ARCHITECTURAL ORIENTATION AND EARTH - SUN RELATIONSHIPS IN PETRA

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Abstract

Using innovative geographic information systems (GIS) and extensive ground-based measurements, a significant number of Petra›s tombs, structures and monuments in this preliminary architectural inventory were found to display distinctive alignments with the Sun on its primary marker days of the solstices and equinoxes. Of Petra›s most prominent monuments, façades and structures, roughly >70% of the Nabataean structures were found to exhibit related orientation. Three categories of alignments to / with the Sun were identified: (1) structures facing the rising or setting sun on a marker day (i.e. Urn Tomb on solstices and equinox); (2) a structure in alignment (i.e. High Place of Sacrifice on the summer solstice sunrise) with the rising / setting sun intersecting a prominent landmark on the horizon (i.e. the peak of Jabal Harun); (3) exhibiting sunlight infiltration into chamber interiors (Palace Tomb at sunset during the winter solstice and equinox) where it illuminates pronounced interior niches, alcoves and / or sandstone glyptic features (i.e. notches; grooves). These findings may support Strabo›s early notion that the religion of the early Nabataeans focused on the worship of the Sun or, at least, it may link an early understanding of Earth - Sun relationships with Nabataean conceptions of urban planning and form, agriculture, philosophy, astronomy, architecture and / or cosmology.

Keywords: Petra; Jordan; archaeo-astronomy; Earth - Sun relationships; Nabataean religion

Roman architect Marcus Vitruvius Pollio (ca 75 - 15 BC) wrote, "One who professes himself as an architect should be acquainted with astronomy and the theory of the heavens. From astronomy we find the east, west, south, and north, as well as the theory of the heavens, the Equinox, Solstice, and courses of the Stars." (De Architectura Libri Decem I: 3,10)

The integration of the Sun in the design and orientation of structures and monuments is an age-old tradition having roots in worship, agriculture, health, wellbeing and comfort. Over time, the orientation of architecture with the annual passing of the Sun took on broader scales to include urban form, with significance placed on solar marker days (i.e. equinox; solstice) that were indicators of the passing year and its harvest (and ritualistic) cycles. The great megalithic structures of Stonehenge, Giza, Chichen Itza, Chaco Canyon and Newgrange, to name but a few, have been linked to these celestial paths (Sofaer 2007).

Our world is divided into four seasons, where the solstices and equinoxes represent gates into each season. The summer solstice marks the beginning of summer on 20 - 21 June, when the Sun is highest in the northern sky with a zenith of 23½°N (and lowest in the southern hemisphere). From the summer solstice, daylight will then decrease in length until the winter solstice on 21 - 22 December, when the length of daylight is the shortest and the length of night-time is the longest. On the winter solstice the Sun is lowest in the northern hemisphere sky, at a zenith of 23½°S, marking the beginning of the longer spans of daylight. The equinoxes, however, mark the midpoint of the solar year when the Sun is directly over the equator at noon (at zenith) and the length of daylight and night-time

are equal across the planet: 12 hours of dark, 12 hours of light on 20 - 21 March (vernal equinox) and 22 - 23 September (autumnal equinox). It is these solar marker days that define our sunlight cycles and dramatically influence agriculture, behavior, architecture and culture. The thrust of this preliminary research is to better understand how the Nabataeans of Petra integrated the Sun›s pathways and its related illumination onto facades and into chambers, to their individual structures and monuments, and also to the larger urban morphology of the city.

In Petra, such relationships have been implied since the early western writings of Brünnow and Domaszewski (1904 - 1909), Libbey and Hoskins (1905) and Bachmann *et al*. (1921). Research in the 1990s addressed relationships regarding the Theatre and its direct alignment with and orientation to the winter solstice sunsets, and the equinoctial orientation of the Urn Tomb (Paradise 1995). However, with the advent of innovative spatial analysis and geographic information systems (GIS), we are able to associate nutated solar paths to Petra's primary tomb façades, structures and chamber interiors (Paradise & Angel 2015). Rising and setting solar tracks, and their apparent horizon crossings on these annual marker days, were combined with tomb façades and chamber orientations. These were measured, analyzed and documented over years of research at Petra, with striking results. Not only were a significant number of façades found to be oriented in relation to solstitial and equinoctial paths, but interior niches and wall glyptics were found to be associated with these seasonal solar markers as well. The thrust of this research was to identify and inventory these associations for later interpretation and inference. However, at this time it is crucial that an inventory is created that records the Earth - Sun relationships with architecture in Petra.

The primary tomb chambers, façades, structures, monuments and broader urban orientations in Petra have been recorded as a part of a holistic research project and GIS (Paradise and Comer 2012). Both hewn and built structures were measured using GPS, laser and remote sensing, in addition to Brunton©, Sunnto© and Sokkia© measurement technologies.These precise locations and dimensions were combined with solar path risings (sunrise) and settings (sunset) on the solstices and equinoxes - vital relationships used in cultural, social, agricultural and religious rituals, designs, reckonings and feast-days (Sofaer 2007).

Analysis of the Urn Tomb was undertaken first since it had been initially identified as exhibiting these relationships of structure design and orientation to inner chamber illumination on marker days when, during the sunsets on both solstices and equinoxes, sunlight penetrated the back chambers of the Urn Tomb to illuminate the rear niches, and only on these days. It would follow that the Urn Tomb was either (1) hewn and oriented specifically to accommodate the entering sunlight or (2) the doorways were modified to permit this sunray penetration. In either case, this phenomena was not arbitrary, but calculated engineering by the Nabataeans. This was a bellwether of more relationships to be found linking the Sun to architecture in Petra.

In recent work, Belmonte *et al*. (2013) used associations between the Sun and facades to identify passing exterior shadows (i.e. ad-Dayr; al-Khazneh) to mark the important seasonal solar markers. Passing seasonal shadow-forms were the predominant focus of their findings - similarly speculated in the design and orientation of Petra's theatre 2,000 years ago (Paradise 1995). However, as our empirical investigations and computer analyses continued at Petra, it became apparent that a growing number of structures were oriented and / or designed and / or modified to create an association between the structure and the Sun›s paths on the seasonal marker days.

Methods

To understand these complex Earth - Sun relationships that were used in Petra›s city planning and architecture during its heyday, it was first crucial to create horizon diagrams, with aspects of precession, nutation and refraction,

in conjunction with topographical, proprietary horizon silhouettes (from each location's perspective) and various geographical data. It was the implementation of GIS technology that enabled this complicated analysis.

