BERUNI AND HIS EXPERIMENT AT NANDANA

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Nandana is situated in District Jhelum, Pakistan, about 60 miles S.E. of Islamabad in straight line and can be reached by road in less than 3 hours. [1] In the long past, Nandana was a capital city of historic importance, and also Nandana was an administrative district until the second half of the 18th century A.D. The place, known locally as Nanânnâ or Nanûnnâ, [2] had remained more or less inhabited upto the 18th century but was abandoned thereafter and the population shifted to Bâghânawâlâ down below in the plain. Presently the site is abandoned, and has recently been protected by the Department of Archaeology. [3] To this day, as one visits it one cannot miss the conspicuous sight of the high mount or its peak point to which Beruni had once climbed up to take measurements for his experiment. These stand out clearly in the light of Beruni's own observations.

Beruni's performance of this unique experiment at Nandana is well known through his own description of it. However, the circumstances under which he worked and visited Nandana have not been correctly interpreted;

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[1] The itinerary of jeepable road: Islamabad/Rawalpindi, Chakwal, Choa Saidanshah, road to Pind Dadankhan, turn on the way to Rawal Cement Factory, Warnali, Bâghânwâla, Nandanâ. Also from Choa Saidanshah 12 miles east through the Ara Valley to the Ara Rest House, and then walk 3 miles south to Nandana. A visit was facilitated for me in 1978 by Mr. Ahmad Nabi Khan the then Superintendent of the Archaeological Circle, Lahore, and we took the jeepable road from Choa Saidanshah via the Ara Valley.

[2] As reported by Malik Ghulam Muhammad who died in 1956 at an advanced age of 107 years. Of the historians of the Ghaznavid period, Gardezi and Baihaqi call it 'Nandūnah' which is more close to the native pronunciation, though Utbi writes it as 'Nârdîn'. (Nazim, Dr. Muhammed: *The Life And Times of Sultan Mahmud Of Ghazna*, Cambridge, U.K., 1931, p. 91 fn. 4).

[3] The site area measures 45 - 16 acres and is entered into the Revenue Record as

"No. Khevat Mâlik 252
No. Khatûnî Kâshtkâr 591
No. Khasrâ 276"

situated in *mahâl* Baghânwâla, *tehsil* Pind Dadankhan, district Jhelum.

the problem and the experimental method whereby he solved the problem have not been fully appreciated; and all the three versions of his description have not been put together and weighted. An attempt is made in the following pages to study and explain these specific aspects of this historic event of great scientific interest.

-I-

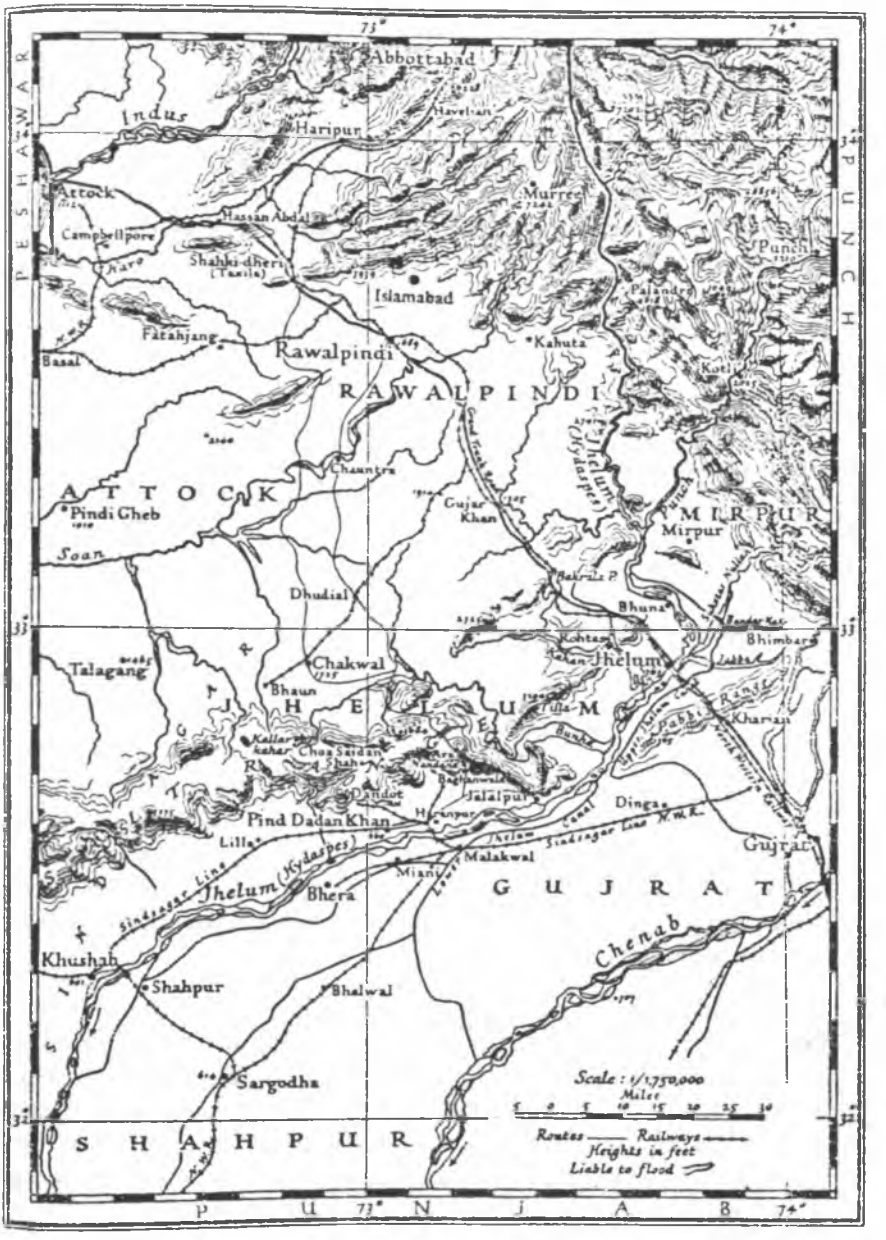
THE PERSPECTIVE: PRIOR TO BERUNI'S VISIT TO NANDANA

Before adverting to his experiment, it needs to be clarified whether Beruni, as it is supposed to be, was a prisoner at Nandana where he performed his memorable experiment. The topography of the place and the terrain around would readily bring it to one's mind that no prisoner brought all the way from Ghazna to be confined in the fort would have been allowed to be so mobile as to have accomplished the task of performing the experiment to its successful conclusion; it must have required hours of daily work in complete freedom, not only outside the fort but much beyond the limits of the city area itself. Moreover, if it is accepted that beginning from his arrival in Ghazna, Beruni was held as a political prisoner or a hostage, in Nandana or elsewhere, during the remaining period of Sultan Mahmud's reign (408-421 A.H.), the continued progress of his purposive scientific activity and remarkable achievements during this period can hardly be explained in the context of such a distorted perspective.

The view that Beruni was taken as a prisoner of war in Khwârizm and held as a prisoner or a hostage even after his arrival in Ghazna, gained currency after the late Dr. Edward Sachau's stretched argument to that effect in his 'Preface' to *Alberuni's India*. Following the tradition of Beruni to uphold the truth, one may venture to say in all humility that the prolonged argument of Dr. Edward Sachau, the most learned editor of Beruni's works whose presence is respectfully felt whenever one thinks of Beruni, to portray Beruni as a prisoner of war and to emphasize Beruni's antagonism towards Sultan Mahmud and *vice-a-versa,* is the least scholarly part of his scholarly edition *Alberuni's India.*

Learned Sachau opens his Preface with a diatribe against Sultan Mahmud: "History paints Mahmud as a successful warrior but ignores him a Maecenas".[4] It would appear as if to disparage Sultan Mahmud, he uses Beruni against him. He gives his readers to understand that Beruni was taken prisoner and held as a hostage by the Sultan to the very end of his reign; restrictions were imposed on him so that he could not carry out his researches

[4] *Alberuni's India* (being an English Edition of Beruni's *Kitâb ma li al-Hind* by Dr. Edward C. Sachau, London, 1910, Preface to vol. I. p. i (Hereafter referred to as 'Preface'in the text of the Paper.)



A Skeleton Map, showing Nandana and the whole region between the Indus and the Chenab Rivers, (Adopted from Sir Aurel Stein's Archaeological Reconnissances etc.).

freely; ill treatment was meted out to him both by the Sultan and his Prime Minister; and that upto the time that Beruni wrote his 'Kitab al-Hind' (421 A.H., the very last days of the Sultan), he was "still suffering from the oppression of King Mahmud" (Preface, xvii). A close examination of all the relevant references shows that such assertions are contrary to the facts on record.

(i) Was Beruni taken prisoner in Khiva and brought to Ghazna along with other prisoners? Learned Sachau has led his readers to believe that it was so. According to him, after having conquered Khiva, Sultan Mahmud returned to Ghazna with "much booty and a great part of the Khiva troops, together with the princes of the deposed family of Ma'mûn and the leading men of the country as prisoners of war or as hostages. Among the last was Abu Raihan Muhammad ibn Ahmad Alberuni" (Preface, ix). But neither Beruni himself has said or hinted in any of his works, including his "Chronicle of Khwârizm" in which he has recounted the circumstances of Sultan Mahmud's conquest of Khiva, that he was taken prisoner, nor any other contemporary or early reliable authority has mentioned Beruni's name among prisoners. [5] The only tale about Beruni having been sent to prison in the fort of Ghazna for six months for having annoyed the Sultan with his exact predictions in response to the Sultan's test questions, is told in *Chahâr Maqâla* by Nizamî ʿArûdî, an author who relied on hearsay and revelled in the lore of the past to recount stories for purpose of literary entertainment. [6] Another literary source often referred to is Yâqût's *Irshâd al-Arîb* or *Muʿjam al-Udabâ'* (written more than two centuries after the event) in which it is mentioned, again on the basis of hearsay, that Beruni was about to be punished with death by the Sultan but only good luck saved him. [7] Even this report does not say that Beruni was taken away as a prisoner to Ghazna.

[5] Abul Fadl Baihaqi was Beruni's contemporary and has included copious extracts from Beruni's 'Chronicle of Khwarizm' *(al-Musâmârah fi Akhbâr Khwarizm)* in his own *History (ef. Tarikh-i Baihaqi*, Persian text, Mashed University, Mashed, 1350/1971, p. 1004). Zahiraddin al-Baihaqi, who in his *Tatimmah* has mentioned Beruni a number of times, does not say that he was taken as a prisoner to Ghazna. He has mentioned the physician Abul Khair Khammâr being taken by Sultan Mahmud to Ghazna but not as a prisoner (*Tatimmah Siwân al-Hikmah*, Lahore, 1951, p. 12).

[6] *Chahâr Maqâlâ*, ed. Muhammad b. Abdul Wahhâb Qazvini (Text, Leyden 1327/1909), Gibb Memorial Series, London, 1910, p. 57.) This tale pertains to the period when Beruni was already in Ghazna and in close company of Sultan Mahmud.

[7] *Mu'jam al-Udabâ*, in 20 parts, Dâr al-Mamun Press, Cairo, XI/186.

Therefore, there was no good reason for learned Sachau to have added Beruni's name to the list of prisoners.

In order to reinforce his argument that Beruni was taken prisoner and forcibly removed to Ghazna, or to somewhat modify this stand, learned Sachau labelled Beruni's departure from Khwârizm to Ghazna as an "involuntary immigration" (Preface, ix). But there is nothing on record to show that he was forced against his will to leave Khwârizm. The question is, why should he have preferred to stay on in Khwârizm when his patron ruler Abû'l-ᶜAbbâs Ma'mûn had already been assasinated by the rebels, disorders had prevailed, Sultan Mahmud's deputy was now to govern the country, and there was no possibility of any Mamunid Prince coming to the throne again? Moreover, it was not for the first time that Beruni had left his homeland. His mission in life was clear: to seek knowledge and advance it wherever opportunities to do so became available to him. He would readily leave a place when his scholarly pursuits were likely to suffer. Long back in 487/488 A.H., he had left Khwârizm when he was no hope to continue on with his plan of astronomical observations which he had pursued during 485-486 A.H., and partly in 487 A.H., [8] because of the disturbed conditions due to the struggle for power between two 'great men of Khwârizm' (*Kabîrai Khwârizm*). [9] Beruni had then decided to leave Khwârizm not because of any external pressure but because of internal disorder. He first went to Ray then to Jilan, and from there to Jurjan. There at the court of Qabus b. Washamgir he stayed for about 5 years (389-394 A.H.), [10] and considerably advanced his astronomical and historical studies which culminated in the composition of *al-Athâr al-Bâqiyah*. But then he left that court and returned to Khwârizm which was now peaceful, with Abû'l-Hasan Ali Ma'mûn as the new ruler. He took to his studies and made astronomical observations of which the one made in Ramadan 394 A.H. is specifically mentioned by him. [11] By that

[8] Cf. Berûnî's *Taḥdîd Nihâyât al-Amâkin li-Tashîh Masâfât al-Musâkin*, Text, ed., Muhammad b. Tawit al-Tanji, Ankara, 1962, pp. 80-81 & 236.

[9] That is how Beruni put it (*Taḥdîd*, p. 81), and he obviously meant Abu Abdullah the last ruler of the House of Iraq and his adversary Ali b. Mamun who won the throne for the new Mamunid Dynasty.

[10] F.A. Shamsi in his Paper "Abu al-Raihan Muhammad ibn Ahmad al-Bayruni" (*Al-Biruni Commemmorative Volume*, Hambard Academy, Karachi, 1979, pp. 260-288) has made useful observations on the chronology of Beruni's departure from Khwarizm, his presence in Ray, Jilan and Jurjan, and his eventual return to Khwarizm.

[11] *al-Qânûn al-Masᶜûdî*, Arabic text, 3 Vols., Hyderabad Deccan, 1954-56. p. 74.

time, Ali assigned him a position in the court, 'which pleased the friends who knew him and upset the ignorant ones'. He was not particularly happy with this assignment (as it was likely to disrupt his studies) with which he had been burdened, [12] but finding no way out of it he remained in that position during Ali's reign. However, he continued on subsequently under more favourable circumstances during the reign of his brother Abul Abbas when he was also able to save some time for his field research. [13]

It was during his close association with the court of the young prince Abû'l-ᶜAbbâs Mâ'mûn that Beruni became better informed about the power and position of Sultan Mahmud and the importance of the Ghazna court as a gateway to India. Abû'l-ᶜAbbâs became a brother-in-law to Sultan Mahmud, and also he reposed full confidence in Beruni whose counsels probably helped to maintain the most cordial relations between the two courts during most of the period of the young prince's reign. In his *al-Musâmarah fi Akhbâr Khwârizm* [14] (Chronicle of Khwârizm), Beruni has stated that he had served prince Abû'l-ᶜAbbâs for seven years; also he has underlined the fact during this period friendship between Abû'l-ᶜAbbâs and Sultan Mahmud was firmly established and that, presumably because of Beruni's advice and influence, Abû'l-ᶜAbbâs always tried his utmost to win the heart of Sultan Mahmud [15]. Also from a statement made by him in his *Kitâb al-Jamâhir*, it appears that most probably Beruni used to supervise the despatch of annual presents from Abû'l-ᶜAbbâs to Sultan Mahmud, which included precious stones of rare quality. [16] Such presents were probably

[12] *Tahdîd*, p. 81. فاكرت ـ من احوال الدنيا ـ على ما حدني عليه الجاهل
واقفل عليّ فيها الغفيق العاقل .

