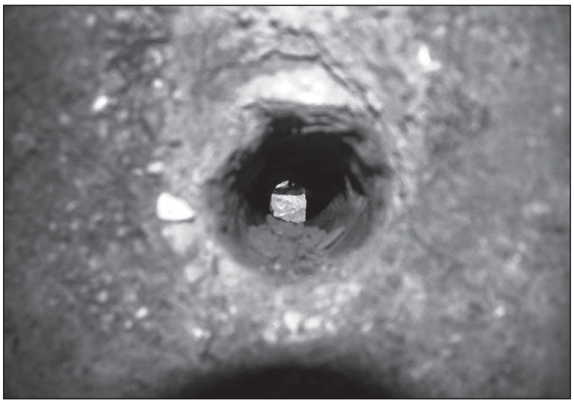
The close examination of the masonry of dam nr 3 has given that, due to learning by doing, it was built in two phases: As the flanking cliffs at the location where the dam was built were very close to each other (the maximum width at the top line of the dam being only 4.78 m) and even conical in shape with the wider opening upstream, the constructors thought a dam with double sided coursed ashlar masonry in a thickness of 80cm would be sufficient for withstanding the water pressure. This was obviously to the case, as several displaced sandstone blocks in the downstream face of the first dam are attesting. As no cracks in the mortar embedment around the displaced blocks may be detected, the damage must have hit the dam even before the lime mortar was carbonized, which means shortly upon completion of the construction. The dam-builders were therefore obliged to reinforce the dam considerably by extending its thickness downstream by 2.36m in the main body and by 1.92m in the uppermost 2.6m. After such intervention the total thickness of the dam squeezed between the conical shaped cliffs reached 3.16m which proved to be sufficient, as no damages in the masonry due to excessive water pressure occurred anymore (FIGS. 6, 8). In order to make the dam water proof its upstream elevation was completely plastered with a hydraulic plaster built up in four layers, reaching a total thickness of approximately 5cm (FIG. 8).

Between the ground and the top layer the mix of the lime mortar adopted varied mainly in the characteristics of the aggregates, which were very rough in the first and rather fine in the top layer. For assuring a perfect adhesion between the layers, layer 1-3 had a very irregular, rough surface, whereas the top layer was meticulously smoothened down. In order to prevent the plaster from being weakened by cracks, crushed charcoal and pottery shards were added to the mortar mix. As a result of the addition of crushed charcoal, which was acting like color pigments, the plaster got a distinctive grey appearance. The plastering was not only restricted to the surface of the dam, but also covered the joints towards the bedrock. In order to avoid any water infiltration along the joints, these were diagonally covered with thick layers of plaster, filling grooves and fissures in the adjacent surface of the bedrock and using rock pinnacles as protective covers. For assuring a constant outflow of the runoff water from the catchment basin an outflow valve was inserted into the masonry of the lowest part of the dam. The valve is only a spare opening with a diameter of 10cm crossing the masonry slightly sloped towards the downstream face with no insertion of terracotta pipes. Its position is in the vertical axis of the dam, 1.35m above its bottom for protecting it from being obstructed by stones which were held back in the tank at the end of the outflow channel (FIGS. 8-10). For hindering mud from backfilling the stone collection tank a small barrier was built inside the outflow channel. Its location was 7m upstream the main dam, its height 85cm and its thickness 20cm (FIGS. 7, 11).

As the interior of the catchment basin had to be cleaned from the alluvial deposits after every winter rain season, a maintenance staircase had to be built for reaching its bottom. The steps of this staircase were hewn into the surface of the western cliff, starting at the northwestern abutment of the small western dam (FIGS. 6, 7, 12, 13).

The width of the single steps ranges between 50 and 60cm, the depth has an average size of 25cm and the height is around 16cm. As the up-

9. View onto the lower part of the upstream face of the main dam with the outflow valve (Photo U. Bellwald).



10. View from the retention basin through the outflow valve at the bottom of the dam in direction of the treasury (Photo U. Bellwald).

