of canopy conductance for tropical crops may need improvement, as well as the soil heat flux formulation. It would be useful to make annual simulations for the central site of Anand with the land-surface scheme only run in an offline mode (e.g. in a PILPS-like study; ref. 21), using hourly atmospheric and radiation forcing to drive the offline land-surface scheme. The uncertainty associated with soil moisture (due to point measurement) and vertical velocity (from NCMRWF Analysis that represents a very large area) might be the reason for poor simulation and therefore these two parameters need to be improved for better representation of the local terrain. These will be attempted in the forthcoming papers on this topic.

1. Viterbo, P. and Beljaars, A. C. M., An improved land surface parameterization scheme in the ECMWF model and its validation. *Climate*, 1995, **8**, 2716–2748.
2. Holtslag, A. A. M. and Ek, M., Simulation of surface fluxes and boundary layer development over the pine forest in HAPEX-MOBILHY. *J. Appl. Meteorol.*, 1996, **35**, 202–213.
3. Ek, M. and Mahrt, L., Daytime evolution of relative humidity at the boundary-layer top. *Mon. Weather Rev.*, 1994, **122**, 2709–2721.
4. Chen, F., Janjic, Z. and Mitchell, K., Impact of atmospheric surface layer parameterization in the new land-surface scheme of the NCEP mesoscale Eta numerical model. *Boundary-Layer Meteorol.*, 1997, **85**, 391–421.
5. Holtslag, A. A. M. and Boville, B., Local versus nonlocal boundary-layer diffusion in a global climate model. *J. Climate*, 1993, **6**, 1825–1842.
6. Chang, S., Hahn, D., Yang, C.-H., Norquist, D. and Ek, M., Validation study of the CAPS model land surface scheme using the 1987 Cabauw/PILPS dataset. *J. Appl. Meteorol.*, 1999, **38**, 405–422.
7. Chen, T. H. *et al.*, Cabauw experimental results for the project for intercomparison of land-surface parameterization schemes (PILPS). *J. Climate*, 1997, **10**, 1194–1215.
8. Qu, W. Q. *et al.*, Sensitivity of latent heat flux from PILPS land-surface schemes to perturbations of surface air temperature. *J. Atmos. Sci.*, 1998, **55**, 1909–1927.
9. Ek, M. and Mahrt, L., Daytime evolution of relative humidity at the boundary-layer top. *Mon. Weather Rev.*, 1994, **122**, 2709–2721.
10. Cuenca, R. H., Ek, M. and Mahrt, L., Impact of soil water property parameterization on atmospheric boundary-layer simulation. *J. Geophys. Res.*, 1996, **101**, 7269–7277.
11. Satyanarayana, A. N. V., Lykossov, V. N. and Mohanty, U. C., A study on atmospheric boundary-layer characteristics at Anand, India using LSP experimental data sets. *Boundary-Layer Meteorol.*, 2000, **96**, 393–419.
12. Vernekar, K. G. *et al.*, *Land Surface Processes Experiment in the Sabarmati River Basin: An Overview and Early Results*, IITM Technical Report, No. RR-087, 1999.
13. Vernekar, K. G. *et al.*, An overview of the land surface processes experiment (Laspex) over a semi-arid region of India. *Boundary-Layer Meteorol.*, 2003, **106**, 561–572.
14. Pandey, V., Kumar, M. and Sheikh, A. M., Agroclimatic features of LASPEX sites. *J. Agrometeorol.*, 2001, **3**, 39–55.
15. Pan, H.-L. and Mahrt, L., Interaction between soil hydrology and boundary-layer development. *Boundary-Layer Meteorol.*, 1987, **38**, 185–202.
16. Noilhan, J. and Planton, S., A simple parameterization of land surface processes for meteorological models. *Mon. Weather Rev.*, 1989, **117**, 536–549.
17. Troen, I. and Mahrt, L., A simple model of the atmospheric boundary layer: Sensitivity to surface evaporation. *Boundary-Layer Meteorol.*, 1986, **37**, 129–148.
18. Davenport, A. G., Rationale for determining design wind velocities. *J. Am. Soc. Civ. Eng.*, 1960, **ST-86**, 39–68.
19. Wieringa, J., Wind representativity increase due to an exposure correction, obtainable from past analogy station wind records, Proceedings of the TECIMO Conference, 1977, pp. 39–44.
20. Wieringa, J., Representation of wind observations at airports. *Bull. Am. Meteorol. Soc.*, 1980, **61**, 962–971.
21. Henderson-Sellers, A., Pitman, A. J., Love, P. K., Irannejad, P. and Chen, T. H., The project for intercomparison of land-surface parameterization schemes (PILPS): Phases 2 and 3. *Bull. Am. Meteor. Soc.*, 1995, **76**, 1335–1349.

ACKNOWLEDGEMENTS. This research has been supported in part by the United States National Science Foundation for Oregon State University (OSU) and the Indian Department of Science and Technology (DST) for the Indian Institute of Tropical Meteorology (IITM). For this study, data obtained in Land Surface Processes Experiment (LASPEX) has been used. LASPEX was sponsored by DST, Government of India. We thank Larry Mahrt at OSU and Bert Holtslag at Wageningen University, The Netherlands for their help in updating the various parameterization schemes or subroutines in the model. We also thank Dr G. B. Pant, Director, IITM, for the facilities provided for this study. Special thanks to Ken Mitchell at NCEP for encouraging continued collaboration with IITM by Michael Ek.