[13] *Loc. cit.*

[14] So is the title mentioned by Saᶜid Nafisi in his *Dar Pairāmun-i Tarikh-i Baihaqi*, Tehran, 1342 (S), (vol 2, p. 1004).

[15] Beruni quoted by Abul Fadl in his *Tarikh*, p. 907. من كه بُو ريحانم مر .
اورا هفت سال خدمت كردم ....وقضيان اوراميرمحمود دوستي محكم خد .... و ابو العباس
دل امير برهمه چيزها نگاه داشتي وازحد گذشته تواضع نمودي (تاريخ البيهقي ص ٩٠٢

[16] *Kitâb al-Jamâhir fi Maᶜrafat al-Jamâhir*, Hyderabad, Deccan, 1355 A.H., p. 56.
وكُنت رأيت بعوارزم في جملة ما كان يصدر في كل سنة من
الهدايا الى الامير يمين الدولة سكينًا صابه ياقوت احمر .
اذا قبضت اليد عليه .....ص ٥٦) .

prepared in his presence so that he could advise on their quality and excellence. As it was an annual affair, the fact of Beruni's expertise and advice should not have remained unknown to Sultan Mahmud.

It would appear that though Abû'l-ᶜAbbâs was a man of noble disposition he was not a great ruler. He could not maintain discipline in his army and also he could not balance his strategic position between the Ghaznavid power on the one side and the Khanates of Transoxiana on the other. In his 'Chronicle of Khwârizm' Beruni has recounted the circumstances which had prevailed during the last years of the prince's reign (406-407 A.H.), and how he had given the best possible advice to the Prince who, with all the regard he had for Beruni, either did not follow his advice or failed to take timely decisions. Thereafter, Beruni would appear to have continued his nominal attachment to the court but, to all intents and purposes, he kept himself aloof so that during 406-407 A.H. we find him busy with his astronomical observations. [17]

In Shawwal 407 A.H., Abû'l-ᶜAbbâs Ma'mûn Khwârizmshâh was slain in the rebellion led by Alptigin and other military commanders, and it is not known what happened to Beruni in the wake of it. There is no doubt that this event had shaken him up badly so that he recounted it in some detail in his "Chronicle of Khwârizm", copious extracts from which are preserved by Abul Fadl Baihaqî in his History. [18] Beruni's account shows that he had no soft corner for the rebels as he particularly mentions the stern punishment they deservedly suffered at the hands of Sultan Mahmud. Beruni must have found a place of safety for himself during and after the rebellion till the time that Sultan Mahmud attacked and defeated the rebel forces. Beruni and others who were attached to the court of Abul Abbas must have heaved a sigh of relief on hearing that the killers of their patron were vanquished and punished, and that they should have turned to Sultan Mahmud thereafter was but natural. Beruni's researches were disrupted by the rebellion, and as a man of practical wisdom he saw no prospects for his staying in Khwârizm and continuing his work. For long, he had been in search of original source books on Hindu astronomy, and he now saw it clearly that for his Indian studies Ghazna was his future destination. That Sultan Mahmud should have shown favour to him for being an eminent scholar and astronomer was but a

[17] In his *Tahdîd* (pp. 49, 53, 89, 101 & 108) and in *al-Qanun al-Masᶜudi* astronomical observations made by him specifically from Shawwal 406 to Rajab 407 A.H.

[18] *Tarikh-i Baihaqi*, (supra fn. 5).

welcome opportunity for him to leave for Ghazna. But neither the circumstances then prevalent at Khwârizm nor the Sultan's treatment of him tend to suggest that his departure from Khwârizm for Ghazna was against his will, or a forced one.

(ii) Was Beruni a politician and an antagonist of Sultan Mahmud?

Beruni was not a 'politician' by any stretch of imagination, and neither he was in a position to be an 'antagonist' of Sultan Mahmud. It would appear that in order to establish a basis for Sultan Mahmud holding Beruni as a hostage and according ill treatment to him because of the supposed antagonism between the two, Dr. Sachau assigned Beruni the role of a politician and capitalised on it. According to him, Beruni "played a political part as councillor of the ruling prince of his country of the Ma'mûn's family" (Preface, viii). Therefore, "from the very outset it is not likely that both the King and his Chancellor, Ahmad Ibn Hasan Maimandî, should have accorded special favours to a man whom they knew to have been their political antagonist for years" (Preface, ix). Dr. Sachau further qualified Beruni as a "cautious politician" implying as if he was an opportunist (Preface, x). There being no statements on record to warrant such conclusions, he attempted to infer this, and much more, from his other equally untenable assumptions such as Beruni's inadequate praise for Sultan Mahmud, his forthright views expressed in the presence of the Sultan, his criticism of him, and his failure to dedicate any of his works to the Sultan. But, Beruni has left enough on record to invalidate such assumptions, provided his reader did not put his own connotations on what was recorded by him. For example, even though Beruni has referred to Sultan Mahmud by his most proper title "al-Amîr Yamîn al-Daulah" and wherever he has mentioned the late Sultan he has sought blessings of Allah for him and recorded the most befitting bendiction after mentioning his name, to Dr. Sachau all this was not expressive enough of Beruni's regard for the Sultan (Preface, x-xi). Also Dr. Sachau failed to appreciate the great virtue of Beruni who would always speak the truth; if he had done so in the presence of Sultan Mahmud it was not because he did not respect the Sultan but because the truth had to be told. It was Beruni's courage of conviction, and not his animosity or antagonism towards the Sultan, that he criticised him for "utterly ruining the prosperity" of India (Preface, xi). In the same vein, he criticised Sultan Mes'ûd whom according to Dr. Sachau, Beruni held in higher esteem than Sultan Mahmud (Preface, xiii-xiv), by pointing out how

he had ruined the prosperity and administration of the State by squandering away all the accumulated treasures which had vanished like smoke as if in a single day.[19] Beruni even did not hesitate to speak the truth while delineating the character of his own prince and patron Abû'l-ᶜAbbas Khwârizmshâh: "He had praisworthy qualities of character, but also he had the unpraisworthy ones", so declared Beruni; and he added further: "I say this in order to make it clear that I cannot be partial to anyone" (while upholding the truth).[20]

To show that Beruni was not favoured by Sultan Mahmud, Dr. Sachau asserts it firmly that "at all events, it is perfectly certain that Alberuni cannot have been in favour with King Mahmud, or he would have dedicated one of his books to him".[21] The argument that Beruni had not dedicated any book to Sultan Mahmud does not establish that the Sultan did not favour him. For that matter, Beruni had not dedicated any of his books even to the princes of his own homeland, with whom his attachment in contrast to his disenchantment with Sultan Mahmud has been taken for granted by Dr. Sachau. Yet Beruni had done at least one favour both to his Khwârizmian prince and to Amîr Yamîn al-Daulah Sultan Mahmud: just as the 'Ring' for astronomical observations used by Abdu'-Rahmân as-Sûfî during the reign named his first 'Ring' after Khwârizmshâh as Khwârzimshâhî, and second one after Yamin al-Daulah (Sultan Mahmud) as *Yamînî*.

(iii) Were any restrictions placed on Beruni's scientific activity after his arrival in Ghazna? Learned Sachau conveys the impression as if it was so, despite the fact that Beruni had the most favourable opportunities available to him so that he updated his earlier researches, extended the scope of fresh inquiries, and was able to study Hindu religion, literature and science directly from Sanskrit sources as also from Hindu scholars

[19] *Kitab al-Jamahir*, p. 27.

زوال النظام من امره وما في يديه كيف تبدّدت امواله الدثرة مكتسبها والموروثة في يوم كيوم الدخان(كتاب الجماهر ص١٢) .

[20] Beyruni's own words in his *Chronicle of Khwârizm* quoted by Abul Fadl Baihaqî in his *Tarikh*, p. 907.

ويرا اخلاق ستوده بود ناستوده نيزهم بود·واين از آن مي گويم تا مقرر گردد كه مهل وتحابا نمي كنم .

[21] *Alberuni's India*, vol. 2, p. 325 (annotation on p. 240 of vol. 1).

themselves. The result was that he was able to author some of the greatest works of his life. Says Beruni in his 'Kitab al-Hind': "What scholar, however, has the same favourable opportunities of studying this subject as I have". [22] But to dispel the notion that he should have done more than what he had presented in this work, he also underlined the fact that after all he had to work under certain limitations. For instance he could not reach every where and have access to all the original Sanskrit sources, and that he also could not engage himself in frank and rational discussions with the Hindu pundits because they viewed him with suspicion and thought him "to be a sorcerer". [23] Dr. Sachau, however, disregards this context and, by suggestion, creates the impression as if the limitations under which Beruni worked were imposed on him by Sultan Mahmud, and that the change for the better came after Sultan Mahmud and his chancellor had died and Masu'd ascended the throne. To this end, Dr. Sachau has pressed into service Beruni's own words (Preface, xiv-xv) and invested them with a new context in his paraphrased translation. [24]

Elsewhere Dr. Sachau brings together the otherwise unrelated observations of Beruni to assert that Sultan Mahmud was the one whom Beruni "accuses of having failed in the duties of a protector of art and science imposed upon him by his royal office" (Preface, xv). In fact, there is no statement of Beruni on record anywhere in his writings to support this view. Since there was no positive evidence available to him, Dr. Sachau attempted to bring together the references from here and there, in a *chain of combinations* loaded with suggestions, to be able to draw the desired conclusions. After

[22] *Alberuni's India*, vol. I, p. 24.

[23] *Ibid*, vol. I, p. 23.

[24] Beruni has made a general statement without reference to anyone having imposed any restrictions on him. What he wants to say, in all humility, is that despite all the difficulties he had done his best: who could do better except the one who would not face such difficulties! Beruni's words ('Kitab al-Hind', Arabic text, Hyderabad, Deccan, 1377 A.H./1958) are:

ولقد اعيتني المداخل فيه مع حرصي الذي تفردت به في اياميٍ
وبذلي الممكن غير قصيح عليه في جمع كُتبهم في البَطان واستحضار
من يهدي لها من السكانين • ومَن لِغيري مثل ذلك إلاّ ان يرزق من
توفيق اللّه ما حرمته في القدرة على الحركات عجزت فيهـــا
من اللبث والبسط في الامر والنهي طوى عنّي جانبها والفكـــر
لِلّه علىٰ ما كفىٰ منهـا •

devoting one-third of his 'Preface' to this forced exercise, he was impelled to record apologitically the following which amounts to saying that his conclusions are based on manipulated inferences:

> In the absence of positive information, we have tried to form a chain of combinations from which we may infer, with a tolerable degree of certainty, that our author, during the thirteen years of his life from 1017 to 1030, after he had been carried from his native country to the centre of Mahmud's realm, did not enjoy the favours of the King and his leading men; that he stayed in different parts of India (as a companion of the princes of his native country?), probably in the character of a hostage or political prisoner kept on honourable terms; that he spent his leisure in the study of India; and that he had no official inducement or encouragement for this duty, nor any hope of royal reward. (Preface, xvi).

(iv) **Conjectures about the place where Beruni was supposedly held as a prisoner.** Having presumed that Beruni was brought to Ghazna as a political prisoner and was held as such thereafter, the question had to be answered as to where was he held? This led to further conjecture and speculation. If the Mamunid princes taken at Khwârizm were sent from Ghazna to the different strongholds for confinement, it was presumed that the same must have been the fate of Beruni. But not knowing where the other hostages were held, the places for Beruni's confinement were conjectured either from references to the forts/cities where any other political prisoners were held during the reign of Sultan Mahmud or even thereafter, or from Beruni's own references to the places which were possibly visited by him. Thus according to Dr. Sachau, Beruni might have been held as 'a state prisoner' at Multan because:

> "the city of Multan is in various places mentioned by the author in such a remarkable manner as makes me think that he knew it, and that lived there for some time. When King Mahmud, A.H. 408 (A.D. 1017), had returned from Khawârizm-Khiva after the conquest of the country, and had carried along with him the princes of the conquered house of Ma'mûn, many scholars (among them Alberuni), officers, and soldiers, did he send some of these (among them Alberuni) as state prisoners to Multan, which he had conquered years before? In this way, nineteen years later (A.H.

> 427), the princes of the family of Altuntash, who had ruled Khwârizm after the Mamunis, were treated by Mahmud's grandson, Majdud, who sent them as state prisoners to Lahore." [25]

On the other hand (following Dr. Sachau's speculation that Beruni had been taken and held as a political prisoner), Syed Hasan Barani thought that it was at Fort Nandana that Beruni was detained:

> Beruni "was most probably, kept as a political detenue in the fort of Nandana after the conquest by Sultan Mahmud in 407 A.H. (1016-1017 A.D.) of Al-Beruni's native land of Khwârizm where he had occupied a very prominent position under the royal patronage." [26]

Being almost sure about the place, Barani even suggested the duration of Beruni's confinement by observing that "this must have been of a very short duration." [27]

These conjectures are obviously based on a series of assumptions: viz that Beruni was taken as a prisoner at Khwârizm, was brought as such to Ghazna along with the Khwârizmian princes, and from there all the hostages including the princes and Beruni were sent for confinement somewhat in the newly conquered strongholds in India. The evidence available from the *qasîda* of the contemporary poet Farrukhî shows that this was not the case and that the princes were sent for confinement to the forts of Ūk, Tâq and Sipahbud (or Ispahbud) in Seistan. [28] Thus, there would appear to be no basis for the conjecture that Beruni along with the princes or any other hostages was held as a political prisoner in Multan, Nandana or anywhere else in the Indian Province of the Ghaznavid Empire.

Beruni's own Statements

In his works Beruni has often given vent to his feelings and expressed his anxieties and worries, but no where has he mentioned that he was brought as

[25] *Ibid, vol. 2, p. 325* (annotation for p. 240 vol. 1.)