11. View from the top of the main dam down into the outflow channel at the bottom of the retention basin (Photo U. Bellwald).

permost steps of the stairs had common joints with the masonry of the western dam, they were integrated into the surface plaster of its masonry. The plaster of the western dam was built up in the same technique as at the main dam, its mortar mix being identical. Conditioned by the structure of the bedrock, the maintenance staircase consists of four flights of steps, arranged in an elongated S-shape, winding down with totally 34 steps from the crest of the western dam to the rim of the outflow channel. A second staircase for assuring maintenance was built in downstream direction along the eastern cliff of the main dam. It starts at the northeastern abutment of main dam crest and leads down for 6m along the eastern cliff in one straight flight of steps until it reaches an almost square landing. From the landing a short second flight of only 3 steps leads to the edge of the gorge (FIGS. 6, 7). As absolutely no traces of a solid construction could be found, the opposite rim of the gorge had to be reached by wooden planks which were temporarily put in position only upon requirement. The end of the second maintenance staircase along the eastern cliff below dam nr 3 corresponds with the end of the spill-over channel in the opposite cliff. This spill-over channel has its mouth at the rim of the rock terrace between dam nr. 3 and the small western dam, its width being average 60 and its depth 30cm. For reducing the velocity of the outflow water the central section of the channel is elaborated as a cascade of 13 steps. The main section of the spill-over channel is straight in course with a length of 10.5m, at the end it is curved and bends for 90° towards the rim of the terrace, from where the water was precipitating into the lower part of the stilling basin downstream the main dam (FIGS. 6, 7).

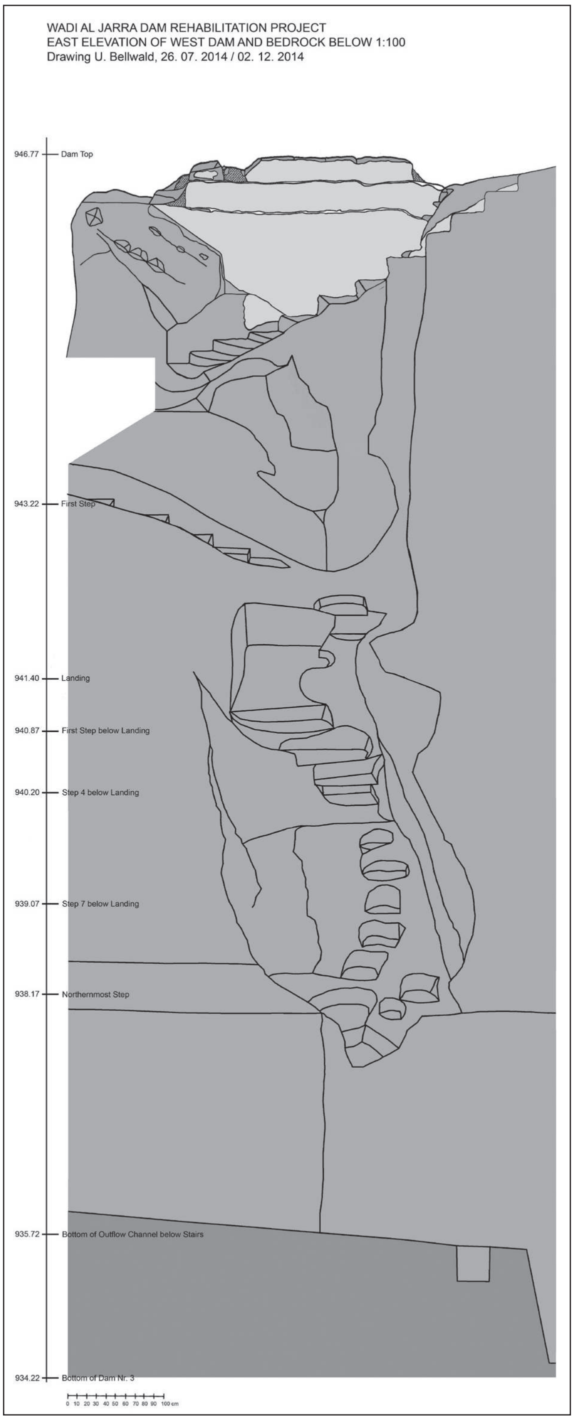
The stilling basin, built for taming down the energy of the water splashing out from the outflow valve or falling down from the spill-over channel, has a length of 10 m and a maximum width of 1.7m. At its downstream end it was closed by a barrier which had a height of 1.4 m and a thickness of 80cm (FIG. 7). In order to enable the workmen to get up to the area where dam nr 3 and its auxiliary constructions had to be realized, a walkway with stepped sections had to be built, starting at the southern end of al-Khaznah Courtyard, first following the western cliff of the western branch of Wādī al-Jarra, then continuing in its central part and from there crossing over to the East, where a narrow walkway was hewn in a vertiginous height into the cliff, without any handrail or similar safety measurements. For preventing unauthorized people from reaching this walkway, it could only be reached with help of a ladder. From the narrow walkway a flight of 4 steps was leading down to the work site (FIGS. 6, 7).

