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# Enhanced Mathematical Method for Visualizing Ptolemy's Arabia in Modern GIS Tools

Keywords: Ptolemy, GIS, digital archaeology, history of cartography, ancient Arabia

*Summary*: In this paper we provide updates and enhancements to the mathematical method for translating ancient coordinates from Ptolemy's *Geography* into coordinates that can be used in modern GIS tools, such as ArcGIS and Google Earth. We also expand our coverage from India to Arabia, another historically important peninsular subcontinent of Asia. The enhancements we have made include novel techniques for identifying duplicates and handling tentatively identified points, instead of just known and unknown ones, surrounding the region of interest by known points from adjacent regions, and modifications to our two primary underlying models, triangulation and flocking. We compare the precision of reconstruction achieved for Ptolemy's Arabia with the precision that we had computed earlier for his India before the Ganges. We also provide improved validation and comparison amongst the methods applied. The combination of these enhancements with the expansion of our coverage to Arabia as described by Claudius Ptolemy represents a novel contribution to understanding of our cultural cartographic heritage by improving our ability to explore the ancient world using familiar and accessible GIS tools.

#### Introduction

This paper presents continuation of our multi-year study of the classical *Geography* by Claudius Ptolemy, a unique source that provides coordinates of 6,300+ locations known to the ancient scientist. These locations comprise capital cities, towns, villages, markets, harbors, anchorages, capes, bays, mountains, islands, boundary points (termini), lakes, river sources, mouths and bends, etc. Ptolemy supplemented his catalog with useful descriptions and other important information, such as the names of the legions that were stationed in certain cities and the names of the numerous tribes that once inhabited the vast territory of Europe, Africa, and Asia. In this work, we extend the scope of our research to Arabia, while refining our methods of numerical analysis of historical data previously applied to Ptolemy's West Africa (Gusev et al. 2005) and most of India (Abshire et al. 2015). A detailed review of the scientific literature relevant to the analysis of Ptolemy's Arabia is provided in the next section.

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Even though Claudius Ptolemy left us a rich and very valuable catalog, its interpretation and visualization pose a formidable challenge to the modern researchers, due to significant distortions of the true shape of the known world and the complications introduced by Ptolemy's book being a compilation. As a result, a lot of painstaking and diligent work is required to unveil the informational treasures of the ancient source and present the finds in a form convenient for the modern reader and viewer of maps. The essential initial step toward fulfilling this task involves identifying and georeferencing as many places as possible, 300+ of which, including some duplicates, are found in Arabia, a large region subdivided by Ptolemy into three provinces — Arabia Petraea, Arabia Deserta, and Arabia Felix. We discuss this complicated process in the third section of the paper. The nature of the data led us to extend our approach to point identification. Instead of just dividing the points into known and unknown ones, we introduced a new category of tentatively identified points, along with a separate category for duplicates.

Following and extending our computational methods previously applied to Ptolemy's India, we then approach the problem of approximate placement of the points that could not be positively or even tentatively identified and georeferenced. The part of India that we dealt with before is confined conveniently by its shores, the borders of the valleys of the Indus and Ganges rivers, and the Himalayas (Imaus Mountains). Taprobane (the modern Sri Lanka) is an island. Even though, like India, Arabia occupies a large peninsula, we need to surround the northern part of it with known points from the adjacent Ptolemaic provinces of Judaea Palestina, Syria, Mesopotamia, and Babylonia, in order to make our triangulation method with Bayesian adjustment work well. This important time-consuming task is covered in the fourth section.

The fifth section of the paper is devoted to the modification of the flocking method, our second numerical technique for approximate placement of points that was first tried on the India data set. A change in the formula for the computation of weights for the point's neighbors will yield an incremental improvement over the original approach.

We anticipated that the precision of numerical reconstruction that our methods can achieve would vary from region to region, according to the quality and quantity of knowledge about each region supplied by the ancient author, and in line with our own ability to identify and georeference points in the region. In the sixth section of our work, we compare the precision of reconstruction achieved for Ptolemy's Arabia with the precision that we had computed earlier for his India before the Ganges. The data for the flocking method for India is updated to reflect the newly introduced change.

Figures 1-4 provide a visual representation of our results achieved for Ptolemy's Arabia. We draw conclusions and outline the future research directions in the final section of the paper.

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Figure 1: Ptolemy's Arabia Petraea.

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Figure 2: Ptolemy's Arabia Deserta.

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Figure 3: Ptolemy's Arabia Felix (West).

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Figure 4: Ptolemy's Arabia Felix (East).

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## Literature Review

The best available complete modern translation of Ptolemy's *Geography*, the preparation of which involved comprehensive comparison of several Greek manuscripts, is the German translation by Stückelberger and Grasshoff (2006). It also supplies an authoritative Greek version of the original text. We used the electronic database of coordinates that accompanies the book and adopted its object IDs. Stückelberger and Grasshoff also suggest modern names for many locations mentioned by Ptolemy. However, in Arabia and the neighboring provinces their identifications often originated from the notes in a much earlier work by Müller (1883-1901). The quality of the only complete English translation by E. L. Stevenson (Ptolemy 1991) is known to be poor (Diller 1935). In particular, many toponyms in that translation are latinised unnecessarily. Nonetheless, we did use this source, along with the Greek original, to translate the German names into English, with minimum latinisation, given that very few if any of the toponyms found in Arabia were of Latin origin to begin with.

We found that the best two sources for point identification were the beautifully printed (Talbert 2000) and the online (Åhlfeldt 2015). They provided excellent coverage of Arabia Petraea and the rest of the ancient Nabataean kingdom. However, their precision in South Arabia often proved insufficient, and the latter of the two sources did not covered all of Arabia's territory. Also, the ancient names preferred by these sources often deviate from the Ptolemaic ones. Along the shores of South Arabia, the *Periplus of the Erythraean Sea* (Schoff 1912) proved a good guide, just like it did in the Western part of India before the Ganges.