[26] Syed Hasan Barani: "Muslim Researches in Geodesy", the paper published in *Al-Biruni Commemoration Volume*, Iran Society, Calcutta, 1951, p. 9 also the same viewpoint repeated by him in his introduction to *al-Qanūn Mas'ūdi*, Arabic text, Hyderabad, Deccan 1954-56, pp. vi & xxxii.

[27] *Ibid*, p. 34, fn. i.

[28] Nazim, *Sultan Mahmud*, p. 59 (fn. 5).

a prisoner to Ghazna and held as a hostage or prisoner thereafter. He has not stated the circumstances under which he stayed at Nandana. He has not done so even in case of the other places which were visited by him during the course of his field studies. Fort Nandana has come under reference in four of his separate works completed on different dates during a period of about 16 years, [29] but no where has he even hinted that he had been a prisoner at Nandana. His mention of "*Qal'â Nandana*" (Fort Nandana) as such, does not mean that Nandana was only a military fort where prisoners were held: by it he meant the fort city of Nandana. [30] It was then an important strategic city, being the provincial capital of the Ghaznavid Empire within India; previously it had been the capital of the Hindu Shahiyah dynasty. [31] Beruni's own words regarding his stay at Fort Nandana do not convey the meaning of a 'forced stay' there. It is but a factual statement, and in Beruni's own style of expression. [32] Besides, Nandana was not the only 'fort city' where Beruni had been or where he had stayed. He had been to Fort Lahaur and Fort Rajagiri in Kashmir where he must have halted even though for a short while. Also he had been to other cities *with forts* such as Peshawar, Waihind (on the Indus), Jhelum, Sailkot, Mandakakor (Fort Lahore) and Multan, and calculated the latitudes of all these places. [33]

[29] *Tahdîd* completed in 416 A.H., *Kitab al-Hind* in 421 A.H. (?), *al-Qânûn* in 427 A.H. and *Kitâb al-Jamâhir* in 432 A.H.

[30] The term '(قلعة فلان)' used earler in Khurasan, came into vogue on the side of Hind after its use by the early Ghaznavid historians such as Abu Fadl Baihaqi and others. *Factually*, it meant 'the place with a fort', but *conceptually* as a strategic and administrative centre of the region, or a capital city of the district /province/country. For instance, when Abul Fadl Baihaqi mentions قلعة غزنة he means 'the capital city of Ghazna' and not just the 'fort' of Ghazna. On the side of India, he has mentioned قلعة ماريكله (Taxila), (قلعة نندنه) (Nandanah) and (قلعة كالنجر) (Kalinger) as capital cities in their respective regions.

[31] After the fall, in 1002 A.D., of Waihand which had been their capital earlier, the Hindu Shahiyah ruler Jaipal transferred his capital to Nandana (Nazim, *Sultan Mahmud,* p. 88 fn. 3). Strategically located, Nandana remained the capital city of the region through the 18th century, Nandana was still a district (*Tibaqat-i Nasiri,* Eng. Edition by Raverty, I/537 fn.).

[32] Beruni's words about his stay at Nadana are (ولمّا اتفق لي المقام بقلعة نندنه) (see below the passage quoted from *Tahdîd* under "The Experiment'). Here, as elsewhere, Beruni in the ordinary sense of :'so it happened'. For instance writing about the date, time and place of his birth, he says " (وقت مولدي قد اتفق بمدينة خوارزم) " has used the verb "اتفق" (quoted from Beruni's (مقالة في حكاية امر الهند في استخراج السر) " by al-Tanji in the introduction to his edition of *Tahdid* p. 5.

[33] *Alberuni's India,* Sachau's Eng. tr., vol. 1, pp. 208 & 317.

So far as his relationship with Sultan Mahmud was concerned, his own version of it is writ large in a number of statements recorded by him in different contexts, which show beyond doubt that Beruni enjoyed a position of close trust and confidence with the Sultan, held him in high esteem, considered him as his benefactor, felt obliged to him and expressed gratitude to him. The more significant statements, some already referred to, may be underlined here in their chronological sequence as they clearly confirm the continuity of cordial relations between Sultan Mahmud and Beruni to the very last.

(a) Beruni's acquaintance with the Ghazna court developed during the long period of 7 years (499-506 A.H.) when he served Abu'l-ᶜAbbas Ma'mûn Khwârizmshâh, Beruni's own observations in his 'Chronicle of Khwârizm' (already referred to) show that he stood for the most friendly relations between Abu'l-ᶜAbbâs and Sultan Mahmud. When Abu'l-ᶜAbbâs failed to respond to Sultan Mahmud's requests and began losing his confidence, Beruni advised him in a manner to help him out of the predicament in which the young prince had placed himself. When this did not work, Beruni kept himself aloof from the court (406/407 A.H.). Beruni remained the most sincere well-wisher of his own prince and also a friend of the Ghazna Court.

(b) In his *Kitâb al-Jamâhir*, Beruni has stated that while at the court of Abu'l-ᶜAbbâs he used to oversee the despatch of royal presents to Sultan Mahmud annually, and he has specially mentioned a fine dagger with a precious ruby handle which was a part of these presents. [34] The high quality of the presents and Beruni's association with their despatch as also his expertise in gems must have been known to Sultan Mahmud as the gifts were despatched over a long period of more than 5 years.

(c) Beruni's personal acquaintance and association with Sultan Mahmud began after the Sultan had defeated the rebel forces and taken over Khwârizm, in Safar 408 A.H. Soon Beruni gamed complete confidence of the Sultan so that within one year after his arrival in Ghazna (Ramadan/Shawwal, 408 A.H.), he had not only availed of the opportunities to conduct field research as far away as Kabul and Lamghan, [35] but he was among those

[34] See fn. 16 above.

[35] See below fn. 44 and fn. 45.

courtiers who welcomed the Sultan when he was returning from his Mathura-Kanauj expedition by the end of 409 A.H. The Sultan was still on his way to Ghazna, but he was so anxious to meet Beruni and show him the precious gems secured from Nahûra that these were displayed before him for his expert opinion. Beruni has made a special mention of the two particular gems which he had then examined more minutely. The one was a fine piece of *baijâzi*[36] (an amber colour yellow-red ruby) and the other a glassy greenish gem which was considered to be the most precious one. Of this latter one, Beruni examined the colour and texture, and then holding it in his hand he began judging its weight and felt it to be somewhat lighter than the best of its kind. The Sultan was keenly watching, and seeing that lest Beruni might openly pronounce his opinion contrary to the popularly held belief about the uniqueness of the gem, he asked it to be returned before Beruni said anything about it.[37] This shows that the Sultan not only recognized Beruni's expertise in precious stones but also the quality of his upright character to declare what he believed to be true without any hesitation.[38]

[36] *Kitab al-Jamahir*, p. 89.

وقد رأيتُ منذ الاشهر بمدينة الدولة مما حمل اليه من بيوت الاصنام بمدينة نهورة قطعة ببجاني على الهيئة الصافية المسلسلة بجريان الماء مطاولة الشكل مفرطحة في غاية الخارية الى خضرة من الغبرة وعلى نهاية الصفاء والنقاء قدرت وزنها فيهما بين المغربين نرصا والثلثين ولم اقلها بيدي

(كتاب الجماهر ص ٨٩) .

[37] *Ibid*, p. 78. some readings given by the editor in the printed text are not appropriate and the alternate readings shown as 'variants'in the foot notes are to be preferred.

وأرانيه في الطريق عند منصرفه * فوجدته مائل اللون الى
خضرة الزجاج ... خلته بيدي فاستخففته ولمح ذلك وامر
باخذه من يدي لئلا اتبيّن فيه بخلاف ما يرى الناس منه (كتاب
الجماهر ص ٢٨) .

* The printed text has وأرانيه instead of ورأيتُ which is the reading.

** The printed text has ذلك الرجل فاخذه instead of ذلك وامر باخذه which is the reading of Mss.

[38] The text and the context of these references do not support the inference drawn by some scholars that what transpried reflect strained relations betwenn the Sultan and Beruni.

(d) Eversince Beruni's arrival in Ghazna, not only all the facilities became available to him but Sultan Mahmud bestowed special favours on him for his learning and quest for knowledge. Beruni was conscious of the Sultan's special favours *vis-a-vis* his own achievements to such an extent that writing in 416 A.H. he blamed himself for not having yet calculated the longitude of Ghazna by his new methods despite all the facilities being available to him. Says he in his *Tahdîd:*

> "When it has been established what I have already stated, I mean the determination of the longitude of a given town on Earth whose position in relation to other towns is known, such as Ghazna of which I have not yet been able to calculate but the latitude; [39I] the calculation of its longitude according to the methods described by me, [39II] however, could not be achieved due to many reasons which prevented me from accomplishing it. And if I excuse myself from determining it (longitude), it will amount to my denying the apparent and the hidden bounties of God (bestowed on me) as well as the bounty of my benefactor which he himself has bestowed on me in abundance. However, I seek the support of Almighty to facilitate (for me) the possibility of undertaking such studies as I have loved. [39]

(e) In his *Kitab al-Jamâhir,* Beruni has made a statement which shows that an intimate relationship of absolute trust and confidence had existed between him and the Sultan who confided in him in matters which were strictly personal and private. After underlining the fact how kings would want to collect treasures in order to maintain their sovereignty and

[39] *Tahdîd,* p. 213.

واذا تقرر ما بدئته ، ومقصودي معرفة طول بلد معين من الارض معلوم الوضع من سائر البلاد وهو غزنه التي لم يحصل لي الى الآن الا رصد عرضها فاما طولها بالاوجه التي نقلت فلم يحصل يتعقد لاسباب عاقت عن ذلك وان اعتذرت بعقتها تصورت نفسي كافراً بنعم الله الظاهره والباطنة ثمّ نعمة ولي النعمة التي سبغت عليّ يده ولكنّي استوفقه تعالى لتسهيل التمكن من المباحث التي عشقتها .... الخ. (تحديد ، ص ٢١٣.

[39I] As already mentioned by him in *Tahdîd* on p. 82 that is " ح م له " = 38-35.

[39II] The longitude of Ghazna as traditionally calculated before Beruni from *Maghrib* (the western most point of N. Africa) was already known, and Beruni has also noted it as صفر - كب - كو = 94° 22′ 24″ (*Tahdîd,* p. 253).

superiority, Beruni quotes what the Abbasid Caliph Mansur had said in that respect. He then states in the same context that the late Amîr Yamîn al-Daulah Mahmud was a man of action and firm determination and as soon as he was about to accomplish one task he would immediately set his eye on another (the time factor being important with him). One day, during the year (408 A.H.) that he had returned from Khwârizm, he inquired from his astrologers how many more years of life he had, and they informed him that it might be between ten to twenty years. 'So what?' he said, 'My fortresses are full of treasures to the extent that even if these were distributed over the number of days of those years for the sake of spending, it would not be possible to exhaust them'. (This often used to be the burden of the Sultan's personal confidential talk with Beruni). Recalling it, Beruni says:

> "This habit of his constantly complaining to me of that (the time factor and non-accumulation and exhaustion of wealth) and purterbing me by showing his anxiety on that account, compelled me to tell him: "Be grateful to your Lord, ask more from Him, and seek His protection of your real asset, viz., the kingship and the good fortune; for these treasures have accumulated only because of them, though disorganized spending for just one day cannot arrest their decay. Thereafter, he stopped (complaining about) it."[40]

(f) In the very last days of his life when Beruni was old and a forlorn figure in Ghazna, he recalled the special favours which Sultan Mahmud, more than anyone else, had bestowed upon him. In the following verses of his *qasida* composed in praise of the learned scholar and poet Abu'l-Fath al-Bustî, Beruni has named and complimented his past patrons (Mansur b. Ali b. Iraq of the royal house of Khwârizm, Shams al-Maᶜâlî Qâbûs b. Washamgîr the ruler of Jurjan, the two Khwârizmian princes Ali and Abû'l-ᶜAbbâs Ma'mûn, and Sultan Mahmud), and of them all it is only Sultan Mahmud to whom he has devoted two verses of his praise and gratitude. Also, it is to be noted that the name of Sultan Masᶜûd (whom Dr. Sachau placed much higher in

[40] *Kitab al-Jamāhir*, pp. 26-27.

Beruni's esteem than Sultan Mahmud) does not incidentally figure in this qasida: [41]

Most of my days passed under bounty's shadow
Occupying respectable positions and chairs of honour.

The house of Iraq nourished me and brought me up,
Of them Mansur having established me well.

Shams al-Maᶜâlî wanted to promote me
Despite my turning away from him—which was hard to endure.

And of the sons of Ma'mûn,ᶜAlî did me
A favour that consoled me in my poor condition;

[41] Yaqut, *Mu'jam al ᶜUdabā*, XI/186-87.

مَنَ أكثرَ الايّام في ظِلِّ نعمةٍ
عَلى رُتَبٍ فيها عَلَوتُ كَرَاسِيَهَا

فَآل عِراقٍ قَدَّموني بِكَرَّمٍ
ومنصورُ مِنهم قد تَوَلّى عِرايَتِيَا

وشمس المَعالي كان بِرتاد خدمتي
على نُفْرَةٍ مِنّي وقد كان قاسِيَا

واولاد مأمونٍ ومنهم عَلِيُّهم
تَبَدّى بِمَنْعٍ صارَ لِلحال آسِيَا

وآخِرُهم مأمونُ رَدَّ حالَتي
ونَوَّهَ بِاسْمي ثُمَّ رَأَّسَ رابِيَا

وَلَمْ يَنْقَضِ محمودٌ عَنّي بِنِعمَةٍ
تَأَنّى وأَفنى مُنْفِيًا عَنْ مِكانِيَا

فَمَنْ عَنْ جِهاتٍ لِلغِنى وأَبْدَى تَكَرُّمًا
وَطَرَّى بِجَاهٍ رونَقي وَلِيَاسِيَا

فَمَنْ عَلى دُنيايَ بعدَ فِراقِهِم
وَلَعَزَّنِي إِنْ لَمْ أَزُرْ قَبْلُ آسِيَا

And the last of them. Ma'mûn, improved my lot,
Brightened my name and then exalted me in position.

Never did Mahmud withhold any favour from me,
He made me wealthy and happy, overlooking my omissions.

He condoned my mistakes and showed magnanimity,
And, by his majesty, added glamour to my dignity and demeanour.

Woe to my life after separation from them!
And what a sorrow not to have met any consoler hitherto!

