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Original article

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

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Abstract

Among the many wars which depicted and documented at the ancient Egyptian history, little of them 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 surrounding land surface. The channel was cleared of debris to 4.3m in 1925, but not to its original depth. Westerman (2008) successfully probed to 10.4m using a metal rod. Seismic data suggest its walls may extend 15m below the water table. Westerman listed 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. δ18O and δD were measured by EAEA and PO4, Cl, Na+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 groundwater by contrast are isotopically lighter, suggestive of recharge at higher elevation during cooler climates. δ18O, δD, PO_4, Cl, Na+K and TDS concentrations suggest Osireion waters are not easily explained by simple evaporation of any supposed end member. δ18O 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. Upfllowing from a semi-confined artesian aquifer, possibly also diffuse regional leakage through the Esna Shale are suggested.

Keywords: *Abydos temple, Groundwater, Isotope Data, Archaeology, Egypt*

1. 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. [1] 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?

2. METHODS

The oxygen (δ 18O) and deuterium, (δ D) isotopic compositions of eleven water samples collected in June 2009 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, and Sohag University, Egypt, fig. (1-a). 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, fig. (1-b), other samples were hand bailed from exposed water sources. Cations, anions and other constituents were analyzed by the Geology Department Laboratory, Sohag University, tab. (1-a, b). Isotopic data from the Sinai Peninsular, were included in some graphs for comparison. These were obtained from [2]. Sinai samples were analyzed for radioactive tracers (14C, 3H) as well as stable isotopic composition (18O/16O and D/H), by the Atomic Energy Authority. Sinai groundwater was 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.

Figure (1) **a** Location of archeological sites in Abydos **b** General view of the site b Sti 1st Temple

Table (1-a): Location and groundwater characteristics

Well Location	EC	TDS	pH
105	815	521	8,5
99	1768	1131	8,1
95	908	581	7,6
106	1464	936	7,5
113	1714	1096	8,0
116	1235	790	7,4
200	1752	1121	7,8
120	1412	903	7,2
122	1184	568	7,8
290	7790	5113	7,7
Nile water	305	195	7,3

Table (1-b): Result of the chemical analysis of water samples

Well Location	Units	Ca	Na	Mg	Fe	Mn	Cat.	HCO_3	SO_4	Cl	Anio.
105	ppm	20,0	126,0	5,0	0,218	0,039	151,3	214,0	71,0	74,0	359,0
99		72,0	184,0	37,5	0,430	0,008	293,9	475,0	83,8	177,0	735,8
95		40,0	92,0	15,0	0,030	0,000	147,0	198,0	67,0	111,0	376,0
106		120	69,0	42,0	1,020	0,150	232,2	250,0	192,0	177,5	619,5
113		56,0	138,0	38,4	0,490	0,000	232,9	317,0	110,0	173,0	600,0
116		120	69,0	36,0	0,290	0,011	225,3	445,0	134,0	74,0	653,0
200		80,0	161,0	42,5	0,102	0,0	283,6	174,0	192,0	301,0	667,0
120		120	80,0	37,0	0,380	0,121	237,5	448,0	62,0	99,0	609,0
122		60,0	175,0	2,5	0,540	0,000	238,0	195,0	240,0	99,0	534,0
290		561	483,0	169,0	0,270	0,000	1213	118,0	1000	1526	2644
Nile water		32,0	7,0	12,8	0,050	0,000	51,9	130,0	20,0	20,0	170,0

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) [8] 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.

3. 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). 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.