We consulted with such classic sources on ancient Arabia as (Bonne 1771), (d'Anville and Horlsey 1791), (Robinson and Smith 1841), (Forster 1844), (Colton 1855), (Kiepert 1856), (Spruner 1865), (Johnson 1870), (Sprenger 1875), and (Dougherty 1930). Sometimes our sources contradict each other, so we have to make a choice. For example, unlike Talbert, Ahlfeldt, Stückelberger and Grasshoff, we take Ptolemy's Baitios River (commonly latinised as Betius) to correspond to Wadi Fa'idah, or Wadi Fayd, a stream that passes by the village of Fa'idah, or Fayd, on its way toward a harbor called Khawr al Buțān. This choice corresponds to the earlier one made by d'Anville and Horsley, who identified Betius as the streams then known as the Bardilloi. From Bonne's map, it is quite clear that one of the Bardilloi is the modern Wadi Fa'idah. Sprenger disagreed with d'Anville and Horsley on this matter and "moved" Betius approximately 630 km south to another suitably named stream, Wadi Baysh. Nevertheless, Sprenger still identified the nearby city of Macoraba as Mecca. Meanwhile, the town of Lathrippa, which Ptolemy places to the northeast from the mouth of the Baitios River, is positively identified by Sprenger as the ancient Yathrib (or Yatreb), the modern Medina, renamed al-Madīnatu n-Nabī ("the city of the prophet") after Prophet Muhammad during the Islamic era. Surprisingly, Stückelberger and Grasshoff miss this identification, even though Talbert and Ahlfeldt agree with it, having corrected the ancient name to read "Iathrippa." We chose to maintain the relative proximity of the Baitios River to both Mecca and Medina, instead of assuming a gross error by Ptolemy for no good reason.

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Useful modern publications relevant to the subject include (Bowersock 1971), (Brice 1974), (Potts 1984), (Groom 1986), (Munro-Hay 1991), (Potts 2001), (Beech 2004), (Almutairi 2011), (Izaksen 2012) and (Haerinck 2012). Gibson (2013) misidentifies Ptolemy's Betius River as Wadi Mawr in Yemen, approximately 780 km south from Wadi Fa'idah, shifts many points south using a simplistic mathematical formula, and takes Macoraba to be the modern city of Marib in Yemen. The latter is actually Ptolemy's Mara, alternatively written in some manuscripts as Marama, Baraba. Stückelberger and Grasshoff correct these misspellings to mean "Maraba." Gibson also misplaces Ptolemy's Prion River (latinised Prionis) to mean Wadi Dhahawn (Tīkhawn) that enters the Indian Ocean near the town of Al Ghaydah under the name Wādī al Jiz'. By this, he misses the significant Wadi Hajr located not far from Ptolemy's city of Mepha (ruins near the modern town of Mayfa'ah) by approximately 450 km. Gibson also misidentifies Ptolemy's Lar River (latinised as Laris) to be Dubai Creek, but it is actually the much longer Wadi al Bațhā' 60 km away, also known upstream as Wadi Lamhah. He is unaware of the aforementioned certain identification of Ptolemy's Lathrippa, and his mathematical manipulations lead, in particular, to Ptolemy's inland town of Mochura being superimposed over the modern Yenbu, or Yanbu, Ptolemy's Iambia village, a readily identifiable coastal place. In spite of these critical comments, we do agree with Gibson's identification of Ptolemy's Ormanus (Hormanus) River as Wadi Bani Khalid, a long and important stream in Oman that maintains a constant flow of water all year long and is known at its mouth as Batha River. We will deal with many other issues pertinent to point identification in the next section of this paper.

Among the publications that do not deal with Arabia, yet provide better understanding of Ptolemy's rationale and methods, we must name the monograph by Berggren and Jones (2000), which presents a nearly complete reconstruction of Ptolemy's Gallia, and the catalog by Tsorlini (2011) covering Ptolemy's Mediterranean and Black Sea region, along with a methodology for derivation of modern coordinates. Numerous references to other publications devoted to the mathematical analysis of ancient maps can be found in the literature review included in our paper on Ptolemy's India (Abshire et al. 2015).

## **Point Identification**

In the course of our earlier work on Ptolemy's India, we mostly used just one other source (McCrindle 1927) to fill the gaps left by Stückelberger and Grasshoff. In that situation, it was reasonably appropriate to divide the Ptolemaic locations into two categories — *known* and *unknown* points. That additional source was specific to India, so it did not cover Arabia. As we began to deal with Arabia, relatively many sources contributed to our decision process, sometimes contradicting each other. Talbert and Åhlfeldt routinely expressed uncertainty about their identifications, especially in Southern and Eastern Arabia. As a result, we found it appropriate to introduce the category of *tentatively identified* points. Meanwhile, in our maps of Ptolemy's India before the Ganges we had already spotted some likely duplicates, such as Salur and Selur, or Kaliur, Kurula and Karura, but left them all in, as they were located very near each other. Ptolemy's work being inevitably a compilation (Bagrow 1985), the decision to also introduce a separate category for *duplicate* points came to us naturally.

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#### Identification of Known Points

It proved relatively easy to positively identify many known points in Arabia Petraea. We corrected a mistake found in (Stückelberger and Grasshoff 2006): Ptolemy's Lydia is not a duplicate of his Lydda (the modern Lod) in Judaea Palestina; rather, it is a place in Arabia Petraea known to Åhlfeldt under the alternative ancient name Libba (the modern Libb). Similarly, Ptolemy's Anitha turned out to be the ancient town also known under the names Hatita, Aditha, and Adeitha (the modern Al Khirbah as Samrā'). However, the difficulty with using the identifications to search for the few remaining unknown points came from the known points apparently forming two overlapping clusters — the "Petra" cluster and the "Bostra" cluster. On a Ptolemaic map, it is fairly easy to see which of the known points "track" with Bostra, including Charakmoba (a duplicate of Corace, the modern Al Karak castle) and Gerasa (the duplicate of Gerasa in Syria, the modern Jarash), and which ones came with Petra (Korake, etc.). Alas, it is hard to tell which of the two clusters the unidentified towns of Gubba and Cletharro belong to. Our triangulation method places Cletharro close to the ancient town and copper mines of Phaino (the modern Feynan, Faynān), but we do not assign much weight to this result. More discussion and examples of point clusters in Ptolemy's *Geography* can be found in (Gusev et al. 2005).

