Prof Sachs

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The following is a preliminary account on my findings at the sites where Hipparchos did observations. It contains information on the physical appearance of these locations, which hitherto was not availabe, or quite dispersed, and it should be useful to those who study the observational data of Hipparchos and wish to investigate in more detail the actual circumstances under which he worked. I would be grateful to be informed by those who - after reading my account- find discrepancies or additional information, or have other constructive critisism.
This problem was first studied during a stay in 1964-5 at the Department of the History of Science and Medicine of Yale University, New Haven. Great help was found in the many discussions with profs. Aaboe, Goldstein and Price and in the excellent facilities of the Yale Stirling library.
On my way back to Beirut I visited Rhodos from Wednesday September 1, 9 am till Friday, Sept. 3, 2 pm. Here I was kindly assisted by the Tourist Office of the Nomikos Lines and by the director of the Institute of Archaeological Excavations, Mr. G. Konstantinopoulos.
I was in Iznik from Tuesday, Sept. 7, 2 pm to Wednesday noon. In preparing for this trip Dr. M. Dizer, director of the Kandilli Observatory near Istanbul was extremely helpful and in Iznik Mr. N. Inceler, professor of French, was an excellent guide.
In the course of this trip I did observations in various places, not reported on here. These will be dealt with separately, when I have worked out the data.
In my search for documents I was assisted in part by a grant from the Rockefeller Fund of the School of Arts and Sciences of the American University of Beirut.

Frans Bruin

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ON THE OBSERVATIONS OF HIPPARCHOS IN NICAEA AND RHODOS

by
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1. Introduction

The purpose of the following is to review the data on the location of the observation posts of Hipparchos, one of the great astronomers of antiquity. I will present information on the towns of Nicaea (modern Iznik) and Rhodos pertinent to the historian of science and make some remarks on general astronomy and its sources for friends in Iznik and Rhodos, where Hipparchos is believed to have carried out his major work.

Information on Hipparchos and these two towns comes to us from various sources. From accounts by Vitruvius ('On Architecture', ten books, written around 30 BC), by Strabo ('The Geography', eight volumes, written around zero AD), and by Pliny ('Natural History', 35 books, written around 70 AD). These are available in modern English editions (Loeb Classical Library). Further from remarks in a number of astronomical treatises, mainly the Handbook of Astronomy (Almagest) by Ptolemy, written around 140 AD, and works like those of Poseidonius (100 BC) and Geminus (70 BC) who lived in Rhodos shortly after Hipparchos. Useful additional information may sometimes be deduced from coins and inscribed stones. Further general data on Hipparchos and his work may be found in:

Rehm, A. Hipparchos, Pauly-Wissova-Kroll, Realencyclopaedie der Classischen Altertumswissenschaft, Band 8,2 (1913)

Dicks, D.K. The geographical fragments of Hipparchos Athlone press, London 1960

Sarton, G. Hipparchos, Encyclopaedia Britannica Volume 11 (1959)

Waerden, B.L. van der, Klaudios Ptolemaios, Pauly-Kroll-Ziegler, Realencycl. d. Classischen Altert. Wiss., new edition Band 23,2 (1959).

Ptolemaeus, K. Handbuch der Astronomie, 2 volumes, edited and translated into German by K. Manitius, Teubner, Leipzig 1963.

2. Astronomical works of Hipparchos

In the course of his life Hipparchos investigated nearly every aspect of astronomy. Unfortunately all of his works but one are lost or preserved in an obscure way. The only treatise which can be attributed to him directly is his 'Commentary on the Phenomena of Eudoxos and Aratos'. Aratos of Soli (modern Cyprus) in 275 BC wrote a poem on the celestial constellations based on an earlier description of the celestial sphere by Eudoxos (370 BC). This astronomer wrote for the latitude of his birthplace Kyzidos ($\varphi = 40^\circ 40'$), about 160 km West of Iznik at the sea of Marmora. From the contents of Hipparchos' 'Commentary' it would seem that it was written in his birthplace (?) Nicaea ($\varphi = 40^\circ 44'$), and that Hipparchos was an industrious and accurate observer and a scrupulous yet gentle critic. Ptolemy affectionally calls him the 'lover of truth' (Almagest, vol 1, p 131).

The major body of later works of Hipparchos is comprised in the Handbook of Ptolemy, which is largely an updated, reorganized and improved edition of the 260 year older work of Hipparchos. The Handbook was the final word on all matters pertaining the heavens till the time of Kepler (1600 AD), and Ptolemaic astronomy should really be called Hipparchian without belittling the truly magnificent and monumental work of Ptolemy. Even of certain parts of the Almagest where Ptolemy does not explicitly credit Hipparchos it is not certain whether the material does not originate from the latter. For example, Ptolemy describes an armillary sphere which is made to observe the positions of the stars, which is also referred to by Geminos of Rhodos (and possibly already mentioned in the poem of Aratos). A table of sines given by Ptolemy to be used for transformation of coordinates, is known to have been used already by Hipparchos, and thus he may well be also the creator of trigonometry. To be sure, much of what Hipparchos knew he must also have inherited from predecessors. It is certain that he had access to accurate astronomical data dating back to the Greeks and Babylonians of say 400 BC. Nevertheless the critical and masterly way in which he rearranged this material and supplimented it with new fundamental observations is of a similar order of magnitude as the work of Ptolemy.

With the aid of Babylonian records Hipparchos determined the length of the solar, lunar and siderial year. His error in the solar year is only 6 minutes, his error in the length of the lunar month less than one second. With baffling accuracy he computed the synodic periods of the planets, the obliquity of the ecliptic and of the moon's orbit, the apogee of the sun and the horizontal parallax of the moon. Hipparchos determined the distance to the sun to be hundred million stadia, a distance so large that apparently Ptolemy had his doubts about it and does not mention it. Hipparchos did not support the heliocentric model of the planetary system as proposed by Aristarchos of Samos (280 BC) for the excellent reason that there was complete lack of observational evidence for such an assumption. Conclusive proof was only found twenty centuries later (1837 AD) in the yearly parallax of the stars.

It is said that the appearance of a new star (perhaps a comet) led Hipparchos to compile a catalogue of over 800 stars with their coordinates (with errors of less than 0.5 degree) and with relative intensities in three orders of magnitude. This was done so as to leave to posterity a document that would allow to detect any changes in the constellations of the fixed stars.

When comparing positions of the star Spica with respect to the moon during an eclipse with earlier observations by Timocharis (166 years earlier) Hipparchos made one of the greatest discoveries in all astronomy: the precession of the equinoxes. He determined this to be about one degree of arc per century, whereas actually it is 1.6 degree. This feat alone places him among the great astronomers of all time.

To Hipparchos are attributed the following works:

On chords in a circle

On simultaneous risings

On the rising of the twelve signs of the zodiac

Commentary on the Phenomena of Aratus and Eudoxos

Critique on the 'Geography' of Eratosthenes

On the sizes and distances of the sun and moon

On parallax

On objects carried down by their weight

On the displacement of the solsticial and equinoctial points

On the length of the year

On intercalary months and days

On the system of the fixed stars

On the motion of the moon in latitude

Catalogue of separate works

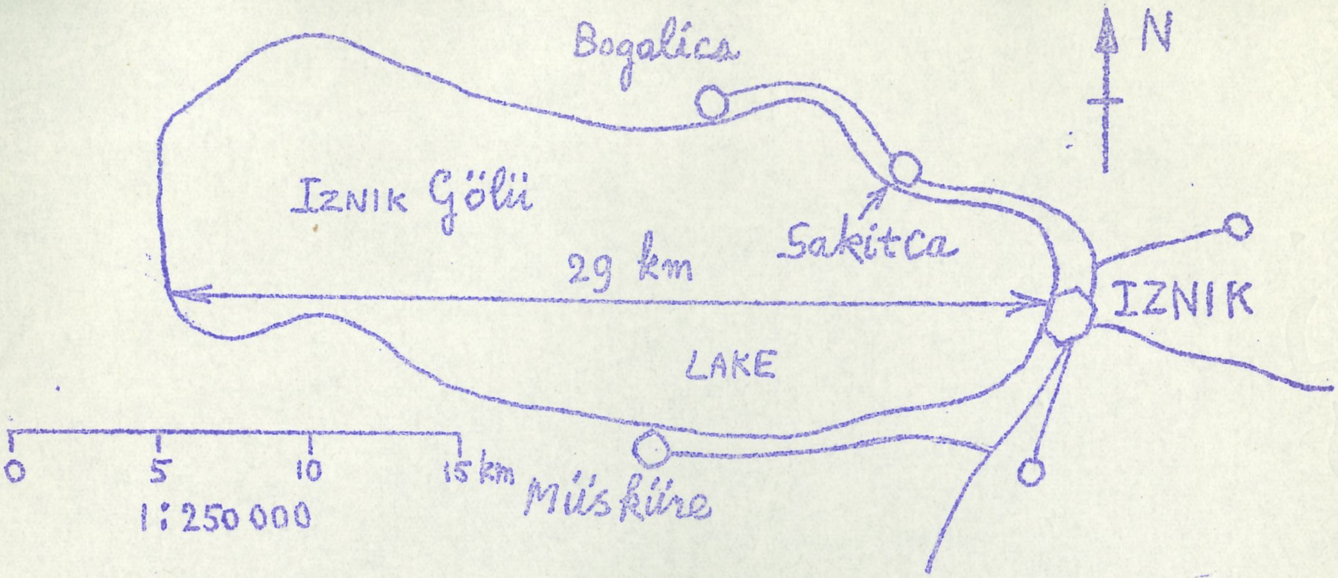
3. The town of Iznik

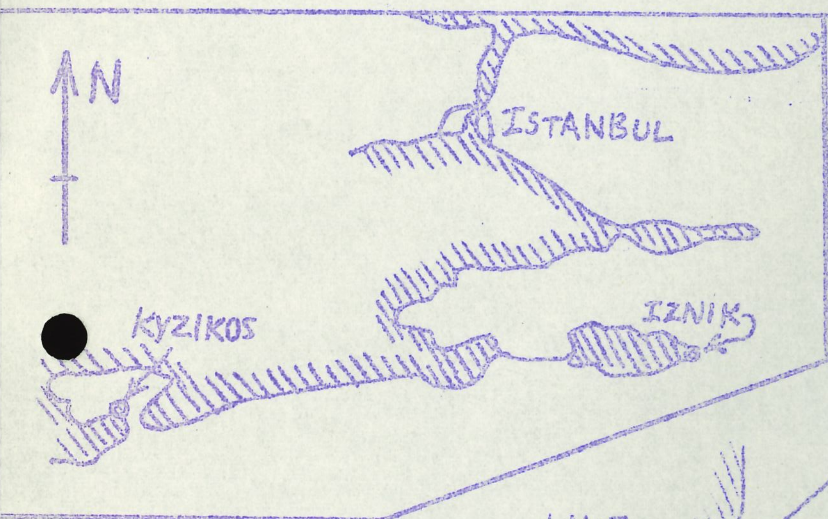
Iznik, with a population of 5000, is a market town on the Eastern shore of lake Iznik in the province of Bursa in Turkey. It lies in a fertile well irrigated plain surrounded by distant mountains. Principal products are grapes, tabacco, olives, nuts, vegetables and fish. The climate is mediterranean: most of the year sunny and hot, little or no rain. Rain falls in March and April and then mostly in the early morning. In winter only occasionally there is one or two cm snow.

In order to reach Iznik one takes the ferry boat from Istanbul to Yalowa (two hours) and from there a bus or taxi (dolmetsch) to Iznik.

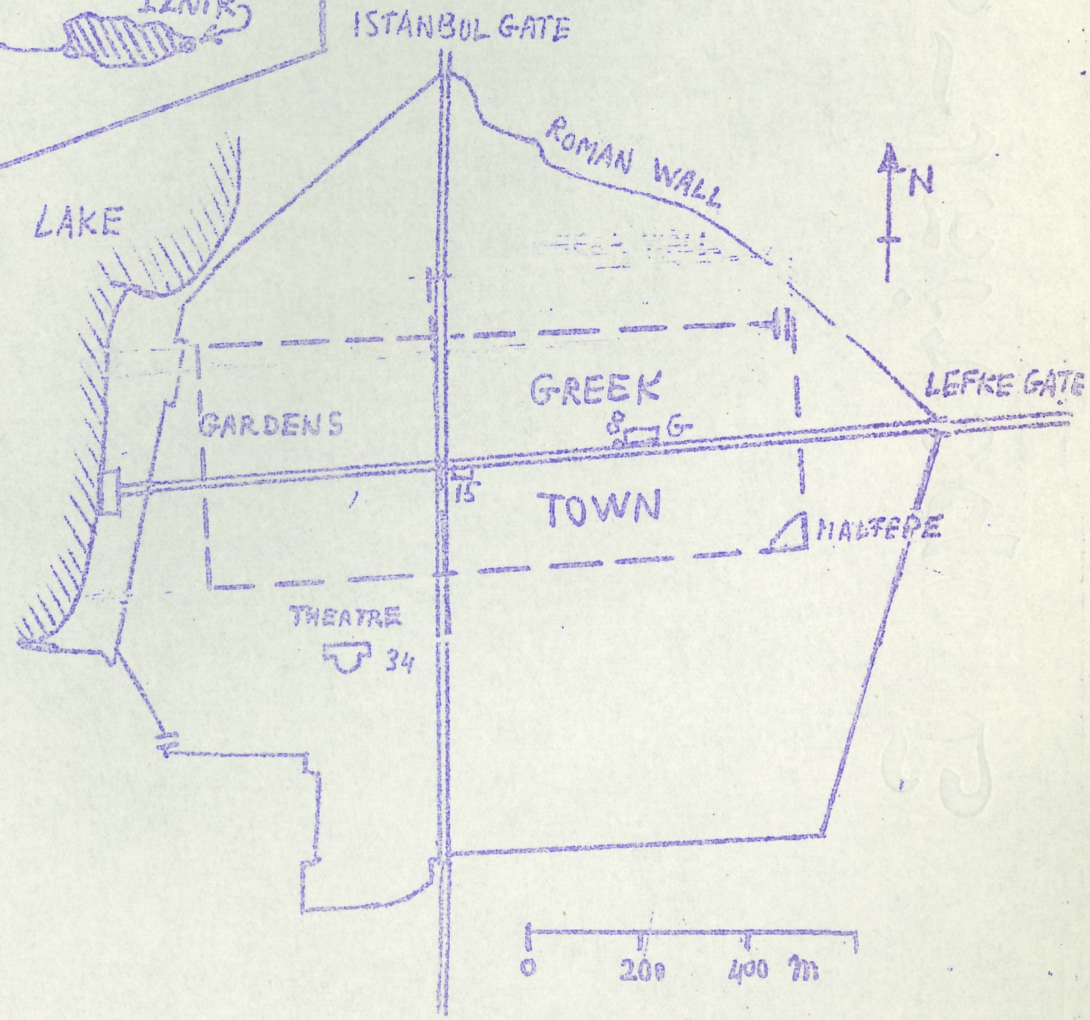
Excavations show that the history of Iznik goes back to the remote stone age (2000 BC). The modern Greek town was founded in 316 BC by Antogonos and named Antigonia. In 310 BC a certain Lysimachus took over and changed the name to Nicaea. Like other Hellenistic cities Nicaea was built according to a rectangular plan and surrounded by walls. Roads diverted from a central square in perpendicular directions through four gates of the city wall. These and smaller streets deviate about three degrees to the East from the celestial North and are in the direction of the present magnetic North.

