THE EXPLORERS CLUB

FLAG 172 REPORT

CLEARING THE OSIREION:

UNDERWATER ARCHAEOLOGY IN THE DESERT

ABYDOS, EGYPT

APRIL 23 – MAY 21, 2010

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Introduction

Following up on the work done in 2007 (see Flag Report 71 May, 2007), James Westerman FN98, along with hydrogeologist Dr. Richard Parizek from The Pennsylvania State University and geologist, Dr.Bahay Issawi from Cairo, Egypt returned to Abydos, Egypt to continue their investigations of the Osireion. This expedition was awarded Explorers Club Flag 172, a flag which Mr. Westerman had carried previously to Egypt in 1999. Mr. Westerman had also been awarded Flag 61 in 2004 and Flag 71 in 2007 for other archaeology work in Abydos.

The goal of this season was to try to dewater a section of the Osireion using dykes and pumps in order to excavate to levels never before reached by previous excavators. Since the foundation of the Osireion has never been seen by modern man, it was hoped that this method of dewatering and clearing of rocks could be used to reach the foundation that this massive building is resting upon. Also Dr. Parizek continued to collect data about water levels and temperatures in the piezometers and well points installed in previous seasons in the Osireion/Sety Temple area in order to try to understand water flow patterns caused by seasonal water level variations and conditions as well as those induced by our pumping of water from the Osireion during this season.

Background Work Done Before This Season

In order to determine the source of water in the Osireion, water samples from wells in the Abydos area surrounding the Osireion were collected by Dr. Ahmed Aziz Moneim of Sohag University, Sohag, Egypt, and sent to the Egyptian Atomic Energy Authority in Cairo for analysis. The results of these isotope analysis show that the water in the Osireion is most likely from the Nile system and not from a hydro logically isolated aquifer. Water samples collected from the Osireion, Nile River and ten water supply and dewatering wells near the Osireion were analyzed for their stable isotopes, Oxygen (g18O) and Deuterium (gD) together with Sodium, Potassium, Chloride, Phosphorous and total Dissolved Solids contents. The Nile sample was most affected by evaporation consistent with the size of Lake Nasser located above Abydos and its extreme desert climate. Oxygen 18 and Deuterium concentrations obtained from Osireion water were strikingly different from two down gradient dewatering wells located less than 10 meters away and water supply wells located in the general area. These data indicate that Osireion waters are derived from a mixed source not typical of the eleven other samples analyzed. Sources likely to have a different chemical signature include water contained in deeper semi-confined alluvial and bedrock aquifers leaking from below and mixing with Nile water. The Osireion isotopic content is not typical of “fossil water”, precipitation that recharged aquifers under a colder paleo climate.

The results of this geochemical investigation were reported at the Fifth International Conference On The Geology of the Tethys Realm held in Qena, Egypt, January 2 -7, 2010 and accepted for publication in the Tethys Society Bulletin. (See Appendices I , II &III))

In conjunction with this work, in October, 2009 a large previously undocumented ancient well was discovered in a workshop building located on the south side of the southern extension of the Sety I Temple. We named this well the New Roman Well. The workshop building was subsequently torn down by the Supreme Council of Antiquities in 2010 and the well was covered by large metal plates. The isotope analysis of the water from this well showed that it is most likely receiving a mixture of waters from the ancient aquifer and from local water.

The New Roman Well

Water data was collected by Dr. Richard Parizek during field seasons in May, 2008 and January, 2009 from previously installed piezometers in order to track temperature and water level variations at different times of the year. This was done to explore for evidence of an ancient drain postulated to underlie the Sety I Temple and used to control water levels in the Osireion.

In May, 2008 a new monitoring well was drilled just to the southwest of the Osireion. This new well was named the Westerman Well in honor of its sponsor. It is being used to monitor water levels immediately southeast of the Osireion and provide stratigraphic information to a depth of 20 meters.

Drilling the Westerman Well

A hand powered impact well was drilled in the eastern channel of the Osireion to try to penetrate down to the foundation level. This effort was unsuccessful as a rock caused the drill bit to be refused short of Westerman's 10.4 meter depth obtained using a metal rod and Dr. Sheldon Alexanders's seismic depth estimate of 15 meters for the Osireion foundation.

In January, 2009 a truck mounted crane was brought to the site to see if such a machine could be used to lift rocks out of the Osireion. This machine proved inadequate for the job since it did not have sufficient counterweight to lift large rocks when its boom was extended to the required length to reach the rocks. This only added to the wonder of the accomplishments and ability of the ancient builders who planned and constructed the Osireion.

In October, 2009 a large capacity electric water pump (1.2 cubic meters/min. capacity) was purchased by Mr. Westerman and installed on the upper level of the southwest corner of the Osireion. This pump was connected to a gasoline powered booster pump and it was in turn connected to the existing discharge piping system left over from when there used to be a pump to drain water from the Osireion. This pumping had been discontinued sometime after May, 2008. It was found that the piping had many leaks which needed to be repaired.

In January, 2010 repairs were made by the SCA to the discharge pipes and a sample drawdown test was done to see if the pumps could lower the water in the Osireion. This test was successful although some small leaks still existed in the discharge pipes next to the new visitor center being built in the Cafeteria Park area in front of the Sety Temple. The results of this drawdown test showed areas in the channel surrounding the central island of the Osireion where large amounts of debris still existed and it was realized that possibly a dyke system could be installed to limit the amount of water that would be needed to be pumped to lower the water level in a segregated section of the surrounding channel. It was also determined that in order to do any continuous pumping the gasoline powered booster pump would have to be replaced by an electric pump.

The April – May, 2010 Season

In April Dr. Richard Parizek from The Pennsylvania State University arrived in Cairo to sign in with the Supreme Council of Antiquities (SCA) office and receive the necessary permission to work in Abydos. Dr. Parizek was accompanied by James Westerman FN98 of the Explorers Club and Dr. Bahay Issawi from Cairo. Leaving Cairo the team went to Sohag, Egypt where they checked in the SCA regional office and were assigned our inspector Abdullah Mohamed Ahmed. In Sohag we were joined by the other members of our team, Dr. Sameh Refat Zaki and Dr. Ahmed Aziz Moneim. During the past few months since our January, 2010 visit, Dr. Zaki had purchased pipes to repair the drainage system as well as a new electric booster pump.

On arrival in Abydos negotiations with the SCA workers and supervisors were done in order to determine a budget and responsibilities for the work which needed to be done. These negotiations took some time to accomplish but finally an agreement was reached. Since Dr. Zaki lives in Girga, the next town north of Abydos, he was well familiar with the prevailing wage rates for workers in this part of Egypt.

First the new booster pump was installed and connected to the existing pump.

The dewatering pumping set-up (view is towards the southwest corner of the Osireion)

Then the discharge piping was repaired. The completed system was tested and found to be watertight. We next entered into discussions with the engineering contractor (Eng. Abdel Moneim) who was in charge of the SCA new engineering projects in Abydos. It was found that the SCA had let a contract to construct a pumping system to completely drain the Osireion. We successfully convinced Eng. Moneim to not tamper with our existing dewatering pipes which ran alongside the new visitor center which was being built. We had one small problem with the construction firm though, as they did some minor landscaping in the area of one of the pipes of our discharge system and caused a break in the pipe. The construction firm took responsibility for this break and repaired it in a timely manner at their expense. Eng. Moneim was very supportive of our work and we got along well with him during all of our season in Abydos, even though we did cause some changes in his schedule of work.

Having the pumping system fully functional we turned it on and drew down the water level in the Osireion. While this was being done we filled 500 sandbags and positioned them in the Osireion so as to create a dyke separating the western channel and upper surface from the rest of the Osireion.

Sandbags surrounding western stairway of central island of the Osireion

This caused the volume of active water to be restricted to a smaller amount thereby making the pumps have less water to pump in order to draw down the water level in the confined area. What we found out by this pumping test surprised us. We lowered the water level 0.92 meters below the starting level and there were only about 5.4 cubic meters of free water left in the confined area, and the pumps were running full out at 670 liters per minute and yet the water level would not go down further. Even though the rated capacity of the pumps was higher than 670 l/min, due to frictional piping loss this was the actual measured rate of flow of discharge.

Minimum water level achieved by pumping (view is of column in southwest corner of central island)

The water inflowing from beneath the confined area was coming in as fast as we could pump it out. There was minimal inflow from above the water line so the inflow could only be coming from below. When we turned off the pumps the water level in the confined area rose right before our eyes and within a little over an hour was back to the original level. We tasted the water that was flowing in from the rivulets located between large foundation blocks above the lowered water line. It tasted very salty, quite different from the normal taste of the Osireion water. This would suggest that the rivulets were inflowing water from a source different from the upwelling water in the Osireion.

Rivulet of water flowing in by north pilaster on west wall of Osireion

We next had a *sibia* augering crew from the area drill three holes in the western channel to sample the material in the channel and penetrate as deeply as possible into the muck in the channel.

Sibia augering in west channel of Osireion

Of the three samples drilled, it was found that the greatest depth was reached in the area just to the north of the western stairs. In all three holes the auger was stopped by the presence of rocks. Since we could not dewater down to the depth of the auger we were not able to view these rocks or look at the submerged walls either. Chips of limestone were recovered at refusal in all three auger holes. It is not known if limestone blocks were encountered that had fallen into the channel or if they were from other sources.

Dr. Bahay Issawi, a prominent Egyptian geologist and long time member of this project offers the following hypothesis based on the encountered limestone chips about the foundation that the Osireion rests upon.

Dr. Bahay Issawi Report for Explorers Club Flag 172 Expedition

April – May, 2010

During the late Miocene (7 million years ago), the Strait of Gibraltar was closed and gradually the Mediterranean Sea became desiccated and converted into salt lakes.

At 5.3 million years, Gibraltar was opened and communication between the Atlantic Ocean and the Mediterranean was resumed. Sea water gushed into the canyon structures in both the African and European plates. In Egypt, sea water reached south of Aswan depositing a thick shale sequence in the Delta sub-surface (1850 meters) and a thin sand/carbonate section (60 – 100 meters) on both sides of the Upper Nile Valley assuming 110- 120 meters above the present sea level. The retreat of the sea off the Egyptian land took place during 3.6 to 1.8 million years ago. While retreating the sea water deposited a limestone section about 15 – 20 meters thick, highly brecciaed, very hard in the form of small and big lenses, approaching beds in both side of the Upper Nile Valley, east and west of the Nile very near to the course of the river. This hard limestone is known as the Issawia Formation and considered of middle Pliocene age (3.6 – 2.6 million years ago). The sand section above the Issawia known as the El Wastani Formation was dated to 2.6 – 1.8 million years ago.

The old Pharaonic engineers building the Osireion used this hard limestone lens as a foundation for the huge sandstone and granite blocks which comprise the Osireion. We drilled in 2008 two wells, one inside the eastern side of the water filled Osireion channel and one outside the channel at the southeastern scarp overlooking the channel. In 2010, three bore holes were drilled by the expedition team inside the western part of the channel. The depth reached in the channel was approximately 6 meters in the three wells before the Issawia limestone fragments were recovered. The well drilled in the southeast scarp reached a depth of 22 meters before the hard Issawia was reached.