In a distance of 18m and 14.4m lower dam nr 4 was built at the very inlet of Wādī al-Jarra into al-Khaznah Courtyard (FIG. 17). It has a height of 8.9m, a width of 3.5m at the top and a thickness of 94cm at the eastern and of 2.3m at the western abutment. From the catchment basin upstream dam nr 4 a spill-over channel leads in a straight course into the western branch of Wādī al-Jarra (FIGS. 6, 7). As in dam nr 3 the outflow valve at the bottom of dam nr 4 ends in a rectangular valve chamber. A maintenance staircase hewn into the eastern cliff leads from the level of al-Khaznah courtyard up to the crest of dam nr 4.

The Finds

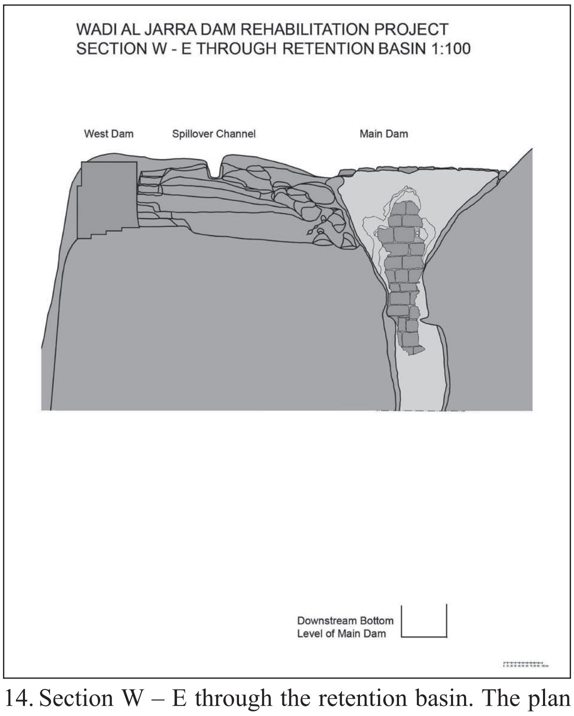
With the full excavation of the retention basin upstream dam nr 3 an enormous amount of single finds was unearthed, almost all pottery, very few objects from glass, metal or stone and only 3 coins. Among the many striking archaeological records revealed by the excavation work was the stratigraphy (FIG. 21): It showed up that only the top layer with an average height of only 30-50cm consisted of flood rubble containing stones of all dimensions, from boulder to small gravels, but almost no sand, because which was driven away by the water flow. From the top layer of flood rubble down to a depth of 265-85cm the stratigraphy consisted exclusively of completely sterile layers of fine, muddy sand without any finds. The only exemption from this record was a deposit of large, well-dressed ashlar blocks made from red sand-stone which came to light immediately inside the dam at a depth of 70-90cm below the dam crest. Tool-marks and fragments of lime plaster made it obvious that these blocks were washed down by flash-floods from a collapsed construction located upstream dam nr 3. The first finds were excavated at a depth of 265-85cm, again in layers of fine, muddy sand. All among the few finds in these layers were pottery shards which may be dated to the 2nd century AD.