Using GIS technologies to investigate Earth and celestial relationships, however, presented challenges. The majority of GIS analyses are appropriate in terrestrial, topographic and distributive analyses, in both two- and three-dimensional landscape analyses. However, it is often difficult to combine terrestrial with astronomical data, especially when the representation and calculation of historic or prehistoric celestial events are required. These complex analyses were achieved by combining ArcGIS Python libraries *(ArcPy©; PyEphem©),* which merged terrestrial, astronomical and historic iterations while compensating for changes in precession and celestial refraction 2,000 years ago. Moreover, it was difficult, but crucial, to validate the legitimacy of these relationships without visualization. It was also necessary to substantiate these associations using the ArcGIS *Matplotlib* library.

The process was simplified by (1) collecting geospatial attributes for each structure, (2) analyzing all possible land-based obstructions between structures and between structures and solar paths, (3) generating a horizon diagram for each structure (i.e. Palace Tomb) and / or monuments (i.e. high places) and (4) overlaying these solar paths for specific events (i.e. sunset summer solstice) for the particular date (*ca* 20 AD). Using ArcGIS's Python libraries and *Matplotlib©*, analyses created topographical data from digital elevation model (DEM) vector data to create horizon diagrams displaying the solar pathways on the solstices and equinoxes.

The key to this study was to determine the solar paths that crossed Petra's skies, then and now. The Sun›s paths were generated for each structure based on their individual attributes (i.e. elevation; latitude; longitude). For example, a starting date was used in *PyEphem©* (i.e. 21 June 20 AD) to identify each solstice and equinox. Rising and setting times were then determined for that day and added to the horizon diagram for each structure. This analysis made it possible to recreate the passing of the Sun and its azimuth and altitude throughout that day - an analytical procedure difficult to conduct without this new technology. Fieldwork was then carried out in 2010 - 2014 to follow-up, corroborate and re-measure ground-based alignments, aspects and horizon diagrams.

Finally, each solar pathway was added to each horizon diagram on each annual marker day (i.e. solstice) from each specific perspective (i.e. from the Corinthian Tomb). In many cases, the sunrise and / or sunset passed below the horizon at a prominent landmark as well (i.e. Umm al-Biyāra; Jabal Hārūn). This upheld the hypothesis that the orientations of many of these structures at Petra were engineered and not accidental or arbitrary.

Findings

It was found that many Nabataean / Roman structures, tomb façades and monuments built during Petra's 'golden age' were designed, constructed and / or hewn in alignment with the Sun on the prominent marker days (solstices; equinoxes). Many of Petra›s primary structures were found to display solar alignments on the major solar marker / feast days with three distinctive purposes: (1) to face the rising or setting sun (i.e. Urn Tomb) and / or (2) to align with the rising / setting sun intersecting a prominent landmark on the horizon (i.e. the peak of Jabal Hārūn) and / or (3) to allow sunlight to penetrate chamber interiors where it illuminated pronounced interior niches, alcoves and / or sandstone glyptic features (i.e. notches; grooves). In addition, some sites and structures were found to have broader relationships with other special landmarks and lines-of-sight (i.e. Jabal Hārūn), or those co-aligned within the urban fabric itself. However, the focus of this research was to investigate the solar pathways and façade / chamber orientations of Petra's primary structures and monuments. Of the

thirty primary Nabataean - Roman structures addressed in the early inventories of Brünnow and Domaszewski (1904), Libbey and Hoskins (1905) and Bachmann (1921), many structures in this study exhibited Earth - Sun relationships - some obvious and significant, and some tenuous **(Table 1)**.

Alignments with the **summer solstice sunrise** were revealed in five (17%) structures including the Roman Soldier and Temple Tombs (Wādī al-Farasa) **(Fig. 6)**, and at Qaṣr al-Bint where the Sun enters between the far left-hand side (eastern wall) and column to penetrate to the back chambers during midsummer's eve. Al-Khazneh (the Treasury) was found to be in direct alignment with the axis of sunrise on the summer solstice. However, it appears that the high cliffs surrounding al-Khazneh at the juncture of the outer and inner siqs may obscure the early morning illumination. Mid-morning

Table 1: Inventory of the principal structures, tombs, and monument facades in Petra. Orientation of 30 facades and chambers were examined for solstitial and equinoctial relationships (sunrise, sunset). 85% of these structures exhibited alignments on a marker day. Note: B&D=Brünnow & Domaszewski documentation number, ESR= Equinox sunrise, ESS=Equinox sunset, WSR=Winter sunrise, WSS=Winter sunset, SSR=Solstice sunrise, SSS=Solstice sunset

* Each dark rectangle represents a relationship

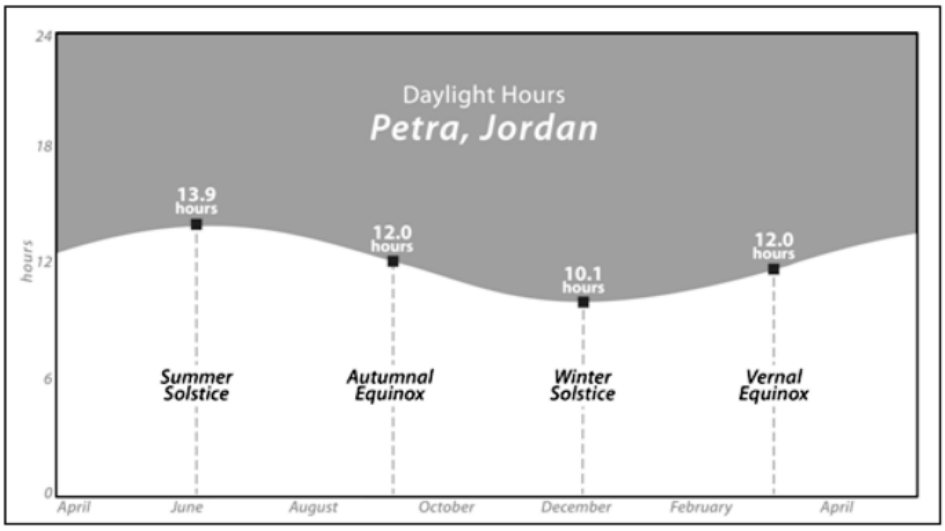
TOMB/STRUCTURE	B&D	ESR	ESS	WSR	WSS	SSR	SSS	COMMENTS
Ad-Deir (Jebel Deir)	462				■			Direct alignment with Jebel Haroun
Armor Tomb (Mughur an-Nasara)	649						■	
Broken Pediment (al-Farasa)	228		■		■		■	
Columbarium (Al-Habis)	395			■				
Corinthian Tomb (Royal Tombs)	766		■		■		■	
Entrance Tomb (Siq al-Barid)	----						■	
Garden Tomb (al-Farasa)	244		■		■			
High Place Sacrifice (al-Madhbah)	86						■	Direct alignment with Jebel Haroun
Southern High Place (al-Habis)	-----	■	■					Direct alignment south, equinox *(hewn face)*
Khazneh (Outer Siq)	62					■		Direct alignment *(although horizon is high)*
Lion Triclinium (Jebel Deir)	452					■		
Obelisk Tomb (Bab as-Siq)	34		■				■	
Obelisks (Madhbah)	90-89	■	■					Direct alignment along equinoctial axes
Palace Tomb (Royal Tombs)	765		■				■	
Pylon Tomb (Wadi Numeir)	270							
Qasr al-Bint (City Center)	403					■		
Renaissance Tomb (al-Farasa)	229		■		■		■	
Roman Soldier Tomb (al-Farasa)	239					■		Direct alignment *(although horizon is high)*
Sextius Florentinus (Mataha)	763						■	
Temenos Gate (City Center)	406							* No Earth-Sun relationship found
Theater (Outer Siq)	----				■			Direct alignment *(although horizon is high)*
Roman Temple Tomb (al-Farasa)	258	■				■		
Tomb 825# (Outer Siq)	825				■			
Triclinium (Bab as-Siq)	35						■	
Triclinium (Wadi al-Farasa)	235		■		■		■	
Turkmaniya Tomb (Turkmaniya)	633			■				
Uneishu (Outer Siq)	813		■				■	
Unfinished Tomb (al-Habis)	396	■						Direct alignment east (hewn cliff)
Urn Tomb (Royal Tombs)	772		■		■		■	
Winged Lions Temple (City Center)	422?							* No Earth-Sun relationship found