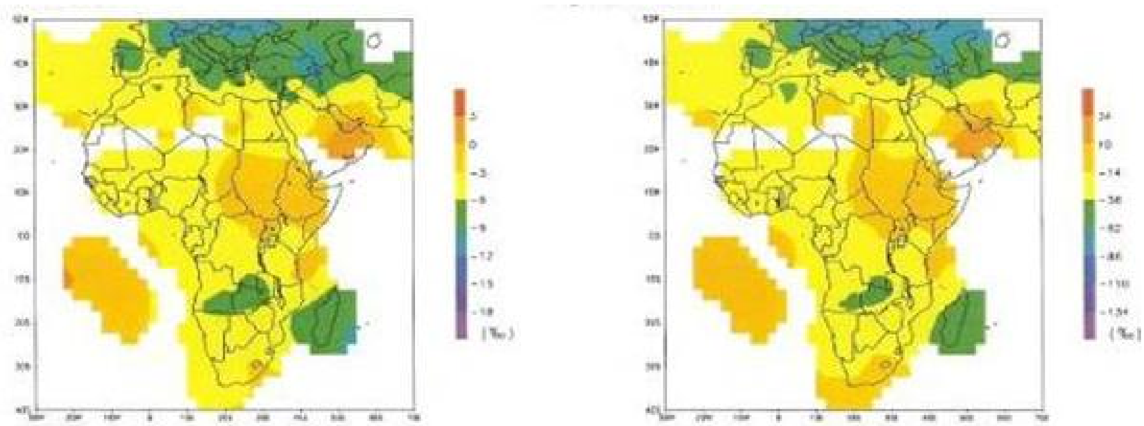

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Figure (2) Weighted annual δ18O and δD precipitation values for Africa.

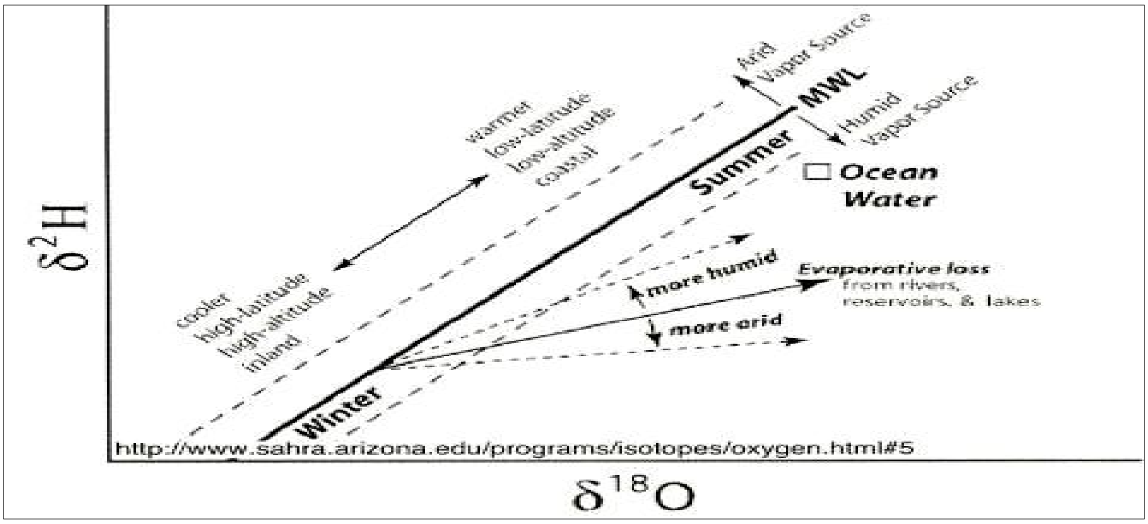

Figure (3) Theoretical trends in δ18O and δD as a function of low-and high-latitudes, low-and high-altitudes, summer and winter season, evaporation under more humid and more arid conditions together with the meteoric water (MWL) and standard mean Ocean.

An analysis of the $\delta^{18}O$ and δD data from the Sinai Peninsula and Abydos region, fig. (4-a), in addition to PO_4, CL, Na+K concentrations and TDS, fig. (5, 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 [2] 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. Of the water samples analyzed from the Abydos region, the Nile River sample appears the most affected by evaporation, fig. (4-b). 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 [3] [4], 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 most chemically dilute of the samples measured, fig. (5-6). Analysis of waters upstream of Lake Nasser is therefore, critical to constraining the degree of permissible evaporation. 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 evaporate 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, fig. (7) 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. (8) 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. (9). 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 [5]. 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 evapotrans-piration 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, fig. (3,4b). 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. 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 180 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, fig. (7), 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. This 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. Abdel 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, fig. (7) 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, fig. (7) 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. [6] ruled out seepage 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 δ 18O 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 locally 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 m2 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 δ 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.