Practically no archaeological research has been done on the lower Greek strata of Nicaea, mostly because the whole town is covered with monuments of early Islamic architecture, which not only attract all attention but also make excavation of the older layers impossible. Presently the only visible Greek remains are a recently excavated gate at the North-East corner of the former Greek city wall. This gate is mentioned by Strabo (XII, 565/6): 'In the North-East of the town is a gate. It is built from large quadrants without chalk cement and its 2.9 meter wide door opening is linearly cut off above'. Further there is the Maltepe (treasure hill) which looks to me as being the remains of the South-East corner of the old wall. Finally there are some ionic pillars East of the St. Sophia mosque. Although these remains are very fragmentary, Iznik is one of the few towns in which the Greek rectangular array of streets has been preserved. Because of this one can still make a guess as to where the Greek city was located (see the map of Iznik on the next page). We are told that Lysimachus surrounded the town with a wall of 16 stadia (2900 m) In my guess as drawn the total length is 3000 m. Strabo writes (XII, 565/6):'The town was designed so regularly that from a stone set up in the middle of the Gymnasium one could see all four gates'. The gymnasium burned down and difficulties in rebuilding it were reported by Pliny (the younger) when he visited Nicaea in 111 AD (Pliny ep. X, 48), One had started to rebuild it again in larger size but did not finish it. The gymnasium presumably was somewhere in the center of the town (near 15) but no remains have yet been found. There were similar difficulties with the rebuilding and enlarging of the theatre, presumably because the clay soil is too weak to carry heavy structures. Impressive remains of the theatre may still be seen (34). It existed already in the time of Hipparchos, for we read in Aelian, de anim. VII, 8: 'In the time of the tyrant Hieron, Hipparchos amazed everyone by wearing a leathern cloak in the theatre, because he foresaw that there was a storm in the offing, although the weather at the time was fine. And Hieron marvelled at him, and





IZNIK TOWN PLAN



congratulated the Nicaeans of Bithynia on their good fortune in having Hipparchos as a fellow-citizen'. This shows among others that Hipparchos was considered an authority in forecasting the weather. At the time forecasting was done, following the Babylonians, by studying the stars and applying the rules of astrology. The 'Commentary on the phenomena' of Hipparchos may have been a study related to this. Further evidence for his work on 'weather signs' we find in the same work of Aelian: 'Among the men who recorded the effect of the influence of the stars (on human affairs) are ...., ..., and Hipparchos of Bithynia. Finally, Ptolemy in his book Phaseis, which also deals with weather signs, also writes explicitly that Hipparchos observed in Bithynia. This is all the evidence I could find that Hipparchos lived in Nicaea and did observations there. Indeed not so much as one would believe from the modern literature.

We have no records on the larger buildings of ancient Iznik other than what is found on coins. Some of these may be seen in W. Roth, A catalogue of Greek coins in the British museum, volume 13, Longmans, London 1889. In this volume plate 31 shows two coins (no. 15 and 16) with the facade of a two story building, with pediment in the center of the upper story. These coins are of the time of emperor Claudius (50 AD). A hexastyle temple of about 300 AD is shown on coins no.9, plate 32 and no. 13,plate 33. Pillars of these temples later have been used freely in the construction of mosques and can be seen today in several of the larger buildings, even in the theatre. The granite of some of these looks like that coming from Aswan in Egypt, as used in Baalbek and Biblos.
Nicaea suffered several severe earthquakes. One of these was in 29 AD shortly before the death of Christ, and ancient writers thought it to have coincided with his death. To make things still more dramatic there was at the same time a total solar eclipse (29 AD, November 23) on which e.g. was reported in 'Eusebius' as follows: 'At the same day (of the death of Christ) from the 6th till the 9th hour the sun was totally darkened and a horrible night pulled over the land. And, as was told, the godless age feared that the night would never end. Neither the moon nor the clouds were in the way of the sunlight, but rather, as was reported, (the moon) at its 14th luner day was at the largest distance from the sun. The stars twinkled in day-time, or rather in this horrible night,over the whole sky. This is confirmed not only by the authority of the Holy Evangalists, but also by some scripts of the Greeks, although they refer these events to the 19th year of Tiberius. Among others also Phlegon, who in the 13th book counts off the Olympiads with the following words: After this, in the fourth year of the 202 nd Olympiad there occurred an enormous solar eclipse and night came at the 6th hour of the day, so that the stars appeared in the sky even. Also a large earthquake happened in Bithynia and destroyed the larger part of the town Nicaea'. Indeed, modern calculations show that a solar eclipse took place in 29 AD at November 23, which had totality in Bythinia (investigated by Ginzel in 1882). Another earthquake took place in 123 AD after which the town was rebuilt under emperor Hadrian. This is all I have been able to collect for a background on the Nicaea of Hipparchos. If one considers that apart from the earth-quakes Iznik was successively sacked by Romans, Barbarians, Byzantines, Salchouks and Ottomans, and that each civilization built on and from the debris of the preceding one, it is clear

that not much direct evidence on Hipparchos will be found any more in modern Iznik. Even some of the Islamic monuments are now more than two meters below the present street level.
The only objects related to astronomy which I could find in Iznik were two corner stones (in the museum) with the heads of the sun and moon (or day and night) which to me looked like Byzantine, and a stone in the wall of a house near St Sophia mosque, bearing the Greek symbol of the sun and a cross (?). Probably noneof these is related to Hipparchos. I took photographs and slides of all objects of interest.

4. Observations at Nicaea

There are reasons to believe that the three books of Hipparchos of 'Commentary on the phenomena of Aratos and Eudoxos' is one of his early enterprises. It is in fact a critical analysis of a large number of risings and settings of stars, which are described by their position in the constellations, or rather by their simultaneous rising and setting. The third book deals with so-called clock stars which accurately mark off 24 hourly sections. The right ascentions of these stars can be obtained to within 1/4 of a degree. Schjellerup (1881) dates the 'Commentary' on the basis of its contents to 140 BC.
If, at the best possible position in Iznik, one looks at the horizon it becomes immediately clear that risings cannot be observed at all because of a mountain range in the East, and that settings over the lake also are subject to an elevation of distant hills, giving an irregular skyline from zero to 3 degrees (see drawings at the end). Because of the lake, correction with respect to the water line would here be possible but still difficult. To observe simultaneous risings and settings is out of the question. The accuracy of the clock-stars poses an additional problem. One might perhaps think that these were observed in meridian transit using an excellent water clock, but then still the peculiar composition of the first two books would have to be explained. A more simple and natural explanation of these two sets of data is that Hipparchos observed the relative position of the stars by means of a kind of cross-staff and then accurately plotted the observed angular distances on a globe. This could be done at any clear night and the results could be checked over again without involving the local horizon. It is even conceivable that Hipparchos did not observe at all but had a globe or table of higher accuracy than the one Eudoxos worked with. Anyhow, once Hipparchos had this globe with stars on it, he could draw poles, equator and ecliptic. For the latter one requires information on the solstices and equinoxes, which I will discuss below. Then by dividing the equator in 24 equal parts one could find the clock-stars without using a clock, and this would be possible with an error of 1/4 degree. Risings and settings could now be simulated by using the local latitude as obtained from a gnomon and placing the globe in a flat horizontal ring, or in a hollow hemisphere. This procedure, although somewhat disappointing from my point of view, is straightforward and fits the well-known ingenious approach of minimum effort of observation typical for the ancient astronomers. It avoids the difficulty of an irregular local horizon. Considering that the sphere was used already by Eudoxos (370 BC) and that Hipparchos was well informed on Babylonian astronomical data, one is tempted to think that the use of the sphere, as described above, was already familiar to the Babylonians. A detailed description of how to make a sphere is given by Ptolemy.