illumination of the façade is speculated, but requires empirical corroboration on the summer solstice.

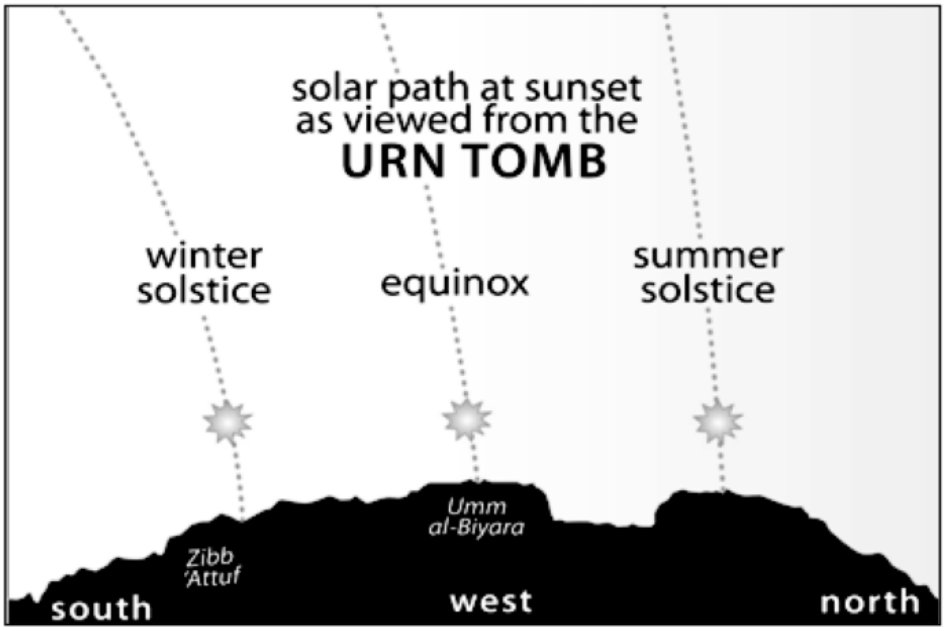
Orientations to the **summer solstice sunset** were found to be associated with ten (33%) structures, including the Palace and Corinthian Tombs (Royal)**(Figs. 2 - 5)**, Renaissance and Broken Pediment Tombs (Wādī Farasa), Triclinia (al-Farasa; Bāb as-Sīq) and the Entrance Tomb in Little Petra›s Siq al-Bārid **(Fig. 6)**. Most of these alignments also exhibited seasonal solar interior illumination of a hewn chamber wall, niche or glyptic feature.

Alignments with the **wintersolstice sunrise** were only related to two (7%) structures: The Columbarium (al-Ḥabīs east) and Turkmaniya Tomb. However, during the wintersolstice sunset, it was found that the Sun illuminates eleven tomb chambers (37%) in the main valley, including the Palace, Urn and Corinthian Tombs of the Royal Tomb Complex **(Figs. 4)**, and the ‹Uneishu Tomb on the western flank of Jabal Khuṭba **(Fig. 10)**.

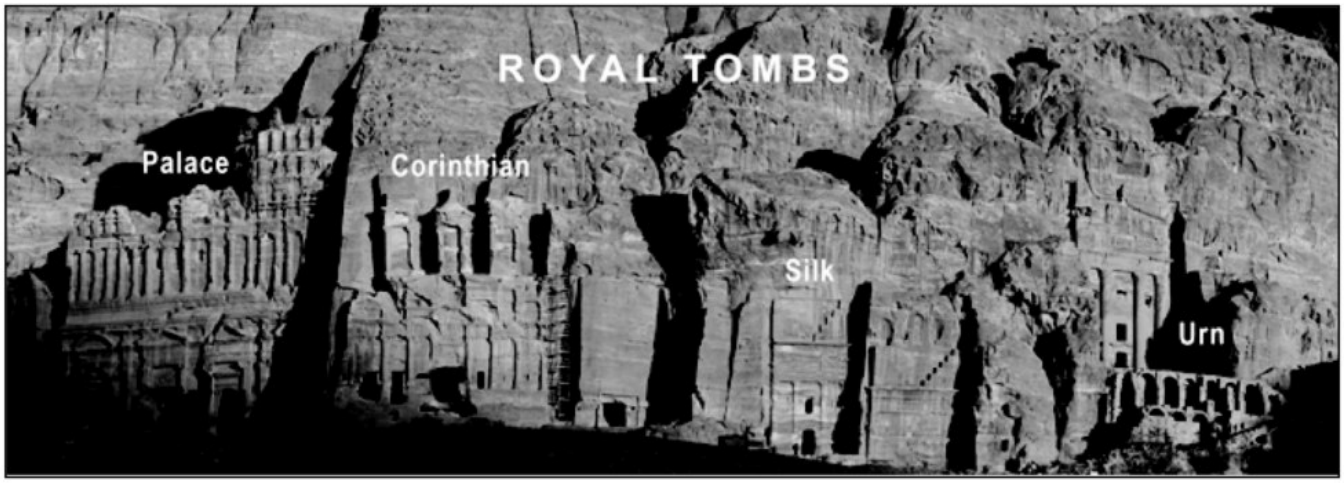
Beyond the main valley, it was found that the Triclinium, Renaissance and Broken Pediment Tombs in Wādī Farasa **(Figs. 6 and 7)**, the Lion Triclinium on Jabal ad-Dayr **(Fig. 10)**, the Obelisk Tomb and Triclinium at Bāb as-Siq **(Fig. 9)** and the Tomb with Armor on Muġhur an-Naṣārah **(Fig. 11)** all displayed alignments