To sum up, the Issawia hard limestone lenses within the general sand/clay section were used as the foundation for this magnificent structure.

Bahay Issawi

We installed two piezometers in two of the auger holes to measure the upwelling action of the water in the Osireion. These piezometers did not give meaningful readings to us since they had not stabilized in the time between when we installed them and when we left Abydos. However, water level measurements useful in determining the direction of groundwater seepage within the channel sediments will be taken in the future.

At the finish of the season we removed all the sandbags from the site and restored it to its original condition from the start of the season.

In addition to our work in the Osireion we looked into the New Roman Well we discovered in October, 2009. When we first encountered it, this well was located under some plates in the floor of a building which had been used as a workshop but which was no longer in use. Prior to our arrival in April, 2010 the engineering firm working on the new visitor center had torn down this building and when we arrived the well was located under some heavy metal plates. This well had never been documented before so we measured and photographed it in some detail. Now that the building which had surrounded it was gone it was much easier to see into the well by shining reflected sunlight into it. Its' walls were constructed of red brick in part covered with plaster so it did not date from the pharaonic period. It is visible in old British aerial photos of the Abydos area, but for some unknown reason was never mentioned in any previous reports about the Sety Temple and in questioning long time residents of Abydos none of them knew of its existence. The dimensions of it are: 2.75 m**.** diameter, 14.77 m. down to water level and approximately .7 meter of free water. Below the free water is loose fill of unknown depth.

The engineering firm contracted to dewater the Osireion by the SCA drilled test wells just to the west of the Osireion. They used a commercial drill rig and drilled five test wells down to a depth of 70+ meters and one down to 103 meters. In all cases they did not hit any rock formations. They did not encounter any evidence of the Issawia formation. All they brought up was Qena sand and Kom Ombo conglomerate. It is still puzzling to us to think that this type of massive building could actually be resting only on water permeated sand. There are very large weight loads on the corners of the central island where the large columns rest, and the fact that they have stood the test of time and remained perfectly upright indicates very good foundation stability. Further, the floor of the island surrounded by the channel varied by only a few centimeters based on water level elevations observed during the dewatering experiments.

We were concerned that the dewatering work being done by the engineering contractor could damage the physical as well as symbolic strength of the Osireion. We believe that the ancient builders wanted water to be part of its design. We also believe that based on our pumping test the water supply into the Osireion is virtually limitless and it will be costly to dewater it. We wrote of our concerns to Dr. Zahi Hawass of the SCA and he looked into the contract. Since he discovered that there did not seem to be adequate preliminary studies done about the dewatering project, he asked the SCA local personnel to stop work on the project until further engineering research could be done. He did not stop the drilling of the remaining drill holes to get core samples of the area surrounding the Osireion to its west. These holes were completed and were to have monitoring wells installed in them for pumping tests to evaluate the hydraulic properties of the saturated sand and gravel aquifer penetrated by the six drill holes. This hydrologic data was needed to design dewatering pumps and pumping schedules needed to control the water levels with the Osireion channel.

Report by Dr. Richard Parizek

Hydrogeologic Investigations

Various investigations were undertaken during the April-May 2010 field season to enhance the understanding of the local hydrogeologic setting of the Osireion. These include: updating the water table configuration, water temperature measurements within the Osireion channel under non-pumping and pumping conditions, drawdown measurements made in wells and piezometers during dewatering tests conducted on the Osireion and shallow soil temperature surveys to search for an ancient drain postulated to have been used to control Osireion water levels. Such a drain would have been located within a valley or canal likely to have been used to transport huge blocks of stone during the construction of the Osireion.

Water Table Configuration

Regional water level measurements indicate that Nile water leaks from the pool created by the low dam at Nag Hammadi up river from Abydos and flows northward to farm wells near Abydos, to the Osireion and beyond. Locally, under non-pumping conditions, Osireion water flows southward toward the Southwestern and Southeastern Dewatering Wells and Westerman Monitoring Well. The Westerman Well is located south of the Southeastern Dewatering Well. Flow also is directed eastward under the Seti-I Temple outer courtyard and toward piezometers located near the entrance staircase of the Temple.

Westerman discovered a previously unknown large diameter Roman Well near the southeastern corner of the Seti I building complex. Its water level was higher in elevation than either the Southeastern Dewatering Well or Westerman Monitoring Well and Osireion channel under non-pumping conditions during the April-May 2010 field season. These elevation data reveal the presence of a trough shape-depression in the water table located between the Southeast and Southwester Dewatering Wells and the new Roman well. A zone of higher permeability must exist in this area to account for these water table elevation data. The zone must extend eastward into Nile flood plain sediments to provide an outlet for groundwater that converges into this trough from the south, north and west. The pump located in the interceptor drain that is located in front of the Seti-I Temple entrance stairway and outer courtyard was not in operation during May-June 2010. Therefore, pumping from this drain did not produce this groundwater trough. It is not known if drawdown induced by pumping from a community water supply well located some distance southeast of the interceptor drain extends northwestward toward the Osireion. If so, use of this well could have influenced water levels in one or more wells used to monitor water level changes during this study. No deep wells exist in the area between the New Roman-Westerman-Southeast and Southwestern Wells and this public water supply well to make this determination.

Osireion Dewatering Experiments

Water temperatures were measured within the Osireion channel both under non-pumping and pumping conditions to identify potential areas of concentrated groundwater inflow (Figure 1).

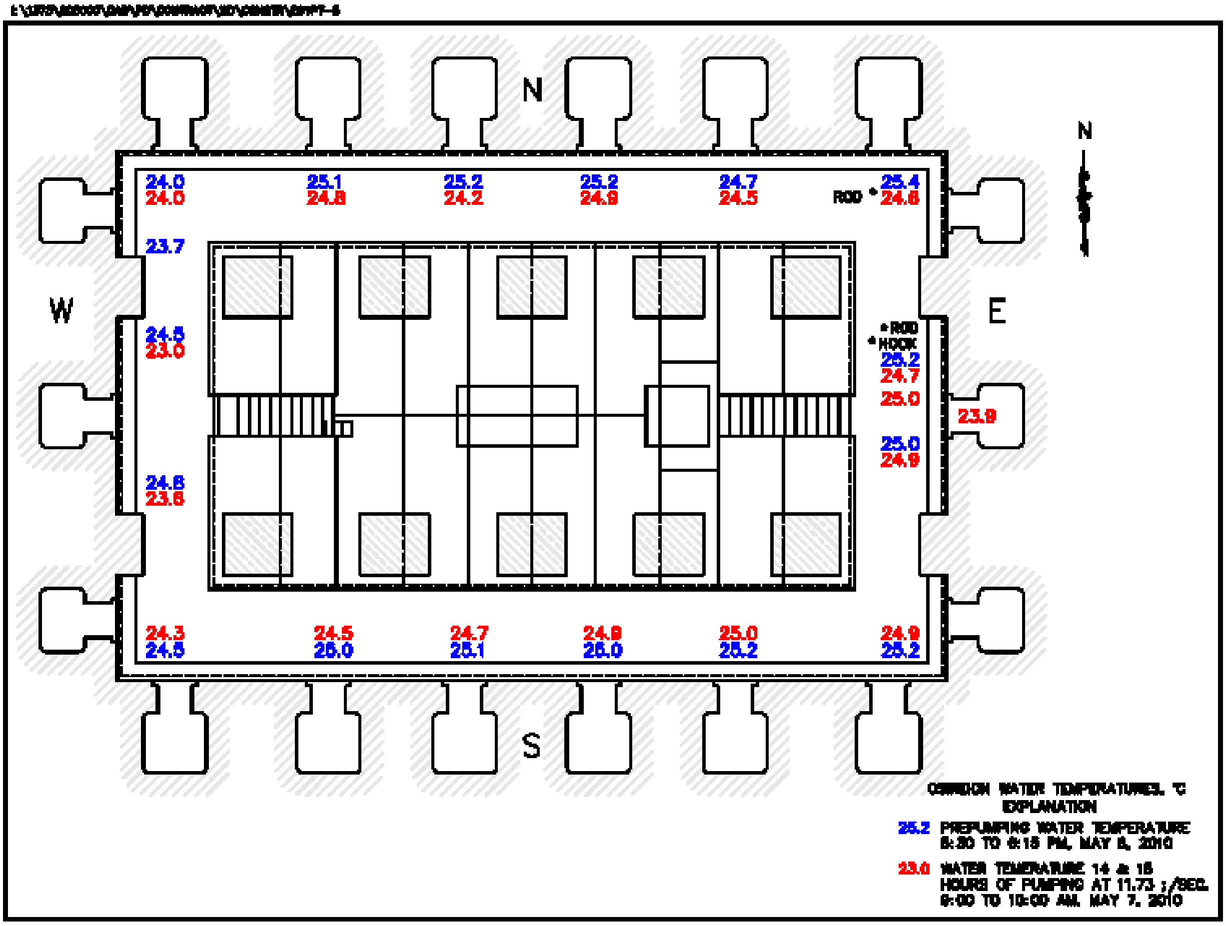

Figure 1. Water temperatures measured within the Osireion channel both under non-pumping and pumping conditions during May 2010.

These were revealed by cooler water temperatures than observed under non-pumping conditions. Cool areas were located near the southwestern, central and northwestern portion of the western channel, and from within the sarcophagus chamber (near the Seti-I Temple Western Wall) as water was induced to enter the main channel from the east. Prior to pumping, water temperatures were higher near the entrance to this chamber. In time, Osireion water levels were lowered by 0.90 meters within the dyked- off portion of the channel well below the pool level that covered the central island at the start of the 2010 field season. Drawdown was measured in all nearby monitoring points during these pumping tests. Drawdown induced by pumping was greatest for some more distant observation points when compared to points located closer to the Osireion. For example, drawdown in the Roman Well was 0.28 meters and 0.91 meters in Line I piezometer No. 8 compared to only 0.087 meters in the Southwestern Dewatering Well and 0.063 meters in the Southeastern Dewatering Well (Figure 2).

Figure 2. Location of wells used to monitor changes in groundwater levels induced by Osireion dewatering experiments.

Drawdown essentially was undetected in the new Roman Well. For idealized aquifers that are more or less homogeneous and isotropic with respect to permeability distribution, well hydraulics theory predicts drawdown induced by a pumping well will decrease logarithmically with distance from pumped wells. Drawdown values observed during Osireion pumping tests were greater in some more distant wells than within nearby wells (Figure 3).