Conclusion

Weighing all evidence on record, it may be concluded that the myth of Beruni being held as a prisoner of war or a hostage and yet conducting remarkable studies and writing some of the greatest works of all times, needs to be buried once for all. For long, Beruni was anxious to have access to the original sources of Hindu literature, astronomy and other sciences. During the peiod of his service (399-406 A.H.) with Abû'l-ᶜAbbâs Ma'mûn Khwârizmshâh, he became better acquainted with the power and position of Sultan Mahmud and the importance of the Ghazna court as a gateway to India. After Abûl-ᶜAbbâs was killed (407 A.H.) by his rebelling commanders and disorders prevailed in Khwârizm, Beruni's hope for continuing scientific studies there was shattered. When Sultan Mahmud defeated the rebel forces and occupied Khwârizm (408 A.H.), Berûnî was well received by him as a scholar, scientist and a friend of the Ghazna Court. He accepted the Sultan's patronage and accompanied him to Ghazna, keeping in view the most promising future for his researches into Indology. Thus, Beruni was fully motivated for his fresh scholarly pursuits even before he had reached Ghazna. He arrived there in fortuitious circumstances enjoying the support of a great King whose realm had extended into the interior of Hind as far as the present territories of Pakistan, where minimum necessary facilities of safe escort, stay and interpretation could become available to him. He himself was conscious of all this: "What scholar, however, has the same favourable opportunities of studying this subject as I have!" And yet it was his own assiduity, patience and perseverance, and above all genius, which enabled him to achieve, in comparable circumstances, the highest scholarly success ever known in history.

II

DATE OF BERUNI'S ARRIVAL AND STAY AT NANDANA

Beruni has not mentioned the date of his visit to Fort Nandana. The chronolgy of events beginning from Beruni's departure from Khwârizm until his visit to Nandana is not clear, but an attempt to trace it may lead us to a more valid conclusion regarding his arrival and stay in Nandana.

(a) Abû'l-ʿAbbâs Ma'mûn Khwârizmshâh was assassinated by the rebels on 15 Shawwal 407 A.H. (17 March, 1017 A.D.), and the rebellous forces led by Alptigin and others were defeated by Sultan Mahmud in Safar 408 A.H. (3 July 1017 A.D.).[42] It was in the spring of 408 A.H., i.e. sometime during the months of Ramadan/Shawwal (February/March, 1018 A.H.) that accompanying the Sultan, Beruni arrived in Ghazna and, presumably, he would not have left the city so long as the Sultan was there. It was during the next year, on 13 Jamada-I, 409 A.H. (27 September, 1018 A.D.),[43] that the Sultan left Ghazna on his expedition against Mathura and Kanauj. It was then that the first convenient opportunity became available to Beruni to move out of Ghazna, and he immediately left for Kabul where he calculated the latitudes of Kabul and other places in the region. Thus, on "Thursday, the 1 st of Jumada-II, 409 A.H.", he was at Jafûr (Jaypur?) "a village in the vicinity of Kabul because of my utmost enthusiasm to calculate the latitudes of these places".[44] After spending some time in this region, he moved on to the Lamghân region where, in the vicinity of Lamghan, he observed the solar eclipse in the month of Dh'il Qa'dah, 409 A.H.[45] Soon thereafter he

[42] Nazim, *Sultan Muhmud*, pp. 58-59.

[43] *Ibid*, pp. 109-110.

[44] كنت بجيفور قرية الى جنب كابل وقد حملتني عدة الحرص على رصد عروض هذه المواضع . *Tahdid*, p. 88 (where حيغتور is a misprint for جيفور . He also calculated the latitude of Sakâvand. For a detailed discussion of the places visited by Beruni in this region, see the Paper by Dr. A.D.H. Bivar ("The Stations of Al-Beruni on the journey from Ghazna to Peshawar") published in Al-Beruni on the journey from Ghazna to Peshawar") published in *Al-Beruni Commemorative Volume*, Hamdard Academy, Karachi, 1979, pp. 160—181.

[45] *Tahdid*, Arabic text, p. 272 where سبع واربعمائة (407 A.H.) is an obvious misprint for تسع وسبعمائة (409 A.H.) because in 407 A.H. Beruni was still in Khwârizm. About the eclipse, Beruni says that the sun was not visible till it had risen above the mountain sky line. At that time, only about one-third of the sun was under the eclipse which was then clearing up.

returned to Ghazna before Sultan Mahmud's arrival from the Mathura-Kanauj expedition. The Sultan had left Kanauj for Ghazna in Sha'ban 409 A.H. (January, 1019 A.D.)[46] and possibly reached Ghazna late in Dhi'l Qa'dah or Dhi'l Hajj, 409 A.H. Along with other courtiers, Beruni welcomed the Sultan while he was still at some distance from the city. It was on this occasion that the Sultan showed him the precious gems he had brought from Nahûra for opinion.[47]

(b) During 410 A.H., though Sultan Mahmud had left Ghazna on his expedition against Kanauj, Bari and Kalinjar in Jumada-II, 410 A.H. (October, 1019),[48] Beruni had most probably remained in Ghazna throughout the year or at least until the month of Sha'ban and carried out several astronomical observations there.[49] Therefore, his visit to Nandana if at all it materialized during 410 A.H. must have taken place after the month of Sha'ban. In *Taḥdîd* which he completed in Ghazna on 22/23 of Rajab 416 A.H., Beruni has for the first time mentioned his stay at Nandana, but the words used by him [('On the occasion) when I had stayed at Nandana'] indicate that neither this happened in 416 A.H. nor in the previous year 415 A.H.[50] but sometime earlier. This leaves a period of 4 years, from the end of

[46] Nazim, *Sultan Mahmud*, pp. 109-110.

[47] See fn. 37 above.

[48] Nazim, *Sultan Mahmud*, pp. 110-111.

[49] He has specifically mentioned the three which were made on Monday 8 Safar; on Thursday, 14 Jumada-I; and on Tuesday, 14 Sha'ban. (Cf. *Taḥdîd*, Arabic text, pp. 248 and 281; *al-Qânûn*, pp. 365, 408 and 647).

[50] The year 415 A.H. may also be excluded for the reason that Beruni was possibly present at the court in that year. It is mentioned by Abul Hasan Ali Baihaqi (*Tarikh-i Baihaq*, Tehran, 1317s./1938, p. 63) that in 415 A.H. (1024 A.D.), King of Bulghar had sent offerings for the mosques of Sabzwar and Khusraugird in the Nishapur region along with presents for King of Khurasan. This may be the same event referred to by Yaqut (Irshad al-Arib, VI/310) that the ambassador "from extreme limits of the Turks" angered Sultan Mahmud by telling him that beyond the sea in the direction of "the Southern Pole" he saw the sun rotate visibly above the Earth. The Sultan then questioned Beruni who satisfied him with the explanation of the phenomenon. Minorsky (in his editon of *Sharaf-al-Zaman Tahir Marvazi on China, the Turks and India*, London 1942, pp. 110-11 onwards, and in his Paper "*On some of Berûnî's Informants*" published in *Al-Biruni Commemoration Volume*, Iran Society, Calcutta 1951, pp. 235-236) has commented on this event mentioned by Baihaqi and Yaqut and explained it in detail. He has pointed out that as the Turks belong to the north 'Southern Pole' might be as mistake for 'Northern Pole' and, that Sultan Mahmud is meant by 'King of Khurasan'. Also in September, 415/1024, Sultan Mahmud was in Balkh (Nazim: *Sultan Mahmud*, p. 53). Therefore, in case the presents were delivered by the Ambassador of Bulghar (Volga) at Balkh, it may be presumed that Beruni had accompanied the Sultan there; and if these were delivered in Ghazna, Beruni was present there in 415 A.H./1024.

410 A.H. to the end of 414 A.H., during which most probably he visited Nandana. [51] But according to his own statement, he had followed up his Ghazna observations of Sha'ban 410 A.H. again in Sha'ban 411 A.H.; "Thursday, 26, Sha'ban" (411 A.H.) is the more specific date recorded by him. [52] Thus, the duration from the end of 410 to the end of 414 A.H. again divides up into the following two specific periods for his visit to Nandana.

Ramadan 410-Rajab 411. In case it was his first oppurtunity to travel deeper into Hind, he was likely to have visited first the more important places where not only facilities for stay and transport but for guides to assist and interpret were to become available. Accordingly Peshawar, Waihand and Nandana would have been his most likely first choices because of their historical importance. Though this period of about 9 months not appear to be sufficient enough for his visits and stay on the way and for his stay and experiment at Nandana, he might have visited Nandana briefly this time and returned to it later for a longer stay.

411 (Sha'ban)-414 A.H. This period was long enough for any of his inquiries and observations before reaching Nandana, for his stay in Nandana, and for his visits in the Nandana region. He might not have remined absent from Ghazna continuously for three years, [53] and yet the period was adequate enough for at least one longer visit to Nandana and his stay there for purpose of experiment. Probably, that was why he specifically prefaced his account of the experiment by clarifying that he performed it on the occasion *when he had stayed* at Fort Nandana.

In choosing his itinerary for the places to be preferably visited by him in the interior of Hind (the parts then constituting the Ghaznaid territory / the present day Pakistan), Beruni must have attached importance to his visit to

[51] It is to be noted that during this period, the Sultan was also heavily involved in his five successive expeditions, in the years 410, 411, 412 and 413.

[52] *Al-Qânûn*, p. 365.

[53] There is not much on record to show that he had any important engagements in Ghazna during this period. In Rajab 412 A.H., he had finished writing his book *Istikhiraj al-Autâr* (as noted in the colophone of the printed editon. Hyderabad Deccan, 1367 A.H./1948) but it is not said that he did this in Ghazna. When he was just over 50 (قد كنت تجاوزت للخمسين), i.e., sometime during 413 A.H., he had consulted astrologers to feel better and re-assure himself, but not because of any serious ailments which afflicted him later when he was sixty (cf. his *Risalat al-Fihrist*, the text published by Dr. Edward Sachau in his introduction to the Arabic text of Beruni's *K. al-Âthâr al Bâqiyah*, Leipzig 1923, pp. xxxviii-xxxxviii). This consultation must have been in Ghazna even though for a very short duration.

Nandana because, as in the past so also during 411-414 A.H., Nandana was a place of considerable importance, historically and geographically. It had been the capital of the rulers of the Hindu Shahiyah Dynasty for about 12 years[54] until 404 A.H./1014 A.D. when it was conquered by Sultan Mahmud. Thereafter, for more than 6 years preceding Beruni's visit, Nandana had remained the capital of the Ghaznavid Indian Province. Geographically also it occupied a position of strategic importance, both commercially and militarily. The main route from the side of Peshawar and Taxila in the north, after traversing the Salt Range plateau descended through the gateway of Nandana into the plains of the Punjab and thence to Sind in the south and the plains of Ganges in the East. In ancient time, Alexander is believed to have reached the plain country through the gateway of Nandana[55] before his battle with Porus and his subsequent march through Sind to the sea. In Beruni's own time, Sultan Mahmud had stormed Nandana in 404 A.H. (March 1014) as it commanded the main route to the Ganges Doab[56] which was the Sultan's next coveted target. For Beruni himself, his visit to Nandana had the advantage of planning his travels further ahead, in the regions beyond it. Though he has not mentioned *all* the places where he had been during his travels in Hind, in one of his references he has named the more important ones which were visited by him and of which he himself had observed the latitudes: these were Purshavur (Peshawar), Lauhar (56 miles from the capital of Kashmir), Waihand (Hund), Fort Nandana, Jailam (Jhelum), Sialkot, Mandakakor (capital of the Lahore region) and Multan.[57] Most probably, he had travelled to Multan directly from Nandana as he has specifically mentioned it that "the distance between the last place (Fort Nandana) and Multan is nearly 200 miles".[58] This time he might not have stayed at Nandana and only passed through it.

During his stay at Nandana, Beruni had accomplished more than one tasks. By halting at Nandana and making it a centre for his inquiries, Beruni was able to extend his visits into the surrounding region which was also rich

[54] Having been vanquished in 399 A.H. (1001 A.D.) by Sultan Mahmud, and afraid of further onslaughts by him, Jaipal, the Raja of Waihand, had shifted their dynastic capital from Waihand to Nandana. (Nazim: *Sultan Mahmud*, pp. 87-88 & fn. 3 on p. 88).

[55] For a detiled discussion, vide Stein, Sir Aurel: *Archaeological Reconnaissances in North-Western India & South-Eastern Iran*, London 1937, pp. 36-44.

[56] Nazim: *Sultan Mahmud*, p. 91.

[57] *Alberuni's India*, fn (33) above.

[58] *Loc. cit.*

in minerals, and Beruni was equally interested in precious stones. A reference to that effect is preserved in his *Kitab al-Jamâhir* wherein he says:

> Within the boundaries of Mankavar not far from Fort Nandana in the territory of Hind, were brough to me stones, small ones and big ones, of the length of a finger or less than that... [59]

In Nandana proper, Beruni observed the latitude of the place which he has noted in his *Kitâb al-Hind* along with the latitudes of other places, which *he had personally visited*. The figure for Nandana (as given in the printed edition) is 32′-0. [60] Later, Beruni also calculated the longitude of Nandana (from the westernmost coastal point of Maghrib, North Africa), revised the figures for its latitude, and recorded both the figures in his *al-Qânûn al-Mas*ʿûdî. In the printed editon of this work, the longitude and the latitude of 'Fort Nandana' are given as 94° — 43′ (E) and 33° — 10′ (N) respectively. [61] This figure for the latitude of Nandana is quite close to the modern figure 32° — 43′.

The third most significant activity in which Beruni engaged himself during his stay at Nandana was his experiment to measure the dimensions of Earth by a new method, the thought of which occured to him when he actually saw the place.

[59] *Kitab al-Jamahir*, p. 95.

وفي حدود منكاور وليس ببعيد عن قلعة نندنه بارض الهند
ما حمل الينا من احجار صغار وكبار في طول الانملة وأقل
يميل بياضها الى قليل حمرة وعفاف ... الخ (كتاب الجماهر ص ٩٥)

In the printed text, the name (نندنه) has been left out, as the editor (F. Krenkow) has not been able to decide upon the three museum variations which are recorded by him in the footnote (صدقه , and صدنه) and which indicate the original reading to be (نندنه).

[60] *Alberuni's India*, vol. 1, p. 317.

[61] *Al-Qânûn al-Mas'ûdî*, vol. 2, Hyderabad, Deccan, 1374 A.H./1955 A.D., p. 562.