Received 24 February 2003; revised accepted 21 November 2003

On the astronomical significance of the Delhi iron pillar

R. Balasubramaniam[1,]* and Meera I. Dass[2]

[1]Department of Materials and Metallurgical Engineering, Indian Institute of Technology, Kanpur 208 016, India
[2]E-1, 154, Arera Colony, Bhopal 426 016, India

The astronomical significance of the Delhi iron pillar has been highlighted by addressing its probable original erection site at Udayagiri and the probable image that was atop the pillar's capital. Based on the astronomical significance of Udayagiri's location on the Tropic of Cancer, and earlier solar observations at Udayagiri, it has been shown that the iron pillar may have been aligned with the cardinal directions such that, on summer solstice day, the early-morning shadow of the pillar fell along a specially cut passageway in the direction of one of the important bas reliefs (in cave temple 15) at Udayagiri site. Evidences have been provided to corroborate the identification of a circular disc-shaped object (20″ diameter and 2″ thick) that was probably atop the Delhi iron pillar capital.

THE Delhi iron pillar has been a major attraction for academics in history, archaeology, metallurgy and science, apart from the general public primarily due to its antiquity,

*For correspondence. (e-mail: bala@iitk.ac.in)

engineering and exceptional resistance to atmospheric corrosion. Its artistic design is also admirable. While the known facts about the Delhi iron pillar have been summarized in a monograph by Anantharaman[1], several new insights regarding its historical, technical and scientific aspects have been compiled in a recent book by Balasubramaniam[2].

The Delhi iron pillar is currently located in the courtyard of the Quwwat-ul-Islam mosque in New Delhi. However, this was not the original erection site of the pillar. The original location of the iron pillar has been described in the 6-line 3-stanza Gupta–Brahmi Sanskrit inscription on the pillar, the oldest and largest of all the inscriptions on the pillar. This inscription records that the pillar was set up by *Chandra* (having in faith fixed his mind upon *Vishnu*)[1] as a standard of Vishnu (*Vishnuordhvajah*) at *Vishnupadagiri*. In the iron pillar inscription, the short version of *pada* (meaning footprint) is provided and not the long version *pāda* (meaning foot). Therefore, *Vishnupadagiri* translates as 'hill of the footprint of Vishnu'. The monarch's conquests have also been poetically described in the inscription. It must be noted that three directions are referred to in the inscription (i.e. east, south and west) and also Vishnu's name appears three times in the inscription, although in different contexts. The inscription has been analysed in great detail elsewhere[2,3]. *Chandra* has been identified unambiguously with Chandragupta II Vikramaditya (AD 375–414) based on a detailed analysis of the archer-type gold coins of the imperial Guptas (AD 320–600)[3]. The original location of the pillar, *Vishnupadagiri*, has been identified as modern Udayagiri, in the close vicinity of Besnagar, Vidisha and Sanchi[3]. These towns are located about 50 km east of Bhopal, in central India, and the region is called Malwa. Literary, archaeological, numismatic and geographic evidences for the identification of modern Udayagiri as ancient *Vishnupadagiri* have been discussed in detail elsewhere[2–4]. If there was one location that Chandragupta II Vikramaditya was personally associated with, it must have been Udayagiri, because it is here that we find two datable inscriptions specifically mentioning Chandragupta II, and, moreover, 19 of the 20 cave temples at this location are from his reign[4]. The antiquity of *pada* (i.e. footprint) worship is well established in the region near Udayagiri as indicated by several evidences[4]: worship of inscribed *Vishnupada* (footprint of Vishnu) at a place near Udayagiri foothill called *Charan Thīrth*, situated at the confluence of rivers Bes and Betwa; the presence of Heliodorous pillar at Besnagar; worship of the tenth Jain *Thirthānkar* Śītalānāthjī's footmarks in cave 20 in Udayagiri (dated by an inscription in this cave to AD 426) and the discovery of a Kushan-period brick with partial marking of a foot at Udayagiri. The word *Vishnupada* occurs in a royal seal, of Chandragupta II Vikramaditya's period, discovered from Basarh, the supposed site of the ancient city of Vaishali. The arguments linking this seal with the identification of Udayagiri as *Vishnupadagiri* have been discussed in great detail elsewhere[5]. A later-day inscription from AD 1036 in cave 19 specifically identifies Chandragupta II of having built the temple at Udayagiri[6]. In order to further emphasize Udayagiri's positive identification as *Vishnupadagiri*, and hence the original location of the iron pillar, Dass[4] provided several evidences for iron-making tradition in the Udayagiri–Vidisha–Besnagar–Sanchi region (iron wedges from Sanchi and Heliodorous pillars, iron slags from several sites near Vidisha, remains of iron-making furnaces, names of nearby places like Lohangi, Lohapura, etc.).

The Delhi iron pillar was re-located to its current location in the courtyard of the Quwwat-ul-Islam mosque (near the Qutub Minar) in New Delhi by Iltutmish[4]. The movement of the iron pillar occurred sometime around AD 1233. The history of movement of the iron pillar from its original erection site at Udayagiri to its current location has been discussed in detail elsewhere[2].