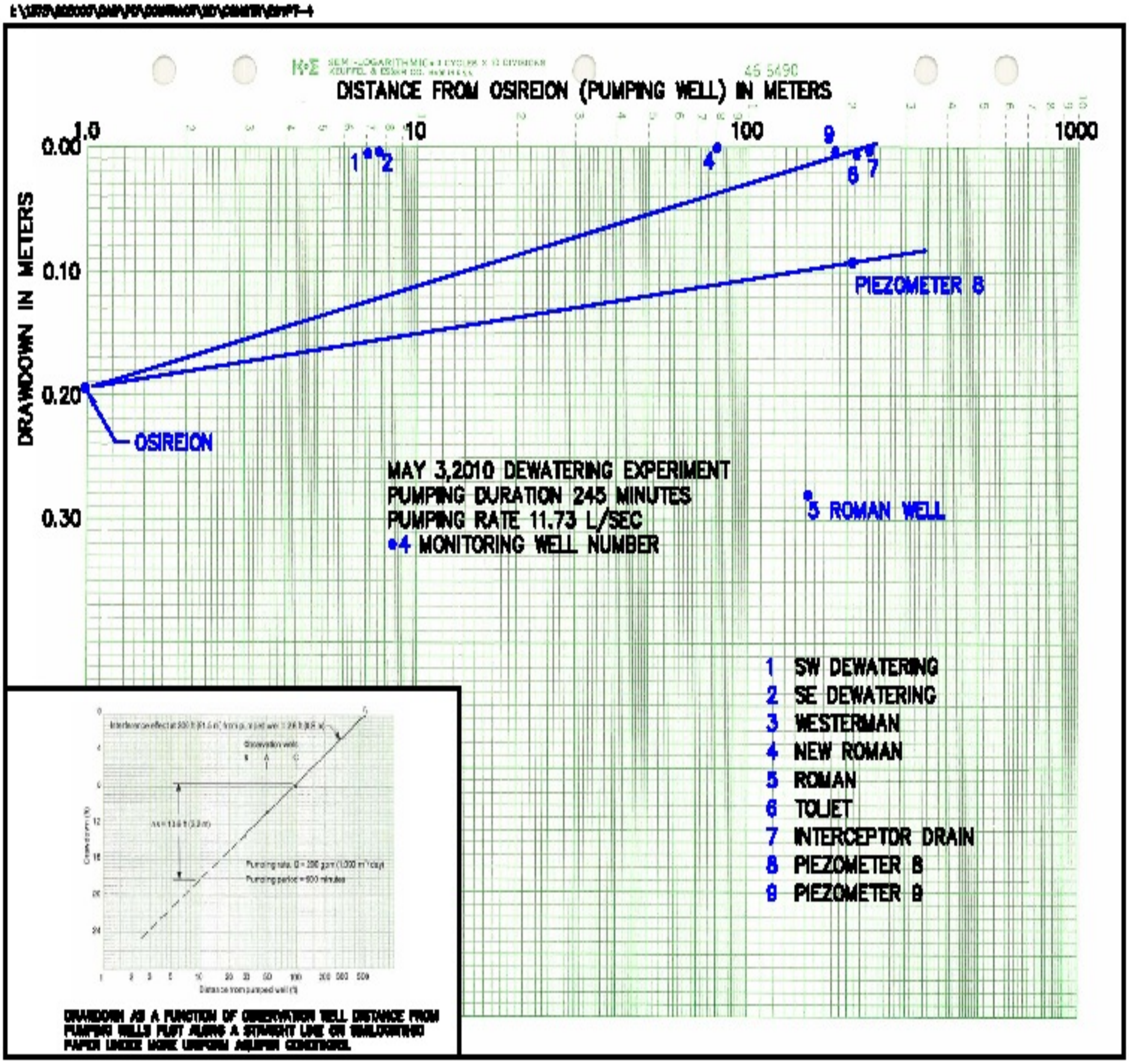

Figure 3. Distance-drawdown data obtained during the May 2010 Osireion dewatering experiment.

This reveals the presence of a more permeable pathway that extend from the Osireion, to the vicinity of the Roman Well and Line I piezometer No. 8 located immediately north of the Seti-I Temple entrance stairway. This asymmetric drawdown pattern is consistent with the presence of a buried drain in this general area used to control Osireion water levels. Alternatively, it may reflect the presence of a buried valley or former canal that is believed to have extended from the Osireion, eastward below the Seti-I Temple, its inner and outer courtyards and toward the Nile Flood plain and Nile beyond. The channel would have to be filled with an elongate body of more permeable deposits to distort the observed cone of pumping depression similar to what would be caused by the presence of a drain.

Map Location Number		Drawdown (meters)	Distances From Osireion (meters)
	Osireion	0.191	0
1	Southwestern Dewatering Well	0.087	7.13
2	Southeast Dewatering Well	0.063	7.86
3	Westerman Monitoring Well	------	16.06
4	New Roman Well	0.03	82.64
5	Roman Well	0.28	151.25
6	Toilet Well	0.01	212.96
7	Interceptor Drainage Well	0.079	238.37
8	Line I Piezometer 8	0.91	208.12
9	Line I Piezometer 9	0.025	188.15

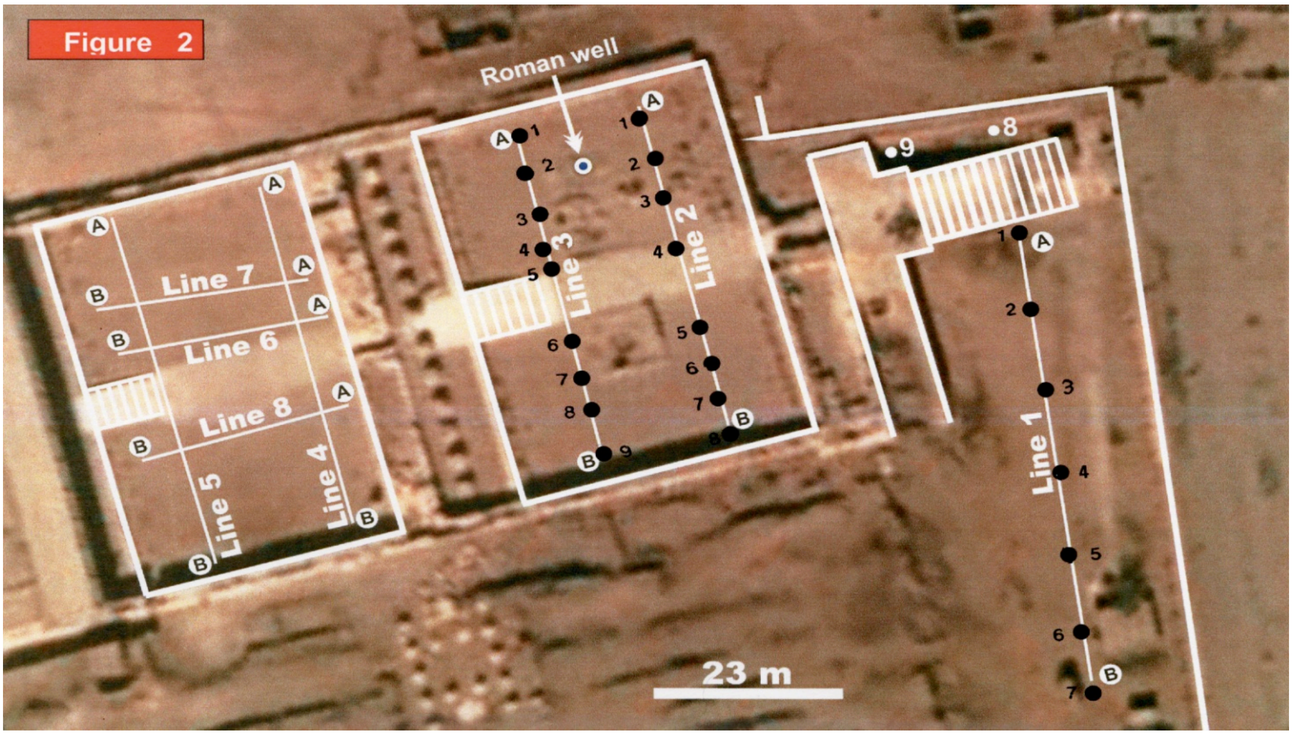

Figure 4. Location of Line I, II and III temperature access holes used to define zones of more concentrated shallow groundwater flow

Shallow Soil Temperature Surveys

Bottom hole temperatures were measured on April 29 and May 13, 2010 within Line I, II and II piezometers. Line 1 is located near the Seti-I Temple stairway entrance; Line II near the eastern portion of is outer terrace and Line III near the western portion of its outer terrace (Figure 4).

Unlike the first and second field seasons when soil temperature access holes were first constructed or vandalized and holes replaced during the second season, thermal disturbances caused by this construction had time to dissipate. Boreholes were in thermal transition, influenced by solar heating and groundwater circulation. Although near surface soil temperatures were heating up following the onset of hot weather, cooler soil temperature anomalies were still evident. Cool areas define shallow zones of more concentrated water circulation that were cooled during the previous winter season (Figure 5).

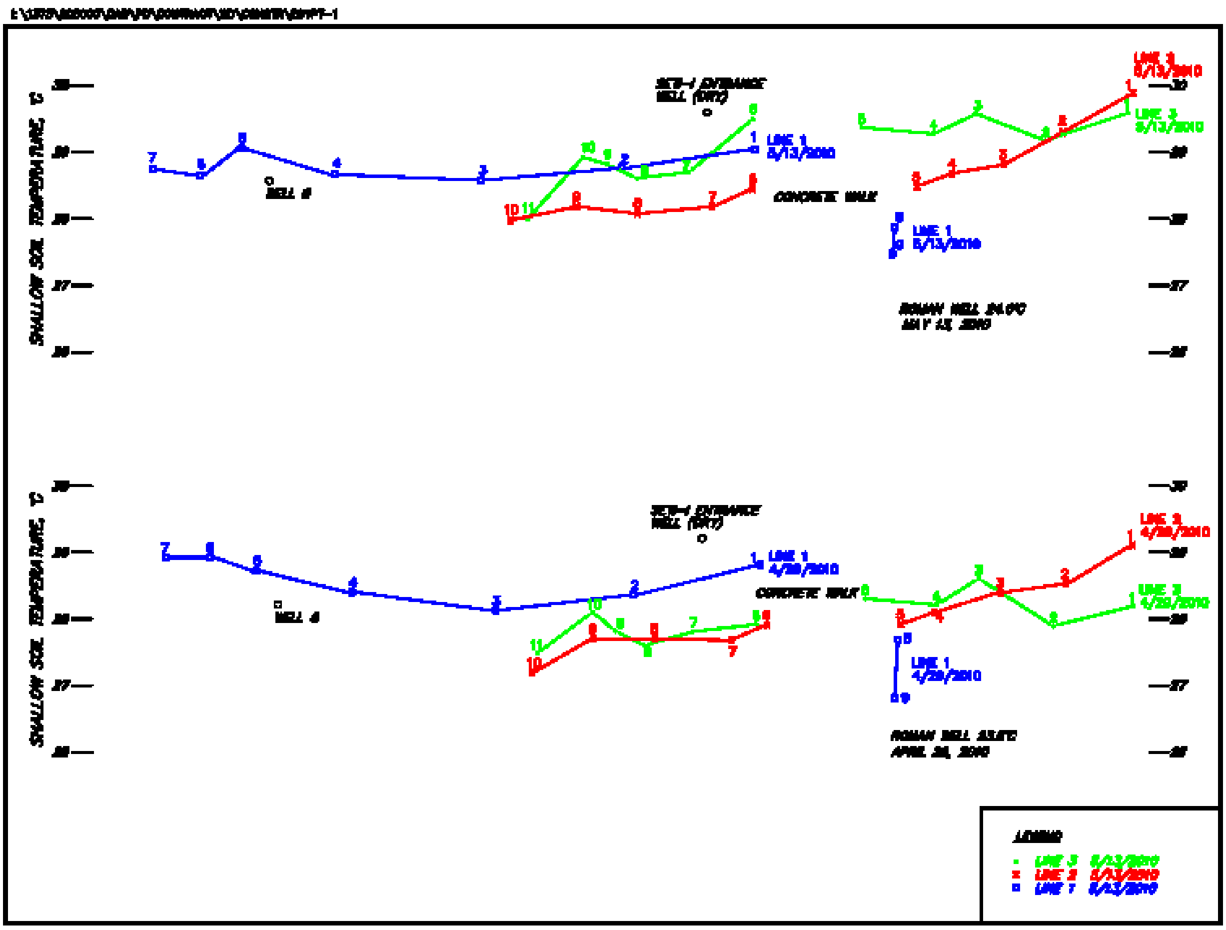

Figure 5. Line I, II and III soil temperature profiles measured on April 29 and May 13, 2010. canal that is believed to underlay the temple, its courtyards and that extended to the Osireion prior to construction of the Seti Temple

Both Line I stations 8 and 9 had low temperature values on April 29 and May 13, 2010, when compared to stations 1 through 7. This is supportive of their proximity to the postulated Osireion drain. The water temperature in the Roman Well was 23.6˚C on April 29, 2010 and 24.0˚C on May 13, 2010 suggestive of active concentrated groundwater circulation directed eastward from the Osireion, where the water temperature above the central island was 23.4˚C on April 29th. The Southeastern and Southwestern Dewatering Wells together with the Westerman Well had higher temperatures by contrast, 26.4˚C, 25.3˚C and 28.1˚C respectively not supportive of a conduit in their immediate area.