II

NANDANA: THE SCENE AND SETTING FOR THE EXPERIMENT

Beruni's approach to Nandana was naturally from the northwest along the age-old route, traversing the roof-like elevated Ara valley and then descending south-eastward (from the sector of the present Ara village and the Ara Rest House) towards the Nandana Pass. The environ enroute to Nandana, as it would have appeared and impressed Beruni, can best be visualized through the vivid description of it left by a modern researcher (Sir Aurel Stein) following the footsteps of Beruni:

> "I may now proceed to give an account of the route leading down from the Salt Range through the Pass of Nandana, and of the remains of the ancient stronghold. From the elevated ground of the Ara Plateau, at a height of about 2,400 feet, a steep winding road leads down over the rocky scarp of the range for close on 2 miles to where a small dip, about 200 yards across, at an average level of 1,300 feet stretches between two small valleys drained by streamlets which further south unite below the ruined stronghold of Nandana. Immediately above the dip referred to, which forms a kind of natural fosse, there rises very abruptly the bold rocky ridge of Nandana. On its top, at a height of about 1,500 feet above sealevel, it bears conspicuous ruined structures, and along the precipitious northern slopes below these, the remains of a boldly built line of wall, defended by bastions. This fortified ridge completely bars further descent on the route; for the two small valleys above mentioned contract on either side of it into deep and extremely narrow gorges, and descend for some distance between almost vertical rock walls, hundreds of feet high." [62]
>
> As one approaches the site, the northern slope of the rocky ridge on which stood the fortified inner city, becomes prominent. Before negotiating its bottom line, one passes through the ruins of the outer quarters of the city. Proceeding further and following the track higher up on the slope, there appear the massive foundations of the fortification wall skirting around this northern side and the remnants of the gateway leading into the walled city. This would

[62] Stein, Sir Aurel: *Archaeological Reconnaissances*, pp. 37-38.

appear to be the only gate, or the only main gate, through which Beruni must have entered the inner city, since there are no traces of a similar entrance, the slope of the ridge both to the left and the right of this gateway being too steep or rugged for a convenient entrance from there.

Inside, along the sloping area to the left there lie scattered the ruins of the inner city quarters extending south-astward up to the massive ruined structure of Budhist monastery standing high on the very south-eastern edge of the ridge. This was the main area of the more ancient Budhist city. To the right of the gateway, and high up on the ridge-top stands the tall edifice of a Hindu temple and a mosque behind it, both in ruins. It was on this high central part of the ridge that the Hindu city developed after eclipsing its Budhist predecessor. Adjacent to the mosque, a broad saddle like depression cuts across the top area and descends to a somewhat lower level below, on the southern side of the ridge, to a spacious semi-circular platform with the remains of its defensive bastions and living quarters. This is *Kanthi (Neck* of the ridge, with its two high shoulders of the upper flat top extending south-east and north-west). This depression (much deepened and broadened by rain waters during the course of centuries) now separates the central temple/mosque side from the other side extending north-westward close to *the high vertical wall-like* face of the mountain. This part of the ridge, on which also stands an early graveyard, was obviously rehabilitated during the Ghaznavid period. When Nandana was conquered by Sultan Mahmud in 1004/1014, it retained its importance as the capital city and the Sultan appointed his trusted officer, Sârugh Sharâbadâr, there as Governor. He was an efficient administrator who, during his long tenure of office of about 20 years or more,[63] developed the Ghaznavid quarters of the inner city, which extended form the mosque north-westward to the tail end of the ridge.

Berûnî visited Nandana when Governor Sârugh was still there and, in all probability, he stayed as a guest of the Governor not far

[63] Thereafter Sultan Mas'ud confirmed him there. According to Baihaqî, it was in 422 A.H./1030-31 that he set free Khawaja Abdul Razzak who was held there and escorted him to his father, Prime Minister Khawaja Hasan Maimandi in Ghazna, who thanked Sârugh but asked him to return to Nandana forthwith because tha fort and the front could not be left unattended (Abul Fadl a-Baihaqi, *Tarikh*, Persian text, Mashed, 1350/1971, p. 183).

away from the mosque. From there, the natural scene and setting around was so very impressive (as it is today) that it would have naturally attracted his attention. The fortified ridge stands across the junction of high spurs of the Salt Range with an opening (the Nandana Pass) on its south, below which extends the plain country. Looking through the Nandana Pass, from the side of the mosque, Beruni could have a clear, though partial, view of the plain extending southward. One high peak of the tail end of the spur stood close by on the right. Its most conspicuous feature which must have attracted Beruni's attention from the Ghaznavid quarters (as it does of any visitor now standing beside the mosque on the rim of the depression or on the other side of it), was its high vertical walk-like face. This well-cut smooth face becomes more and more visible, from the peak point to the foot, as one walks (beyond the Ghaznavid graveyard) closer to the edge of the ridge which is separated from the mount-wall by a narrow deep gorge, through sphere curiosity that the impressive scene inspires. Here was an ideal situation which must have enthused Beruni to experiment with his novel method there! The peak to bottom face of the mountain being smooth wall-like and vertical, its perpendicular height could be measured conveniently and more precisely. The other important requirement for his experiment was the vast level plain adjacent to the mountain and extending far away to the horizon. Though Beruni had a partial view of the plain through the Nandana Pass from his own quarters, he could not have a full view of it unless the either went on the other side of the Pass or climbed up the mountain. He preferred to go up to the mountain top so that he could size up the plain and also the peak point from where vertical measurement to its foot could be taken. To do so, he must have come out of the fortified part of the city, passed through the lower part of the city, traversed a long way toward north-west, crossed the shallow rivulet waters flowing downwards into the gorge, climbed up the slopes of the spur along its north-western shoulder and reached high up on the top before he could have a full view of the plain. When he did so and had a full view of the vast level plain extending southward far off to the horizon, he took the final decision to try out his new method for determining the dimensions of Earth. This is obvious from his own statement wherein he says that when he "*climbed up the mountain ... and looked up the plain extending southward' it occurred to me that I should test this method there*".

IV

THE PROBLEM AND THE METHOD FOR SOLUTION

As already discussed, Beruni stayed and performed his experiment at Nandana, more probably during the period 411 (Sha'ban) 414 A.H. (1020-1024 A.D.). However, solution of the specific problem, viz., a more precise determination of the length of one degree of the arc of the meridian circle, had been on his mind for many years before.

In his different works, Beruni has referred to the subject of dimensions of Earth and traced its study in historical perspective beginning from the views of the early Greek and the Indian astronomers, the more precise results obtained by actual measurement by Caliph Ma'mûn's scientists, and finally Beruni's own anxiety to verify their result in view of the discrepancy in their reported figures. The subject had fascinated him so much that he kept working on it for years and finally recorded his views and findings in detail particularly in his two works — *Taḥdîd Nihâyât al-Amâkin* and *al-Qânûn al-Masʿûdî*. His account of the studies carried out before him and the problem with which he was concerned may be summarized here keeping close to his own observations.

(a) Beruni has observed that besides mere tales and hearsay, what is specifically known about dimensions of Earth is that which is recorded in Greek and Hindu sources *(min jihat al-Rûm wa al-Hind)*.[64] However, they differ in their views and in their calculations of the length of arc of the meridian circle for the angle of one degree at Earth's Centre, and consequently in their figures for other dimensions. The Hindus differ on this in their main works, the five *Sidhantas*, and so also the Greeks in their results as recorded in the works of Galen and Ptolemy. The figures given in their units of measure, such as *yojana and stadia*, did not talley, and also values of these measures had varied from time to time. Again due to their language and the terminology used by them it became difficult for the later day scholars to grasp the correct meaning implied in their writings.

(b) The Abbasid Caliph Ma'mûn (198-218 A.H./813-833), therefore, asked his astronomers to re-examine the whole problem, and obtain exact measurements on their own. They proposed to ascertain the length of the arc

[64] *al-Qânûn*, p. 528.

of one degree so that the whole circumference as also the radius and the diameter could be worked out. This they planned to do by actual measurements in the plains of Sinjar in the region of Mosul. Elaborate arrangements were made, special instruments were devised, technicians were assembled and two groups of experts super-vised and conducted the whole operation. 'They specified a particular site for the observation of the Sun's altitude at the meridian. Then they proceeded from that point in two groups — Khâlid al-Marvarrûdî with one party of surveyors and technicians heading towards the Northern Pole, and Ali b. Isa al-Usturlâbî (the maker of astrolabes) and Aḥmad ibn al-Bukhtraî al-Zarrâ^{c} (the expert in zara survey) with another party in the direction of the South Pole. Both the parties observed the Sun at the meridian till they found it declining to one degree, without making any alterations in their straight course. While thus preceeding, they marked their paths with the measuring sticks and fixing arrows at the points. When they returned they once more verified their survey for the second time, till, both the parties came together at the place whence both had started. They found the single arc of the Earth as fifty-six (56) miles. Ḥabash believes that he heard Khâlid dictating this (figure) to Qâzî Yaḥyâ bin Aktham. So he got this information from Khâlid. Abû Hâmid al-Sâghânî has also narrated similarly from Thabit bin Qurrâ, but from Farghani is reported $\frac{2}{3}$ more in addition (to 56 miles). I have found all the other accounts agreeing about this $\frac{2}{3}$.' [65]

In *al-Qânûn,* Beruni further explains that "Ma'mûn's astronomers relying on the Celestial Pole in its Progression and Retrogression kept in view the conditions of guaranteeing the maintenance of a straight course in the day as well as in the night. They had observed the altitude of the North Pole by their instrument. When they had taken every possible care in the matter, they found out one of the 360 supposed degrees (of the Earth's circumference) to be 56 $\frac{2}{3}$ miles. Everyone of these miles consisted of 4000 *zara al-Sauda,* and every zara had the breadth of 24 fingers. Three of such miles make one *farsakh*". [66]

(c) As a scientist, Beruni was perturbed on account of this difference of two thirds of a mile between the two results of Ma'mûn's astronomers. He led developed a keen interest in astronomical studies at an early age, and had

[65] *Taḥdîd,* pp. 202-203 (following the translation of Barani).
[66] *al-Qânûn,* p. 529.

made some astronomical calculations, as he says, "when he was young, probably around the year 380 A.H. by using 'Zîj Ḥabash' "[67] (A Handbook of Astronomical Tables). He was then about 18 years old and, what is more significant, he was using "Astronomical Tables" compiled by the eminent astronomer of Ma'mûn's days-Ahmad b. ᶜAbdullâh al-Marvazî, professionally known as Habash al-Ḥâsib. It was in his other work (*Kitâb al-Abᶜâd wa al-Ajrâm)* that Habash had recorded what he had himself heard Khalid al-Marvarudi confirming that the result of their measurements in the plains of Sinjar was 56 miles to one degree. It could be that the two differing results of Ma'mûn's astronomers engaged Beruni's attention since 380 A.H. or soon thereafter, and he kept thinking about verifying the exact figure by taking measurements himself. This he did eventually sometime during 389-394 A.H. when he was under the patronage of Qâbûs b. Washamgîr, the ruler of Jurjan. For his measurements, he selected the plain country between northern Dihistan adjacent to Jurjan and the settlements of the Guzz Turks, but he did not succeed in this effort due to non-availability of precise instruments and adequate staff who could render necessary assistance to him.[68]

(d) However, Beruni did not give up the idea altogether and contemplated an alternate method, the idea of which probably struck him after reading a statement of one of Ma'mûn's scientists Abû Tayyib Sanad b. ᶜAlî (an associate of Khâlid who had earlier carried out the straight surface measurement between the towns of Raqqa and Tadmur and found the length for one degree arc to be 57 mile), who had probably used this method for the first time. Says Beruni:

> ᶜAbû al-Tayyib Sanad b. ᶜAli has reported that he was with al--Ma'mûn on the occasion when the Caliph had set out for al-Rûm and passed by a lofty mountain rising high on the sea (coast). There, al-Ma'mûn summoned him and directed him to climb up the mountain and observe the dip of the setting sun from the peak. He did so, and by this method he obtained the circumference of Earth'.[69]

[67] *Tahdîd*, pp. 234-35.
[68] *Tahdîd*, p. 204 and *al-Qânûn*, p. 530.
[69] *Tahdîd*, p. 209.

Beruni has explained the process how, by this method, different measurements could be taken from the peak by adjusting the 'observation apparatus' and the radius can be calculated first and then the circumference. "This exactly is the method whereby al-Ma'mûn had obtained the circumference of the Earth". [70] But, from his explanation it is obvious that the trigonometrical concept of sine formula was to be used in calculations, while it is not on record that this concept was fully developed by Ma'mûn's astronomers. Therefore, most probably, this was Beruni's own theoretical explanation of Abû Tayyib's calculation. Beruni had been contemplating the solution by himself and was led to it, as he has mentioned it, by a reference in the work of astronomer Abû'l-ᶜAbbâs al-Nairîzî (d. 300 A.H. It was on that basis that he had recorded the following theoretical explanation of calculating the circumference of Earth by observing the dip of the Setting Sun in the horizon in his earlier work *al-Kitâb fi al-Ustarlâb*.

> To know this method is quite conceivable in imagination, and it rests on sound deductions. It is difficult to carry it out in practice only owing to the smallness of the astrolabe (or other instruments) and the little size of the thing on which we have to base our solution. And that method is this. You climb a mountain situated close to the sea or a level plain, and then observe the setting of the sun and find out the value of the dip of the horizon we have already mentioned, and then find the value of the perpendicular of this mountain. You multiply this height into the sine of the complementary angle of the dip, and divide the total by the versed sine of this dip itself. Then multiply (the double of) the quotient into 22 and divide the result of this mutiplication by 7. You will get the length of the Earth's circumference (in the same terms or proportion in) which the height of this mountain has been fixed. We have not so far been able to experiment with this dip, and its value in any high place. We were led to this method by Abû'l-ᶜAbbâs al-Nairîzî who states, that Aristothenes (?) has mentioned that the heights of the peaks of the mountains would be 56 $\frac{1}{2}$ miles when the length of the radius of the Earth is 3.200 miles approximately. For the solution of this problem, it is necessary mathematically that the dip of the horizon in the mountain wherein the perpendicular is so high should be

[70] *Ibid*, p. 207-209.

> about 1/3 degree. Such matters, however, need actual experiments, and could be verified only by testing. The Almighty and Wise God alone can help me (in obtaining success in such ventures). [71]

This was a new method, the 'method of dip measure of sun set from a mountain peak' in contrast to the 'method of surface measurement with reference to sun's changing altitude'.

(e) It would appear that Beruni worked further on this new concept, and developed it in its general application to 'the dip of horizon' independent of 'the dip of the setting sun'. He has explained this method theoretically in *Taḥdîd* [72] before adverting to its application in his Nandana Experiment. He had fully developed it earlier and wrote a special treatise in 60 folios on this method entitled *Maqâla fî Istikhirâj Qadr al-ʿArḍ bi Raṣad Inḥitât. al-Ufqʿan al-jibâl* which is no more extant. The date of its completion is not known, but it is included in the list of his works which was compiled by Beruni himself in 427 A.H. [73]

It may, therefore, be concluded that the method of finding, by trigonometrical calculation, the circumference or other dimensions of Earth by observing the dip of horizon from the peak of a mountain was a fresh contribution by Beruni. He applied this method for the first time in his Nandana Experiment during 411-414 A.D.