The aim of the present article is to highlight the astronomical significance of the Delhi iron pillar as revealed by its probable erection site at Udayagiri. The astronomical symbolism of the pillar would also be additionally addressed based on the identification of the probable image that was originally placed atop the pillar's capital.

The astronomical significance and importance of Udayagiri, i.e. *Vishnupadagiri* during the Gupta period, has been established, for the first time, from several archaeological evidences by Dass[4]. The location of Udayagiri is quite close to the important places of ancient central India, namely Vidisha, Besnagar and Sanchi. The importance of this region in the context of ancient Indian history, culture and trade has been well documented[7]. The antiquity of sun worship and astronomical observations at Udayagiri site have been explained in detail by Dass and Willis[8]. The most significant aspect of the location of Udayagiri is that it is situated at 23°31′ lat, almost on the Tropic of Cancer. The Tropic of Cancer is an important latitude in the northern hemisphere like the Tropic of Capricorn in the southern hemisphere. It is generally considered to be located 23.5° north of the equator for the sake of simplicity. The tropics are, however, not static but move due to natural oscillations of the angle of the earth's tilt axis. The Tropic of Cancer[8] was located at 23°42′ in 100 BC, 23°39′ in AD 400 and 23°26′ in AD 2001.

It is important to note that sun temples and associated observatories for astronomical observations were established along the Tropic of Cancer in ancient India, as provided by ancient Indian texts on astronomy[9,10]. Several evidences have been analysed in detail elsewhere[8] to establish that Udayagiri served as a major centre for astronomical observations in ancient India and was an important centre for sun worship. Astronomical studies were being conducted at this location, even in times prior to the Gupta period[8]. The relationship between Surya and Vishnu was emphasized, especially at Udayagiri, during the Gupta period[4,8]. During the reign of Chandragupta II, this connection was symbolically extended to a greater length by the invocation of Chandragupta's epithet *Vikramā ditya,* meaning 'valorous sun'. The adoption of the title *Vikramāditya* by Chandragupta II appears to signify several different meanings. The word is a combination of *Vikrama* and *Āditya*. The term *Vikrama*, apart from signifying valour, has connections in Vaishnava philosophy with the concept of *Trīvikrama* striding over this universe and in three places planting His step. Philosophically, the 'three steps' were interpreted in ancient Indian astronomical treatises as being the three positions of the sun at its rising, culmination and setting, thus linking *Vikrama* as *Āditya*, or Vishnu as the Sun God[4,9]. At Udayagiri, it is this aspect of *(Trī) Vikrama-āditya* which Chandragupta II sought to use for his own metaphorical representations. It is, therefore, emphasized that the Udayagiri site during the Gupta period was an important religious site, related to Vishnu and Surya worship, and had strong connections with astronomical observations[8].

Attention will be focused briefly on the layout of Udayagiri and its associated architecture to understand its astronomical significance. Chandragupta II Vikramaditya established 19 of the 20 cave temples in this mountain. Some of these are not temples in the real sense of the word, but rather bas-reliefs carved on the rock face[11]. The complete layout of Udayagiri is provided in Figure 1 *a*. The first general observation of the overall hill site layout is that it is shaped like a foot. A saddle connects the northern and southern hills. A specially aligned passageway is located at the place where the northern hill meets the saddle. The Gupta period embellishments, modifications and constructions at Udayagiri were concentrated around this passage (shown hatched in Figure 1 *a*). The passage is important because it is the only path leading to the west of the hill and it is the main approach to Gupta-period sun temple on the northern hilltop and remains enroute to it. Most of the cave temples are located around the passageway. The precise locations of the cave temples around the passageway are provided in Figure 1 *b*, which is the detailed map of the hatched region in Figure 1 *a*. The relative orientation of the caves that have been indicated in Figure 1 *b* is based on initial survey of the area. It is important to note that all the carvings and the caves along the passageway are cut into the south wall (Figure 1 *b*). The other cave temples are carved on the east face abutting the passageway (Figure 1 *b*). In Figure 1 *b*, the cave temples have been numbered within circles according to the existing classification system[12]. The most important and architecturally significant bas-reliefs at Udayagiri are that of *Varāha* (in cave 5) and *Anantaśāyin* Vishnu (in cave 13). Detailed descriptions of these images are available in the literature[13,14]. The *Varāha* panel in cave 5 is located on the east face abutting the passageway and, moreover, faces the rising sun on *all* days in the year. The *Anantaśāyin* panel in cave 13 is located at the west end of passage. The *Anantaśāyin* panel is aligned east-west with the feet of Vishnu, depicted in cosmic sleep on the coils of *Ananta,* on the west. The panel is cut at a particular angle with respect to the cardinal directions, and it faces north. The angle of cut of the passageway is an important consideration and this will be discussed in detail later.