Arabia Deserta was so sparsely populated that Ptolemy assigned several towns located on the fringes of the adjacent provinces to it. For example, Ptolemy restricted Mesopotamia to the area between the Euphrates and Tigris rivers so overly rigorously that many towns located on the southern bank of Euphrates were assigned to Arabia Deserta. One of such Mesopotamian towns formally assigned to Arabia Deserta is Ptolemy's Addara, the modern Deir ez-Zor. On the other side of Mesopotamia, the Assyrian town of Chatracharta (Hatra) was placed on the wrong side of the Tigris River. In reality, Assyrians lived on both sides of the Tigris. Likewise, Ptolemy's Eudrapa (Dura Europos) is found in Mesopotamia and therefore placed incorrectly on the northern bank of the Euphrates. Our main achievement in Arabia Deserta is that we have located the cluster of Ptolemaic towns consisting of Save (the modern As Suwayda, also known under the alternative ancient names Soada and Dionysias), Barathena (the modern Busan, also known as Bosana), Choke (the modern Shaqqa), and Aurana (Hobran) on the Syrian border, much closer to the Alsadamos Mountains (Jabal ad Durūz, Tall Hawrān) than shown by Ptolemy. We have also corrected the identifications of two towns assigned to Arabia Deserta, yet located on the outskirts of Arabia Petraea. Ptolemy's Artemita corresponds to the modern Ma'an, also known under the alternative ancient name of Ammatha, and not to Qasr Amra, which, in its turn, matches Ptolemy's Alata, the northernmost of the two Arabia Deserta locations so named. Stückelberger and Grasshoff follow Müller (1883-1901) in identifying Ptolemy's Dapha as El-Djob, and that's Al Jawf, the name of a province and formerly of a city called Algwaf in (Johnson 1870) and apparently swallowed by the nearby Sakakah, Schakik in (Johnson 1870).

The rest of the discussion in this subsection will be devoted to identification of known points in Arabia Felix. Conference Proceedings ISSN ..... - Riga, Latvia, 20-22 April 2016

In Arabia Felix, we were especially delighted to locate the source of water of the Styx River — "Wasser der Styx-Quelle" of the German translation by Stückelberger and Grasshoff (2006), "the fountain of the Stygian waters" of E. L. Stevenson's English translation (Ptolemy 1991). As the reader might recall, Styx is the mythical river of the Greek Underworld. It flows in the realm of Hades, and gods swear their oaths upon Styx. In Yemen, 32 kilometers away from historical Dhafar (Zaffār) that Ptolemy knows as Sapphara, the town of Hammām Damt (Damt, Demt) surrounds a spectacular volcano with a lake of hot mineral water in its crater. A tunnel was built in the volcanic rock to let the water out and establish a bathhouse. (The Arabic word *hammām* means 'bath'.) Hammām Damt is Yemen's premier mineral water resort featuring several sulphated hot water fountains (Al Kubati et al. 2015).

It was almost equally exciting for us to find Ptolemy's Vodona by following a fascinating story told by a 17<sup>th</sup> century French traveler Jean-Baptiste Tavernier (1677). We quote the relevant fragments of the story below, complete with our notes.

During the difference between the King of Persia and the Hollanders, the Emir of Vodana an Arabian Prince offer'd to shew them an easie Road from Mascaté [Muscat, Ptolemy's Kryptos, i.e. "hidden" harbor] to Balsara [the modern Basra, Iraq]... Had it been yielded to, the way had been from Balsara to Elcatif [the modern Al Qatif, Saudi Arabia, Ptolemy's Magindanata according to Hamad bin Seray (1997)] a Sea-Town in Arabia the Happy, where there is a Fishery for Pearls that belongs to the Emir of Elcatif. From Elcatif to Mascalat [Ptolemy's Masthala, tentatively identified as Mezairaa (Muzayri'), UAE] another City of Arabia, and the residence of another Emir. From Mascalat to Vodana, a good handsom City seated upon the meeting of two little Rivers that carry Barques to the Sea, and run together by the single name of Moyesur. The Soyl about Vodana produces no Corn, and very little Rice; but it abounds in Fruits... There are extraordinary good Melons and great Store of Grapes, of which the Jews, who inhabit the best part of the City, are permitted to make Wine... From Vodana to Mascatè it is but fifteen Leagues, though by the Maps, which are Erroneous, the way is describ'd to be much longer.

Slot (1995) mentions that, in a remark aside, Tavernier said that "Amir of Vodena later conquered Muscat." Slot further explains that this "Amir of Vodena" must have been Imam Sultan bin Sayf, who captured Muscat in 1650. Sultan bin Saif was the cousin of Imam Nasir bin Murshid bin Sultan al Ya'Aruba, the ruler of Nizwa, who died there in 1649. He left no sons, so Sultan bin Sayf was selected by the noblemen to succeed him.

Clearly, Nizwa is not Vodona, because Sultan bin Sayf could not be ruling it at the time of the meeting described by Tavernier. The name Nizwa is not similar to Vodona. Moreover, Nizwa is more than 130 kilometers away from Muscat by a straight line. This distance far exceeds 15 leagues (~72 km). Having previously identified Ptolemy's Lar River as Wadi Lamḥah, we were not surprised to learn that the Ptolemaic map was wrong here. At first, the wadi proceeds upstream in the southern direction from the Gulf for approximately 50 km, then turns east, toward its source, Wadi Sifūnī.

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However, on the road from Nizwa to Muscat, past a known archaeological pre-Islamic site at Samail, we find a place where two wadis meet to form Wādī Manṣaḥ (Tavernier's *Moyesur*). These two streams are named Wādī Bidbid and Wādī Nafʿah after the nearby towns. Of those two towns, Vodo-na must be Bidbid, known for an old fort. The town's name is likely derived from the Arabic word *nabidh* that means 'wine', cf. Hebrew *nofet*, 'honey'. The original name would have been Nabidh-Nabidh, offering some similarity to Vodona.

The route proposed by the Emir would lead from the mouth of Wādī Buḥayyiş or Wādī Samā'il up the river to Bidbid, then across the mountains to Nizwa, then, most likely to Ibri (literally, the Hebrew town, Ptolemy's Laibris), then to Mascalat (Ptolemy's Masthala), then to Elcatif (Magindanata). On the Ptolemaic map, the part of this route from Vodona to Magindanata bypasses the Lar River, which happens to be correct. But the relative positioning of Vodona and the "nearby" Nagara — the modern city of Najran, Yemen, actually located 1,600 kilometeres away from Bidbid — is terribly erroneous, so the vast Rub' al Khali sand desert is eliminated. If this mistake did not happen, we'd likely see the name Arabia Deserta elsewhere on the map.