From the depth of 285-545cm below the main dam crest the sand layers revealed an enormous amount of pottery shards which may be dated to the late 1st until the early 2nd century AD. The layers from a depth of 545 down to 645cm contained masses of pottery shards which may be dated to a period from the early to the late 1st century AD. The dating of the pottery finds is confirmed by a coin of king Aretas IV and queen Shaqilat minted 20-40AD, which was found among the pottery shards in a depth of 635cm. The following layers in a depth between 645 and 750cm revealed a huge amount of pottery shards which may be dated to a period spanning from the late 1st century BC to the early 1st century AD. The lowest layers from a depth of 750cm to the bottom of the dam at a depth of 1245cm were literally packed with pottery shards which may all be dated to the last quarter of the 1st century BC. Only one single



12. Elevation from the bottom of the outflow channel up to the top of the western dam upon completion of the excavation of the retention basin. The plan reproduced here is not to scale (Drawing U.Bellwald).

13. View from East onto the Western dam and the maintenance stairs leading down into the retention basin (Photo U. Bellwald).

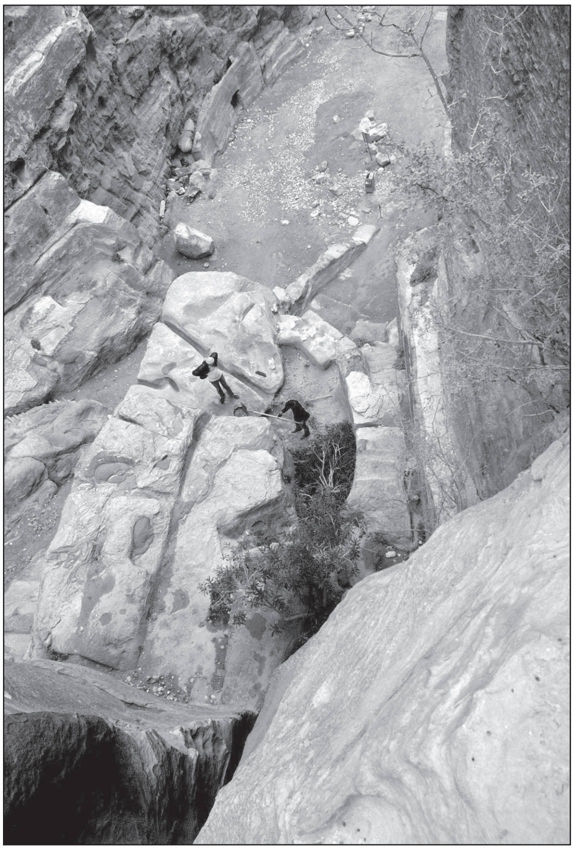


14. Section W – E through the retention basin. The plan reproduced here is not to scale (Drawing U.Bellwald).

15. View onto the crest of dam nr. 3, assembly of orthogonal photo shoots. The illustration shows well the double sided masonry of the first dam (bottom) and its downstream extension (top) (Photo U. Bellwald).

fragment of a painted fine ware bowl dating to the mid of the 1st century BC was discovered at a depth of 1215 cm inside the outflow channel. The second striking archaeological record was the discovery of totally 7 votive deposits (FIGS. 18, 19, 20), all of them consisting of a great number of vessels of various types, mainly unpainted fine ware vessels, some painted fine ware bowls and some large coarse ware pots or jars. The single fine ware vessels in the votive deposits were meticulously piled up with the large ones at the bottom and the small ones inside or above the large ones. At the end the piles of fine ware vessels were covered and hence protected by large scale coarse ware pots or jars (FIG. 20).