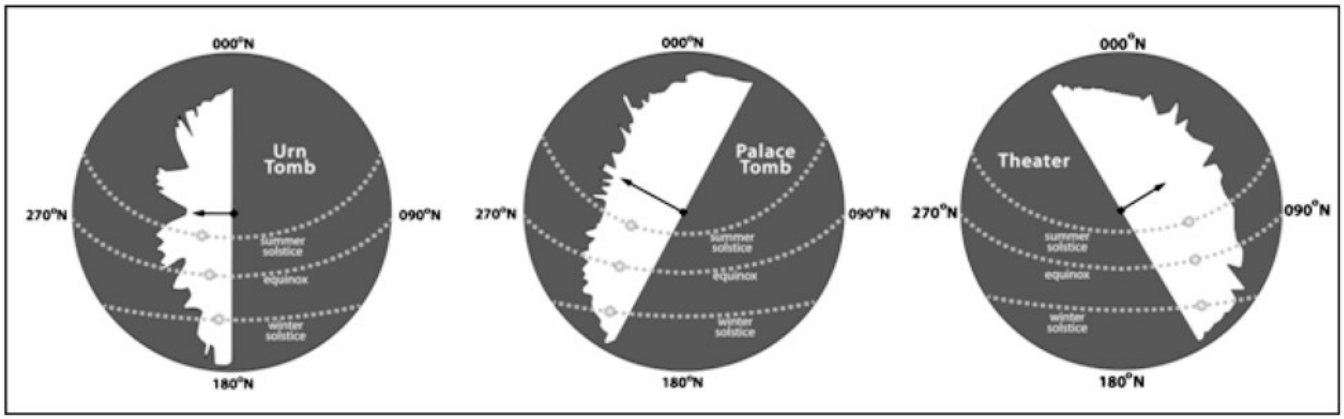
1.The illustration represents the daylight and night-time variation in Petra, Jordan (latitude 30°). On the summer solstice (the longest day of the year) Petra receives 13.9 hours of daylight, while on the shortest day of the year, the winter solstice, Petra sees 10.1 hours of daylight.



2. The graph represents the solar pathways of the Sun from the front of the Urn Tomb, on the marker days of the Solstices and Equinoxes.



3. The Royal Tombs are located at the base of Jebel Khutba and consists of the Palace, Corinthian, Silk, and Urn Tombs. On the summer solstice and equinox sunsets, sunlight illuminates the far corner niches of the main chamber of the Urn Tomb where the façade was aligned precisely along the true west cardinal alignment of 270°N. (see Figures 2, 4, 5).

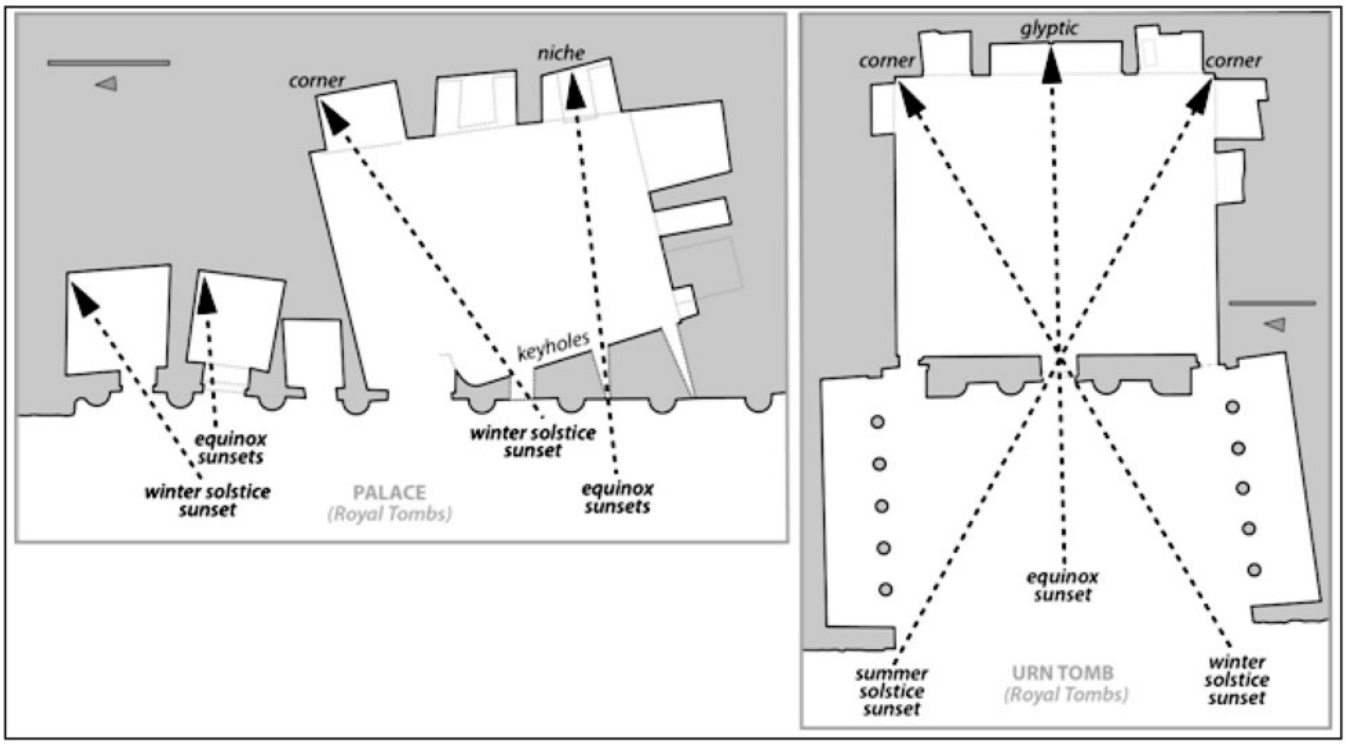


4. Horizon diagrams of two Royal Tombs, the Urn and Palace Tombs, and the Theater, displaying their marker solar paths. The two adjacent tombs (Urn, Palace) have distinctive, differing horizon markers during the summer solstice sunsets where the Sun sets on prominent horizon features: the towering plateau of Umm al-Biyara (Palace Tomb), and the famous burial site of Aaron, Moses brother, on Jebel Haroun (Urn Tomb).