(Handbook, volume 2, Book 8, chapter 3). Here the coordinates of the stars are taken from a table obtained through accurate observation by means of special instruments, and only after this plotted on the sphere. This does not contradict the previous interpretation, but simply means that, as higher accuracy was sought, the old method was replaced by a superior one. The later data due to Hipparchos while he was in Rhodos imply that this is what in fact happened.
The only astronomical instruments of the time before Hipparchos, of which we have it on record that they were used, are the gnomon and the sphere. Schlachter and Gisinger in their book 'Der Globus' (1927) mention a gem of the collection of Mrs Sibylla Mertens-Schaffhausen (1846) on which one sees Hipparchos (?) sitting before a globe and measuring on it with compasses. Boeker, while writing on Aratos (1952) gives the same illustration and calls it an antique Kameo of the museum Borbonico. It is not clear why the figure shown should be Hipparchos. In the above mentioned catalogue of Greek coins by W. Roth, volume 13, there is a coin (no. 97 on p 167) which shows Hipparchos (ιππαρχ). He wears himation over his lower limbs, is seated left on a chair, his right leg extended. In front of him on a pedestal is a globe. A very similar but different coin is reproduced in the book of Schlachter and Gisinger (no. 46). Except that these two coins bear the name 'Ipparx' they also show the name 'Nikaieon'. Unfortunately for both coins the face of Hipparchos is worn away. They may also be later issues commemorating a great citizen but not being an accurate image.

A second set of basic observations were those on the sun. Data that seem directly measurable and important are the obliquity of the ecliptic, the angle of lowest and highest meridional transit and the winter and summer solstice, and the exact moments when the sun is in the equinoxes or in the solsticial points. The obliquity, the equatorial altitude (the latitude) and the equinoxes may be found with high precision from observation of the solar solsticial altitudes at noon by means of a gnomon. It is not clear however how the ancients determined the precise moments at which the sun is in the solstices.
The equinoctial points may be obtained from the gnomon by simple interpolation on the meridian line between the points of crossing the day before and after the equinox. From this the moment of the equinox may be obtained to within 1/4 day. A series of equinox observations in the Almagest and originating from Hipparchos, (Volume I, book 3, p 130) shows clearly that interpolation was a common practise. One of these equinoxes was found to have occurred at midnight! When the sun approaches a solstice the same method of interpolation may be applied but it becomes less accurate. I have not yet determined this error myself, but feel that it could be done to within a day.
The solstices may also be measured from the position of the setting sun with respect to landmarks on the Western horizon. For this an irregular mountain range is very suitable, but it should be distant and not more than say of one degree of elevation, as seen from the position of observation. Such a situation prevails in Iznik as well in Rhodos (see the drawings). It seems to me that if the possibility was there both methods would be applied, the direct horizon observation being used as a check on the interpolation with the gnomon. The simple observation of the setting sun on the same suitable day N times 4 years apart, using the diameter of the sun (32') as a measuring stick, would supply the length of the year with high accuracy, without using any instruments.

5. Possible places of observation in Iznik

The most conspicuous monuments in Iznik are St. Sophia mosque, the remains of the theatre and the city wall. The latter was built in an irregular polyangle, 4400 meters long, around 260 AD at the time of the Roman emperors, probably because in 259 AD Nicaea suffered attacks from the barbarian Germans. A view of the entire wall is shown on a coin of the younger Macrian and on a coin of Quietus (261 AD). The two gates originally were free standing arches built in 78 AD. The whole structure therefore did not exist at the time of Hipparchos, and only consumed much of the material that formed the original Greek town. The theatre is located near the lake and is built on a slight elevation. It would be suitable for observation of settings, if no high trees were in the way, as is the case at present. I tend to rule out the theatre as being an artificial choice. Big structures are often built on the foundation of an older big structure. The St. Sophia mosque is such a large building, and its foundation looks older. Here in the center of town may have been the gymnasium and the center of cultural activities. A gnomon would require a large floor of flat stones, which is very hard to find back. I still have the feeling that it is near to this mosque that Hipparchos spent most of his time.
Water enters the town through an aqueduct from a well at the foot of the Elmalidağ mountains in the East and is lead along the main street to the lake. The street finally passes through gardens and ends at a small square quay at a beach of coarse grey sand. Benches and chairs are placed here and in the evening people sit here drinking tea and admiring the sunset over the lake. It is likely that Hipparchos also strolled down here in the evening to enjoy the quiet of twilight and occasionally to be admired for his learned observations on the setting sun. The beach is a natural and very pleasant place for observations on settings. Since water was only available at street level, the clock that Hipparchos might have used - if any - would have been of the simple clepsydra type. Water had to be carried to the spot of use. People in town not using the aqueduct used wells with water at least five meter below ground level. One such old well near the Maltepe was shown to me, but it was no longer used.
Observations on the stars as reported on in the 'Commentary' could have been carried out from the roof of any house, or from the Greek city walls. It impresses the modern towndweller to see how clear and bright the sky can be in a place where the air is not yet polluted by modern industry and electric lights are still a luxury.
To sum up, I feel that Hipparchos did his observations near the town center and on the quay of the harbour.

Further information on Iznik, mostly later than Greek:
Soelch, J. Bithynische Staedte im Altertum, Klio 19(1923-5)144-188 Description of Iznik on p 152-4. Diest, W. von, Die Landschaft zwischen Nicaea und Nicomedia, Asia 2(1903)p149, with map. Schneider, A.M. and Karnapp, W., Die Stadtmauer von Iznik (Nicaea) Istanbuler Forschungen, Band 9, Berlin 1938. Schneider, A.M., Die Roemischen und Byzantinischen Denkmaeler von Iznik (Nicaea), Istanbuler Forschungen, Band 16, Berlin 1943.

6. The town of Rhodos

The town of Rhodos is built on the Northern tip of the island of the same name. Mythology has it that the island rose from the sea and was ruled by Apollo Helios, the sun-god. Its name may originate from the bright red pomgranate flower (modern Greek: rodia) which is found on old coins. Compared to the other Greek islands Rhodos is geologically young and not related to the Turkish mainland. In the course of its history it suffered many earthquakes, and the mythological creation may have to do with that.
The Greek town was designed by the architect Hippodamos (of Milete) around 440 BC, but was destroyed by the earthquake of 227 BC. Also the temples and the famous bronze colossos were destroyed. The ancient city had an acropolis near where is now the crusader castle and another one on the slope of mount Stephanos. This mount has a plateau of 80-90 meters high (see drawing with view from the sea) which forms the foot of a mountain chain running along the middle of the island. On top of mount Stephanos stood the temple of Athena Polias and Zeus which, judging from the remaining drums (with diameter of about 1 m) must have been a magnificent structure. At the side of the hill is the ancient stadium and nearby a small amphitheatre (800 seats, 27x23 square meters), now completely restored. From its small size one would say that it was used as an auditorium and not for plays. Above the stadium rise some columns of the upper temple of Pythian Apollo. There is also a lower one near the crusader castle.
After the destruction by the earthquake of around 227 BC, money, architects and workers were sent from other Greek settlements to assist in the reconstruction. Mithridates, king of Pontus, also sent gifts. The year 168 BC marks the end of the Roman-Macedonian war. In 166 Rhodos lost independence. In 164 the Romans signed a treaty with the Rodians and this resulted in renewed cultural activity. For example, at Tralleis in Caria (in Turkey) about 150 BC Apollonius and Tauriscus cast for Rhodos a collossal bronze group, now known as the Farnese Bull.(The original was lost. A Roman marble copy of the third century AD was later repaired by Michaelangelo, was housed some time in the Palazzo Farnese and is now in the museum of Naples). The philosopher Panaitios, famous member of the stoic school, lived in Rhodos from 190-110 BC, and the Syrian philosopher and historian Poseidonius (130-70 BC) is said to have brought new fame to the university.
For tourists the main attractions in Rhodos are the beaches in the modern part of the town in the North, and the small picturesque Crusader town in the East, which is still almost as it was in crusader times. The latest Italian occupation of Rhodos, has given an Italian flavour to a city that was adored already over the centuries. Rhodos is indeed a very pleasant place to visit.
Of the Greek city only a rectangular pattern of streets remains on the Eastern slope of mount Stephanos. The hill has a steep cliff on the North-West - a scar of an earthquake - and from its highest point one has a magnificent view over the sea. In the late afternoon one sees people go up to watch sunset, and to pay tribute to Helios, the god of the island.