Temperatures measured in Lines I, II and III stations all showed a cooling trend (1.0˚C or more) proceeding from north to south. Line II temperatures were significantly cooler, approaching the central paved walk leading to the Seti-I Temple entrance during both the April and May surveys. This zone is more or less aligned with the cool temperatures observed within Line I, stations 8 and 9 together with subsidence measured on either side of the Temple's entrance.

Temperatures were noticeably cooler along the southern portion of survey lines II and III in the outer Seti-I courtyard and along Line I stations proceeding southward from the temples entrance stairway. Especially prominent on April 29th, was a low temperature zone extending between survey stations 1 through 6. Station 5 showed no evidence of drainage from the cesspool reported to serve the public restrooms located nearby. However, a warming trend was noted near station 5 on May 13th. This broad area of low temperatures defines a shallow zone of enhanced groundwater circulation that extends below ground in front of the Seti-I courtyards and westward beneath the outer courtyard. It may define the zone of enhanced permeability that accounts for the water table depression (trough) that was detected between the Roman Well discovered during 2010 and the Southeastern and Southwestern Dewatering Wells and Westerman Monitoring Well noted previously. This cool zone is significantly wider than the subsidence trough that was measured within the front terrace and interior of the Seti-I Temple, 29.30 to 30.07 meters. This zone of subsidence may define the width of the original valley or extension of a natural buried channel west of the Osireion is suggested by a claybed exposed in the Merneptah tunnel excavation that provided a western entrance to the Osireion. This clay, assigned to the Dandara Formation, is nonexistent along the northern portion of the excavation, but thickens progressing southward at least to 4.0 meters at the termination of the tunnel. An erosional channel containing more permeable sand and gravel may underlie and be defined by this claybed. The clay was encountered in a new 102 meter deep dewatering well drilled during May-June 2010 by the Egypt Antiquity Organization. This well, one of five planned to be drilled to a depth of 70 meters, is located on the desert surface just southwest of the Osireion.

Geologic logs of these wells may reveal the presence and orientation of the channel revealed by the Dandra claybed exposed in the Merneptah tunnel excavation. Further, if pumping tests are to be conducted on one or more of these dewatering wells, time-drawdown and distance-drawdown together with water quality data should be collected from all new wells together with observation points used in our study. High permeability trends, if present, will be revealed by these data similar to that observed during our Osireion dewatering experiment. This trend extended eastward from the Osireion to the Roman Well and Line I piezometers 8 and 9.

Summary

Changes in water levels observed in available wells during Osireion dewatering experiments confirm a pathway of high permeability that extends from the Osireion, to the Roman Well and Line I piezometers 8 and 9 located east of the Seti-I Temple. This zone is independently confirmed by shallow soil temperature surveys conducted along Line I, II and III piezometers, especially a cool area defined by Line I piezometers 8 and 9.

Subsidence of the Seti-I Temple is symmetrical about its eastern terrace entrance, central interior hall and eastern wall of its inner (upper) terrace. Loss of soil support rather than original design is believed to account for subsidence observed. This could result from differential compaction of valley or canal fill placed after construction of the Osireion, but before construction of the Seti-I Temple or subsurface erosion of soil within a drainage tunnel following temple construction.

A zone of enhance permeability just to the west of the Seti-I entrance stairway and outer terrace is revealed by cooler shallow soil temperatures. This trend may account for a zone of lower water levels (groundwater trough) located between a new Roman Well located just south of the Seti Temple and dewatering wells located immediately south of the Osireion. This zone of enhance permeability may be revealed by and underlie a claybed exposed in the Mermeptah tunnel entrance to the Osireion.

Concentrated areas of cool inflowing groundwater were detected within the southwestern, west-central and northwestern portions of the Osireion channel and from the sarcophagus chamber on the east during dewatering experiments. Piezometers were set in two drill holes located near the west-central and southwest corner of the channel to confirm the occurrence of upwelling groundwater. This is implied by isotopic and other water quality data obtained from the Osireion in comparison to other nearby monitoring locations including the Nile. The Osireion isotopic content is unique when compared to other water samples analyzed and must include a mixture of deep upwelling groundwater and Nile irrigation return flows together with leakage from the Nile and possibly water supply canals. Osireion isotopes did not indicate residual water recharged under colder paleoclimatic conditions.

Analysis of Osireion water following prolonged dewatering experiments should remove influences of water losses and concentration of mineral mater related to pool exposure and evapotranspiration. Geologic logs, water quality analyses, water level elevation and pumping test data collected from five new along with existing wells used in this study should shed further light on the origin of Osireion groundwater together with pumping rates that would be required to lower and control water levels within the Osireion. This is necessary.

Richard A. Parizek

Summary

There are six fundamental questions about the Osireion that we are trying to answer. They are:

1. Why was it built?
2. When was it built?
3. How was it built?
4. Why was it built in water?
5. What is the source of the water?
6. What if anything is in the cavaties in the central island?

The building is a physical reality, but the live water that apparently issues forth from either below it or conceivably its interior is nothing short of amazing. How the ancient Egyptians decided to build here and then successfully did so is truly one of the most perplexing puzzles in archaeology.

We wish to thank the Egyptian Supreme Council of Antiquities for allowing us to continue our research efforts at the Osireion and especially the following individuals: Our inspector Abdullah Mohamed Ahmed, the director of the Abydos area Magdy El Badry, the director of the Sohag Prefecture Zein El Zaki and the director general of the SCA Dr. Zahi Hawass.

Respectfully submitted;

James Westerman FN98

APPENDIX I

ISOTOPIC DATA: IMPLICATIONS FOR THE SOURCE(S) OF OSIREION GROUNDWATER, ABYDOS, EGYPT

Richard R. Parizek,* Ahmed Aziz Abdel Moneim, Matthew S. Fantle,* James S. Westerman,*** and Bahay Issawi,******

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ABSTRACT

The Osireion, formerly concealed within a West Bank Nile terrace, is thought to have been an important building to the Ancient Egyptians. Its huge building blocks define a rectangular central stone island surrounded by a water-filled channel nearly 13m below the desert. The channel was cleared of debris to 4.3m in 1925, but not to its original depth. Westerman successfully probed to 10.4m using a metal rod. Seismic data suggest its walls may extend 15m below the water table. Westerman (2008) lists six questions that elude archeologists and Egyptologists. Why, when and how was the Osireion built? Is in the interior of the island hollow? Why was it built in water? What is the source of the water? Eleven water samples were collected including the Nile, Osireion, two nearby idle dewatering wells, an active eastern French drain and six active water supply wells. $\delta^{18}O$ and δD were measured by EAEA and PO_4, Cl, N_a+K and TDS by Sohag University. Factors such as evaporation, mixing, relative humidity, surface elevation and recharge climate can influence isotopic contents. The Nile sample appears most affected by evaporation, consistent with Lake Nasser's great size and arid climate. Water samples fall below the GMWL and paleowater line in a region expected of modern precipitation in arid, low latitude climates. Sinai groundwaters by contrast are isotopically lighter, suggestive of recharge at higher elevation during cooler climates. $\delta^{18}O$, δD, PO_4, Cl, N_a+K and TDS concentrations suggest Osireion waters are not easily explained by simple evaporation of any supposed end member. $\delta^{18}O$ and δD concentrations are strikingly different from two nearby down groundwater gradient, dewatering wells most likely from a mixed source not typical of the ten other samples. Upwelling from a semi-confined artesian aquifer, possibly also diffuse regional leakage through the Esna Shale are suggested.

INTRODUCTION

The Osireion, formerly concealed within a West Bank Nile terrace, Abydos, Egypt, is thought to have been an important building for the Ancient Egyptians. Osiris was the main god of the Abydos, which became cult center of this god, burial site of kings of Dynasty I and II and high court dignitaries in pharaonic times. The structure is constructed of huge blocks of Aswan granite, sandstone and limestone. It intersects the water table nearly 13 meters below the desert surface. Its outer walls surround a water-filled channel and central hall. The channel defines a massive rectangular central stone island. The channel was cleared of boulders derived from the breakup of the upper portion of the temple and sediment accumulations to a depth of about 4.3 meters during H. Frankfort's 1925 expedition. Excavation was limited by capacity of the 16 hp, 4-inch diameter steam- powered pump available at the time. It was able to lower the water level 3.7 m below the ledge or top of the island. The groundwater inflow capacity has not been defined to date. Westerman (2008) lists six principal questions that have eluded archeologists and Egyptologists. Why was the Osireion built? When was it built? How was it built? Is in the interior of the island hollow? Why was it built in water? Of interest here are observations resulting from more recent hydrogeological investigations concerned with the source or sources of groundwater that nourish the Osireion: the sixth question, Was it located at the site of a spring or did the foundation of this deeper than expected structure penetrate the water table during its construction? If the latter is correct, how might its artisans have lowered water levels to allow placement of its huge stone blocks and then control levels following completion of the temple?

Methods

The oxygen (δ ^{18}O) and deuterium, (δ D) isotopic compositions of eleven water samples were measured by the Egyptian Atomic Energy Authority. Staff from the Authority collected, transported and stored water samples. Sample locations were identified and selected by Professor Ahmed A. Abdel Moneim, Geology Department, Faculty of Science, Sohag University, Egypt (Fig 1). He assisted in this sampling effort. We assume therefore, that no headspace was left in sample containers that might allow evaporation, hence change isotopic contents and that all necessary protocols were followed.