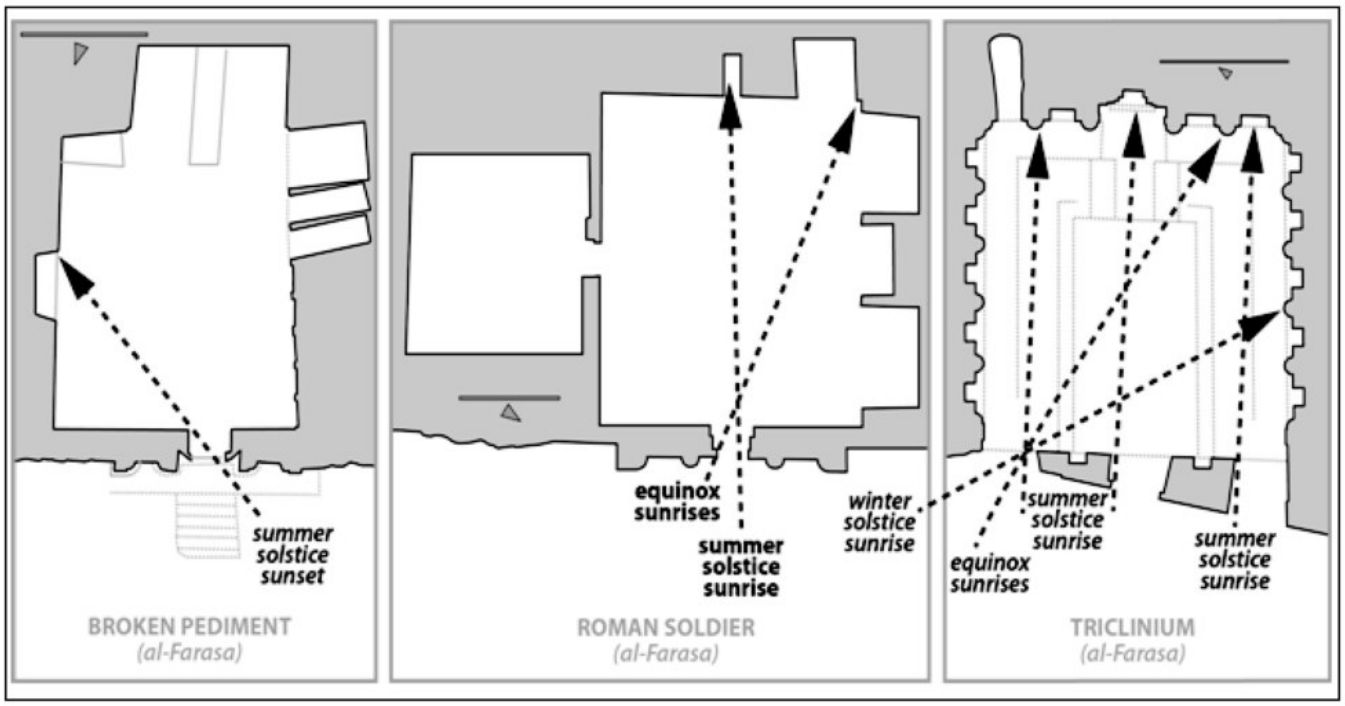
with the winter solstice. Direct winter solstice alignments were found in the main theatre on the outer siq and the Garden Tomb in Wādī Farasa **(Fig. 7)**, however the high cliffs which surround each site obscures the seasonal light-fall on these marker days at sunset.

Unusually, small "keyholes" or specific holes were hewn directly into the sandstone of many of these tombs and structures, in alignment with marker day illumination. Many of these keyholes do, indeed, allow sunlight to penetrate into tomb chambers like the Palace Tomb. However, we must ponder why similar ‹keyholes› were painstakingly worked into the stone at the Garden Tomb, with engineering precision, while the cliff faces obscured the possibility of in-chamber illumination on a marker day. For structures like the Theatre or Garden Tomb, we must question whether the precise orientation of these structures was planned or arbitrary, given that the equinoctial and solstitial illumination is actually somewhat obscured. However, when the alignment is within two degrees of meticulous solstitial alignment, were these alignments habitual and customary even when actual sunlight penetration (whether fully or partial) was not possible?