16. View onto the fully exposed and cleaned crest of the western dam in April 2012 (Photo U. Bellwald).



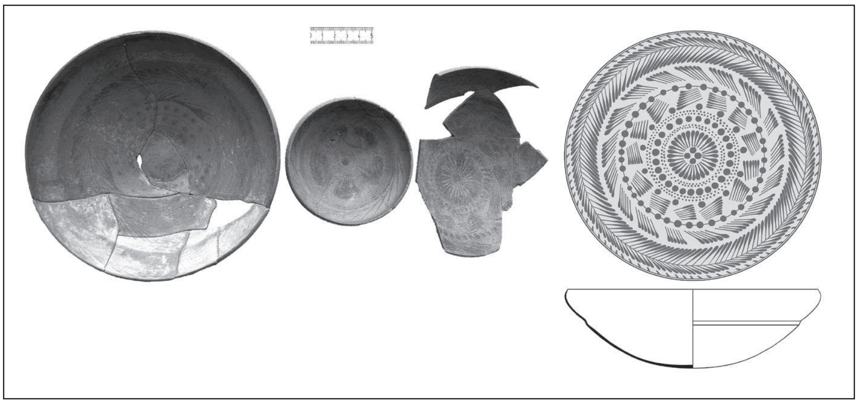
17. View from the top of dam nr 3 down onto dam nr 4 and al-Khaznah Courtyard, photograph taken on November 25th, 2014 (Photo U. Bellwald).

A third striking archaeological record was the discovery of a great number of completely preserved, unbroken vessels. This fact is even more astonishing if the depth where the vessels were found is taken into consideration: Most of the completely preserved, unbroken vessels were excavated in the lowest layers at a depth between 750 and 1245cm, where the pressure of the backfill above was extremely high. Furthermore it has to be hint at the fact that many of the completely preserved vessels were not excavated as part of a votive deposit, but as single pieces. The fourth striking archaeological record is the observation, that all coarse ware vessels have been used for preparing food before having been buried in the deposit inside the catchment basin. Al of the coarse ware vessels still were covered by a thick and dense layer of soot at their bottom, proving that they had been standing in a fire just before having been deposed. The soot layer was such heavy that it still painted our fingers in black during the recovery of the vessels. The fourth striking archaeological record was the identification of a very big number of vessels of throw-out ware, misfired, lousily turned on the potter's wheel, pushed in by fingers before firing or otherwise deformed. The fifth striking archaeological record was the detection of several bottoms of broken, unpainted fine ware bowls which were serving as circular game chips. The sixth striking archaeological record was the discovery of a certain number of painted and unpainted fine ware bowls in toy size; all of them dating to the last quarter of the 1st century BC with the exception of one dating to a period between 20 and 70 AD (FIGS. 19, 20).

A First Interpretation of the Finds

The fact that the lowest layers of the stratig-

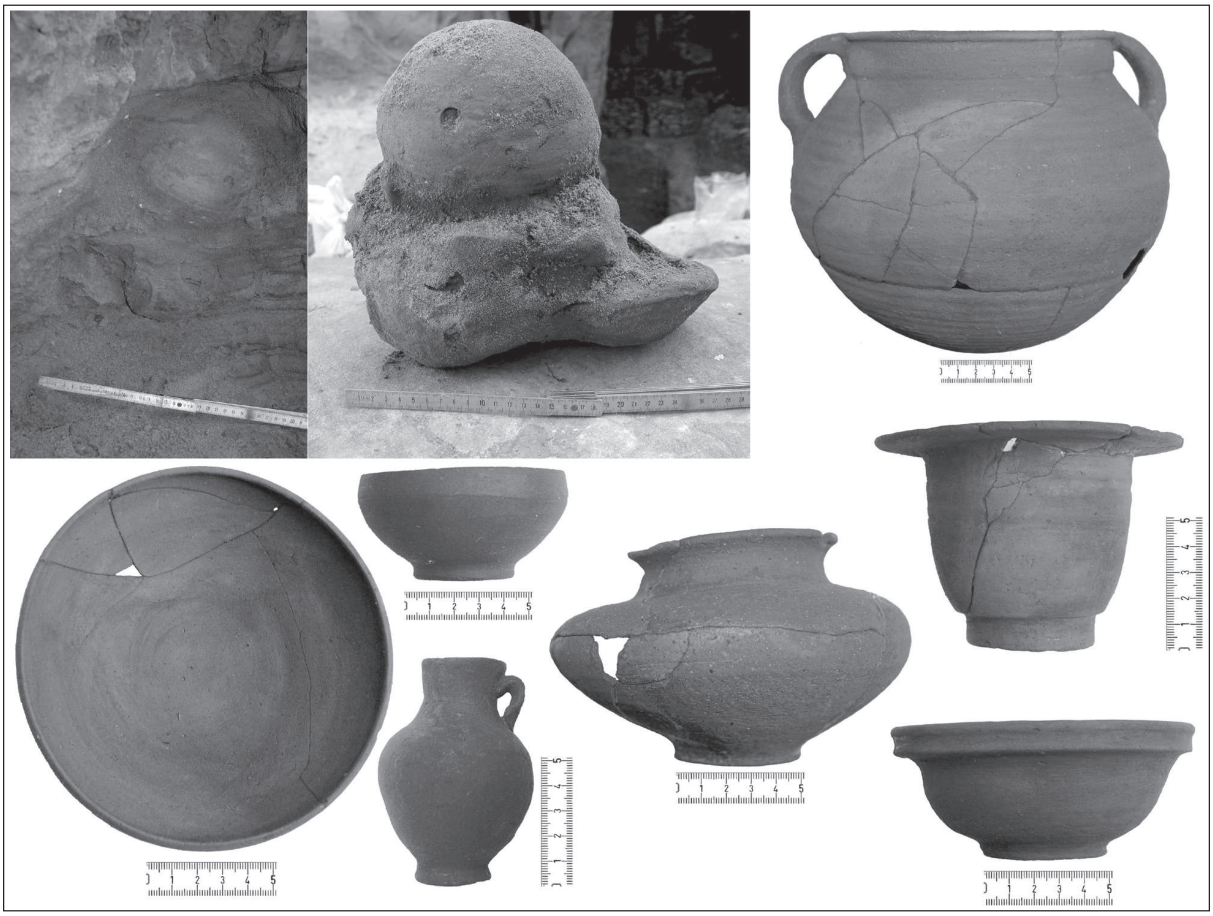
18. Layer 4 of a votive deposit of ceramic vessels excavated on September 29th, 2014 (Photo U. Bellwald).