Following the shore south from the mouth of Ormanus (Batha) River, we spotted Khawr Barr al Hikmān, a convenient harbor located between a town called An Nuqdah and a matching cape, Ra's an Nuqdah. We identify this harbor as Ptolemy's *Neogilla anchorage* and further suggest that the Ptolemaic name is a likely corruption of *Neogidda*,  $\Lambda\Lambda$  written mistakenly instead of  $\Delta\Delta$ .

D'Anville and Horsley (1791) reported that the city of Badeo had retained the name of Badea in its maritime position. A "point of land" which formed the southern boundary of the creek (Wādī Fāţi-mah), at the mouth of which the modern port of Jeddah is situated, was still called Ras Bad back then. The old downtown of Jeddah is presently known as Al-Balad, so we can safely identify Ptolemy's Badeo as Jeddah. This identification is consistent with that of the Baitios River mouth situated just north from Badeo, and with those of Mecca (Macoraba) and Medina (Lathrippa).

Numerous certain identifications of points marking the route along the southern coast of Arabia, from Muza market (the modern Mocha) to Ausara (Hasik), Zenobiu Islands (Khuriya Muriya), and the Island of Sarapis (Masirah) rely upon the valuable information found in the *Periplus of the Erythraean Sea* (Schoff 1912). Here's an illuminating fragment of the periplus, with our brief notes.

Beyond the harbor of Moscha [Sumhuram, Khawr Rawrī] for about fifteen hundred stadia as far as Asich [modern Hasik, Ptolemy's Ausara], a mountain range runs along the shore; at the end of which, in a row, lie seven islands, called Zenobian [modern Khuriya Muriya]... Sailing along this coast well out at sea for two thousand stadia from the Zenobian Islands, there meets you an island called Sarapis [Masirah], about one hundred and twenty stadia from the mainland. It is about two hundred stadia wide and six hundred long, inhabited by three settlements of Fish-Eaters, a villainous lot, who use the Arabian language and wear girdles of palm-leaves. The island produces considera-

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ble tortoise-shell of fine quality, and small sailboats and cargo-ships are sent there regularly from Cana [Qana', Hişn al Ghurāb].

Taking one (Ptolemaic or Attic) stade to be approximately 185 m long, it is straightforward to make sure that the size and location of Masirah Island are specified with good precision here. To give just one more example where the periplus helps, Ptolemy's Pseudocelis is confidently identified as Khawr Shūrī, the only harbor that can be mistaken for Khawr Ghurayrah, the harbor of Ocelis (Bi'r al Hālī) that, in its turn, can be easily identified from its description in the periplus. The Arabic word *bi'r* means 'well', and we can speculate that, unlike Ocelis, Pseudocelis did not provide fresh water.

The Greek name of Katakekaumene Island means 'burnt', 'burned down', so this must be a volcanic island. The modern name of one of such islands, Jebel at Tair, means 'Bird Mountain' in Arabic, so it is identified as Ptolemy's Ierakon Island, the 'island of hawks'. (Stückelberger and Grasshoff mistakenly translate "der Adler", i.e. 'of eagles'.) Another notable volcanic island, Jabal Zubayr, is then identified as Ptolemy's Katakekaumene Island by its relative positioning.

Unfortunately, the size of this paper does not allow us to discuss all identifications of the known points in detail. The tables of modern coordinates for known locations in Ptolemy's Arabia Petraea, Arabia Deserta and Arabia Felix are provided in Appendix A at the end of the paper.

## Identification of Duplicates

In addition to the aforementioned duplicate pairs (Corace-Charakmoba and two instances of Gerasa), Ptolemy's Adra (the modern Daraa) from Arabia Petraea has two duplicates in Syria — Adra and Adrama.

In Arabia Deserta, we believe that Luma is a duplicate of Lugana from Arabia Felix, the modern Linah in Saudi Arabia. Johnson (1870) shows this place as Lyneh. The town of Gauara is a possible duplicate of Koara or Goaria in Syria (ancient Sauara, modern Aş Şawarah al Kubrá). Idicara is a likely duplicate of Iucara (the modern Jahra), or, perhaps, even of Idicara in Babylonia, the modern Hīt, a town located near the point where Wadi 'Īdī enters the Euphrates. Gadeirtha is a possible duplicate of Addaia in Mesopotamia, the modern Haditha. Contrary to the identification proposed by Stückelberger and Grasshoff following Müller (1883-1901), Gadeirtha is definitely not Ğedeide, the modern Jedeide (Jdaide, Jdeideh) in Lebanon, which is too far away.

Ptolemy lists three places in Arabia named Salma. The one assigned to Arabia Deserta is not Hail, in another contradiction to Stückelberger and Grasshoff. Rather, it's the modern Sihmah, the town called Salema by Bonne (1771) and Selimah by Johnson (1870). The Salma located near Hail, Al Samra (next to a mountain called Jabal Samrā') is, actually, Salma-2 from Arabia Felix. Salma-3 corresponds to the ruins near Al Yamamah, 5 km away from the modern As Salamīyah. We believe that these three places are not duplicates.

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In Arabia Felix, Mariama is a duplicate of Marimatha, the modern Maryama. Saruon is a duplicate of Sylaion, the modern As Sarw. Sochchor is placed inland, where it may be a duplicate of Sachle, the modern As Safra'. Alternatively, it may correspond to the coastal city of Ash Shiḥr. Dela is a duplicate of Hyaila, the modern town of Ad Dali, also known as Dhalie, m-Dakhla, and m-Dakhayla. One of the towns named Gorda is a possible duplicate of Giratha (the modern Haradh). Carna is a possible duplicate of Carman: the word *qarn* means 'horn' in Arabic, so we should expect to encounter a place named Carna in the mountainous area. Atia is a possible duplicate of Appa. Marasdu and Amara are possible duplicates of Maraba (the modern Marib).

Laththa is a likely duplicate of Lattha, which is tentatively identified as the modern archaeological fort of Maleha, a place also called Al Malaiha, Meliha, Maliha, Mlayha, Mulayhah, Mileiha, and Mleiha. Alternatively, Lattha may correspond to Lamhah, a dune adjacent to Wadi Lamhah, Ptolemy's Lar River, while Laththa may represent the oasis of Layla.

Ptolemy's Atta is a likely duplicate of his Magindanata, tentatively the modern Al Qatif. Hamad bin Seray (1997) plausibly derives the name Magindanata from the Aramaic *mdinta Hatta*, an equivalent of the Arabic Madinat al-Khatt. He explains that Qatif used to be called al-Hatt, or Al-Khatt. A cape named Ra's al Khaththāq currently exists nearby.