The three versions of his description of the Experiment, along with comments and calculation, follow under the next section (V). Attention may be drawn to an important explanatory comment which Beruni has made in the more elaborate 3rd version recorded by him in *al-Qânûn* to the effect that the perpendicular of the height if projected *straight down shall necessarily pass through Earth's Centre on account of all the weights gravitating to it.* In other words, if a stone were dropped from the peak *straight down* along the height line, and if it were not blocked at the bottom by the surface, *it shall gravitate straight down to the Centre of the Earth.* It is to be noted that Beruni and his contemporaries were so very conversant with the concept of gravitation that he only underlines the fact but does not see the need to explain it further. This

[71] Quoted by Syed Hasan Barani (after Nallino) in "Muslim Researches in Geodesy", pp. 32-33.

[72] *Taḥdîd*, p. 210.

[73] *al-Fihrist*, reproduced by Dr. C. Eduard Sachau in his introduction to Alberuni's al-Athâr al-bâqiya un al Qurûn al-Khâliya, Arabic text, Leipzig 1923, p. xxxxi.

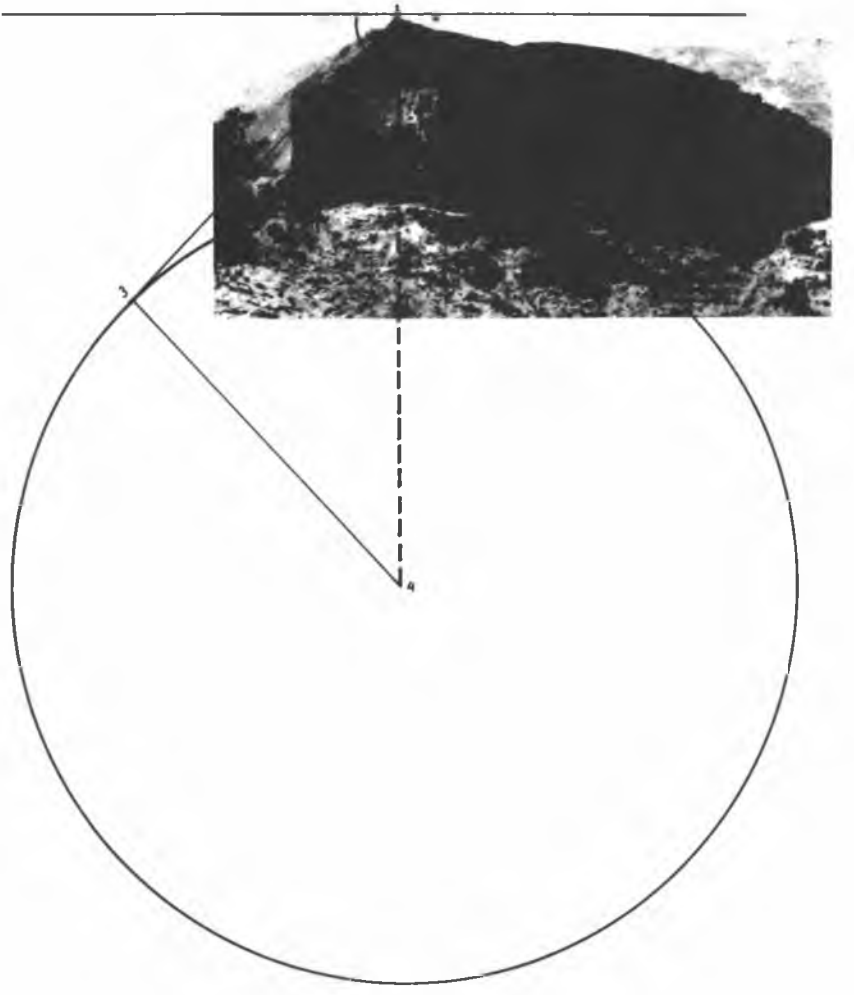
phenomenon of bodies *with weight* gravitating *straight down* to Earth's Centre would appear to have been experimentally verified and confirmed, and some of the distinguished contemporaries of Beruni used this established concept to experiment further and infer that Earth was not stationary but in motion, and that (along with it) the matter outside (within its orbit) had two types of motion (at the same time). Beruni refers to this view in *al-Qânûn* (Part-1, Chapter II, pp. 50-51) as under:

> "I have seen a certain astronomer, who is one of the perfect masters of the science, supporting the theory (of the Earth's rotation) by suggesting that heavy weight does not fall on the Earth in a perpendicular line, but always diverting from it in different angles which have not been yet determined or recorded. This gentleman is of the view that the matter outside the Earth has two movements, one circular, on account of the part naturally being attracted to the whole, and the other straight on account of its being attracted to its own original source".

Here he has not given the name of this distinguished scientist, but he was Abû Saʿîd Aḥmad b. Muḥammad b. ʿAbdu'l-Jalîl al-Sijzî whom Beruni recognised as one of the 'perfect masters of the science'. Abu Saʿîd believed in the rotation of the earth on its axis, and had also constructed an astrolabe on this basis. [74]

[74] *Kitâb Isti'âb al-Wujûh al-Mumkanah fi Sana'at al-Usturlab* (Ayasufiya museum No. 2576 in Süleymaniye, and museum No. 3319 in Kitâb Khâna i Millî-i Malik, Tehran). (ii) al-Kitab fi al Usturlâb.

THE NANDANA MOUNTAIN
A VISUAL DIAGRAM OF THE ACTUAL SITUATIONAL SETTING FOR THE EXPERIMENT



[1] The peak Point (Top) where Beruni stood and took measurements.

[2] The Bottom Point: Beruni measured the perpendicular height of the mountain from the top to the bottom (from 1 to 2).

[3] The Horizon Point, which lay in the plain to the south of the Nandana mountain towards the present Baghanwala village.

[4] Centre of circle, i.e. centre of Earth the circle corresponding to the circumference of the earth.

V

THE EXPERIMENT

Beruni's record of his experiment at Nandana is presently available to us in two his works, *Taḥdîd* which he completed in 416 A.H. and *al-Qânûn al-Masᶜûdî* which he completed in 427 A.H. He has also referred to it in his *Kitâb al-Tafhîm li Sana'at al-Tanjîm*.[75] In *al-Qânûn*, he has referred to it twice: first briefly in Part-I under Chapter 2, and then more elaborately in Part-V under Chapter 7. The two latter versions are brought under reference by Syed Hasan Barani in his paper on "Muslim Researches in Geodesy" wherein he has discussed the last one in detail. The version given in *Taḥdîd* has not been discussed so far; the late Syed Hasan Barani only made a brief reference to it as the text was not then available to him. It is intended here to record, in their correct text, the three versions in order to comprehend all aspects of Beruni's description of the experiment.

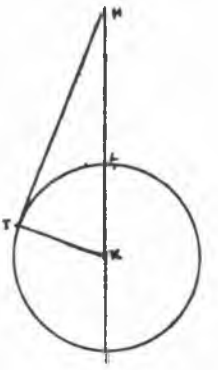
I. THE FIRST VERSION RECORDED IN TAḤDÎD

The first description of the experiment was recorded by Beruni in *Taḥdîd*. Its original Arabic text is reproduced from the printed edition under *Appendix I*. The translation, close to the original, follows:

> "(On the occasion) when I stayed at 'Fort Nandana" in the territory of Hind, and climbed up the mountain rising high above it on the west and looked up the plain extending southward from it (mountain), it occurred to me that I should test this method there. So I ascertained the sight line (extending) from the mountain peak (and) touching where the earth and the blue sky met (the horizon). The line so visualised from (my) standing position (on the peak) dipped against the (horizontally) fixed line by (an angle of) 0° 34′. Then I measured the (peak to bottom) perpendicular height of the

[75] After mentioning the results obtained by Ma'mûn's astronomers (length of degree = 56 2/3 miles and circumference 20,400 miles) he says: "I also verified its (length of one degree) accuracy in other ways in the land of Hindostan, and did not find it much different from the value mentioned by me in the above" (Quoted by Syed Hasan Barani in "Muslim Researches in Geodesy", p. 16).

mountain, and found it to be 652-3-58[751] *zirâ*^{c} (cubits), reckoned by the *zirâ*^{c} used as a cloth measure at that place (Nandana). Let this be HL in the diagram. Now angle T is a right angle, angle K equal to (the angle of) the dip (= 0° 34′), and angle H as its complementary = 89° 26′. So if the angles of the triangle HTK are known, its sides will also be known by the proportion of TK and *sinus totus* (= 1). By this proportion , TK will be 59° 59′ 49″ while the excess between it and *sinus totus* is 0° 0′ 11″. But that is the perpendicular height HL which is known in *zirâ*^{c}, and the ratio of its (HL) *zirâ*^{c} to the *zirâ*^{c} of LK is the same as the ratio of 0° 0′ 11″ to 59°



59′ 49″. Now 652-3-58 *zirâ*^{c} of HL multiplied by 0° 0′ 11″ degrees of LK comes to 39121-53′ 27″ 28″ 42[751II] which when divided by 0° 0′ 11″degrees of HL comes to 12853337-2-9. This in zira, is the half of the diameter of Earth. Therefore, its (Earth's) circumference in *zirâ*^{c} will be 80478118-30-39. Of this, the portion for one degree out of 360 (degrees) comes to 223255-59-45.[751III] When I divided this by four thousand, the (length in) miles for one degree came to 55° 58′

[751] In the Arabic text, this figure in print is given as ٦٥٢-٣-٥٨ and one may read the 2nd digit-form ' ' as (= 8), and the last digit-form ' ' as (٣ = ٣٠) = 53, thus the whole figure as 652-8-53. But by taking > = 3, ٣ = 8, the whole figure = 652-3-58. By this figure the *actual* calculation approximates to Beruni's.

[751II] In the text, the digit-Form ' ' is a misprint for ' ' (= 27).

[751III] In the text, the 2nd digit-form is ' ' which may be read as (= 19) or (= 59).

55". [75IV] This is not far from the report of Habash-and God is the support (in truth)." [76]

Comments and Calculations

As an expert, Beruni wrote for the experts of his days who were fully conversant with the subject, and understood the underlying concepts and the tenor of his arguments. Beruni believed in brevity and strict economy of words, and abhored jargon. Therefore, his expression is usually terse and loaded with meaning. Brief comments and calculations are being offered so that the general reader may fully appreciate the contents of the text. For convenience, the terms and expressions employed are explained below sequence wise as they occur in the text.

• *This Method.* His reference is to the method of finding the circumference of Earth (*Daur al-ᶜarḍ*) by the dip angle of horizon from the peak of a high mountain, as discussed by him in the previous pages (pp. 207-211) of *Tahdîd*. By calculation, it is a trigonometrical method of finding the radius first, and then obtaining the circumference. As already pointed out, this method was developed by Beruni himself.

• *the zirâᶜ used as a cloth measure in Nandana.* The figure 652-3-58 given for the perpendicular height of the mountain is in the *zirâᶜ* unit of measure which was then being used in Nandana. It might have been officially introduced by the Ghaznavid governor, and hence called *zirâᶜ*. If it were an indigenous measure with a local name, it would not have escaped Beruni's attention. This figure as given by him in *al-Qânûn* is $652\frac{1}{20}$ *zirâᶜ*. Thus, the two figures differ although the unit of measure is the same. Was it that the earlier figure recorded in *Taḥdîd* was later rounded of by him in decimal expression as "652 + *nisf ushar zirâᶜ*" = $652\frac{1}{20}$ (?)

• *Let this be HL in the diagram.* Though Beruni refers to his diagram (al-surat), he only specifies HL as representing the perpendicular height of the mountain, and leaves the rest of the diagram undescribed. In his somewhat more elaborate description in *al-Qânûn* (recorded hereafter), he has explained the diagram fully. By his explanation there the present diagram may be described as under:

[75IV] In the text, the 2nd digit-form is printed as ٤ which may be read as ٥٩ (= 59) or ٥٣ (53); while the last digit-form is printed as ٥ which may beread as ١٥ (= 15) or ٥٥ (= 55).

[76] *Taḥdîd*, Arabic text, pp. 212-213.

Now let the mountain's perpendicular height be HL (in the diagram) positioned erect on the Earth's sphere TML, and we project it straight down as TML. This shall necessarily pass through Earth's Centre on account of all the weights gravitating to it. Now let K be the Centre, and the line from the peak to the earth and touching it at the horizon as HT. We join K and T, and thus is obtained the triangle HKT of known angles with a riht angle at T.

• *If the angles of a triangle are known, its sides will be known by the proportion of TK and sinus totus.* The sides will be known by the proportion of TK and sinus totus. The sides will be known by the concept of sine formula of plane triangle, and Beruni was the first to have proved this formula [77] and made full use of it in his works. In *al-Qânûn,* it is dealt, with by him under Chapter 8 of Part-III:

$$\frac{a}{\text{Sin A}} = \frac{b}{\text{Sin B}} = \frac{c}{\text{Sin C}}$$

That is, the sines of angles of a triangle are proportionate to the sides opposite to the angles. His expression "by the proportion of TK and sinus totus', implies two parameters ('side' & 'angle') the ratio of which is implicit in the sine formula.

• *Sinus totus.* The term used by Beruni is الجيب كله (lit. the whole of the sine), i.e., the whole sine, sine of the whole angle of 90 degrees, or *sinus totus* of which the value = 1. That is, Sin < 90 = 1.

• *By this ratio, TK will be equal to 59° 59′ 49″.*

By application of the sine formula:

$$\frac{HK}{TK} = \frac{\text{Sin T}}{\text{Sin H}}$$

$$TK = KH \times \frac{\text{Sin H}}{\text{Sin T}} \quad \text{..... (i)}$$

[77] "None of his predecessors, from Ptolemy to Battani proved the sine formula" (Kazim, M.A.: "Al-Biruni and Trigonometry", the Paper Published in *Alberuni Commemoration Volume,* p. 169).

$$TK = 1 \times \frac{\text{Sin H}}{\text{Sin T}} \qquad \text{(Beruni has taken HK = 1)}$$

$$\text{Or} \quad = 1 \times \frac{\text{Sin } 89^{\circ}\ 26'}{\text{Sin } 90}$$

$$\text{Or} = 1 \times \frac{\text{Sin } 89^{\circ}\ 26'}{1} \qquad (\text{Sin } 90 = 1)$$

$$\text{Or} = \text{Sin } 89^{\circ}\ 26'$$

$$89^{\circ}\ 26' = 89\ \frac{26}{60} = 89.4333^{\circ}$$

$$\text{Sin } 89^{\circ}26' = \text{Sin } 89.4333 = 0.9999511$$

This number converted into degrees:

$$0.9999511 \times 60 = 59.99706$$
$$0.99706 \times 60 = 59.8236$$
$$0.8236 \times 60 = 49.416 = 59^{\circ}\ 59'\ 49''$$

Thus, $TK = 59^{\circ}\ 59'\ 49''$ ..... (ii)

the excess between it (TK) and sinus totus is $0^{\circ}\ 0'\ 11''$

$$TK = HK \times \frac{\text{Sin H}}{\text{Sin T}} \qquad \text{(By (i) above)}$$

$$TK = (HL + LK)\ \frac{\text{Sin } 89^{\circ}\ 26'}{\text{Sin } 90} \qquad (HK = HL + LK)$$

$$TK = (HL + LK)\ \frac{\text{Sin } 89^{\circ}\ 26'}{1} \qquad (\text{Sin } 90 = 1)$$

Now $TK = 59^{\circ}\ 59'\ 49''$ (By (ii) above)
But $TK = LK$ (being radii of the same circle)
$LK = 59^{\circ}\ 59'\ 49''$
Now $LK + HL = HK$
i.e. $TK + HL = HK$

This means that HL is in *excess* of TK or LK

HL = HK-LK
HL = 1-LK (Beruni takes HK = 1)
HL = 60° − LK (Beruni's integral unit is subdivided into 60 parts, each part again into 60 parts .... Therefore, 1 =60)

LK = 59° 59′ 49″

So, HL = 60 − (59° 59′ 49″)

HL = 0° 0′ 11″ ..... (iii)

That is, the excess (HL) between TK and sinus totus is 0° 0′ 11″.