19. Painted fine ware drinking bowls found in layer 3 and 4 of the deposit. They represent phase 2b and date to the last quarter of the 1st century BC (left). Reconstruction drawing of the large painted bowls (right) (Photos and drawings U. Bellwald).

raphy (FIG. 21) at a depth between 750 cm and the level of the bottom of the dam at a depth of 1245 cm are fully packed with pottery dating to the last quarter of the 1st century BC proves that dam nr. 3 was fully operational at that period of time, which means that it must have been built between 50 and 25 BC. Such a result corresponds perfectly with all results from the Sīq excavations where all dams closing the adjacent *wadis* and faults proved to have been constructed in exactly the same period (Bellwald 2003: 75). The subsequent layers of fine sand sediments, again fully packed with pottery shards in a depth between 385 and 750cm reveal, that the retention basin upstream dam nr 3 was further backfilled by natural sedimentation and used as a deposit for the leftovers of ritual activities accompanied by meals. Following the dating of the excavated pottery shards these activities must have been performed from the late 1st century BC throughout the entire 1st century AD until the early 2nd century AD. The uppermost layers are completely sterile with absolutely no finds, proving that besides the natural backfilling with fine sand no other activities took place at the site. Such a result corresponds perfectly with the outcome of the excavations in the area of the Madrass High Place (Bellwald and Keller 2003: 96-97) and the Obodas Chapel (Tholbecq 2005: 299-311, 2008: 235-254), where activities came to an end at exactly the same period.

In conclusion, the archaeological excavation work in 2011-2014 has shown that the retention capacity of dam Nr. 1 and the effect of the diversion channel from dam Nr. 2 into the wide western branch of Wādī al-Jarra was such efficient, that maintenance for dams Nr. 3 and 4 was already reduced since the late 1st century BC and throughout the entire 1st century AD.



20. Votive deposit of ceramic vessels excavated on November 11th, 2014 at the lower end of the outflow channel in front of the upstream face of dam nr 3. Photograph taken *in situ* (above left) and after recovery (above center). The coarse ware cooking pot covering the deposit upside down after restoration (above right) and some of the well preserved vessels of the deposit (below). All vessels may be dated to the last quarter of the 1st century BC (Photos U. Bellwald).