Pumps were used to obtain water from two American House water supply wells, farm wells located west and south of the Osireion and a house well in Abydos. Other samples were hand bailed from exposed water sources. Cations, anions and other constituents were analyzed by the Geology Department Laboratory, Sohag University. (Table 1). Isotopic data from the Sinai Peninsular, were included in some graphs for comparison. These were obtained from a draft copy of Shawki Sami Hassan Bader El-Din's dissertation approved by the Faculty of Science, Cairo University. Sinai samples were analyzed for radioactive tracers (^{14}C, ^{3}H) as well as stable isotopic composition ($^{18}O/^{16}O$ and D/H), by the Atomic Energy Authority. Sinai groundwaters were contained in artesian aquifers at various distances and depths from potential recharge areas that are higher in elevation than the Abydos area. Age dates also indicate that recharge occurred under wetter climatic conditions than exist at present.

(1a)

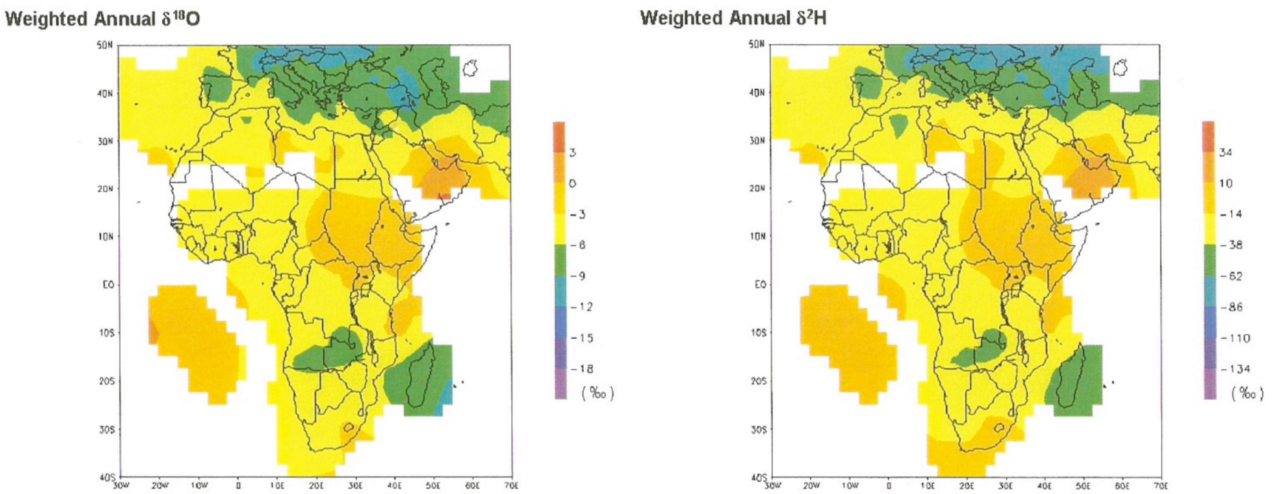
(1b)

Fig. 1: Water sample locations within the Abydos study area (a) and a close up of Osireion and Seti-I Temple (b).

The central portion of the Sinai is in an arid transitional zone between a desert and North African and southwest Asian Mediterranean climates. Both arid and semi-arid conditions prevail. Dames and Moore (1985) recognized six climatic regions. The region is noted for extreme aridity, low erratic rainfall, high evaporation, high summer temperatures and vigorous winds. Rainy months begin from October and extend until May. Mean annual rainfall ranges from 8.1 mm at El-Sheikh Attia toward the south to 35.4 mm at Saint Katherine station. Intense short duration storms result in floods. Surface elevations vary from <200 to more that 1,626 m above sea level.

ISOTOPIC DATA

Weighted annual $\delta^{18}O$ and δD values of precipitation in Africa are shown in Fig. 2. These data constrain the isotopic content of precipitation and, therefore, the initial isotopic composition of groundwater recharge. Various factors, such as evaporation, mixing, and relative humidity, influence both $\delta^{18}O$ and δD in time and space (Fig. 3).



http://www.science.uwaterloo.ca/~jjgibson/

Fig. 2: Weighted annual $\delta^{18}O$ and δD precipitation values for Africa.

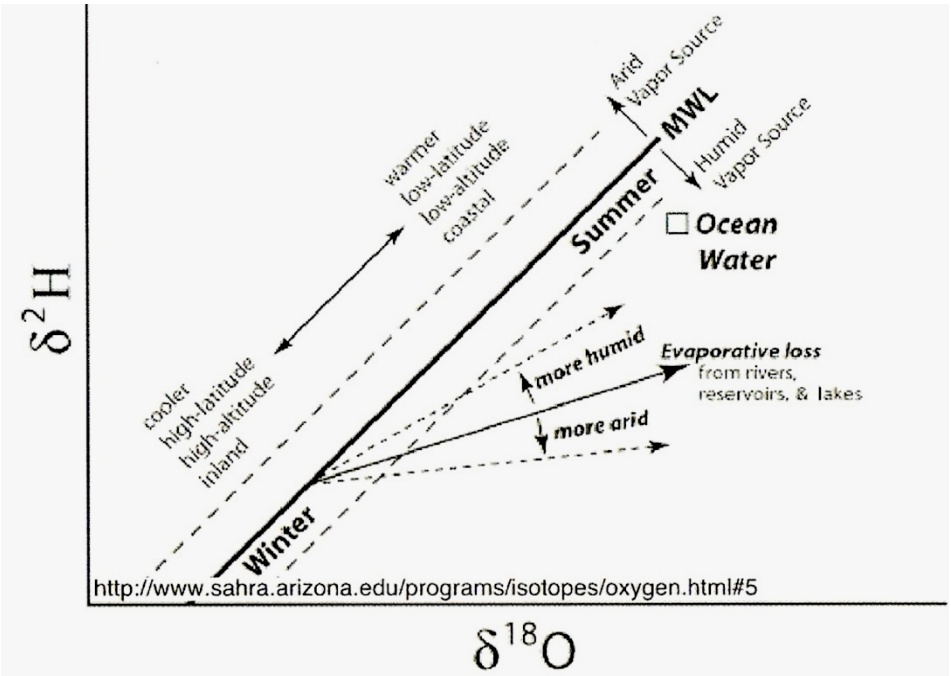
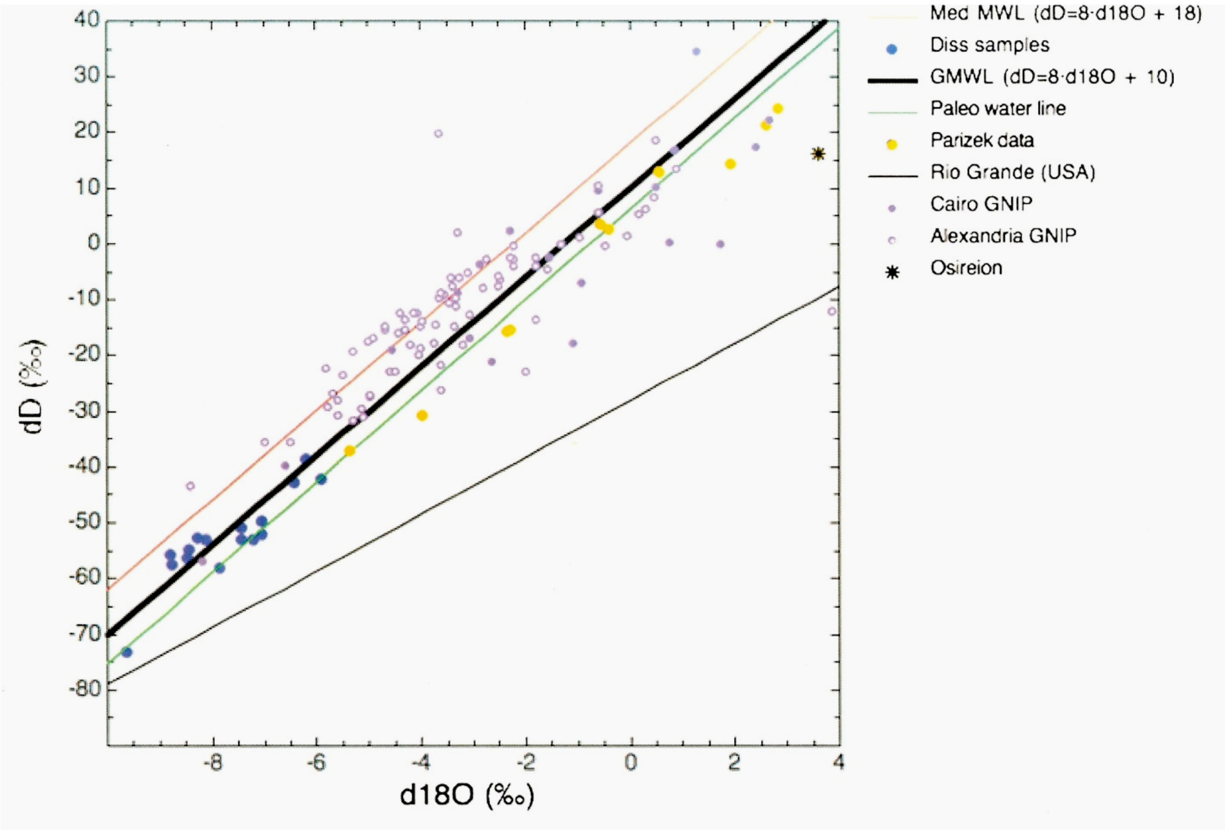