Thabba may be a duplicate of Sabbatha, which corresponds to one of the two Yemeni towns named Shabwah, specifically, to the ancient capital of Yemen located at lat = 15.3684, lon = 47.0228. Talbert and Åhlfeldt mistakenly use coordinates of the other Shabwah: lat = 14.5440, lon = 45.9097. It is not inconceivable that Thabba represents this other Shabwah.

Ptolemy lists two locations in Arabia Felix named Sabe. Yemen, the land of ancient Sabaeans, offers many tempting choices for tentative identification, which will be discussed in the next section.

In Mesopotamia, Ptolemy's Rhesaina and Sacane are both believed to be duplicates of his Rhisina, the ruins of which are located on a hill called Tell Fecheriye, next to a modern city known as Ra's al 'Ayn and Sari Kani. To conclude the subsection, let us give an example where the names of the duplicates do not look or sound similar. Ptolemy's *Aspis colonia* and *Clypea colonia* in the province of Africa are actually one and the same place. Aspis means 'shield' in Greek, and Clypea (or Clupea) means the same thing in Latin. This error in Ptolemy's *Geography* was discovered a long time ago (Sale et al. 1747-1768). We wonder if Ptolemy actually knew Latin, and if he did, whether he knew it well.

## Tentative Identification

In Arabia Petraea, we tentatively identify Ptolemy's Maliattha as the present day ruins of Moaa, also called Horvat (=Khirbet=Kharabat, i.e. 'ruins') Mo'a, Moyat Awad, and Moyat 'Awad. Talbert and

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Åhlfeldt tentatively idenify these ruins as Ptolemy's Calguia. We tentatively identify Calguia as Ajloun. Following Talbert and Åhlfeldt, we tentatively identify Ptolemy's Lysa as the ruins called Kharabat Lussan and located near Wadi Lussan. Likewise, we take their suggestion and tentatively identify Ptolemy's Gypsaria as the ruins of an ancient fort near Al Kuntillah. Following Stückelberger and Grasshoff, we tentatively identify Maguza as the modern Hammāmāt Mā'īn, a resort located near the slopes called Ad Dabbūsah.

Stückelberger and Grasshoff identify Ptolemy's Gubba as "Wadi el-Gubey" following Kiepert (1856), who illustrated (Robinson and Smith 1841). The modern names of this stream are Wadi Abu Guweia, Wadi Abu Juway', and Wadi al Ghubah. The ruins of interest would be located in the vicinity of the modern Themileh. However, it is also possible that Ptolemy's Gubba is the ancient Phaino (the modern Feynan, Faynān) located near Wadi Ghuwayr. A third likely possibility is that Gubba is the old fort of Quweira.

In Arabia Deserta, we tentatively identified the legendary Thapsacus as Ath Thawrah, formerly Al Tabqah, where a modern dam was built to create the Lake Assad reservoir. Thapsacus was a historically famous point for crossing the Euphrates River, but we don't actually know where the city once stood. The word Birtha means 'fortress' in Syrian, so we tentatively identified Ptolemy's Birtha with the ruins of the ancient fortress of Zenobia located near the present day Halabiyah. Many other tentative identifications were made. For example, Ptolemy's Rheganna was tentatively identified as the present day Ar Rahaliyah known for remains of early Christian churches. We placed the identification of Themme as 'Ayn Tamr proposed by Stückelberger and Grasshoff into the tentative category. Three different possible locations for Ptolemy's Erupa were found: Rutba, Ruhbah, and Ar Rukbān. Only the second of them, under the old name Er-Ruhbe, was given by Stückelberger and Grasshoff following Müller. We tentatively identified the second Alata with the al-Rajajeel ruins located near a ravine named al 'Uqdah.

The tentative identifications proposed for the places that Ptolemy mentions in Arabia Felix are too numerous to list here. It was especially difficult to locate Ptolemy's Cape Syagros. Ptolemy moved it relatively to the Moscha harbor, contrary to the opinion of Marinus of Tyre, his predecessor and most valuable source. West to east, we considered Ra's Fartak, Ra's Sajir, Ra's Raysūt, the cape next to Jabal Qinqarī, and Ra's Ṣawqirah. The *Periplus of the Erythraean Sea* (Schoff 1912) relays the following.

Beyond Cana, the land receding greatly, there follows a very deep bay stretching a great way across, which is called Sachalites... On this bay there is a very great promontory facing the east, called Syagrus; on which is a fort for the defence of the country, and a harbor and storehouse for the frank-incense that is collected... Immediately beyond Syagrus the bay of Omana cuts deep into the coast-line, the width of it being six hundred stadia; and beyond this there are mountains, high and rocky and steep, inhabited by cave-dwellers for five hundred stadia more; and beyond this is a port estab-

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lished for receiving the Sachalitic frankincense; the harbor is called Moscha, and ships from Cana call there regularly...

We share the viewpoint of Beeston (1981), who argued in favor of Ra's Raysūt being Cape Syagros, because it faces east, allows a fort to be built on it, and shields a convenient harbor of Raysūt.

Ptolemy's inland city of Maccala was often identified to be the modern port of Al Mukallah. While this remains a possibility, we tentatively identify Maccala as the modern Mukayris. Al Mukallah or the nearby Ash Shihr might be Ptolemy's Tretos harbor. However, it is difficult to imagine Tretos harbor not being near Trete Island, tentatively the modern Barrāqah Island.

We tentatively identify Ptolemy's Thebai as the modern Thuwal, Ailu as Al Jāḥ al A'lá, Mada as Al Mijda, Abissa as Ar Ru'ays (it could be Arissa,  $\rho$  instead of  $\beta$ ), Rhegama as the known archaeological site called Al Jazira Al Hamra, Carada as Karranah (another known archaeological site), Gerra as Al 'Uqayr (this is the dominant version in the literature), Bilbana as Bi'r Abū 'Idbūlah, a well situated at or near the location suggested by Spruner (1865), Pharatha as Buraydah, Gaia as Ghayl al-Waggag (near Tayma), Ibirtha as Ābār 'Irj, Sata as Sadus, an old village on Wadi Hanifa, Inapha as Diriyah, also on Wadi Hanifa, Atia as Afi or Khatt, Appa as Afi or Al Kamil Wal Wafi, Thumata as Thamūdah, Iula as Al Huwaylah, Lachchere as Laḥij, etc.