The climate of Rhodos is pleasant and steady, temperatures never going below 9°C. In August it may be very hot, especially in the Eastern part of the island which is blocked from the North-western winds which prevail the year round, making mount Stephanos a relatively cool but windy summer resort. About 80 cm of rain falls from December to April. The sky is mostly clear, with about sixty cloudy days per year, but more often there are clouds at the horizon.

7. Observations at Rhodos

That Hipparchos actually did observe in Rhodos follows from direct quotations of Ptolemy in his Almagest. In book 5, chapter 5 (Manitius Volume 1, p 271) he writes: Hipparchos assures us that he has observed the moon with instruments in Rhodos on May 2 127 BC at $6^h\ 20^m$ in the morning. His record says: 'While the sun was sighted in Taurus $7^{\circ}\ 45'$, the apparent position of the lunar center was found to be Pisces $21^{\circ}\ 40'$, the exact position $21^{\circ}\ 27'\ 30''$. Consequently at the given time the exact moon was separated from the sun by $313^{\circ}\ 42'$ in the direction of the signs, without the error of observation.'
And on July 7, 127 BC, at 4^h in the afternoon (Vol. I, p 274): 'When at this hour the sun was sighted in Cancer $10^{\circ}\ 54'$, the
F: Leo apparent position of the moon was found to be exactly 29°. This was also the exact position, because in Rhodos in the last third of Leo, about one hour after culmination the moon does not show a parallax in longitude.'
It is therefore certain that Hipparchos was in Rhodos in the summer of 127 BC. Furthermore, if these statements are taken literally, it would seem that by that time Hipparchos used quite sophisticated and precise instruments for observation. If indeed he measured along the ecliptic, this would require an armillary sphere with sights and a precise clock to set it. In the second quotation 'about one hour after setting of the moon' means literally that he measured time at night, so that he was using a water clock. It therefore seems that Hipparchos in the later part of his career gradually developed a better technique of observation and that he was using larger instruments in a permanent position, including armilles and a water clock.
Hipparchos mentions (Almagest, Vol.I, p 130, book 3) the accurate observation of six autumnal equinoxes (from 162 BC to 143 BC) and three vernal equinoxes (from 146 - 128) but it is not clear whether he made these himself or if they were made in Rhodos. They could have been made by others and somewhere else (Alexandria). But, since we know from the 'Commentary' and the Critique on the 'Geography' of Eratosthenes that Hipparchos was very critical of observations of others, we may assume that he did the above observations himself. The way in which this material is presented in the Almagest makes one believe that the autumnal equinoxes were less reliable than the vernal equinoxes, and that most of these were Hipparchos' early observations in Iznik. Only the vernal equinoxes were made with great care and under superior circumstances in Rhodos.
A partial lunar eclipse was observed in Rhodos on January 27, 141 BC (Almagest, Book 6, chapter 5, Manittius Vol. I, p 351). Since no other astronomer is known, good enough to be used by Ptolemy, one would again like to assume that Hipparchos made the observation. Again this is not certain. With these assumptions Hipparchos lived in Rhodos from around 140 to 127 BC, of which the later date is definite.

In my search for the place from which Hipparchos did his observations I was originally lead by the idea that unobstructed sunrises and sunsets should be observable over the sea and that there should be a source of water to run a water clock. Later I became inclined to believe that Hipparchos did few observations at the horizon, except for the convenience that one can look directly at the sun. The actual horizon is usually ill-defined and most of the time there are clouds. It may be that it was used only in early primitive astronomy and perhaps by shepherds for knowing the time at night. Horizontal observations are essential for measurements on the diameter of the sun. A free Eastern and Western horizon is of great help in finding the equinoxes, even when instruments are used, like the equatorial ring, or when using a sundial.

Of the fact that Hipparchos used a water clock we find further evidence with Synesios of Cyrene, however this man lived nearly six hundred years after Hipparchos (400 AD) and was a Bishop and not an astronomer. Synesios writes that Ptolemy and his successors were content to make use of only so much of stereographic projection of the celestial sphere as was needed for the construction of the night-clock with its sixteen stars, 'which were the only ones Hipparchos rearranged and entered on his instrument.' This fits nicely with my conclusion above, and also with the assumption that originally Hipparchos used a sphere, and later sought ways to replace it by something that would give higher accuracy. In Roman times water clocks (clepsydras) were used to limit an orators time in court. At the time of Hipparchos the Romans considered Rhodos as the greatest center of Arts and letters. A school of rhetoric was founded by Aeschines in Rodini near Rhodos. Cicero, Brutus, Julius Caesar and Marcus Aurelius all studied rhetoric in Rhodos. One should therefore expect that a water clock was used for the small auditorium near the temple of Pythan Apollo, on mount Stephanos, and that it is through this that the Romans became familiar with its use. A hollow sun-dial can still be seen above the theatre of Dionysos on the Acropolis of Athens. Water was led from the higher mountains along mount Stephano by large and extensive underground aqueducts, which still exist but have not yet been fully explored. In fact all of the Acropolis on mount Stephanos is waiting for systematic excavation.

Having established that Hipparchos actually did observations on Rhodos, our next problem is to find out where exactly this could have been. It is to be expected that Hipparchos lived in a cultural center, and this limits the possibility to Lindos and Rhodos. Lindos, a town much older than Rhodos, also enjoyed cultural activities, but had no university like the one on mount Stephanos. Also, even when one goes up to the acropolis of Lindos, which is placed on a high cliff, one cannot see the Western horizon, because mount Marmari (460 m) is in the way (see the drawings). We are thus left with mount Stephanos. Here the best place for observations is a little East of the temple of Zeus, which was already in ruins at the time of Hipparchos. There is another spot that would be acceptable, a little lower on the hill towards the North (just above the caves), but it is inferior to the former for winter risings of the sun and further away from the university complex. In both places there is a foundation of large blocks which seem to be Greek. I could not find any other location that seemed suitable or showed remains of a building. The Greek streets on mount Stephanos were laid in a rectangular pattern deviating from celestial North by 3 degrees to the East (like in Iznik). The two foundations were in line with this and almost parallel to the present magnetic North. The spot which somewhat optimistically I will call the 'Observatory'' consisted of a solid piece of cut rock of about 3x 4 square meters, around two sides of which large blocks were placed (see schetch). A little square at the side had a hole presumably leading down to a cistern, as was confirmed by local people. The foundation was too strong to be meant for an ordinary house and would have been ideal for placing some instruments like a gnomon and an equatorial ring. From this block one could see 3/4 of the total horizon and I observed sunrise and sunset from it. In fact I have never seen a place more suitable for ancient observations than this one. No marks or signs were found that would confirm the assumption that originally this was an observatory. If, however, my conclusions are correct - and at present, 5 months after the investigation I still think so - then here we have the first and oldest permanent astronomical observatory in the world.

The observation of the fixed stars

Little has been said about the instruments that may have been used for observation and about the (lost) star catalogue that was compiled by Hipparchos and re-measured and expanded by Ptolemy. Ptolemy refers to a set of star-alignments and to the star Regulus as measured by Hipparchos in 129-8 BC. It would seem that Hipparchos did his precise measurements on the stars in order to make a catalogue around that time. It also looks as if Hipparchos for these observations measured directly in declination, whereas Ptolemy - with the implications of the precession in mind - built special armilles for observing in ecliptic coordinates. The whole subject of measurements on the stars and the equipment used by Hipparchos and Ptolemy deserves a special study and will not be dealt with further here.