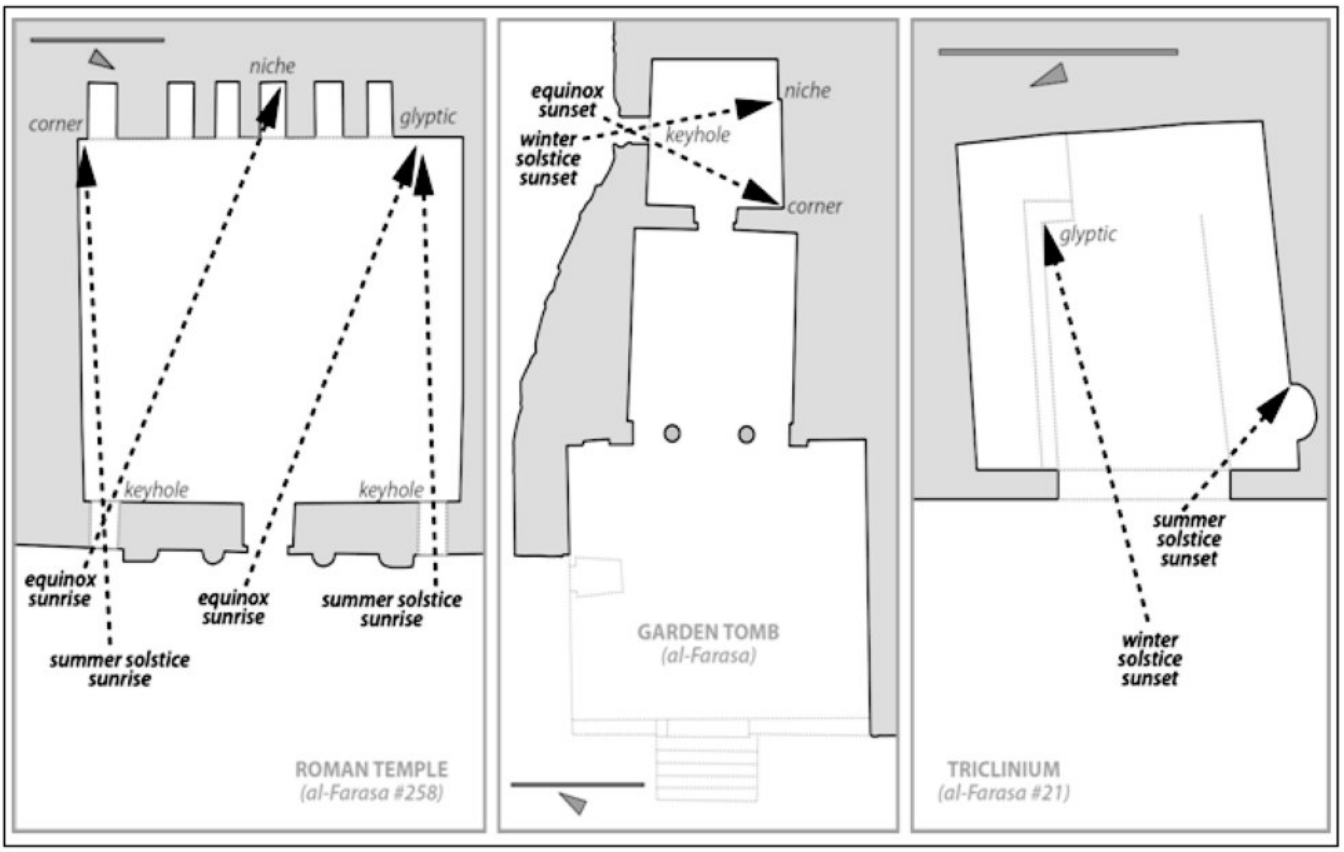
Equinox Sunrises were found to align with four (13%) structures, including the Unfinished Tomb (al-Ḥabīs east) and the Roman Soldier and Roman Temple Tombs in Wādī Farasa **(Figs. 6-8). Equinox sunsets** were found to align with and illuminate



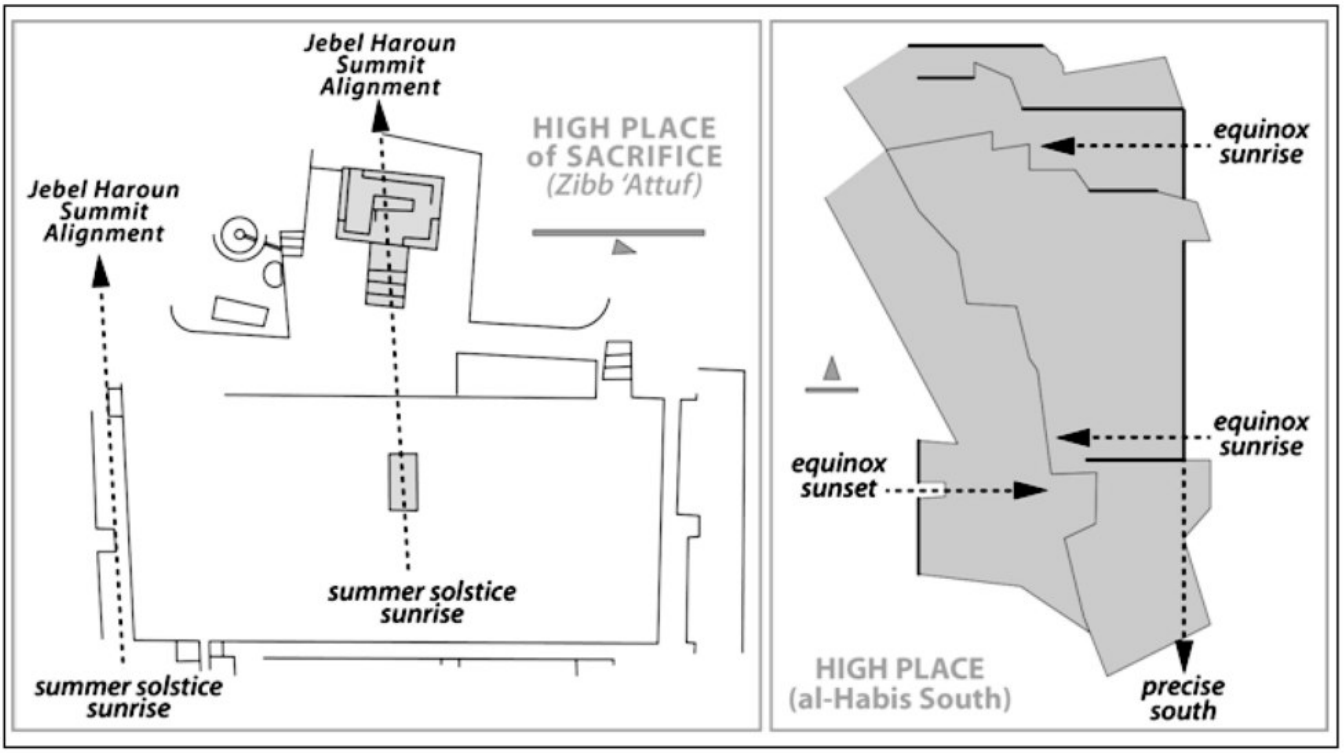
5. Plans of the Palace and Urn Tomb chambers illustrating the paths of incoming sunlight on solstices and equinoxes. The sunlight enters the Corinthian tomb through distinctive wall slits and doorways in the tomb façade. While in the Urn Tomb the sunlight enters through the central doorway. Not only do both tomb façades face prominent solistitial sunset points on the horizon, but also display remarkable (and engineered) internal illumination on the same solsititial sunsets.