We tentatively identify Ptolemy's Cauana as ed-Dur, a famous archaeological site located near the modern Umm Al Quwain, alternatively spelled Umm al Qaywayn. The name ed-Dur merely means 'houses', reflecting the present state of the ruins. Some sources suggested that ed-Dur might be the mysterious Ommana. We tentatively identify Ptolemy's Omanum market with the modern Ajman, once a small old fishing village. Hopefully, the earlier discourse about Ptolemy's Vodona prepared the reader to take our version seriously. Our suggestion is reasonably consistent with the *Periplus of the Erythraean Sea*, which states:

Sailing through the mouth of the [Persian] Gulf, after a six-days' course there is another market-town of Persia called Ommana.

Following the old sources, we tentatively identify Ptolemy's Carman as the ruins of Al Manzil, formerly known as Qarn-al-Manazil (lat= 19.2729, lon=41.9650). This place was hard to find!

It is unclear if Ptolemy's Baiba is the historical Al Abwa, or Baḥwil, a village located near Dabyah on the comparably historical Mecca-Medina road.

Ptolemy's Sabe-1 in Yemen is either Zabid, or Shibam (lat=15.5092, lon=43.9032), which should not be confused with another Shibam, Ptolemy's Thabane (lat=15.9264, lon=48.6260), also known as "Manhattan of the Desert". Ptolemy's Sabe-2 could be Jabal Şabir, As Sawā'il (Talbert 2000), or Ash Shi'bah.

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## **Surrounding Arabia**

While we do know some of the modern equivalents of places in Arabia that Ptolemy mentions, very many of them remain unknown, especially in Arabia Felix. Our *triangulation model* (Abshire et al. 2015) uses three Ptolemaic points for which we know their modern coordinates to form a spherical triangle surrounding a point to be predicted, and then triangulate to find the unknown point. The method works reasonably well, but the restriction that each of the unknown places to be predicted must be enclosed by a spherical triangle formed by known points poses a problem for many points located on the borders of the area under investigation.

In order to remedy this problem for Arabia, we surrounded its northern part with the known points from Ptolemy's Judaea Palestina, Syria, Mesopotamia, and Babylonia, which can be seen in Figures 1 and 2. For Arabia Felix, the known points from Arabia Petraea and Arabia Deserta came in handy.

In addition to that, we post-processed the results using our *Bayesian adjustment* technique developed for India (Abshire et al. 2015) with the prior for Arabia shown in Figure 5.



Figure 5: The Bayesian calculation prior for Ptolemy's Arabia.

This way, we have assured that the points located near the coastline were not placed in the sea. We have also eliminated the possibility of the unknown points' crossing over to Iran. Islands have to be taken into account carefully when the Bayesian correction is applied.

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#### **Flocking Modification**

In our *flocking model* (Abshire et al. 2015), we take the *k* known nearest neighbors of the unknown point  $y_p$ , use their respective distances from the unknown point to compute weighted average of the movement, and use this average to move the unknown point so that it becomes its modern match

$$y_m = y_p + \sum_{i=1}^{\kappa} v_i w_i$$

where y is the predicted point vector  $\lambda_m$  and  $\varphi_m$ ,  $v_i$  is the difference of the *i*<sup>th</sup> nearest neighbor of y's k neighbors of its modern coordinate to its Ptolemy coordinate, and  $w_i$  is the weight for the *i*<sup>th</sup> neighbor. In our newly corrected version of the algorithm, the weight for each neighbor is computed as

$$w_i = \frac{\sum_{j=1}^k d_j - d_i}{(k-1)\sum_{j=1}^k d_j}.$$

This way we assure that the unknown point "tracks" its closer known neighbors to a greater extent than the ones that are situated relatively far away from it.

#### **Precision Analysis**

In our previous paper (Abshire et al. 2015), we predicted that the precision of our methods for numerical prediction in other regions may surpass the one achieved in India. The new results allowed us to compare the predictive performances of triangulation and flocking models before and after the Bayesian correction for India before the Ganges, Taprobane, Arabia Petraea, Arabia Deserta, Arabia Felix, Judaea Palestina, and Syria. The error histograms for the take-one-out known point predictive analysis using the modified flocking model with Bayesian adjustment for Arabia Petraea and India before the Ganges are contrasted in Figure 6. Clearly, we're better off in Arabia Petraea.





#### **Conclusions and Future Work**

We modified and adjusted our computational methods for numerical analysis of historical data from Ptolemy's *Geography* and extended their application to Arabia. This new achievement allowed us to

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perform the additional model validation and region-to-region comparison of predictive performances of our two models (triangulation and flocking) before and after the Bayesian adjustment. Our results represent a novel research contribution to understanding of our historical cartographic heritage by improving our ability to explore Ptolemy's *oikouménē*, the "known world" of the ancients, using familiar and available GIS tools, such as Esri ArcGIS and Google Earth.

In the future, we plan to apply our methods to other regions from Ptolemy's *Geography*. We also intend to further modify the techniques to enable tentative identification verification. Yet another natural extension is to improve our reconstruction of Ptolemy's Arabia, where a lot of uncertainty remains as to locations of many ancient objects. Ideally, we'd love to see field archaeologists travel to a suggested location and discover a lost ancient city mentioned by Ptolemy.

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## **Appendix A. Tables of Known Points**