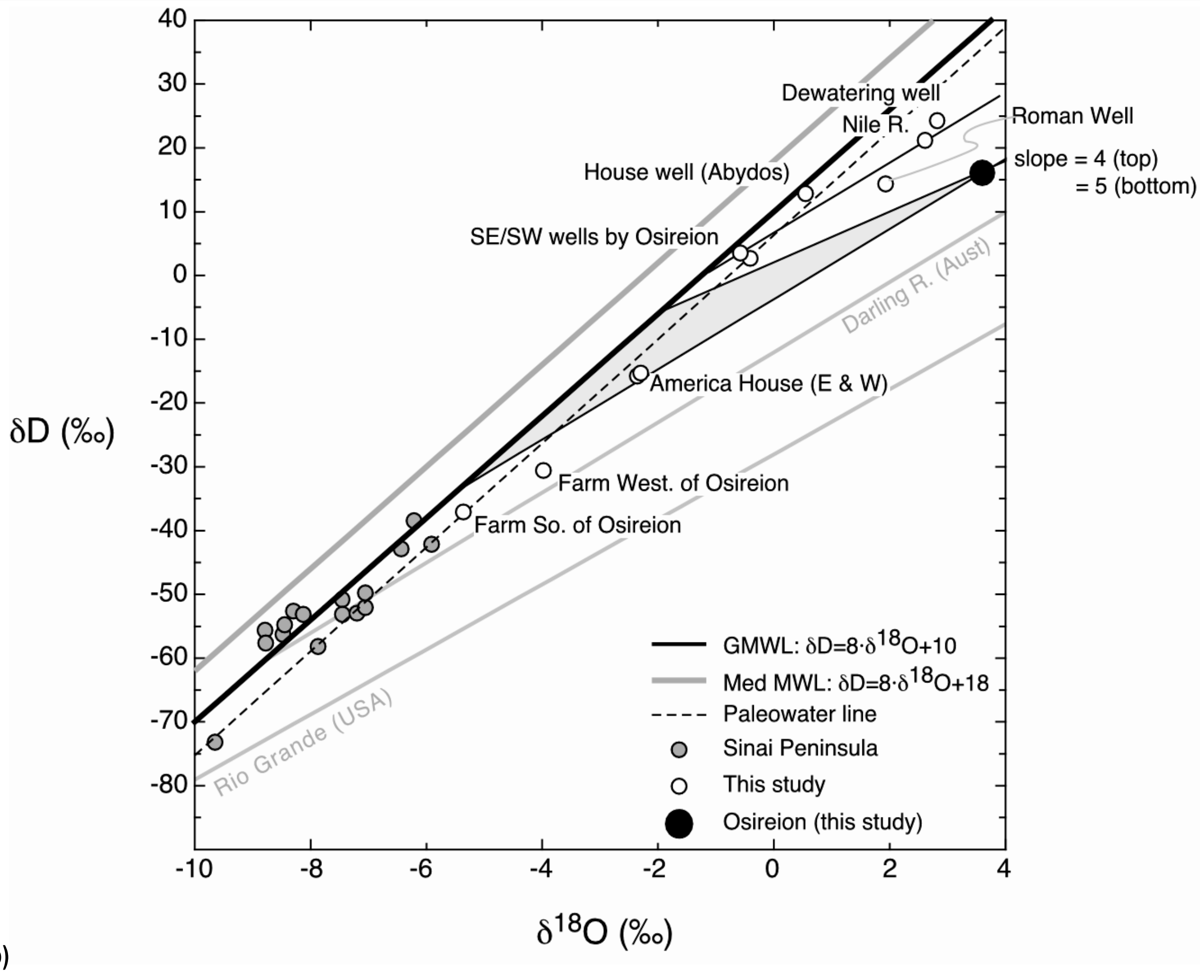
Fig. 3: Theoretical trends in $\delta^{18}O$ and δD as a function of low-and high-latitudes, low-and high-altitudes, summer and winter season, evaporation under more humid and more arid conditions together with the meteoric water (MWL) and standard mean Ocean.

In our study region, evaporation of ground-and surface waters can severely affect the isotopic composition of waters. We should note that climatic factors also affect the isotopic composition of precipitation, thus groundwater added to aquifers in the past ostensibly in wetter and cooler conditions, can differ substantially from present-day recharge.

An analysis of the $\delta^{18}O$ and δD data from the Sinai Peninsula and Abydos region (Fig. 4), in addition to PO_4, CL, Na+K concentrations and TDS (Figs. 5 and 6), suggest that waters sampled at Osireion are not easily explained by simple evaporation of any of the supposed end members. With regard to the isotope data, water samples collected in the Abydos region generally fall between the Global Meteoric Water Line (GMWL) and the previously-identified paleowater line (Bader El-Din) in a region expected of modern precipitation in arid, low latitude climates. In contrast, while the Sinai groundwater fall between the GMWL and the paleowater line, they are significantly lighter isotopically, suggesting that Sinai groundwater is comprised of water from cooler climates and/or higher altitudes. Radioactive ^{14}C data reveal that these waters are indeed older and were likely replenished under pluvial, inland climatic conditions.



(a)



(b)

Fig. 4: Evaporative slope trends for the Rio Grande River, USA, Darling River, Australia, the Meteoric Water Line (a), Sinai Peninsular, Egypt and Abydos water samples(b).

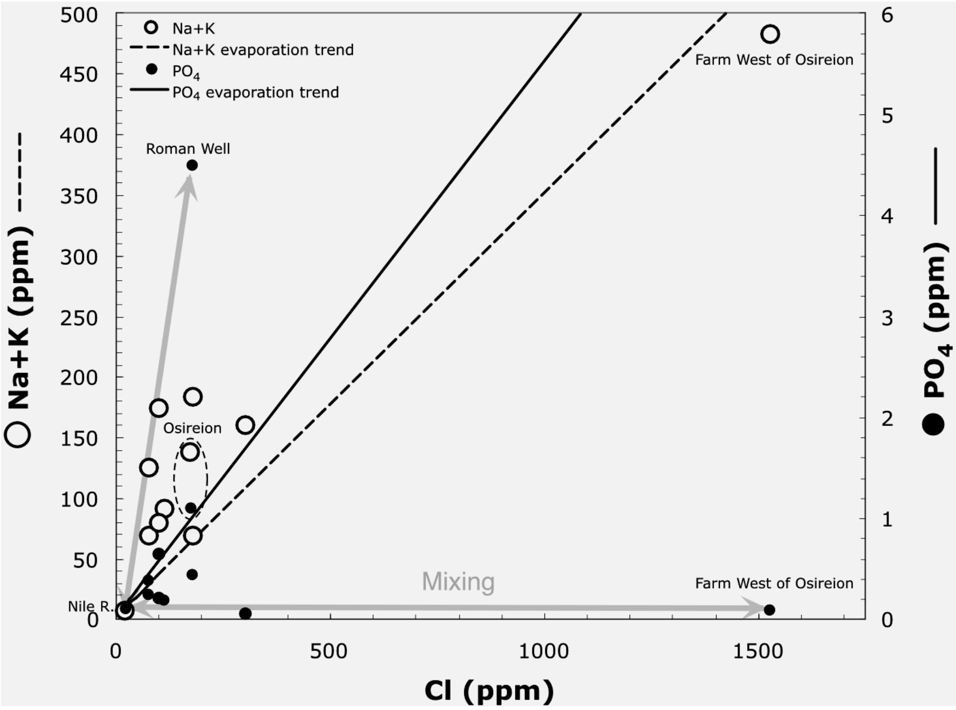


Fig. 5: Evaporation trends and mixing for sodium + potassium and phosphorous together with chloride.

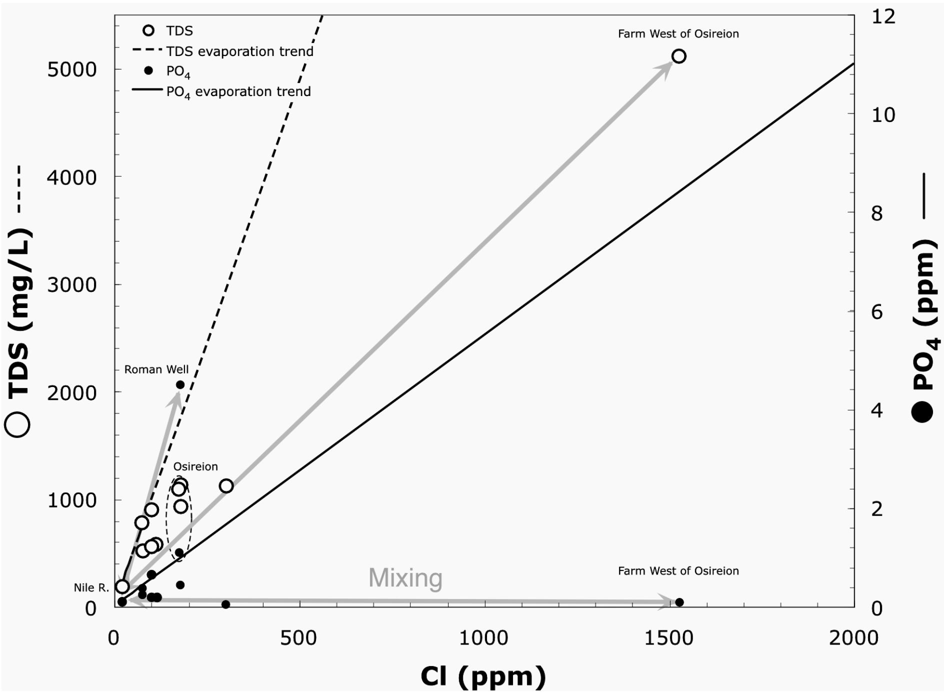


Fig. 6: Evaporation trends for total dissolved solids, phosphorous and mixing for chloride.

Of the water samples analyzed from the Abydos region, the Nile River sample appears the most affected by evaporation (Fig. 4b). This hypothesis is consistent with the degree of evaporation expected at the >500 km long Lake Nasser upstream, given the arid climate and significant surface area of the lake. Yearly evaporation and seepage losses in Lake Nasser average about 10.8 percent by volume of water in the reservoir estimated to be 140 billion cubic meters when filled to its maximum level (Sampsell, 2003). Abdel Moneim (1988) estimated the degree of aridity at Sohag as 0.267, indicating a desert condition, and estimated the rate of evaporation to be 2.4 m/year. While the isotopic data support the importance of evaporation, it is interesting to note that the Nile River sample is amongst the most chemically dilute of the samples measured (Fig. 5 and 6). Analysis of waters upstream of Lake Nasser is therefore, critical to constraining the degree of permissible evaporation.

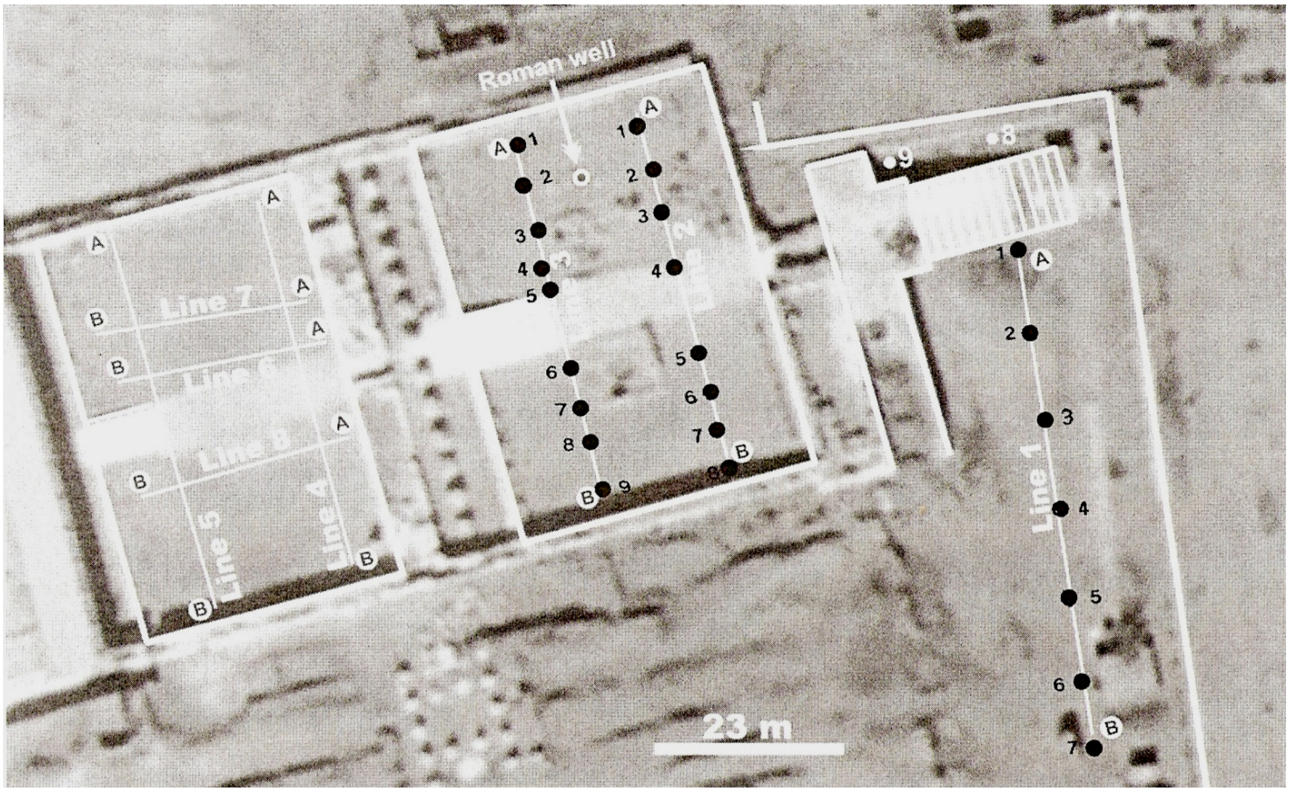


Fig. 7: Location of piezometers immediately east of the Seti-I Temple courtyard, interceptor and dewatering well.