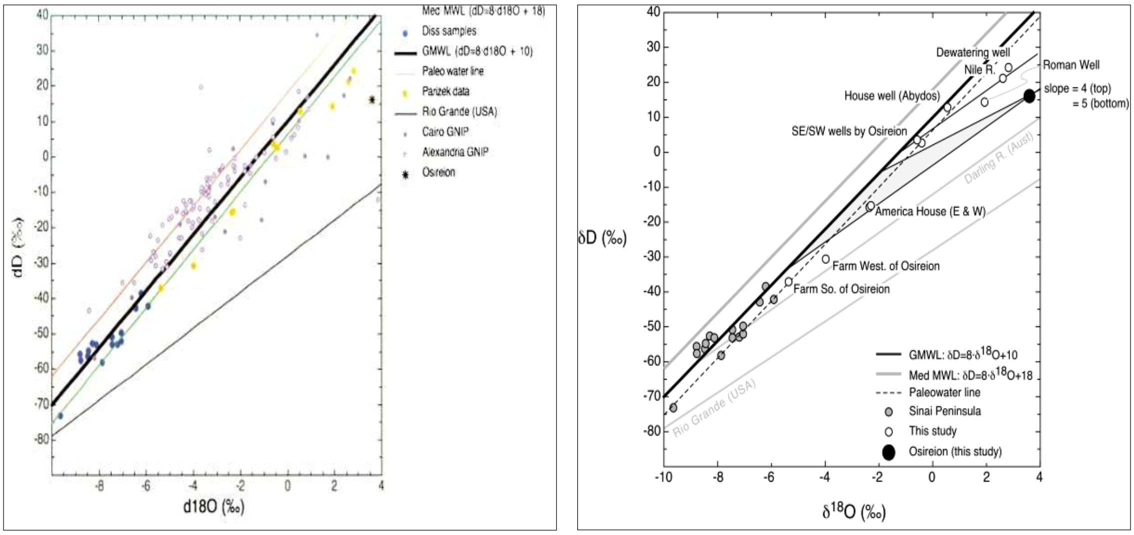

Fig. 4: Evaporative slope trends for the Rio Grande River, USA, Darling River, Australia, the Meteoric Water Line, **a** Sinai Peninsular, **b** Egypt and Abydos water samples.

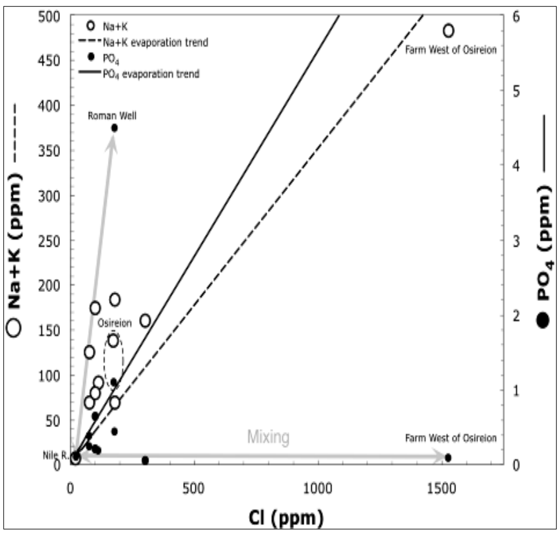

Fig. 5: Evaporation trends and mixing for sodium + potassium and phosphorous together with chloride.

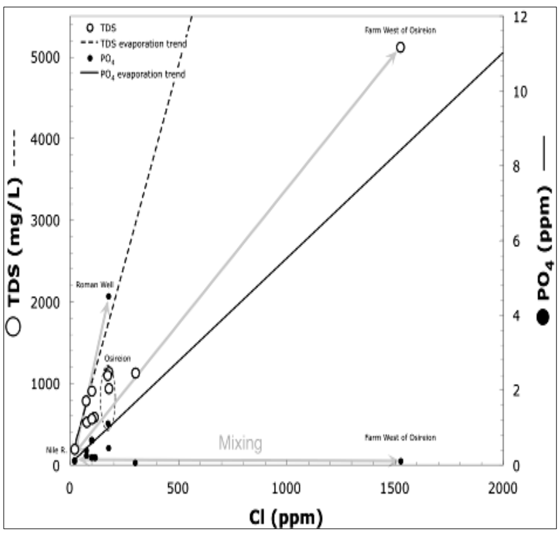

Fig. 6: Evaporation trends for total dissolved solids, phosphorous and mixing for chloride.