## Table 1. Modern coordinates for known locations in Arabia Petraea (Book 5 Chapter 17).

Ptolemy ID	Ptolemy Name	Modern Name	Ptol. Lat.	Ptol. Lon.	Mod. Lat.	Mod. Lon.
5.17.01.05	Tip of Arabian bay	Suez bay	29.83	63.50	29.9588	32.5588
5.17.01.08	Cape Pharan	Ras Muhammad	28.50	65.00	27.7242	34.2510
5.17.01.10	Bend of Elanite bay	Ras Gasabah	29.00	66.00	28.0242	34.6243
5.17.01.11	Pharan	Feiran	28.67	65.00	28.7051	33.6340
5.17.01.12	Elana	Ailan	29.25	65.67	29.5337	34.9989
5.17.04.01	Eboda	Avdat	30.50	65.25	30.7944	34.7735
5.17.05.01	Petra	Petra	30.33	66.75	30.3291	35.4425
5.17.05.03	Auara	Humayma	29.67	66.17	29.9499	35.3458
5.17.05.04	Zanaatha	Aş Şadaqah	29.83	66.75	30.1611	35.4949
5.17.05.05	Adru	Ayn Udhruḩ	29.92	67.00	30.3292	35.5957
5.17.05.06	Zoara	Ghour al Safi	30.50	67.33	31.0468	35.5022
5.17.05.07	Thoana	Wadi at Tawānah	30.50	67.50	30.7501	35.7268
5.17.05.08	Necla	Nijil	30.25	67.50	30.5150	35.5392
5.17.05.10	Моса	Mukawir	30.17	67.83	31.5673	35.6243
5.17.06.01	Esbuta	Tell Hesban	31.00	68.92	31.8006	35.8090
5.17.06.02	Ziza	Al Jiza	31.00	68.75	31.7031	35.9523
5.17.06.04	Medaba	Madaba	30.75	68.50	31.7191	35.7941
5.17.06.05	Lydia	Libb	30.67	69.00	31.6058	35.7611
5.17.06.06	Rabathmoba	Ar Rabbah	30.50	68.50	31.2705	35.7376
5.17.06.07	Anitha	Al Khirbah as Samrā'	31.25	68.67	32.1805	36.1634
5.17.07.01	Surattha	Al Thugra	31.17	69.25	32.2723	36.2273
5.17.07.02	Bostra Legio III Cyrenaica	Buşrá ash Shām	31.50	69.75	32.5176	36.4816
5.17.07.03	Mesada	Masada	31.50	69.33	31.3187	35.3542
5.17.07.04	Adra	Daraa	31.33	69.67	32.6126	36.0994
5.17.07.05	Corace	Al Karak castle	30.08	68.00	31.1809	35.7017

## Table 2. Modern coordinates for known locations in Arabia Deserta (Book 5 Chapter 19).

Ptolemy ID	Ptolemy Name	Modern Name	Ptol. Lat.	Ptol. Lon.	Mod. Lat.	Mod. Lon.
5.19.03.07	Addara	Deir ez-Zor	34.17	74.33	35.3357	40.1449
5.19.04.04	Iucara	Jahra	29.25	79.00	29.3514	47.6760
5.19.05.01	Barathena	Busan	33.00	73.33	32.6873	36.7893
5.19.05.02	Save	As Suwayda	33.00	73.00	32.7079	36.5653
5.19.05.03	Choke	Shaqqa	32.50	72.50	32.8968	36.6975
5.19.05.05	Aurana	Hobran	32.67	73.25	32.6054	36.6370
5.19.05.07	Alata	Qasr Amra	32.00	72.50	31.8030	36.5886
5.19.06.03	Thauba	Qasr Tuba	30.50	72.75	31.3260	36.5708
5.19.06.04	Sevia	Subayhah	30.50	73.50	30.0323	38.8356
5.19.06.05	Dapha	Sakakah	30.50	74.25	29.9930	40.2019
5.19.07.01	Obaira	Bā'ir	30.75	71.00	30.7615	36.6793
5.19.07.02	Artemita	Ma'an (Ammatha)	30.17	72.25	30.1915	35.7386
5.19.07.04	Dumetha	Dumat Al-Jandal	29.67	75.00	29.8114	39.8673
5.19.07.06	Bere	Qara	29.50	76.67	29.8860	40.2139
5.19.07.07	Calathua	Qalat al-Tuwair	29.50	77.50	29.9084	40.1942
5.19.07.08	Salma	Sihmah	29.50	78.33	26.3894	47.8292

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## Table 3. Modern coordinates for known locations in Arabia Felix (Book 6 Chapter 7).

Ptolemy ID	Ptolemy Name	Modern Name	Ptol. Lat.	Ptol. Lon.	Mod. Lat.	Mod. Lon.
6.07.02.04	Onne	Aynūnah	28.67	66.33	28.0933	35.1994
6.07.02.07	Hippos	Duba	26.67	67.00	27.3541	35.6834
6.07.03.03	Cape Chersonesos	Ra's Abū Madd	25.67	67.00	24.8329	37.1594
6.07.03.04	Iambia	Yanbu	24.00	68.00	24.0877	38.0635
6.07.05.05	Centos	Al Qadeimah	21.50	69.33	22.3464	39.1497
6.07.05.07	Baitios R. mouth	Wadi Fa'idah	20.67	69.50	21.9512	39.2735
6.07.05.08	Baitios R. sources	Wadi Fa'idah	24.50	76.00	21.9416	39.8404
6.07.06.02	Badeo	Al Balad, Jeddah	20.25	70	21.4736	39.1899
6.07.06.03	Ambe	Al Qahma	19.50	70.67	18.0002	41.6764
6.07.06.05	Adedu	Hudayda	17.17	72.25	14.7987	42.9538
6.07.07.06	Muza market	Mocha	14.00	74.50	13.3166	43.2497
6.07.07.07	Sosipu harbor	Dhubab	13.00	74.75	12.9426	43.4102
6.07.07.08	Pseudocelis	Khawr Shūrī	12.50	75.00	12.7506	43.4755
6.07.07.09	Ocelis	Bi'r al Ḩālī	12.00	75.00	12.6895	43.5084
6.07.07.10	Cape Palindromos	Ra's Bab al	11.67	74.50	12.6770	43.4622
		Mandab				
6.07.08.05	Cabubathra M.	Jabal Kahbūb	11.25	76.25	12.9378	43.6507
6.07.09.06	Arabia market	Aden	11.50	80.00	12.7791	45.0365
6.07.10.07	Cane	Qana'	12.50	84.00	14.0083	48.3217
6.07.10.09	Maithath	Mijdahah	13.00	84.33	14.0101	48.4509
6.07.10.11	Prion R. mouth	Wadi Ḩajr	13.50	85.00	14.0446	48.6772
6.07.10.12	Prion R. sources	Wadi Ḩajr	17.50	82.00	15.0486	47.2685
6.07.10.13	Embolon	Burum	13.50	85.50	14.3629	48.9816
6.07.10.15	Thialemath	Salalah	14.00	87.00	17.0065	54.1399
6.07.10.16	Moscha harbor	Khor Rorī (Sumhuram)	14.00	88.50	17.0389	54.4343
6.07.11.04	Ausara	Hasik	16.75	87.33	17.4463	55.2709
6.07.11.07	Neogilla anchorage	Khawr Barr al Hikmān, near An Nuqdah	19.00	89.00	20.8006	58.7194
6.07.11.08	Ormanus R. mouth	Batha River	20.17	89.50	21.9971	59.6583
6.07.11.13	Cape Corodamon	Ra's al Hadd	20.25	93.00	22.5352	59.7941
6.07.12.02	Kryptos harbor	Muscat	21.50	92.67	23.6154	58.5946
6.07.12.04	Black M. (Endpoint of seaside)	Ra's Musandam	22.00	93.00	26.3827	56.5258
6.07.12.05	Cape Asabon	Ra's Shuraytah, near Khasab	23.33	92.50	26.3868	56.3783
6.07.14.08	Lar R. mouth	Wadi al Bațhā'	23.50	86.50	25.6437	55.7327
6.07.14.09	Lar R. sources	Wadi Sifūnī	18.00	81.00	25.0807	56.1839
6.07.17.02	lthar	Dārīn	25.00	80.00	26.5450	50.0763
6.07.17.03	Gulf of the Magi	Tarout Bay	25.33	80.00	26.7072	49.9976
6.07.18.03	Cape Chersonesos	Zibārat al Ma'abbar	26.50	80.33	27.1903	49.3889
6.07.19.02	Holy bay	Dawḥat al Musallamīyah	28.25	79.25	27.4116	49.2643
6.07.19.05	Mesanites bay terminus	Ra's aş Şabīyah	30.17	79.00	29.5151	48.1677
6.07.20.11	Nameless Mtns N. of Asabon Mtns	Jabal Shams	22.50	88.00	23.2364	57.2627
6.07.27.02	Aramaua	Ramm	29.17	67.50	29.5778	35.4146