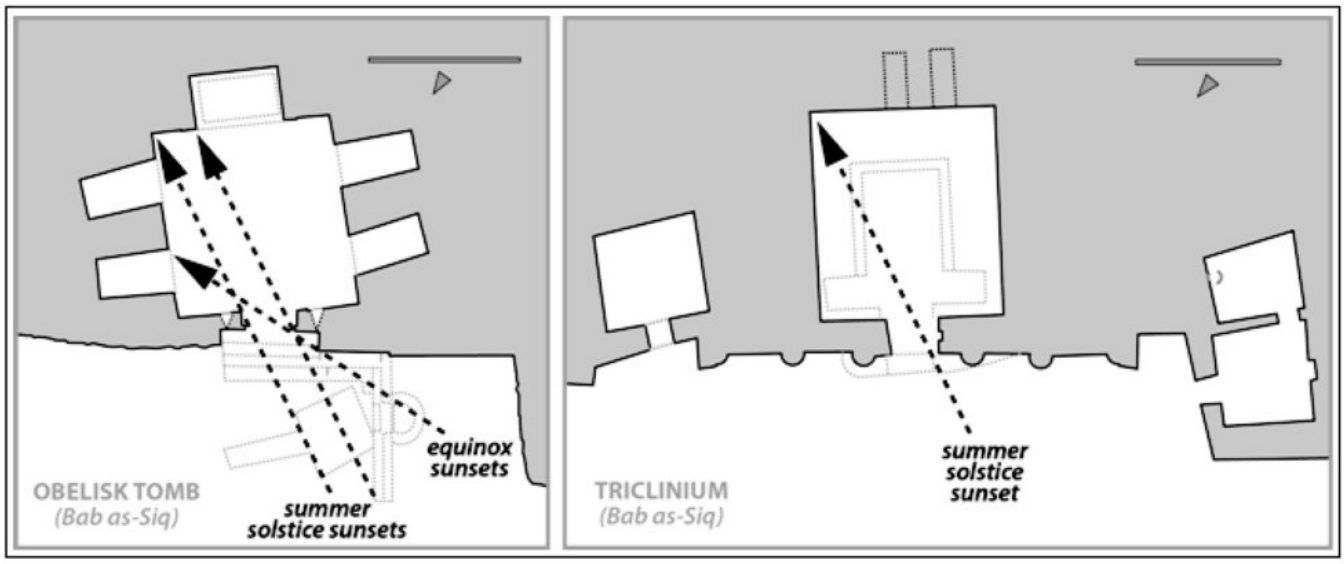
6. Plans of Broken Pediment, Roman Soldier, and Main Triclinium in Wadi al-Farasa showing interior chamber illumination on marker days: summer and winter solstices, and the equinoxes.



7. Plans of Roman Temple, Garden, and Triclinium #21 in Wadi al-Farasa showing interior chamber illumination on marker days: summer and winter solstices, and the equinoxes.



8. Plans of the High Place and Plaza (of Sacrifice), and the Southern High Place and Plaza on al-Habis showing alignments to distant landmarks (Jebel Haroun), and marker days illumination: summer solstice sunrise, and the equinox sunrise.



9. Plans of the Triclinium and Obelisk Tomb in the Bab as-Siq showing interior chamber illumination summer and equinox sunsets.

twelve (40%) structures, including ad-Dayr (the Monastery), the Lion Triclinium on Jabal ad Dayr, the Armor Tomb and Tomb of ‹Uneishu **(Figs. 10 and 11)**, and the Obelisk Tomb at Bāb as-Sīq **(Fig. 9)**. These structures were aligned with the east - west axes of the equinox, with primary aspects facing the sunrise in the east or sunset in the west.

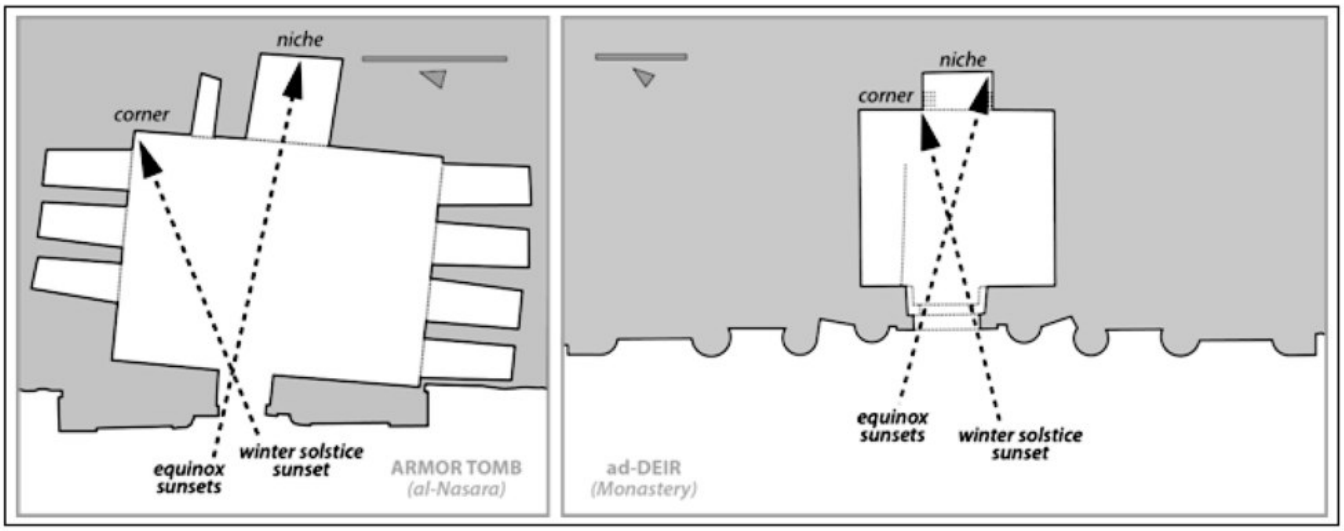
Some monuments and structures were found to have east - west alignments along the equinoctial axes without a specific aspect or façade, such as the prominent obelisks atop Jabal al-Madhbaḥ. Monument alignments with or along an east - west axis were use commonly to signify or define the passage of time between the dark and light halves of each year (on each equinox). The passing of the solar path between the northern and southern hemispheres marked the beginning and end of the dark (dormancy) and light (growth) stages on Earth - widely held notions of our earliest ancestors which represented agricultural, ritualistic, societal and practical divisions (Frazer 1900). Prior research indicates that the obelisks were objects of worship with little or no religious significance attached to their east - west alignment:

...They (obelisks) may have been left standing in the quarry in respect and reverence for Dushara, a kind of monumental group of standing stones, while all rock around was cut away. (Wenning 2001: 91).