The water sample obtained from the interceptor drain dewatering well at Abydos east of the Seti-I Temple, also shows an evaporative influence and is isotopically similar to Nile River water in this locale (Fig. 4b). The TDS-Cl and phosphate-Cl data support the idea that the drain water is derived from evaporation of a local Nile-like water, while the Na+K-Cl data suggest some degree of mixing and/or water-rock interaction in the system. This drain intercepts shallow groundwater intended to protect the Seti-I Temple against rising ground- and capillary-water and further accumulation of destructive evaporite salts. This drain is located somewhat distant from the western margin of the Nile flood plain where flood irrigation allows crop production on a year round basis. Waste water also is released from homes located immediately north and south of this drain as well as opposite the inner and outer Seti-I court yards located to the west of the drain. Nine piezometers were installed immediately in front of the Seti-I Temple outer court to define the water table configuration and to support a geothermal geophysical exploration program in search of a conduit that has been postulated to have been built to control the water level in the Osireion. Fig. 7 shows the locations of these piezometers.

Depths to the water table vary from 1.67 to 1.95 m within these piezometers set in silty sand and silty clay deposits. Their fine grain size facilitates the rise of capillary water. Destructive salts are present 1.0 to 1.5 m above the land surface on the stairway and outer retaining wall of the Seti I outer courtyard (Fig. 8). The height of capillary rise can range from 0.50 m for fine-grained sand to 3.0 m for coarse silt and 7.5 m for fine silt (Fetter, 1988).

Depths to groundwater within the interceptor drain vary from 0.955 to 3.64 m below land surface depending upon its pumping schedule. High groundwater evapotranspiration rates are to be expected within both vegetated and non vegetated areas near this drain because of the desert climate, shallow water table and fine-textured soils encountered in auger holes located in the area. Evaporation accounts for its isotopic value that plots below the GMWL (Figs 3 and 4b).

The dewatering well and interceptor drain are rather distant from existing cropland. All of our groundwater elevation data collected to date shows that groundwater flows eastward from the Osireion toward the Roman well and drain whenever the interceptor drain dewatering pump is idle or in operation (Fig. 1). Drawdown was 3.64 m after several hours of pumping. According to the operator, Abdel Hamed, this pump is activated about once a week. It would draw water eastward from the vicinity of the Seti I outer terrace and westward from paved areas and a small Ministry of Antiquities garden located to the east. This brief pumping schedule is not likely to draw irrigation return flows from cropland located some distance to the east of the interceptor drain, paved areas and garden.

Up until about the last two years, water was pumped from the Osireion and piped to the interceptor drain-dewatering well drainage system before being released to a drainage canal. During the 2007 field season, we observed that when the Osireion pump was in operation, groundwater levels were higher in elevation within the nine piezometers that were installed in front of the Seti-I Temple than when the pump was idle. These levels receded when the Osireion pump was shut down. The Osireion pump was idle during our May 2008 field season and removed for repairs before our January 2009 field season. Isotopic water samples obtained from the dewatering well were collected after the Osireion pump had ceased to operate for more than a year, hence was not likely to include a mixture of Osireion and local groundwater.

Osireion water would have to follow the existing eastward directed hydraulic gradient past the Roman well to reach the drain. Water along this flow path may contact natural undisturbed sediment as well as the postulated ancient Osireion drain.

The Roman well was hand dug and is open to 6.45 m within the outer Seti-I Temple courtyard (Fig. 1). Depths to water vary from 5.98 to 6.22 m. Very likely, this well is partially filled with wind blown sediment and debris. Its water plots below the GMWL reflecting evaporative enrichment. Evapotranspiration losses of local groundwater are precluded by the nearly 6.0 m deep water table and presence of coarse-grained sand and gravel that restricts the height of the capillary fringe within the outer courtyard.

Fig. 8. Accumulation of evaporite salts 1.5 m above the desert surface along the Seti-I Temple outer courtyard retaining wall. Dissolved salts are transported by capillary action. Hieroglyphs within limestone blocks are now almost completely destroyed. Shallow groundwater also is more highly mineralized near these walls reflecting the high rate of localized evaporation.

Domestic wastewater is disposed of in cisterns approximately 100 m to the north. It is not known if evaporative loss of domestic wastewater and animal wastes might contribute to its position below the GMWL. Osireion water enriched with $^{18}0$ and D flows toward the Roman well and may account for its isotopic content. The Roman well has a high Na^{+} +K content relative to Osireion water and a somewhat similar chloride content (Fig. 5). Chloride data support an eastward migration of Osireion groundwater but chemical reactions must account for elevated Na +K values noted. Elevated PO_4 may be derived from domestic sewage disposed of within the complex of homes located 5 or more meters above the level of the Seti I outer terrace that contains the Roman well. These houses are located on the Nile terrace above archeological debris, wind blown sand and the accumulated rubble of former homes that over time have raised the land surface. A small groundwater mound nourished by sewage and drainage from small feedlots may underlie these homes. If so, this could be a contributing source of PO_4 noted for the Roman well.

Birds frequent the Roman well, roost and seek shelter within niches in its brick walls and obtain drinking water. Their droppings could contribute to elevated PO_4 concentrations. No crops are produced within the desert surface that extends to the north, south and for some distance to the west of the Roman well hence, fertilizer sources of PO_4 are ruled out.

Water samples obtained from farm wells located west and south of the Osireion (Fig. 1) plot below the GMWL and are influenced by evaporative losses. These combination hand dug and drilled wells tap Nile alluvial terrace aquifers that are covered with archeological debris mixed with aeolian sands. The western Shafai Farm well is located along a shallow elongate depression, a short section of a small stranded wadi channel. Crops are irrigated on several small farms in the area. High evapotranspirative losses of irrigation water will enrich return flows in chloride and total dissolved solids. However, some mixing with other sources of water is required to account for the chemistry reported in the western farm well. To get 1,500 ppm chloride, Fantle concluded that you would need 99 percent evaporation of Nile water, the most dilute water in the system. This is regarded as too high an evaporative loss because the water table is deep within this Nile terrace setting. The property owner indicated that the water table was encountered at 27 m in this 65 m deep well constructed in 1993. The presence of sand and gravel together with deep water table precluded evaporative loss of groundwater directly from the underlying capillary fringe as a mechanism. Also, irrigation rates have to be high enough to prevent the lethal build up of salt within cropland. This should limit the chloride concentration of return irrigation flows that recharge the water table near these isolated, small farms.

The presence of elevated nutrient concentrations in the western farm well indicate that irrigation returned flows enriched with fertilizers is occurring on farmland west of the Osireion. No farm animals were observed in this area. However, both organic and inorganic fertilizers may be applied to this cropland. Moneim indicated that the water obtained from the western farm well may have been held in an open surface storage facility for some time hence, may not be truly reflective of local groundwater quality. Its chloride and total dissolved solids contents therefore, may be caused by excessive surface evaporation while in storage as suggested by Fantle's calculations.

The farm well south of the Osireion is newer and is used to irrigate an orchard on a second Nile terrace (Fig. 1). At present, water is obtained from a combined hand dug and hand drilled well 70.7 m deep. The water table was 24.2 m deep when the well was constructed. Previously, an aqueduct-like system was used to transport water from a northern well located lower in elevation along this or a younger Nile terrace to the orchard.

Regional groundwater flow is believed to be directed northward in the vicinity of this well within terrace deposits. A precise elevation of its wellhead has not been obtained. Brooks and Issawi (1992) ruled out leakage from the Nile low dam at Nag Hammadi and then to the south of Abydos. The Nag Hammadi pool elevation was reported to be 65 m in elevation, which was reported to be lower in elevation than the 66 m Osireion water level measured during this earlier study. On May 8, 2008, the Osireion water level elevation was 63.949 m and 62.819 m on January 14, 2009. These recent water level elevations would allow leakage from Nag Hammadi pool and northward flow toward the Osireion assuming that its pool elevation was still 65 m.

The eastern and western American House water wells are located north northwest of the Osireion (Fig. 1). These dug-drilled combination wells are located along a wadi drainage swale that leads toward the sacred gap in the western limestone desert plateau. This is the same swale that contains the western farm well. Local recharge is likely during rare-major-storm-flood events. Small gardens are present at the American House and wastewater is disposed of on site. New crop land is under preparation less than 0.5 km to the west along this drainage swale, but the first crops were not planted by the January 2009 field season. Water table elevations are not available for these two wells because of their seals. Isotopically, they deviate from the MWL reflecting evaporative influences. Of interest are differences in the δ D and $\delta\ ^{18}O$ concentrations in the two dewatering wells located just southwest and southeast of the Osireion (Fig.1). The southwestern well was hand dug 13.24 m deep and had a 2.89 m deep column of water during January 2009. The southeastern well is 14.87 m deep and contained a 2.25 m column of water. The water levels in these two wells are lower in elevation than within the Osireion. Neither of these two wells were pumped during the last two years nor was water pumped from the Osireion during the 2008 and 2009 field seasons. These water level elevations indicate that groundwater is flowing southward, possibly radially outward from the Osireion, whereas the regional gradient is eastward toward the Roman well and interceptor drain.

The Osireion isotopic composition is strikingly different from the two dewatering wells despite their close proximity. This may be attributed to evaporative loss of water. Westerman measured a 473 m^2 water surface within the Osireion when the central island is submerged. Water loving vegetation is present in a small hall immediately west of the island and very likely transpires more water per unit area than evaporates from standing water. The water level was 0.005 m below the level of the island on January 19, 2009. It had declined by 0.130 m between January 6 and 19, 2009. Older water stains are evident 1.5 m above the island but water stood only from 0.305 to 0.33 m above the island during our May 2008 field season. Some variations in conductance, specific conductance, salinity and temperature are noted depending upon where measurements are made in the channel.

The surface water level in the Osireion is approximately 13 m below land surface, which shields it somewhat from wind and exposure to sun. Stone block walls at and above the water level are beautifully dressed. Despite their tight fitting, joints are not likely to be impermeable. If the Osireion isotopic composition is enriched mainly by evaporation and groundwater flow is to the south, why are its $\delta\ ^{18}$O and D values in the Osireion so different from the dewatering wells? These data suggest that Osireion water is trapped in a nearly water tight structure, flow to the south is small, and most water is lost by evaporation and/or directed eastward along a postulated ancient drainage structure. If this were true, the dewatering wells would have to tap a different source of shallow groundwater that dilutes and masks southerly leakage from the Osireion.