. The ratio of its (HL) zirâ^{c} to the zirâ^{c} of LK is the same as the ratio of 0° 0′ 11″ to 59° 59′ 49″.

TK = 59° 59′ 49″ ..... (By (ii) above)

LK = 59 ° 59′ 49″ (TK = LK).

HL = 0° 0′ 11″ ..... (By (iii) above)

Now HK = HL + LK

Since HL and LK are two parts of a straight lines (in the diagram), therefore, by comparison, the ratio of length HL (in *zirâ^{c}*) to the length LK (in *zirâ^{c}*) is the same as the ratio of 0°-0′-11″ to 59°-59″-49.″

$$\text{i.e. } \frac{HK}{LK} = \frac{0^{\circ}\ 0'\ 11''}{59^{\circ}\ 59'\ 49''} \quad \ldots\ldots (iv)$$

Now 652-3-58 zirâ^{c} of HL multiplied by 59° 59′ 49″ degrees of LK comes to 39121°-58′27′28″-42. The following calculations are based on our assumption that one unit of zirâ^{c} is divided into 60 equal parts, each part again subdivided into 60 parts.

$$\frac{HL}{LK} = \frac{0^{\circ}\ 0'\ 11''}{59^{\circ}\ 59'\ 49''} \quad \text{..... (By (iv) above)}$$

or $LK \times (0\text{-}0\text{-}11) = HL \times (59\text{-}59\text{-}49)$ ..... (v)

$$HL = 652 - 3 - \frac{58}{60} \text{ (1 unit = 60 divisions)}$$

$$HL = 652\ \frac{3.96667}{60}$$

$$HL = 652.06611$$

$$59^{\circ}\ 59'\ 49'' = 59\text{-}59 - \frac{49}{60}$$

$$= 59 - \frac{59.8166}{60}$$

$$= 59.99694$$

Now 652. 06611 zirâ^{c} of HL multiplied by 59.99694 degrees of LK

$$= 652.06611 \times 59.99694$$

$$= 39121.97127$$

$$= 39121 - 58 - 16 - 34 \text{ (by our calculation)}$$

. *Which when divided by 0°0'0''11''' degrees of HL, comes to 12853337°-2'- 9''.*

Now LK × (0-0-11) = 39121.97127 ..... (by (v) above)

or $LK = \frac{39121.97121}{0 - 0 - 11}$

Degrees of HL $^{\circ} = 0\ 0' - 11'' = 0 - 0 - \frac{11}{60}$

$= \frac{0.1833}{60}$

$= .003055$

$LK = \frac{39121.97127}{.003055} = 12805882.57$ zirâ^{c}

$LK = 12805882\ ^{\circ}\text{-}34'12''$

• *This in zira^{c} is the half of diameter of Earth.* This is the value of LK in *zirâ^{c}*. But LK is the radius which is half the diameter of the circle which corresponds to the circumference of Earth's Globe. Therefore, the figure 12805882.57 in *zira^{c}* is half of the diameter of Earth. Radius (LK) is = 12805882-34′-12″ by our calculation (as against 1285337-2′ 9″ of Beruni, a difference of 47454-27-57 *zira^{c}*, i.e. 0.369 %).

• *Therefore, its (Earth's) circumference in zirâ^{c} will be 8047811 8-30′-39″.* This figure has been arrived at (i) by the value of π and (ii) by the formula π 2r or π D, for calculating the circumference of a circle. Beruni was fully familiar with both these concepts. In his *al-Qânûn al-Mas^{c}ûdî,* Chapter 5 of Book-III is devoted to the calculation of the value of π. As pointed out by M.A. Kazim (in his paper "Al-Biruni and Trigonometry", *Al-Biruni Commemoration Volume,* op. cit., p. 165): "He first determines the ratios of the diameters to the primeters of regular polygons of 180 sides, inscribed and circumscribed in the unit circle which corresponds to, $\frac{2}{360 \sin 1^{\circ}}$ and $\frac{2}{360 \tan 1^{\circ}}$ He, then, deduces that the value of it is intermediate between the two values $3^{p}\ 8'\ 29''\ 35'''\ 24^{iv}$ and $3^{p}\ 8'\ 30''\ 59'''\ 10^{vi}$ and applies Ptolemy's method of taking the arithmetic mean between the two values, and thus getting the result correct to the sixth order as $3^{p}, 8'\ 30''\ 17'''\ 46^{iv}\ 46^{v}\ 30^{vi}$. He further transforms the whole thing to the vulgar fraction as

$\frac{1628681471}{518400000}$ which comes out as 3.1417482. It was for the first time perhaps that Al-Biruni gave the result so correctly". (By our calculation the above vulgar fraction = 3.14117466).

The modern accurate value of π = 3.14159295, which is usually taken approximately as $\frac{22}{7}$.

Now, by Beruni's value of π :

Radius LK = 12853337-2′9′′

Circumference = π 2r
= 3.1417466 × 2 × 12853337-2′9′′.
= 3.1417466 × 2 × 12853337.0358
= 80763855.82 (as calculated)
80478118-30′39′′ (as in the text)

. *Of this, the portion for one degree out of 360 comes to 223255-59-59".*

By Beruni's figures:

Circumference = 80478118 - 30′39′′
= 80478118.51083

Portion for 1° = $\frac{80478118.51083}{360}$ = 223255.3291

= 223255 - 19 - 45 (as calculated)
223255 - 59′ 49′′ (as in the text)

• *When I divided this by four thousand, the (length in) miles for one degree came to 55° 58′ 55".* It has ben explained by Beruni in *al-Qânûn* (*op. cit.*, p. 529) that one mile was taken to be equal to four thousand *zirâ*^{c} which was known in the days of Ma'mûn as *zirâ*^{c} *al-saudâ'*. Therefore, he divided the figure in *zirâ*^{c} by 4000 in order to convert it into miles. Thus, the result is 55° 58′ 55″. It may be presumed that the fractions are expressed in terms of one *zirâ*^{c} *being*

divided into 60 parts, and again each part subdivided into 60 parts. If so calculated, the actual figures comes to 55° 48′ 48″, while in the text it is 55° 58′ 55″. The same figure given in ʿal-Qânûn al Masʿûdî' is 56° 5′ 50″ 6‴. This difference between the two values (as recorded in *Taḥdîd* written in 416 A.H., and again in *al-Qânûn* written in 427 A.H.) has been explained by Syed Hasan Barani ("Muslim Researches in Geodesy", *Al-Biruni Commemoration Volume*, p. 42) as under:

> "The only possible explanation to our mind seems to be that Al-Birunî had kept with himself the data of his observations at Nandana, and, as the subject continued to retain his interest to the end, he revised his previous calculations, and has embodied his better estimations".

• *This is not far from the report of Habash.* The reference is to the astronomer Aḥmad b. ʿAbdullâh al-Marvazî (originally from Merv but settled in Baghdad) known as Habash and his report on measurements taken by Ma'mûn's astronomers in the plain of Sinjar in the region of Mosul whereby they had determined the distance of the arc of meridian circle for one degree. Beruni calls it as 'Habash's report', because Habash himself had not participated in the experiment but had heard Khalid one of the participants, dictating to Yahya b. Aktham al-Qazi that the length of arc for one degree was found to be 56 miles. Habash later recorded what he had heard, in his book *Kitâb al-Abʿâd wa al-Ajrâm* and also used the figure 56 in all his calculations both in his Kitâb al-Abʿâd wa al-Ajrâm and in his Handbook 'Zîj Ḥabash'. The other figure for one degree length recorded by the other party was $56\ \frac{1}{3}$ miles. [78]

II. A BRIEF VERSION UNDER PART I OF AL-QÂNÛN

In *al-Qânûn*, under Chapter 2 of Part I, Beruni for a while reverts, during the course of his other arguments, to the subject of 'Dimensions of Earth' and briefly mentions the value of the length of arc of one degree angle at Earth's Centre determined in the past prior to his experiment at

[78] *Taḥdîd*, pp. 199, 203, 245.

Nandana. The original text of this version, which is translated below, is reproduced from the printed edition of *al-Qânûn* (pp. 51-52) under *Appendix II.*

> According to Eratosthenes, it (the length of arc of one degree) was 70 *stadia* as is mentioned by Galen in his 'Book on Reasoning and 500 *stadia* as stated by Ptolemy in his 'Book on Shape of Earth'. But the true value of this term *(stadia)* is unknown (to us) in the terms of our own units of measure. Therefore, the matter was re-examined in the days of Ma'mûn, and the length of (arc of) the angle (of one degree) was found to be $56\frac{2}{3}$ miles, the mile consisting of *4,000 zirâ*^{c} *saudâ*, and one *zirâ*^{c} having the width of 24 fingers.
>
> The Indians (on the other hand) have taken approximately twice this figure (for this length) in miles. Actual observation (on the spot) being more important than (relying on) mere report, I investigated this (figure of the length) in their own territory.
>
> I obtained the extent of the dip of the horizon at the peak of the mountain of Nandana, already of known height. From it (extent of the dip), I ascertained the value of that angle. (So the other angles and sides of the triangle became known, leading to the calculation of Earth's circumference). From it, I obtained the value (of the length of the arc) of that angle (of one degree) at Earth's Centre, which came within 57 miles.
>
> Therefore it is, that we have relied upon the result of the Mosul verification.

Comments.

• *Mountain of Nandana.* The reading in the printed edition is 'جبل میرته'. In a text which was available to Syed Hasan Barani ("Muslim Researches in Geodesy", p. 18) it 'جبل میرنه'. Both these readings are misprint for 'جبل نندنه'.

• *Of known height.* From this, it *may* be inferred (?) that Beruni had *first* measured the perpendicular height of the mountain and then the dip of the horizon.

• *Which came within 57 miles.* Literally, 'hovered around 57 miles'; but, then, this would also mean 'more than 57 miles'. Considering that the figures given by Beruni in two other versions (the previous one and the one that follows) are '56 minus' and '56 plus' respectivelly the expression here "والخمسين السبعة" may be the scribe's (or Beruni's?) error for "الستة والخمسين" (= 56).

• *The Mosul verification.* That is, the verification of the earlier figure obtained in the Greek sources. As recorded by Beruni (quoting from original sources) earlier in *Taḥdîd* (pp. 202-203) and also under Chapter 7 of Part V in *al-Qânûn*, the verification was ordered by Caliph Ma'mûn and carried out by his astronomers in the plain of Sinjar in the region of Mosul.

III. THE FULL VERSION UNDER PART V OF AL-QÂNÛN

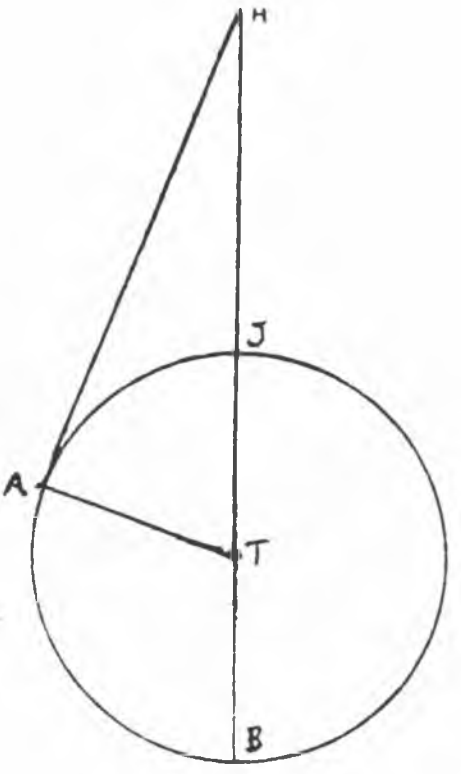
A more complete description of his Nandana experiment is recorded by Beruni under Chapter 7 of Part V of *al-Qânûn*. This version has been fully discussed, with copious commentary and calculations, by Syed Hasan Barani in his excellent Paper "Muslim Researches in Geodesy". The Arabic text is reproduced from the printed edition[79] under *Appendix III*. The translation below is based mainly on Barani's, with some slight modifications.

> "My extreme anxiety to verify it for myself, and my choosing (for this purpose) a level plain in Northern Dihistân which is in the territory of Jurjân, and eventually my failure due to exacting difficulties and want of earnest helper in the task, led me to adopt another method for it.
>
> When in the territory of Hind, I found a mountain rising high beside a level-faced plain, as level as if it were the surface of sea. I then imagined the sight (extending) from its peak to the junction of Sky and Earth, that is the horizon. Through my instrument, I found it dipping from the (horizontal) East-West line[78] (at peak position)[791] a little less than 1/3 and 1/4 degree. So I took it (the dip of the horizon) as 34 minutes. I then ascertained the (peak to bottom) perpendicular height of the mountain by measuring the height of its

[79] *al-Qânûn al-Masʿûdî*, vol. 2, Hyderabad, Deccan 1374/1955, pp. 530-31.

[791] The actual direction is somewhat S.E.-N.W.

peak from two positions, both (these height lines) being parallel to perpendicular height, and (by averaging them) I found it to be 652 $\frac{1}{20}$ *zirâ*^{c} (cubits).