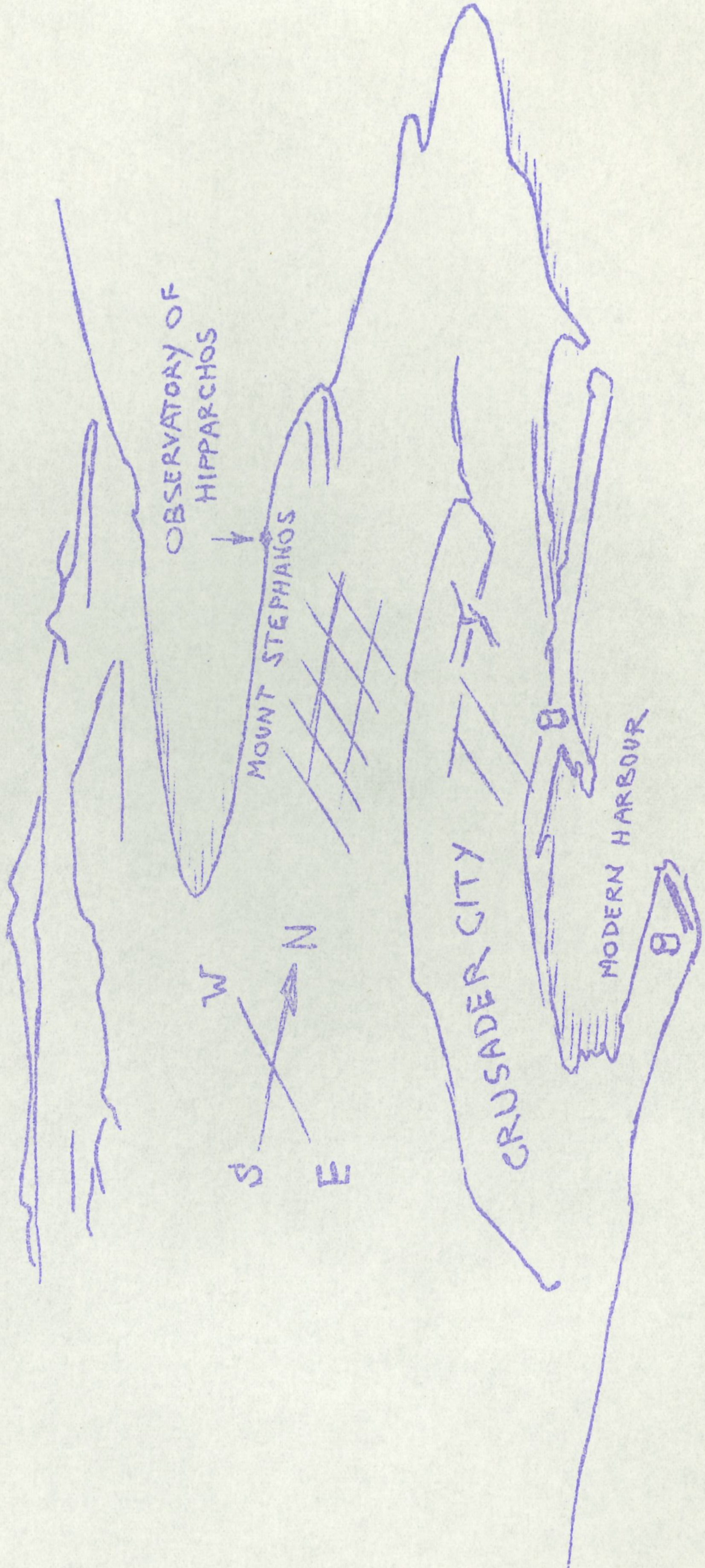
8. Remarks with the maps and drawings

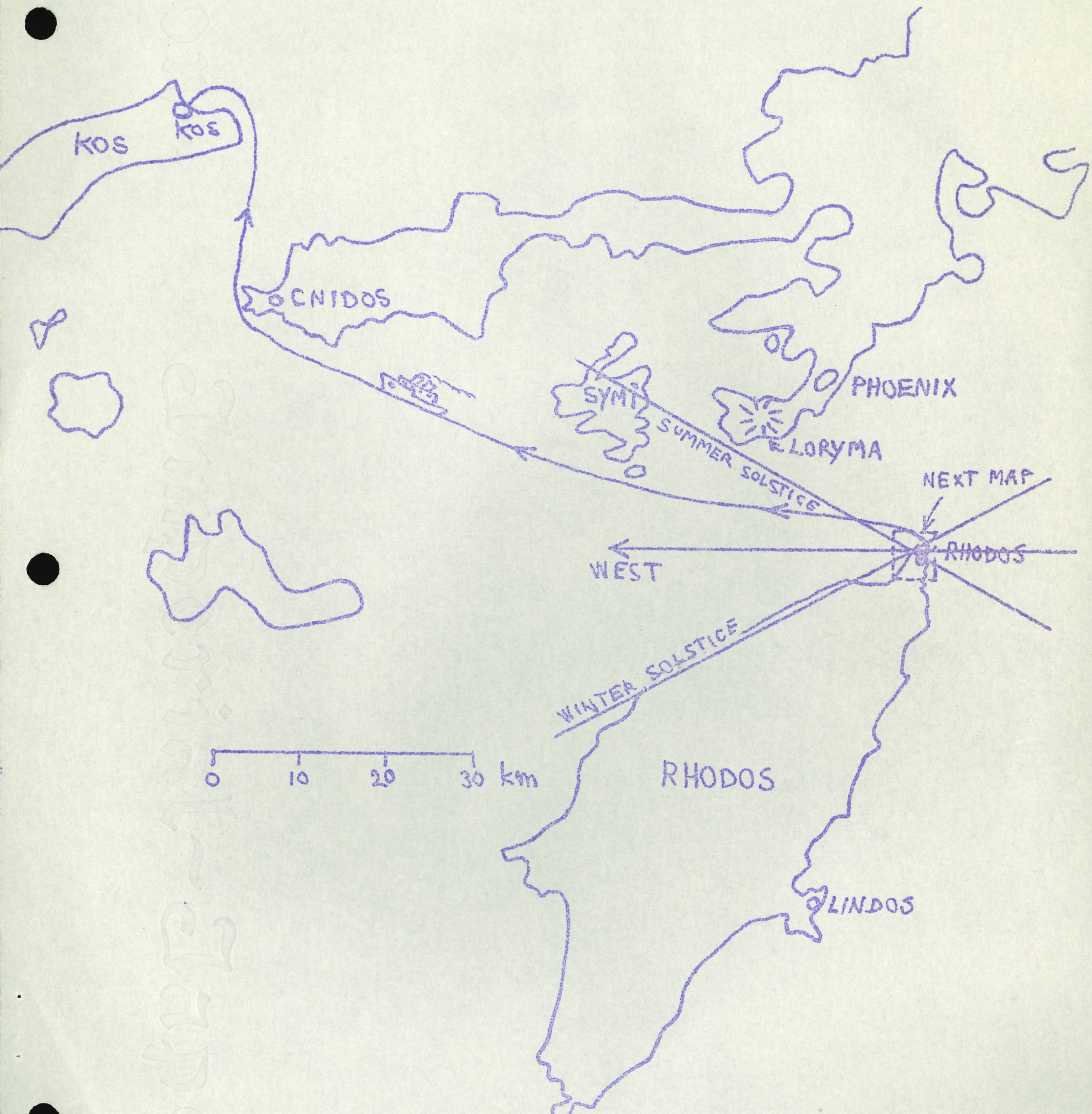
There is no detailed map of Iznik. The one copied in outline on page 5 is taken from A.M. Schneider and W. Karnapp, Die Stadtmauer von Iznik. Istanbuler Forschungen, Band 9, Berlin 1938. This book issued by the German Archaelogical Institut in Istanbul also contains a large panoramic photograph of Iznik. Drawing 1, page 15, is after a photograph from a plane. It was difficult to find a detailed reliable map of the town of Rhodos. Newton in his 'Travels and discoveries in the Levant', Volume I, London 1865, gives maps of the island and town of Rhodos, reproduced from the British Admiralty Charts no. 1637 and 1667. However, little was known about the acropolis at that time. Newton noticed the drums of the temple of Zeus, and on his map is indicated a fountain, which showed that there might have been water on the hill.
The director of antiquities in Rhodos, Mr Gregor Konstantinopoulos, had a large size map of the town, and very kindly supplied me with a copy of the interesting part. However I found deviations between details on this map and the one of the Admiralty and also with the actual situation (discrepancies up to 50 meters). My map no.4 on page 18 is a superposition and interpolation of old and new maps and should serve as a guide only. Mr Konstantinopoulos told me that good maps may be found in