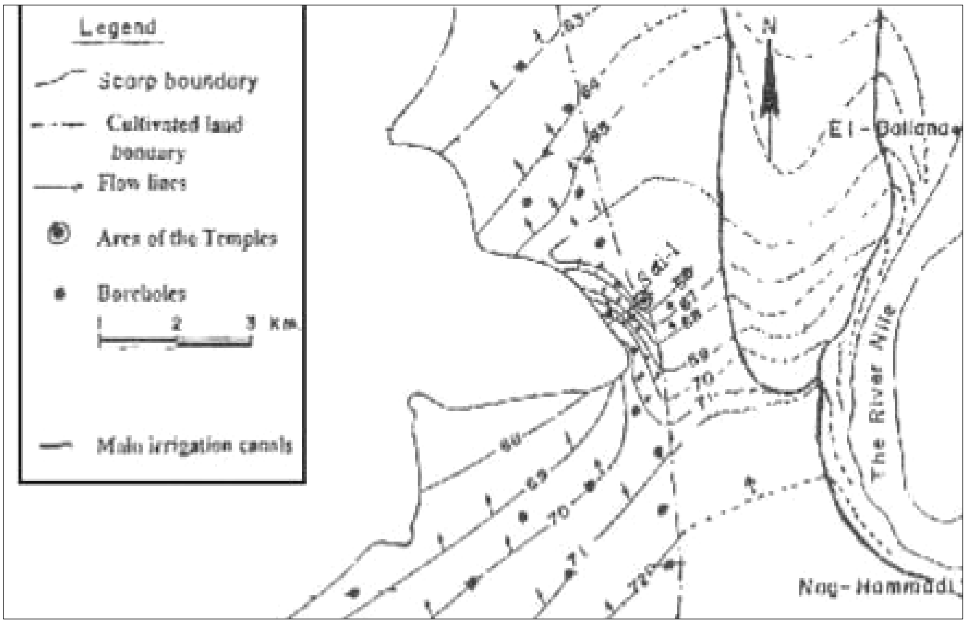

Fig.(7) Water table Map of the study area

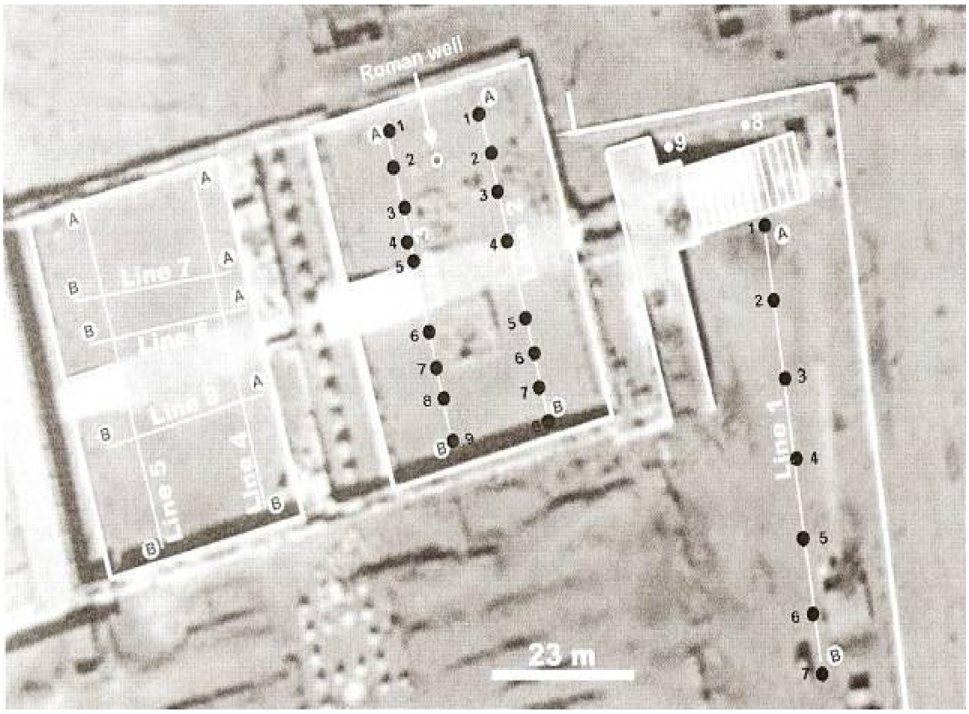

Fig. 8: Location of piezometers immediately east of the Seti-I Temple courtyard, interceptor and dewatering well.

4. Conclusion

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 PO4, 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; Abdel 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. Hydrogeological 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 episodic 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 auguring 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.

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