The arrangement of the Vishnu images in *Anantaśāyin* and *Varāha* panels indicates the special role of the sun with respect to these images. For example, the early-morning sun lights up the *Varāha* panel on *all* days in the year. However, it is only in the period preceding and following the summer solstice day that the alignment of sun with the site is such that the *Anantaśāyin* panel is lit by the sun, particularly in the evening, because of the unique alignment of this panel with respect to the cardinal directions. It must be noted that this is the time of the year when the sun rises and sets 23.5° north of the east and west directions respectively at Udayagiri and the sun is at its northernmost declination. This issue will be discussed in greater detail in the next section. Therefore, clearly, the designers of the structures were well versed with astronomy and cleverly blended astronomical events with architectural imagery.

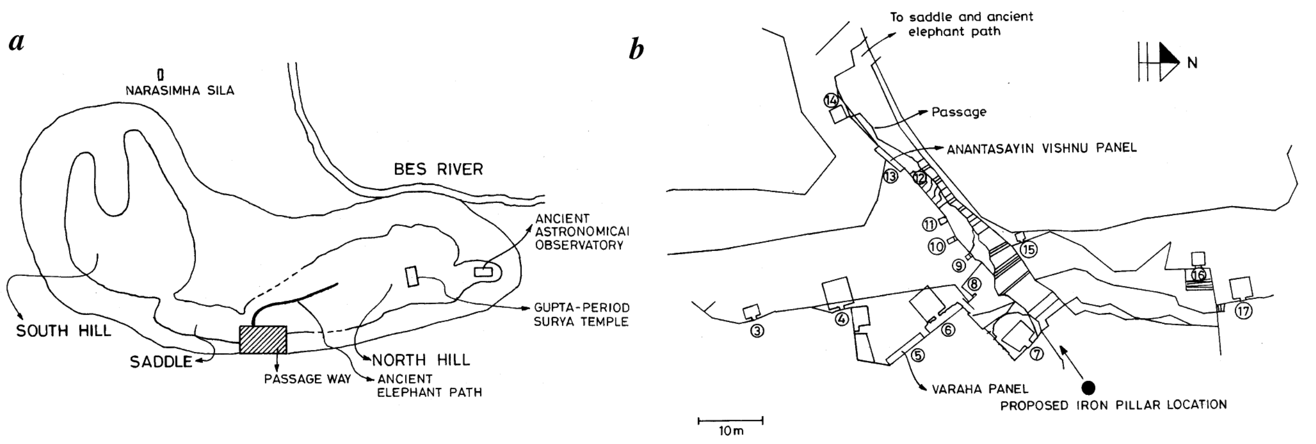

Figure 1. Layout of (***a***) Udayagiri hill and (***b***) important caves (3–17) around the passageway.

The probable original erection site of the iron pillar at Udayagiri (in front of the passageway, ahead of cave 7) has been deduced based on epigraphic and archaeological evidences[5]. Cave 7, which is presently empty, occupies a significant location with respect to cave temples 5 and 13. Incidentally, cave 7 contains an important inscription of Vīrasena Sāba, the chief minister of Chandragupta II Vikramaditya, who records that he had come there, accompanied by the king in person, who was seeking to conquer the whole world[15]. The importance of this cave in the overall architectural scheme of Udayagiri is not immediately obvious because the ground levels have been modified by misguided restoration work, the building of a wall and the construction of a road. This cave, carved into an unusual conical rock formation with a disc-like top (Figure 2), is like a reception kiosk to the complex. The location of the *Anantaśāyin* panel (in cave 13) has been marked with an arrow in Figure 2.

The probable original location of the pillar has been marked with a dot in Figure 1 *b*[5]. Considering the pillar's probable location, it must have been possible to view both the *Varāha* panel in cave 5 and the *Anantaśāyin* panel in cave 13. This can be understood from the photograph (Figure 2) taken in 1914 from the front of cave 7. The position from where this photograph was taken approximately provides the probable original erection site of the iron pillar. It must be carefully noted that from this location in front of the passageway, the *Anantaśāyin* panel is visible on the right (marked with an arrow in Figure 2) while the *Varāha* panel is visible on the left side. (Two side walls and an overhanging roof have now been constructed by the Archaeological Survey of India around the *Anantaśāyin* panel and therefore, this panel is no longer visible from the bottom of the passageway.) The pillar must have been oriented such that the Sanskrit inscription faced east because this was the entrance direction to the complex in Udayagiri. Interestingly, the imagery provided in the iron pillar inscription ('*Chandra* having in faith fixed his mind on Vishnu') is visually evident in Chandragupta's images in both the *Varāha* and *Anantaśāyin* panels[12,13]. Therefore, the visual effect of one of the statements of the iron pillar inscription must have been available right in front of the viewer as one entered the temple complex during the Gupta period.

Figure 2. Details of cave 7 and the passageway photographed in 1914. The *Varāha* panel is seen on the left of the photograph. The location of the *Anantaśāyin* panel (in cave 13) has been marked with an arrow. (Photograph courtesy: ASI).