J.D. Koudis
Das Stadtbauplan Rhodos
Mitt. des Deutsch. Arch. Inst. Athen
Band 73 (1958)
Publ. Mann. Berlin

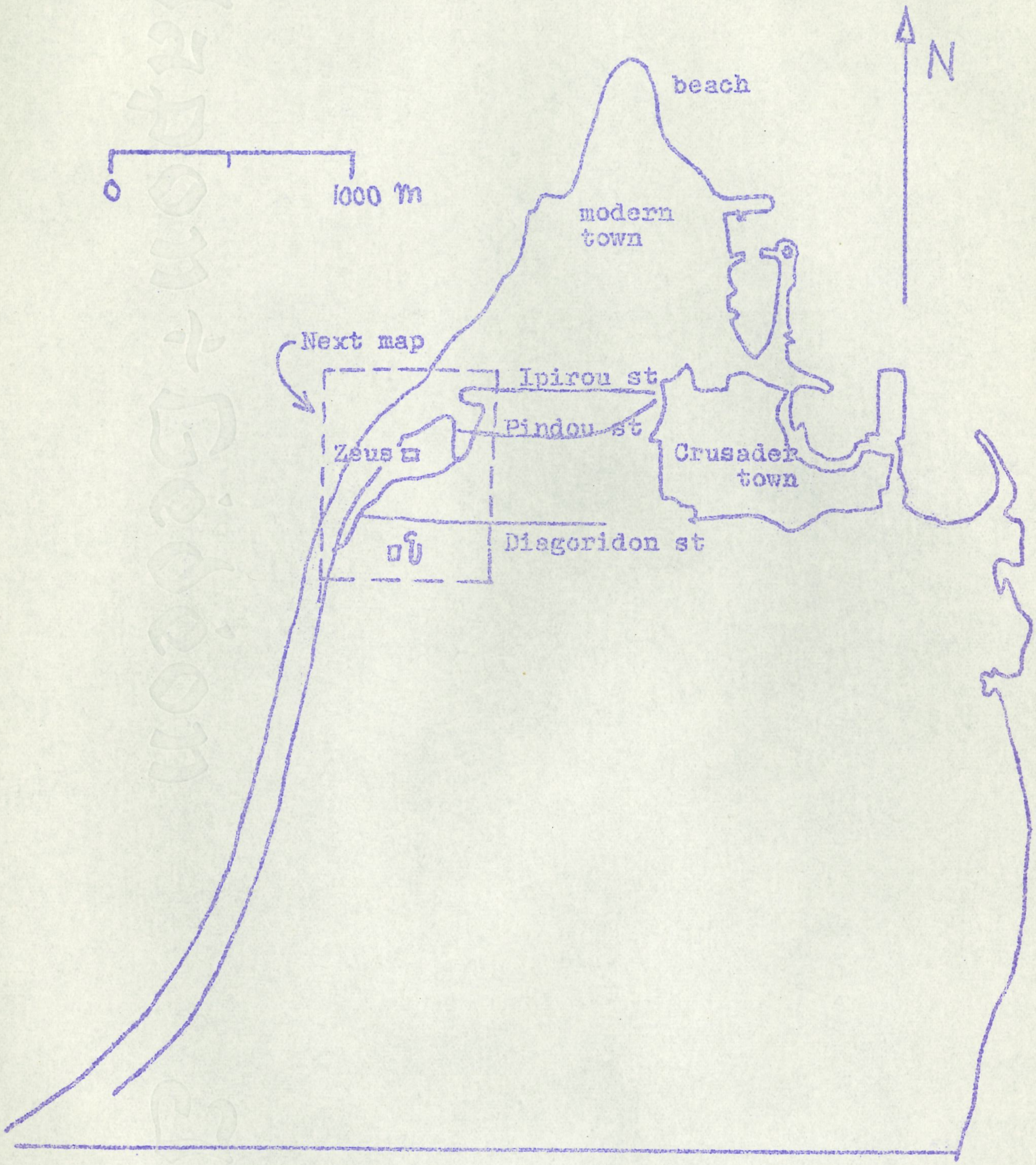
The German Archaeological Institute in Athens is in the Vidion st 1. The same Institute in Istanbul is near Taksim square.
The best description of ancient Rhodos is by Van Gelder, Geschichte der alter Rhodier, p 343.
Drawings 5, 6 and 7 give the skyline as copied from projected photographs.