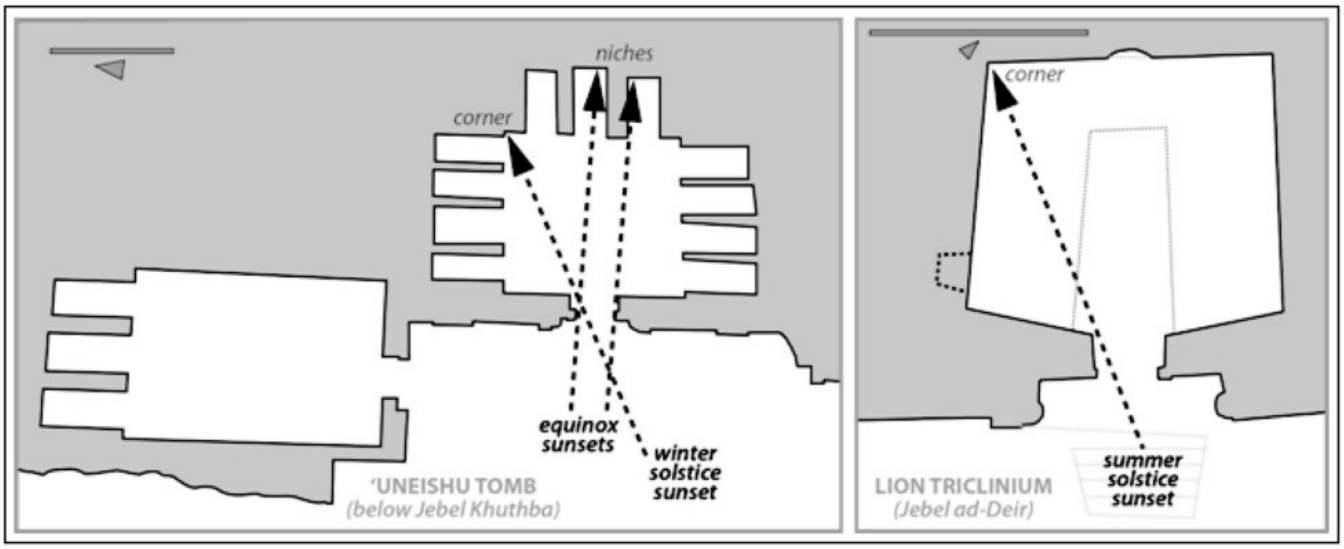
However, in addition to the obelisks on Jabal al-Madhbaḥ, the Southern High Place on al-Ḥabīs also displays distinctly aligned grooves, platforms and couloirs hewn into the sandstone along precise east - west lines. So, were these simply objects representing divine aniconic betyls (Wenning 2001), or were they also used to link this deific symbolism (i.e. Dushara block or betyl) to their aegis (i.e. agriculture; harvest; the Sun), with the equinox heralding the beginning and end of the harvest cycles. Whatever the motivation or function of these equinoctial alignments, they are seemingly intentionally engineered in their construction, location and precision.

Summary

Overall, this preliminary study represents a watershed work from which further research can be initiated and developed. These primary monuments, façades and structures represent some the earliest, and most prominently discussed and recorded, in Petra (Brünnow and



10. Plans of Tomb of Armor, and ad-Deir (Monastery) showing interior chamber illumination on the sunsets of winter solstice, and the equinox.



11. Plans of the Tomb of 'Uneishu, and the Lion Triclinium on Jebel ad-Deir showing interior chamber illumination on the sunsets of winter solstice the equinox.

Domaszewski 1904). Many exhibit distinctive alignments and / or orientations with the rising and setting sun on the solstitial and equinoctial marker days - many strong and obvious (i.e. Urn Tomb) and some lesser and relatively tenuous (i.e Qasr al-Bint). However arbitrary or accidental these alignments may appear, these early findings indicate that they might indeed be intentionally planned and engineered. The integration of the solar calendar into life and culture has been believed to be fundamental to Nabataean religion since Strabo first described individual homes as having altars for Sun worship on their rooftops (Strabo 25 AD). From early epigraphic evidence, it is believed that the Nabataeans "venerated celestial bodies" as a vestige of their origins in northern Arabia (Healey 2001). The worship of heavenly bodies commonly included the more visible planets (i.e. Venus), stars (i.e. Sirius) and the Moon. However, the Sun often represented the primary focus of adoration and observation since it was a marker of the seasonal cycles that influenced weather, comfort and agriculture (Sofaer 2007).

If the religion of the Nabataeans focused and / or exalted the power of the high places within

their theology / cosmology (Healey 1987) and these locations across Petra display distinct cardinal orientations (east; west; north; south) used in solstitial and equinoctial observations, ritual and / or celebrations, then Strabo›s reference to ubiquitous sun altars at Petra may imply that Nabataean worship of the Sun may, to date, have been somewhat underrated. It would follow that this preliminary inventory of Petra's prominent structures and monuments associated with Earth - Sun relationships is crucial to our understanding of Nabataean religion and society. As we delve into the complexities of Petra›s past, an understanding of the links between the Sun›s annual pathways and their relationship with Nabataean architecture may be vital to understanding Petra's culture, society, agriculture and even urban morphology and civic planning during its 'golden age' roughly 2,000 years ago.

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Bibliography

Bachmann, W. von, Watzinger, T. and Wiegand, T.
1921 Petra, Wissenschaftliche Veröffentlichungen des Deutsch-Türkischen Denkmalschutz-Kommandos.

Belmonte, J.A., Gonzales-Garcia, A.C. and Polcaro, A.
2013 "Light and Shadows over Petra: Astronomy and Landscape in Nabataean Lands". *Nexus Journal* 15: 487-501.

Brünnow, R. E. and Domaszewski, A. von.
1904-1909. *Die Provincia Arabia, 1 (1904),* 125–428.

Frazer, G.F.
1900 The Golden Bough. Macmillan Publishing (1920 reprint) Pp. 864.

Healey, J. F.
2001. *The Religion of the Nabateans*. Leiden-Boston-Köln-Brill Publishers. Pp.244.

Libbey, Wm. and Hoskins, F.E.
1905 *The Jordan Valley and Petra*. London and New York: G. P. Putnam›s Sons/ Knickerbocker Press.

MacKenzie, J.
1990 *The Architecture of Petra.* New York: Oxford University Press. Pp. 209.

Paradise, T.R.
1995 Sandstone Weathering Thresholds in Petra, Jordan. *Physical Geography* v.16: 205-22.

Paradise, T.R. and Comer, D.C.
2012 Cultural Heritage Management and GIS in Petra, Jordan. *ESRI Arc News Bulletin* (ANB).

Paradise, T.R. and Angel, C.C.
2015 Nabataean Architecture and the Sun: a landmark discovery using GIS in Petra, Jordan. *ESRI Arc User*: Winter-Spring 2015.

Sofaer, A.
2007 The Primary Architecture of the Chacoan Culture: A cosmological expression. *The Architecture of Chaco Canyon, New Mexico*. (S. Lekson, editor): University of Utah Press.

Strabo. 25 AD. *Geography of Strabo*. (Volumes 1-7, Books 1-16). Harvard University Press (reprinted 1967). Pp.516.

Wenning, R.
2001 The Betyls of Petra. *Bulletin of the American Schools of Oriental Research* (*BASOR*) 324: 79-95.