As the Udayagiri site was astronomically significant[8], it is reasonable to anticipate that the iron pillar must have been located at a calculated position with respect to the cardinal directions and important cave temples. If the iron pillar was located in front of cave 7, then several facts regarding the shadow of the pillar in early-morning sunlight on significant astronomical periods in the year can be deduced based on detailed solar observations at Udayagiri[8]. Dass and Willis[8] visited the site in different seasons, and on equinox and solstice days. The summer solstice day was found to be significant because the sun rose in direct alignment with the passage. Moreover, the sunrays illuminated the north wall of the passageway after dawn without shadows[8]. As Udayagiri is located on the Tropic of Cancer, the sun stands directly overhead on 90° on summer solstice day. Significantly, it was noted that there was virtually no shadow in the passage on the summer solstice day because the passage directly paralleled the sun's east-west axis[8]. Based on the estimated location of the Tropic of Cancer[8] in AD 400 at 23°49′, which is north with respect to Udayagiri (i.e. 23°31′), it can be reasonably concluded that the south wall of the passageway (containing the cave temples, including the *Anantaśāyin* Vishnu panel) would have been lit by the sunrays as it progressed across the sky in summer solstice day, during the Gupta period.

Therefore, based on modern-day solar observations in Udayagiri site during summer solstice day[8] and based on the known location of the Tropic of Cancer in AD 400, it is realized that during the Gupta period, the sunrays must have struck the *Anantaśāyin* Vishnu's panel in cave 13 only in the time preceding and following the summer solstice day. This must have been the intended effect of the architects of cave temples at Udayagiri temples cut-out along the passageway. The scientific proof for the same will be provided based on astronomical phenomenon. The summer solstice day will be considered in particular because of the observed[8] special alignment of the sun's movement with the passageway on this particular day. Interestingly, the day ('Samvatsare 80 2 Asadha-masa-sukle(ai)kadasyam' meaning 'In the year 80 (and) 2, on the eleventh lunar day of the bright fortnight of the month Asadha) mentioned in the dated Chandragupta II Vikramaditya period inscription in cave 6, referred to as the Sanakanika inscription, has been calculated to be very close to the summer solstice of the year AD 402 (A. Sharan and R. Balasubramaniam, unpublished). Therefore, this indicates that the summer solstice day was considered to be a significant day at Udayagiri.

As mentioned earlier, Udayagiri is located on the tropic of Cancer. The tropics are related to the tilt of the earth's rotational axis by 66.5° from the horizontal. As the earth revolves around the sun, significant astronomical events occur repeatedly every year depending on the relative position of the earth with respect to the sun. These events will be considered by referring to the location of Udayagiri, i.e. on the Tropic of Cancer (known in Indian terminology as *karka rekhā*). The longest day in the year occurs on summer solstice day (21 June). On this day, the sun rises at 23.5° to the north of the east direction, and sets at 23.5° to the north of the west direction. Moreover, the sun traces a path in the sky on this day in such a manner that at noon, there would be no shadow cast on the ground for a vertically standing erect object, like the iron pillar. The other complimentary astronomical event in the year in the northern hemisphere occurs on the winter solstice day (21 December). On this day, the sun rises exactly 23.5° to the south of east direction and sets at 23.5° to the south of the west direction for an observer located at the Tropic of Cancer, because the declination of the sun (i.e. angle of the sun with respect to the earth) is on the Tropic of Capricorn. The sun rays at noon on this day will cast a shadow, falling north, that makes an angle of 47° to a vertically erect object. The two other significant annual astronomical events are the spring (21 March) and autumn (21 September) equinoxes, the days of equal day-time and night-time for all positions on the earth. These events occur between the summer and winter solstices. The angle that an erect object makes with its shadow (falling north) at noon on these days would be 23.5°. These astronomical aspects have been described here because they are relevant in understanding the astronomical significance of the iron pillar at Udayagiri.

From the known declination of the sun on significant annual solar days (like equinox and solstice days), the direction of early-morning and late evening sunrays is depicted in Figure 3. At any location on the Tropic of Cancer, the sun reaches its northernmost declination on summer solstice day and the southernmost declination on the winter solstice day. On the equinox days, the sun rises in the exact east direction and sets in the exact west direction. The passageway was cut out at a specific angle with respect to the cardinal direction as is evident from the following. On the summer solstice day, the sun rises at 23.5° to the north of the east direction. During this time, the shadow of an erect object located at the entrance of the passageway must fall in the direction of the *Anantaú âyin* panel because of the observed astronomical fact that the sun rose in direct alignment with the passage[8]. This direction has been shown by arrows in Figure 1 *b*. Another minor point of interest is that Vishnu in the *Anantaśāyin* panel is shown lying with His head in the eastern side and foot in the western direction. Therefore, the alignment of the *Anantaśāyin* panel was such that the morning sun on summer solstice day would have illuminated only Vishnu's feet, which is symbolic of the name of Udayagiri during the Gupta period, i.e. *Vishnupadagiri*.

The above discussion reveals the engineering and architectural genius of the creators of the Udayagiri site such that the allegorical representations of both Vishnu *pāda* and Vishnu's cosmic sleep were successfully accomplished by a careful blend of astronomical and architectural knowledge. The creation and development of Udayagiri site appears to have been clearly guided by a highly developed astronomical knowledge. The flowering of astronomical knowledge under prominent astronomers like Aryabhata, Varahamihira and Brahmagupta during the Gupta period has been well established[16]. The positioning of the iron pillar would have additionally served to highlight the astronomical intelligence, knowledge and advancements prevalent during Chandragupta II Vikramaditya's time. Considering the astronomical significance of the Udayagiri site, it is interesting to note that there exists, on the northern hilltop, a flat platform commanding a majestic view of almost the entire skyline. Several astronomical marks have been identified at this platform[4], thereby suggesting that this must have been the site of an ancient astronomical observatory. Its location has also been indicated in Figure 1 *a*. This observatory needs careful study by knowledgeable astronomers.