Now let the mountain's perpendicular height be HJ (in the diagram) positioned erect on the Earth sphere ABJ, and we project it straight down as JTB. This shall necessarily pass through the Earth's centre on account of all the weights gravitating to it. Now let T be the Centre, and the line from the peak to the earth and touching it at the horizon as HA. We join T and A, and thus is obtained the triangle HTA of known angles with a right angle at A, the angle AHT being complementary to the angle of the dip of the horizon (= 0-34′) is, therefore, equal to 89°-26 with a sine of 0^{p} 59′ 59″ 49‴ 2⁗; and the angle NTA being equal to the dip angle itself,

that is 0′ 34″ with a sine of 0^{p} 0′ 35″ 36‴[79II]. And, thus, this (triangle) also becomes of known sides in the proportion in which TH is *sinus totus* (sine 1, of 90 degrees) and also that TA (half chord) will be sine of the angle complementary to the dip angle. Therefore, HJ will be the excess in *sine totus* (= 1) over the sine for the angle complementary to the dip angle, and that is 0^{p} 0′ 0″ 10‴ 57⁗ 32⁗′[79III] and its ratio to TA, the sine for the complementary angle to the dip angle, would be the same as the ratio of the cubits of the HJ perpendicular height of the mountain (652 $\frac{1}{20}$ cubits) to the cubits of TA, the half of the diameter radius) of Earth.

Therefore, the radius of Earth would be 12851369, 50′ 42″ cubits, the circumstances 80780039, I′ 33″ cubits, and (the length of the arc of) its one degree out of the 360 degrees 224388, 59′ 50″ cubits. The length in miles for one degree would be 56 5′ 50″ cubits. The length in miles for one degree would be 56, 5′, 50″, 6‴. That comes close to the result of those people (Ma'mûn's astronomers): it rather corresponds with it. And so my mind was set at rest (satisfied) about what they had reported (as being the distance for one degree). We have, however, adopted (their figure) for use because their instruments were more precise, and their labour in obtaining it (result) extremely exacting and painstaking.

As for the method of converting the miles of the distances into the degrees (of the meridian circle) so that the established process can be applied in all cases, it is that we multiply it (the mile figure) by 3 so as to make it three-fold, and divide it by 170 which represents thrice the miles of a single degree. Conversely, when it is intended to convert the degrees of a distance into miles, may multiply (the degree figure) into 170 and divide the result by 3. But since the multiplication of the result into 20 minutes is the substitute of the division of it by 3, it is, therefore, necessary to multiply the parts of the distances into 170 and the result into 20 minutes so as to get the miles."

[79II] In the printed edition, the last two numbers are given as نو، كو = 34,26.

[79III] In the printed edition, the figures are (لب ، نز ، ٠، ٠) i.e., 0.0,57,32. These are to be corrected as (لب ، نز ، ي ، ٠، ٠) i.e. 0,0,10,57,32 as given by Barani in his version of the text in his article "Muslim Researches in Geodesy" (*Albiruni Commemorative Volume*, Iran, Society, Calcutta 1951, p. 371) though ' نو ' therein is a misprint for ' نز '

Comments and Calculations

The following calculation and selected comments are reproduced from Syed Hasan Barani's Paper "Muslim Researchs in Geodesy" (*Al-Biruni Commemoration Volume*, pp. 46-54).

جیب تمام الخطط

$= \sin$ اهـ ط $= \sin 89^\circ 26' = 0^p\ 59'\ 59''\ 49'''\ 2''''$

$= 0 + \frac{59}{60} + \frac{59}{3600} + \frac{49}{216000} + \frac{2}{12960000}$

$= .98333333333$
$+ .0163888888$
$+ .00022685 18$
$+ .0000001543$
$= .999949228$ (correct to 9 decimal places onyl).

*These and other notations in Arabic refer to the diagram under Appendix – III.

جیب کل مفضل $= \sin 90^\circ = 1$
$=$ هـ

$= 1 - \sin 89^\circ 26'$
$= 1 - 0^p\ 59'\ 59''\ 49'''\ 2''''$
$= 0^p\ 0'\ 0''\ 10'''\ 57''''\ 32'''''$

$= \frac{10}{216000} + \frac{57}{12960000} + \frac{32}{777600000}$

$= .00004629629$
$+ .00000439815$
$+ .0000000411$
$= .000050735$ (correct to 9 decimal places only).

هـ cubits $= 652\frac{1}{20}$ cubits $= \frac{13041}{20}$ cubits

Now $\frac{\text{هـ}}{\text{ط}}$ cubits $= \frac{\text{excess هـ}}{\text{half chord ط}}$ or $\frac{13041}{20} = \frac{.000050735}{.999949228}$

or $\frac{20}{\text{cubits}}$

i. e. the radius of the Earth in cubits. $= \frac{13041}{20} \times \frac{999949228}{.000050735}$

$= \frac{652016894 1174}{507350}$

$= 12851421$ cubits.

As compared with Al-Beruni's calculation of the radius of the Earth. i.e. 12851369 cubits, our result is only 52 cubits in excess. But if we substitute in the above calculations 507352 instead of 507350 as the divisor, we get almost the same result as Al-Beruni had reached in calculating the radius of the Earth. In any case on the given data his result stands most approximately tested, and verifies the various values assigned in the text.

Now let us take up Al-Beruni's own measurements as given in Al-Qânûn:

1 degree	= 224, 389 zirâ^c or 56^o 0′ 50′′ 6′′′ or 363, 115 English feet.
Circumference	= 80,780,039 zirâ^c or 24,778$^{1/2}$ Eng. miles
Radius	= 12,851,370 zirâ^c or 3,939 miles.
Diaeter	= 7,878 miles.

Al-Beruni's site of measurement being the fort of Nandana, which according to Al-Qânûn had a latitude of 34° 10′, the length of the arc, therefore, would come to about 364,150 feet, a value which exceeds that of Al-Beruni's by 1,035 feet or a little more than $\frac{1}{5}$ of a mile only.

Al-Beruni's circumference is some 80 miles less than the true circumference, but if we take the Earth a perfect globe then the difference is about 70$\frac{1}{2}$ miles only.

According to Al-Beruni the Earth's radius is more than 12,851369 *zirâ*^{c}, i.e.

$$\frac{12851369 \times 6473}{4000} \text{ feet}$$

$$= \frac{12851369 \times 6473}{4000 \times 5280} \text{ miles}$$

$$= 3938.774 \text{ miles.}$$

The difference between the modern measurements and Al-Beruni's measurements of the Earth's radius is equal to

$$3959.738 - 3938.774 = 11.964 \text{ miles.}$$

Al-Beruni's arc being about 224,389 *zirâ*^{c} or 363, 115 feet, with a difference of 1,035 feet, the whole difference in the circumference, if the Earth were a complete globe, would be 70.568 miles only. [80]

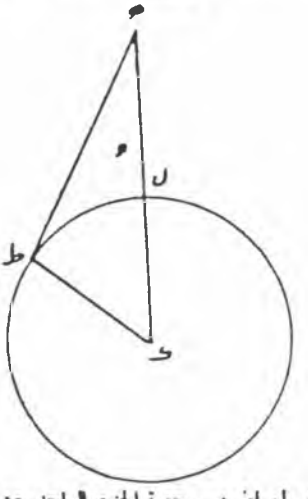
[80] The calculation is as follows:

$$1035 \text{ ft.} \times 360 = 372.600 \text{ ft.} = \frac{372,600}{5280} \text{ miles} = 70.568 \text{ miles.}$$

APPENDIX — I

Description of the Experiment as recorded in Tahdid Nihayat al-Amakin

ولما اتفق لى المقام بقلعة نندنه (١) من أرض الهند ، واشرفت من الجبل المطلّ عليها غربيا ، و عاينت البيداء الجنوبية عنه ، بتدكّل أن أتحن هذا الطريق بها ، فقست على قُلّة الجبل ما يحسّ من انتهاء الأرض واللون اللازوردى ، فانحط خط الإدراك عن القيام على خط الانتصاب لد ، و قست عمود الجبل فوجدته ٦٥٢ حـ ع فراعا بذراعان الثياب المستعملة فى تلك البقعة ، وليكن هـ ل من الصورة ، فلأن زاوية ط قائمة ، و زاوية ك بمقدار الانحطاط ٠ لد ، و زاوية هـ بمقدار تمامه قط كو ، فان مثلث هـ ك ط معلوم الزوايا ، فيكون معلوم الأضلاع بالمقدار الذى به ط ك الجيب كلّه ، و بهذا المقدار يكون ط ك نط نط مط ، و فضل ما بينه و بين الجيب كله ٠٠ ما و هو عمود هـ ل لكنه بالأذرع معلوم ، ونسبة أذرعه الى أذرع ل ك كنسبة ٠٠ ما الى نط نط مط ، ومضروب ٦٥٢ حـ ع لأذرع هـ ل فى نط نط مط لجزاء ل ك هو ٣٩١٢١ غ كز كه ٠ ب ؛ فاذا قسم على ٠٠ ما أجزاء هـ ل خرج ١٢٨٥٣٣٣٧ ب ط ، و هى أذرع ل ك نصف قطر الأرض ، فأذرع



دورها ٨٠٤٧٨١١٨ ل لد ، و حصة الجزء الواحد من ثلاثمائة ٠ و ستين ٢٢٣٢٥٥ ط مه ، فاذا قسمته على أربعة آلاف خرج لنيل الجزء الواحد نه نح مه ، و ما ذلك ببعيد عن حسّابة حبّش ، والله الموفق .

APPENDIX — II

Text of Beruni's Description of the Nandana Experiment. As Recorded under Chapter 2 of Book-I al-Qânûn al-Masʿûdî, Printed Edition Vol. I (pp. 51-52), Hyderabad Deccan, 1373 A.H./1954.

باعتبار ارطسثانس سبع مأية اسطاذيا كما فى كتاب البرهان لجالينوس، و على ما ذكره بطليوس فى كتاب صورة الارض خمس مأية، لكن معنى هذا الاسم غير معلوم بما عندنا من المقادير، و لهذا جدد الامتحان فى ايام المأمون فوجد لتلك الزاوية حصّتها ستة و خمسين ميلا و ثلثى ميل، والميل اربعة الف ذراعٍ سودا هى اربع و عشرون اصبعا، والهند يذهبون فى هذه الاميال الى قريب من ضعفها، و العيان اولى من الخبر و قد اعتبرتُ ذلك بارضهم و حصّلتُ مقدار انحطاط الافق فى قلّة جبل صيّرتُه معلوم العمود و استخرجت منه قدر تلك الزاوية فحام حول السبعة و الخمسين ميلا، ولذلك اعتمدنا الامتحان الموصلى .

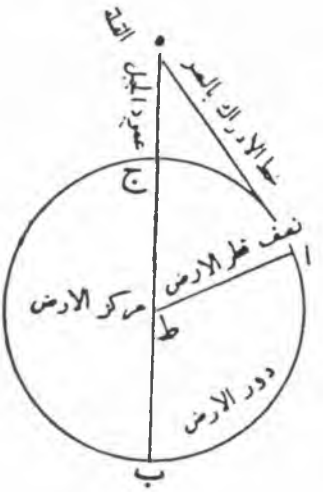
APPENDIX — III

Text of Beruni's Description of the Nandana Experiment Recorded under Chapter 7 of Book-I al-Qânûn al-Masʿûdî, Printed Editon. Vol. II (pp. 530-31). Hyderabad Deccan, 1374 A.H./1955.

على شدّة حرصى ان أتولى الاعتبار و اختيارى له قاعا صفصفا فى شمال دهستان التى بارض جرجان، ثم عجزى عن المفاوز المتعبة و المعين الصادق عليه عدلت فيه الى طريق آخر لما وجدت بأرض الهند جبلا مشرفا على صحراء مستوية الوجه ناب استواؤها عن ملاسة سطح البحر، فقست على ذروته ملتقى السماء و الارض فى المنظر أعنى دائرة الأفق، فوجدته منحطّا فى الآلة عن خطّ المشرق و المغرب بأنقص قليلا من ثلث و ربع جزء فأخذته اربعا و ثلاثين دقيقة، و استخرجت عمود الجبل باخذ ارتفاع ذروته فى موضعين هما مع اصل العمود على خط مستقيم فوجدته ست مائة و اثنين و خمسين ذراعا و نصف عشر ذراع.

(١) و ليكن عمود الجبل: هج، قائما على: اب ج، كرة الارض و نخرجه على استقامته على: ج ط ب، و لا بدّ من مروره على المركز لهبوط الأثقال اليه، فليكن: ط. و الخط المماس للارض من الذروة

هو المارّ على الافق، فليكن : ه ا ، و نصل : ط ا ، فيحصل مثلث : ه ط ا ، قائم زاوية : ا ، معلوم الزوايا، و ذلك ان زاوية : ا ه ط، بمقدار تمام انحطاط الافق وذلك : فط ، كو، وجيبه : (٠ ، فط ، نط ، مط ، ب) ، و زاوية : ه ط ا، بمقدار تمام انحطاط الافق ، وذلك نفسه وهو : ه ، لد ، وجيبه : ه ، ه ، لد ، كو، و هو اذن معلوم الاضلاع بالمقدار الذى به : ط ه ، الجيب كله، وذلك ان : ط ا ، يكون فيه جيب، تمام الانحطاط فـ : ج ه ، يكون فضل الجيب كله أعنى جيب تمام الانحطاط و ذلك : (٠ ، ٠ ، نز ، لب) ، و نسبته الى : ط ا ، جيب تمام الانحطاط كنسبة أذرع : ه ج ، عمود الجبل الى أذرع : ط ا ، نصف قطر الارض، فتكون اذرع نصف قطر الارض: (١٢٨٥١٣٦٩، ن، مب) ، و اذرع المحيط: (١٨٥٧٨٥٥٣٩ ، لج) ، و أذرع الجزء الواحد من ثلاثة مائة و ستين جزءا : (٢٢٤٣٨٨ : نط ، ن) و يكون أميال الجزء : (ن نو ، ه ، ن) فقد قارب ذلك وجود القوم بل لاصقة ، و سكن القلب الى ما ذكروه فاستعملناه اذ كانت آلا تهم ادق و تعبهم فى تحصيله اشدّ و اشقّ، و طريق تحويل أميال المسافات الى الاجزاء ليتمكن من عمل ما تقدّم فى سائر الابواب ان نضربه فى ثلاثة ليصير أثلاثا و نقسم على مائة و سبعين التى هى أثلاث أميال الجزء الواحد .



و فى عكسه اذا اريد تحويل أجزاء مسافة الى أميال ان نضرب فى مائة و سبعين و يؤخذ ثلث المبلغ لكن ضرب هذا المبلغ فى عشرين دقيقة ينوب عن القسمة على ثلاثة، فلذلك يجب ان يضرب اجزاء المسافة فى مائة وسبعين و ما اجتمع فى عشرين دقيقة فيحصل أميالها .

N.B.: This article is a reproduction, with the exception of some of its pictures, of the following publication of N.A. Baloch: N.A. Baloch, *Beruni and His Experiment at Nandana, International Conference on Science in Islamic Polity,* Islamabad, November 19-24, 1983.

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