#### [22]

20th MAGIC Conference "The one who wants to last is the one who is willing to change": old maps for new user profiles

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6.07.27.05	Macna	Maqnah	28.75	67.00	28.3995	34.7465
6.07.27.07	Madiama	Al Bad'	28.25	68.00	28.4875	34.9990
6.07.28.01	Achrua	Qurayyah	28.25	70.00	28.7827	36.0042
6.07.29.01	Thaima	Tayma	27.00	71.00	27.6340	38.5573
6.07.29.04	Lugana	Linah	27.25	76.50	28.7609	43.7380
6.07.29.06	Soaca	Shawāq	26.25	68.00	27.3532	36.4961
6.07.29.07	Negran	Madain Saleh	26.00	70.50	26.7891	37.9518
6.07.29.08	Salma	Al Samra	26.00	74.50	27.4956	41.7181
6.07.30.04	Phigeia	Thaj	26.00	79.00	26.8726	48.7162
6.07.30.07	Iabri	Yabrin	25.00	74.50	23.2606	48.9858
6.07.31.03	Aluare	Al Buwayra	24.25	71.00	24.9524	38.9771
6.07.31.05	Salma	Al Yamamah	24.33	73.33	24.1867	47.3341
6.07.31.09	Lathrippa	Medina	23.33	71.67	24.4682	39.6106
6.07.32.03	Catara	Hofuf	23.33	79.50	25.3787	49.5720
6.07.32.05	Macoraba	Mecca	22.00	73.33	21.4234	39.8250
6.07.35.03	Laibris	Ibri	20.25	82.00	23.2352	56.5060
6.07.37.01	Maraba	Marib	18.33	76.00	15.4620	45.3257
6.07.37.03	Nagara	Najran	18.67	81.75	17.4899	44.1319
6.07.37.06	Sylaion	As Sarw	17.00	76.67	15.3287	44.6919
6.07.37.08	Thumna	Am Hajar	17.25	79.00	15.0201	45.8057
6.07.38.01	Vodona	Bidbid	17.33	80.00	23.4126	58.1265
6.07.38.02	Marimatha	Maryama	17.67	85.17	15.9609	48.8269
6.07.38.06	Sabbatha	Shabwah	16.50	77.00	15.3684	47.0228
6.07.39.03	Thabane	Shibam	16.33	85.67	15.9264	48.6260
6.07.39.04	Meiba	Māti'	15.33	74.33	14.1582	43.3661
6.07.40.01	Source of water of Styx	Hammam Damt	15.00	78.00	14.0909	44.6725
6.07.41.01	Mepha	Mayfa'ah	15.00	83.25	14.2643	47.5717
6.07.41.03	Sapphara	Dhafar	14.50	78.00	14.2114	44.4033
6.07.41.07	Thuris	Taizz	13.00	75.25	13.5779	44.0213
6.07.41.09	Hyaila	Ad Dali	13.83	79.00	13.6961	44.7311
6.07.43.02	Aenu I.	Jazīrat Tīrān	27.33	65.75	27.9373	34.5593
6.07.43.07	Ierakon I.	Jebel at Tair	19.00	69.50	15.5419	41.8353
6.07.44.02	Cardamine I.	Kamaran	16.00	71.00	15.3568	42.5901
6.07.44.04	Katakekaumene I.	Jabal Zubayr	14.50	70.50	15.0535	42.1783
6.07.44.05	Malichu Islands (2)	Jabal Zugar	14.00	71.67	13.9981	42.7422
6.07.44.06	Adanu Islands (2)	Hanīsh Islands	12.50	72.50	13.7001	42.7249
6.07.45.02	Agathocleus Islands (2)	Abd al Kuri I.	10.00	81.33	12.1780	52.2518
6.07.45.03	Cocconatu Islands (3)	The Brothers	9.00	83.00	12.1416	53.0694
6.07.45.04	Dioscuri I. (E. end)	Rhiy di-Irīsal	9.50	86.67	12.5427	54.5341
6.07.45.05	Dioscuri I. (W. end)	Ra's Shū'ab	12.50	85.00	12.5357	53.3063
6.07.46.02	Zenobiu Islands (7)	Khuriya Muriya	16.50	91.00	17.5050	56.0232
		Islands				
6.07.46.04	I. of Sarapis	Jazīrat Maşīrah	17.50	94.00	20.4191	58.7890
6.07.47.03	Ichara I.	Khark I.	25.00	82.00	29.2384	50.3093
6.07.47.04	Tharo I.	Jazīrat Tārūt	24.75	85.25	26.5705	50.0587
6.07.47.05	Tylos I.	Bahrain (Dilmun)	24.67	90.00	26.0551	50.5524
6.07.47.06	Arathos I.	Jazīrat al Muḩarraq	24.67	91.67	26.2702	50.6301