The original image atop the Delhi iron pillar has been speculated to be generally a Garuda[2,4]. The strongest argument against the identification of a Garuda, as a standalone figure atop the capital, is the specific statement in the Delhi iron pillar inscription, that the pillar was intended as *Vishnuordhvajah*, i.e. 'standard of Vishnu'. The inscription has been analysed in great detail elsewhere[2,3]. Moreover, the nature of the cut in the topmost surface of the iron pillar capital, probably due to the forced removal of the object, also indicates that an exclusive Garuda need

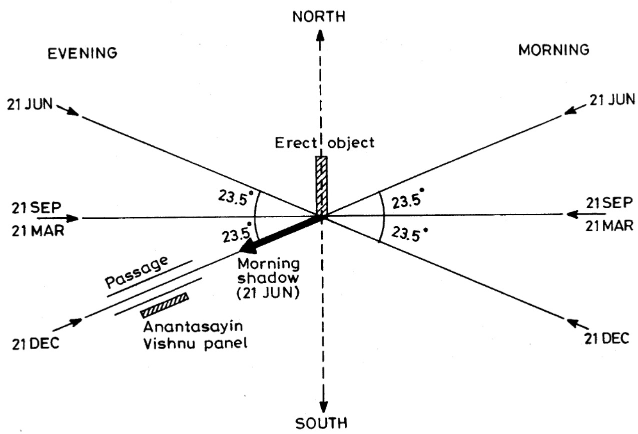

Figure 3. Direction of the morning rising sunrays and evening setting sunrays on important solar (equinox and solstice) days in the year. The direction of the early-morning shadow of an erect object placed in front of cave 7 at Udayagiri on summer solstice day has been indicated. The shadow falls along the specially-cut passageway in the direction of *Anantaśāyin* Vishnu in cave 13.

not have resided atop the pillar. It was also suggested earlier[2] that as the iron pillar inscription specifically refers to *Vishnuordhvajah*, the other possibilities were images of Vishnu's *chakra* or *chakrapurusha*. The probable image that was atop the iron pillar has been recently identified based on archaeological and iconographic evidences[17]. The astronomical symbolism of this image would be briefly addressed here after discussing the nature of the object.

It has been established elsewhere[17] that a *nakshatra-chakra* image resided atop the Udayagiri northern hilltop pillar, which was contemporary to the iron pillar that was located at the bottom of the hill. This aided the deduction of the image that was originally atop the Delhi iron pillar capital[17]. A detailed description of the components of the decorative bell capital of the Delhi iron pillar (Figure 4) has been provided elsewhere[18]. There are seven components to the capital and these are (on moving from the bottom to the top of the capital), the fluted inverted-lotus bell structure, the slanted rod structure, three rounded discs with serrated edges, a circular disc and finally the box pedestal. They have been intelligently shrunk fit around a hollow iron cylinder[18]. Special attention will be focused on the topmost box pedestal structure. The square box-like structure possesses projecting top and bottom faces (Figure 5). On careful observation of the bottom portion of this box-like structure, an apparent gap is seen between its bottom and the lower circular disc, thereby indicating that the box pedestal is a distinctive unit. The box-like design represents a pedestal (abacus) atop which an idol/emblem was normally placed. The pedestal (which can be either circular or square) is another characteristic feature of pillar designs of North India from the Mauryan times (400 BC). Precise measurements of the dimensions of the box pedestal of the Delhi iron pillar indicate that its top and bottom faces are exactly 12″ in length on the sides and are 2″ thick. The total height of the box-like structure is 8″. Particular attention must be focused on the two bands that go around the pedestal below the top face and above the bottom face of the box pedestal (clearly noticed in Figure 5). This is a unique feature of the box pedestal of the Delhi iron pillar capital and is also important for the discussions to follow.

The bottom face of the structure has four 0.5″ diameter holes that are located symmetrically at the four corners of the base (Figure 6). Only one of them is completely open, and the other three contain fractured iron rods protruding from them. The open hole shows no sign of rusting or distortion at this region. On corresponding locations in the bottom of the top face, fractured rods can be seen at three corners. The function of these holes has been hypothesized as being probably meant for fixing some figures. It was earlier proposed that this could have been used for fixing four lion figures at each corner of the box pedestal[18]. Holes have been specifically provided at these locations. This would have been relatively more difficult to incorporate in the box pedestal compared to providing solid rods at these locations. This implies that the figures could have been changed periodically and different figures/images could have been used for different times in the year. This is probable considering the astronomical significance of the Udayagiri site[8].