BIRDS EYE VIEW OF RHODOS



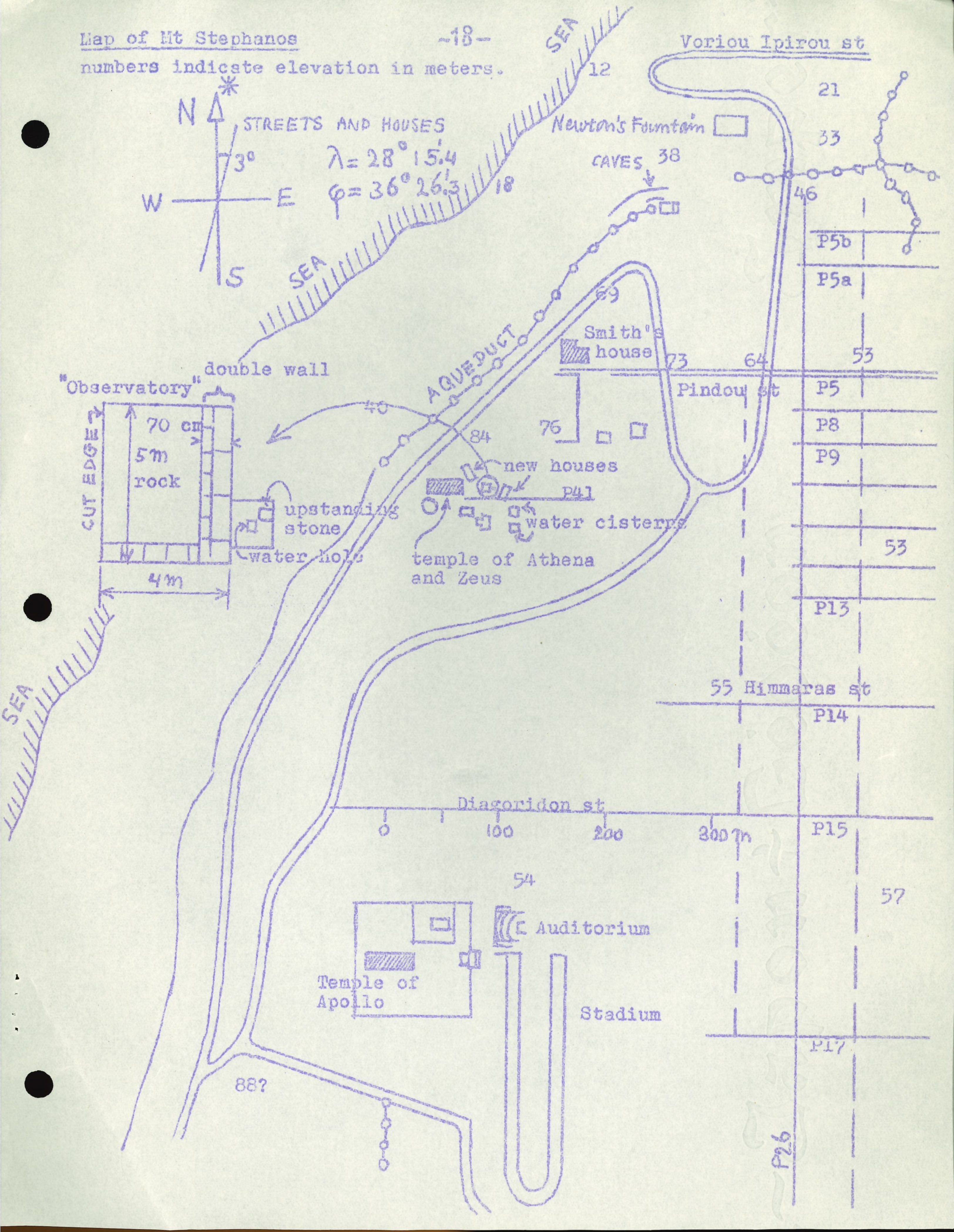

KOS
KOS
CNIDOS
SYMI
PHOENIX
LORYMA
SUMMER SOLSTICE
NEXT MAP
RHODOS
WEST
WINTER SOLSTICE
0 10 20 30 km
RHODOS
LINDOS

Map of the town Rhodos

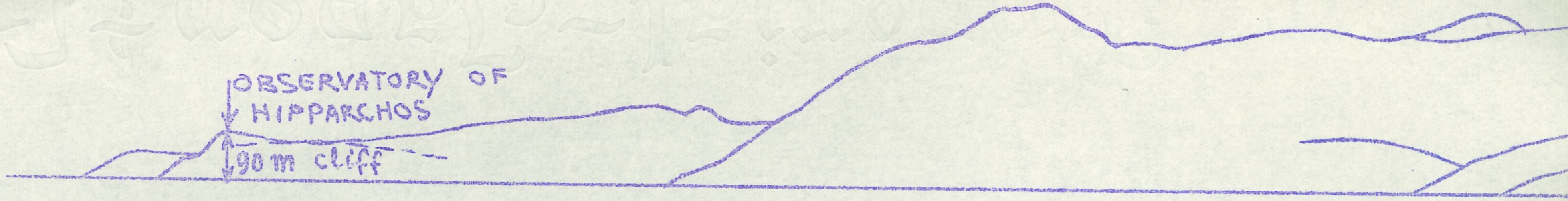


Map of Mt Stephanos

numbers indicste elevation in meters.

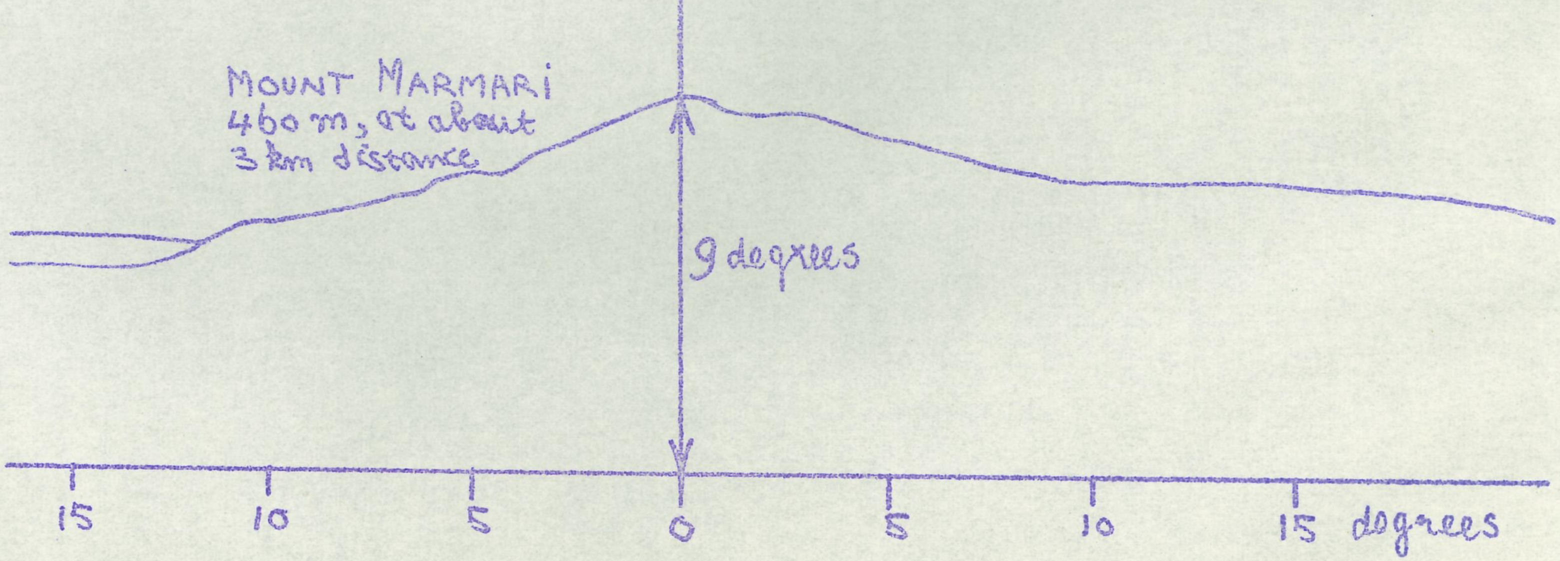


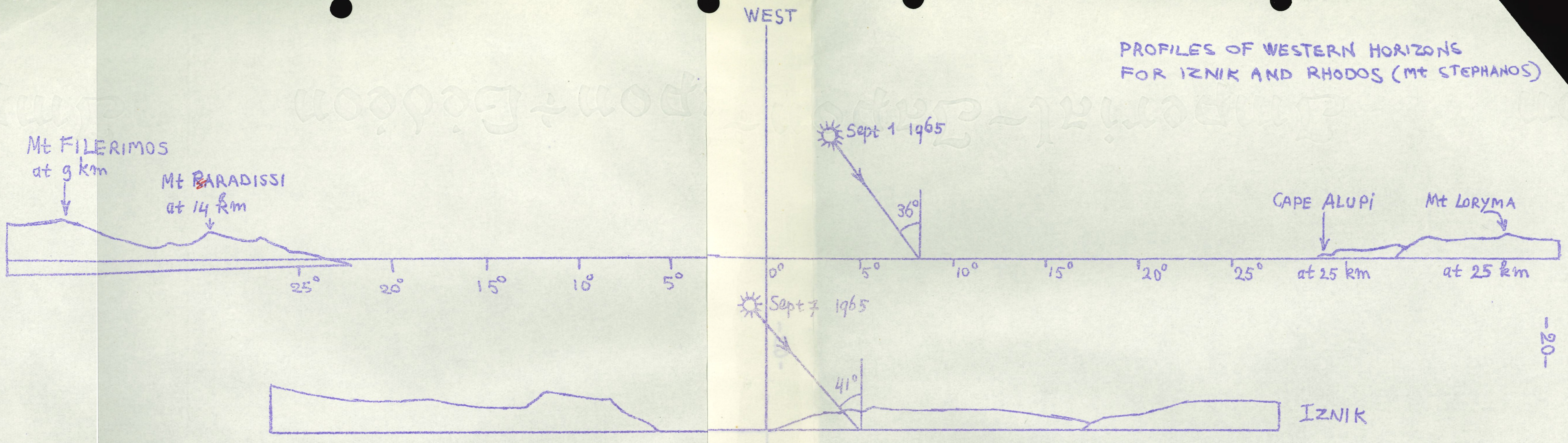
PROFILE OF NORTHERN TIP OF RHODOS, AS SEEN FROM THE WEST



LINDOS. PROFILE OF HORIZON FROM ACROPOLIS, LOOKING WEST

West




PROFILES OF WESTERN HORIZONS
FOR IZNIK AND RHODOS (Mt STEPHANOS)
WEST
Mt FILERIMOS
at 9 km
Mt PARADISSI
at 14 km
Sept 1 1965
36°
CAPE ALUPI
Mt LORYMA
25°
20°
15°
10°
5°
0°
5°
10°
15°
20°
25°
at 25 km
at 25 km
Sept 7 1965
41°
IZNIK