Latest with the beginning of the 2nd century AD the maintenance work for both dams in the lowest section of the narrow eastern gorge was heavily neglected and hence the retention basins upstream the dams were more and more backfilled by fine sand sediments. When the disastrous earthquake of 363AD took place, both retention basins were almost backfilled to the height of the dam crests. The sandstone blocks from dams 1 and 2, which collapsed during the earthquake of 363AD were swept down by floods and some of them were retained by the uppermost section of the preserved masonry from dam nr. 3, laying on top of the sand layers of the backfill accumulated in the retention basin since the 1st century AD. The archaeological excavation work in 2011-14 has furthermore clearly shown that the flash flood retention system in Wādī al-Jarra was no more restored and rebuilt after the partial collapse during the earthquake of 363 AD. Therefore during rainfall in winter time the runoff water took again its natural outflow along the narrow eastern gorge of Wādī al-Jarra. As the retention basins of dams nr. 3 and 4 were at that time already completely backfilled, the runoff water spilled over the preserved dam crests. Later, the outflowing storm water scoured a channel into the backfill material along the southern rim of the retention basin upstream dam Nr. 3, partially destroyed the masonry of the western auxiliary dam and, by natural erosion of the weak sandstone, grinded a valve into the cliff separating the eastern section of the gorge with the wide western branch of Wādī al-Jarra. This situation didn't change any more until nowadays.

WADI AL JARRA DAM REHABILITATION PROJECT STRATIGRAPHY OF CERAMIC AND OTHER FINDS				
Depth below Main Dam Crest	**Various Finds**	**Phase Painted Fine Ware**	**Phase Unpainted Fine and Coarse Ware**	**Time Period**
70 cm	Sand-Stone Ashlar Blocks			Earthquake Debris 363 AD
365-385 cm		3b		2nd century AD
385-435 cm			3a, 3c	Late 1st-2nd c. AD
385-435 cm		3a, 3b	3a, 3b, 3c	Late 1st-2nd c. AD
435-470 cm		3b	3a, 3b	Late 1st-2nd c. AD
470-525 cm		3a	3a, 3b, 3c	Late 1st-2nd c. AD
525-545 cm			2a, 2b, 3a, 3b, 3c	Late 1st-2nd c. AD
545-605 cm		2c, 3a	1, 2a-c, 3a-c	Early-late 1st c. AD
592	Votive Deposit	2c, 3a	1, 2a-c, 3a-c	Early-late 1st c. AD
605-645 cm		2c	1, 2a-c	Early 1st c. AD
635 cm	Bronze Coin Aretas IV			Minted 20-40 AD
645-650 cm		2b, 2c, 3a	1, 2a-c	Late 1st c. BC- early 1st c. AD
650-700 cm		2b, 2c, 3a	1, 2a-c	Late 1st c. BC- early 1st c. AD
700–750 cm		2b, 2c	1, 2a-b	Late 1st c. BC- early 1st c. AD
750-800 cm		2b	1, 2a-b	Last Quarter 1st c. BC
760-800 cm	3 Votive Deposits	2b	1, 2a-b	
800-850 cm		2b	1, 2a-b	Last Quarter 1st c. BC
850-900 cm		2b	1, 2a-b	Last Quarter 1st c. BC
840 cm	Votive Deposit	2b	1, 2a-b	Last Quarter 1st c. BC
900-1000 cm		2b	1, 2a-b	Last Quarter 1st c. BC
1000-1050 cm		2b	1, 2a-b	Last Quarter 1st c. BC
1045 cm	Votive Deposit	2b	1, 2a-b	Last Quarter 1st c. BC
1050-1100 cm		2b	1, 2a-b	Last Quarter 1st c. BC
1075 cm	Votive Deposit	2b	1, 2a-b	Last Quarter 1st c. BC
1100-1150 cm		2b	1, 2a-b	Last Quarter 1st c. BC
1150-1200 cm		2b	1, 2a-b	Last Quarter 1st c. BC
1200-1245 cm		2b	1, 2a-b	Last Quarter 1st c. BC

21. Table showing the stratigraphy in relation with the respective pottery finds, their type and their dating (Drawing U. Bellwald).

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