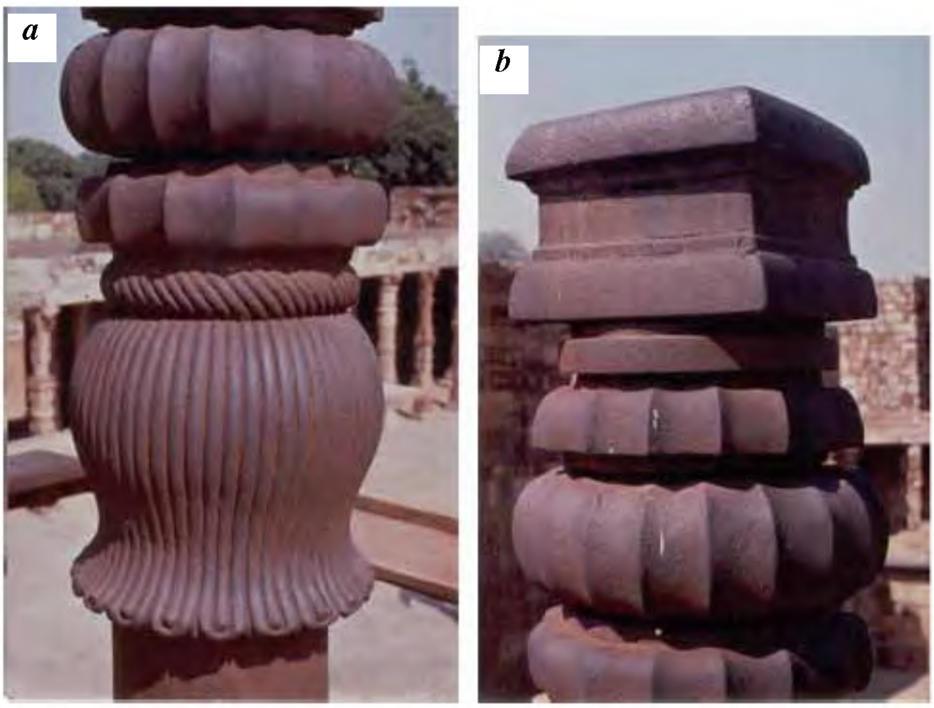

Figure 4. Decorative bell capital of Delhi iron pillar. ***a*** Bottom portion; and ***b***, Top portion.

Figure 5. Topmost box pedestal of Delhi iron pillar bell capital.

Figure 6. One of the four holes provided in the lower base of the box pedestal.

One of the four corners of the top protrusion of this box-pedestal structure is partially fractured (see top right of the box-pedestal in Figure 5). A detailed investigation of this region indicates that the box-like assembly is a single piece of metal and not constructed out of plates[18]. The box pedestal possesses a square section at the top. On the top surface, the presence of a circular cylinder of diameter 8″, intersecting the surface, is evident from the oblique and vertical views of this surface presented in Figure 7. The function of this hollow cylinder in the fitting methodology of the seven components of the decorative bell capital of the Delhi iron pillar has been explained in great detail elsewhere[2,18]. A circular slab covers the hollow cylinder. This slab contains an irregular rectangular 6″ × 2″ slot at the centre. This was the location where the original object was anchored with the capital. The object is now missing. The open slot has now been sealed with wax so that water does not accumulate inside the hollow cylinder. The top surface of the box pedestal provides valuable clues to the method by which the object that was originally atop the pillar capital, was connected to the capital. The object was joined to a circular base. Subsequently, the flat, circular base was welded onto the top of the iron cylinder. The circular base and the welded regions are clearly distinguishable in the top surface of the iron pillar capital (Figure 7). The horizontal slot is the remnant after the object had been removed.

The nature of the horizontal slot (Figure 7) provides a strong clue that the shape of the object, which was removed from this location, must have been either rectangular or circular. Detailed archaeological evidences have been provided elsewhere[17] to establish that the object was a circular disc – *chakra* (discus). It is also reasonable to propose that its thickness must have been similar to the width of the slot seen, i.e. 2 inches thick. Based on a detailed dimensional analysis of the Delhi iron pillar[2,18,20], it is known that the height of the object atop the capital must have been 20″. The diameter of the *chakra* must have therefore measured 20″. A conjectural reconstruction of the *chakra* image that was probably atop the Delhi iron pillar, has been presented in Figure 8. In Figure 8, the relative dimensions of various sections have been strictly maintained according to the detailed analysis of the dimensions of the decorative capital[18]. The iron pillar was probably located in the entrance to the main complex at Udayagiri facing the east direction[9]. In such a case, the entire pillar would have brilliantly lit up every morning by the incident sunrays on all days of the year. Careful chemical analyses of minute amounts of metal scrapings from the slot region (Figure 7) may provide clues about the material of construction/solder of the original image atop the pillar.

The identification of the *chakra* image has strong archaeological support. At Udayagiri, there are at least seven comparatively small images of the four-armed Vishnu standing straight, static and in a frontal pose with weight equally distributed on both feet. In all these images, Vishnu's two rear arms rest on His weapons, *gadā* (mace) and *chakra* (discus). These are either indicated directly by providing the actual weapons or alluded indirectly by representation of *gadādevī* and *chakrapurusha.* For example, the Vishnu panel located to the left of the entrance to cave 6 depicts *gadā* and *chakra*, whereas the Vishnu panel to the right of the entrance depicts the weapons as *gadādevī* and *chakrapurusha.* The Vishnu image located to the left of the entrance of cave 6 is the one to focus special attention on. The *chakra* is shown to the proper left of Vishnu in this image. The *chakra* is shown resting on an object (Figure 9) that is a copy of the top box pedestal of the Delhi iron pillar. As mentioned earlier, the unique feature of the Delhi iron pillar box pedestal is the narrow band that goes all around the section just