A pump was used to lower the water level in the canal to allow excavation during H. Frankford's 1925 expedition. The groundwater inflow rate exceeded the capacity of the 16 hp steam driven 4-inch diameter pump. This limited the depth of excavation within the channel that surrounds the island to about 4.3 m. Ten or more meters of silt, sand, gravel and boulders remain in the channel based upon Westerman's mechanically probed depth of 10.4 m and Alexander's seismically estimated wall depth below the island of 15 m. Auger samples obtained during the 2008 field season showed that channel debris to a depth of 1.5 m below the water surface near the northeast corner of the Osireion contained a significant percentage of fine-grained sediment that could restrict upward leakage of groundwater through nearly 10 m of fill. Some of the water encountered during Frankford's expedition must have entered the channel along joints between stone blocks in addition to flow up through channel debris. If the walls are indeed nearly watertight, water may escape via a drain postulated to exist below the Seti I Temple to the east.

Fantle did a simple Rayleigh-type calculation to determine if Osireion water is mainly a result of evaporation of a meteoric source. On this assumption, isotopic data suggest somewhere between 20 to 25 percent evaporation at about 25 percent humidity, not a bad estimate for Luxor. However, the chloride data alone suggest more than 88 percent evaporation, so this hypothesis is not consistent with the two data sets. A deep source of chloride might be diffusing through or derived from the Esna Shale, possibly also from remnants of the Issawi Formation not exposed in the area. Chloride also could be derived from other poorly permeable strata within the thick Qena Formation within the Nile Valley. These are suggested as an alternate source of chloride. Osireion water plots alone with respect to the GMWL (Fig. 4b) when compared to other water samples obtained from the Abydos area and Sinai Peninsular.

The suggestion that water may be welling up within the Osireion under artesian head and flowing radially outward toward the southeast and southwest dewatering wells is supported by the following observation of Frankfort. When using a probing stick to attempt to determine the depth of its structure…"when, on the other hand, the stick was pressed down vertically, we found everywhere that a certain depth- 7.80 m below the ledge- the water acted with particular force upon the stick, and in fact pressed it upwards, spouting up after it when it was withdrawn…" Westerman also noted a flow of bubbles and water when his metal probing rod was withdrawn from its maximum 10.4 m depth of penetration. Aside from artesian pressure, gas bubbles also could be involved. CO_2 or other gases, for example, could be produced by decaying organic matter likely to be present deep in the channel, possibly also within the conduit assumed to extend eastward below the Seti Temple and beyond.

Had we been successful in drilling more than 8.05 m below the water surface within the canal during the 2008 season, a piezometer would have been left in the drill hole. It would have shown whether or not artesian flows help nourish the Osireion and would allowed for chemical analyses of deep v shallow sources of Osireion water. A boulder was encountered at the site where a single borehole was attempted. It could not be penetrated with the drilling equipment provided by the contractor.

SUMMARY

Osireion water shows a Nile isotopic signature but departs from the meteoric water line (MWL) due in part, to evaporation. Other ions present such as Na+K, CL and PO_4, indicate that its isotopic content cannot be accounted for entirely by evaporation (Figs. 4, 5, and 6). It is rather unique in the isotopic data field. The Osireion must contain water from a mixed source not typical of other waters included in the present Abydos data set. Possible sources likely to have a different chemical signature include water contained in deeper semi-confined pre-Nile alluvium and possible leakage from the Issawi Formation, which is not exposed near Abydos. Water also could originate for deep regional seepage even diffusion through the Esna Shale. The geologic map for the Sohag region shows normal faults with visible dips and probable, although concealed faults (Mostafa, 1979; Moneim, 1998). Faults with northeast-southwest and northwest and southeast trends are shown. These extend into the Eocene Limestone and very likely also into the Esna Shale below. Minor seepage associated with a regional groundwater flow system, the discharge area of which must be centered along the Nile Valley, could occur along such faults. Other sources of nourishment for the Osireion also are possible.

If artesian flows are an important source of nourishment, Osireion water must be flowing outward to the southwestern and southeastern toward dewatering wells as indicated by differences in water level elevation. This water must be diluted by shallow groundwater with a different chemical signature in order to account for the contrast in their isotopic content when compared to Osireion water. Westerman is correct in his belief that "Osireion waters are special" and justify further scientific investigation.

RECOMMENDATIONS

1. Various groups are interested in understanding the hydrogeologic setting of the Osireion and Abydos region. These include the Penn State-Sohag University - Westerman mission, efforts by the Egyptian Army on behalf of the Ministry of Antiquities, individuals from Switzerland and others. These site characterization efforts should be coordinated to maximize the value of information to be collected by these various groups, while at the same time protecting this unique archeological treasure.
2. Additional drilling is justified in the vicinity of the Osireion and Seti-I Temple for scientific and engineering stability reasons. Cores and drill cuttings should be collected and carefully logged for all new drill holes. These will reveal the presence and spatial variations of aquifers, confining beds and semi-confining beds that underlie the area, provide foundation support to archeological structures and that may have allowed deep excavation during ancient times.
3. All test wells should be screened, cased, capped and locked. This will allow monitoring of future changes in water levels and water quality, acquisition of hydraulic properties of these various units using pumping testing methods and the calibration of surface and subsurface geophysical signals. Some test wells should extend below the seismically estimated depth of the Osireion or below 15 m to address foundation stability and hydrologic issues.
4. Various independent lines of evidence suggest that a shallow unconfined and deeper semi-confined or confined source of waters nourish the Osireion. These sources are likely to differ in age and chemical character. New test and monitoring wells will support these investigations and should be completed to variable depths in search of hydraulic head and water quality variations..
5. A pumping test is planned to estimate the groundwater inflow rate to the Osireion. The lack of adequate pumps has thwarted this effort to date. Time-drawdown measurements should be made in all existing nearby monitoring and dewatering wells during this test. These data will shed light on the spatial variability of permeability within strata that surround the Osireion. Pumping levels should not be lowered substantially below those achieved by Frankford during 1925, without conducting a detailed concurrent subsidence survey on the Osireion and Seti-I Temple. Compressible

soils may underlie the Seti-I Temple and excessive drawdown could enhance subsidence of this unique temple by increasing effective stresses in response to reduced buoyancy. The central portion of the temple already shows evidence of differential subsidence.

6. **Two lines of test holes, each containing three wells, should be drilled in the inner and outer Seti-I courtyards. These would confirm the presence, width and depth of a natural valley or ancient canal extending eastward beyond the Osireion. These holes would be used to calibrate existing seismic survey, radar, soil temperature, water level, water quality and subsidence data that together, indicate the presence of a buried channel that extends eastward below the Seti-I Temple and courtyards.**
7. **Continuous soil cores should be taken from these drill holes in search of engineered voids, and compressible, organic sediments. The distribution of deposits encountered would differ if confined to a canal v having been deposited as layers or lenses of organic clay on the Nile or a pre-Nile flood plain or within an earlier drainage system. Carbon 14 dates should be obtained for any organic matter that might be recovered. If organic matter appears along a narrow east-west canal, ^{14}C dates are likely to reveal the age of organic matter than began to accumulate shortly after the canal was constructed. Judging from the vegetation that chokes existing water supply and drainage canals, only a few years might be required to accumulate sufficient datable material. These data would offer the best evidence of the minimum age of the Osireion and help answer the question, when was it built?**
8. **Organic rich sediment may exist near the base of the channel within the Osireion and could provide a minimum estimate of its age. Plants did not grow within the Osireion when its roof was intact and sunlight excluded. However, if ancients built a drain to control water levels or this drain was used to raise water levels in response to Nile stage changes, fine-textured organic matter may have been flushed into the Osireion during the annual flood. Sediment samples should be retained for ^{14}C dating and study as excavation proceeds to the base and foundation of the channel.**
9. **Hydrogeologic data obtained during our May 2007 field season revealed that water pumped from the Osireion entered the dewatering well and interceptor drain located east of the Seti-I Temple. This raised the water level in the drain and adjacent sediment extending westward at least to the Line 1 piezometers. Groundwater levels were raised in front of the Seti-I outer terrace in an eposodic manner each time the Osireion pump was activated thereby enhancing damage to the Temple rather than protecting it as intended. We recommended that a check valve be installed in the Osireion and interceptor drainage systems or other changes be made to prevent repeated future back washing and recharge of Osireion discharge water into sediment adjacent to this drain. Since the Osireion dewatering pump has been idle (2008) and removed (2009), this concern has been eliminated. A new design is needed when this dewatering system is rebuilt. When the interceptor trench dewatering pump operates alone, it lowers the water level in the drain as intended. Drawdown extends westward to the Line 1 piezometers by an undefined amount. Any lowering of the water table helps to protect the Seti-I Temple. However, water levels in several of the Line 1 piezometers that penetrated groundwater during the 2008 and 2009 field seasons is still too shallow to prevent capillary water from contacting Seti-I outer courtyard walls and staircase. The fine-grained nature of silt, silty sand and fine sands recovered when augering and constructing Line 1 piezometers supports a capillary fringe more than 2 m high.**
10. **Precise leveling of additional water supply wells located south, east and north of the Osireion is justified. More detailed seasonal water level maps could be prepared that reveal patterns of groundwater flow, changes in water levels and quality resulting from ongoing and future changes in land use.**

<u>APPENDIX II</u>

ABYDOS WATER ANALYSIS

EGYPT ATOMIC ENERGY AUTHORITY

Sample Location	Deuterium % vs. SMOW
A. DEWATERING WELL	24.26
B. NILE RIVER	21.20
C. OSIREION	16.12
D. ROMAN WELL	14.37
E. HOUSE WELL ABYDOS	12.83
F. S.W. WELL BY OSIREION	3.55
G. S.E. WELL BY OSIREION	2.69
H. NEW ROMAN WELL	-10.30
I. AMERICA HOUSE - EAST	-15.73
J. AMERICA HOUSE – WEST	-15.29
K. FARM WEST OF OSIREION	-30.57
L. FARM SO. OF OSIREION	-37.07

SMOW = STANDARD MEAN OCEAN WATER

APPENDIX III

ABYDOS WATER ANALYSIS

EGYPT ATOMIC ENERGY AUTHORITY

Sample Location	O18 % vs SMOW
A. DEWATERING WELL	2.85
B. NILE RIVER	2.61
C. OSIREION	3.60
D. ROMAN WELL	1.93
E. HOUSE WELL ABYDOS	0.55
F. S.W. WELL BY OSIREION	-0.58
G. S.E. WELL BY OSIREION	-0.41
H. NEW ROMAN WELL	-1.50
I. AMERICA HOUSE - EAST	-2.36
J. AMERICA HOUSE – WEST	-2.30
K. FARM WEST OF OSIREION	-3.98
L. FARM SO. OF OSIREION	-5.36

O18 = OXYGEN 18 ISOTOPE

SMOW = STANDARD MEAN OCEAN WATER