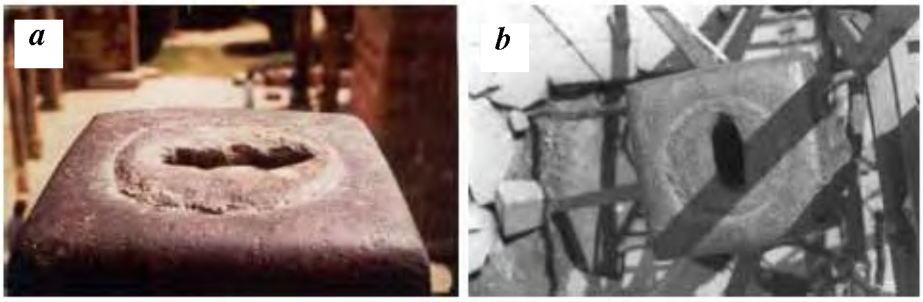

Figure 7. Top surface of the Delhi iron pillar capital. The presence of the hollow slot and the welding lines delineating the cylinder's dimensions should be noted. ***a***, oblique view photographed in 1993. ***b***, vertical view photographed in 1961. (***b***, Photograph courtesy: ASI).

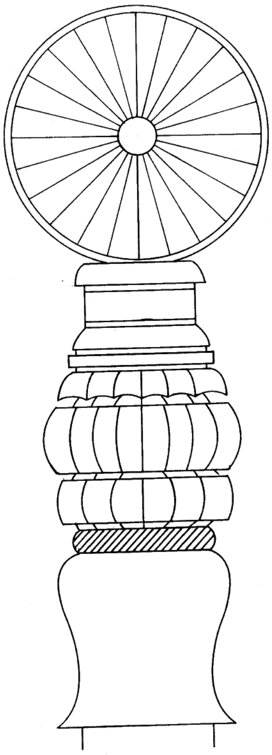

Figure 8. Schematic of *chakra* image atop the Delhi iron pillar capital. The relative proportions of the various sections have been strictly maintained based on actual measurements.

Figure 9. Standing Vishnu panel to the left of the entrance of cave 6 at Udayagiri (Photograph courtesy: Kern Institute Leiden and G. Foekema).

below the top face and above the bottom face of the pedestal (Figure 5). This feature is also duplicated in the box pedestal on which the *chakra* rests in the Vishnu panel at the entrance to cave 6. Therefore, it appears that the creators of this particular Vishnu image have left behind an actual depiction of the image of the decorative bell capital of the iron pillar. The *chakra* image proposed in Figure 8 utilizes this representation for schematic depiction. The details that appear *inside* the *chakra* image, depicted in Figure 8, are hypothetical. Radiating spokes have been shown in this image to indicate its possible relation with the *nakshakra-chakra* capital of the Udayagiri hilltop pillar[17].

The astronomical significance of the *chakra* image may also be noted. It has been earlier shown that Surya (i.e. sun god) has been identified with Vishnu at the Udayagiri site during Chandragupta II Vikramaditya's time[4,8]. The symbolism of the pillar with *chakra* capital has been discussed and elaborated in great detail in the classic book on this subject by Agrawal[20].

The astronomical significance of the Delhi iron pillar has been addressed by considering its probable erection site at Udayagiri (ancient *Vishnupadagiri*) and the probable image that was located originally atop the Delhi iron pillar. Based on observation of solar events at Udayagiri[8], located on the Tropic of Cancer, it has been shown that the iron pillar may have been probably positioned such that, on summer solstice day, the early-morning shadow from the pillar fell in the direction of *Anantaśāyin* Vishnu in cave 13. Moreover, on the important summer solstice day at Udayagiri, the motion of the sun across the sky was in line with the specially cut passageway and the evening setting sun completely illuminated the *Anantaśā yin* Vishnu panel in cave 13. The image that was probably atop the Delhi iron pillar capital has been deduced to be disc-shaped, approximately 20″ in diameter and 2″ thick. The nature of the top surface of the iron pillar capital indicated that the disc-shaped object was fitted vertically on a flat, circular base, which was subsequently welded onto the top of the cylinder, around which the components of the decorative bell capital were shrunk fit.

1. Anantharaman, T. R., *The Rustless Wonder – A Study of the Delhi Iron Pillar*, Vigyan Prasar, New Delhi, India, 1997.
2. Balasubramaniam, R., *Delhi Iron Pillar: New Insights*, Indian Institute of Advanced Study, Shimla, 2002, pp. 8–46.
3. Balasubramaniam, R., Identity of *Chandra* and *Vishnupadagiri* of the Delhi iron pillar inscription: numismatic, archaeological and literary evidence. *Bull. Met. Mus.*, 2000, **32**, 42–64.
4. Dass, M. I., *Udayagiri – Rise of a sacred hill, its art, architecture and landscale – A study.* Ph D thesis, DeMontfort University, Leicestershire, UK, 2001, pp. 105–155.
5. Dass, M. I. and Balasubramaniam, R., Estimation of the original erection site of the Delhi iron pillar at Udayagiri. *Indian J. Hist. Sci.*, 2004, **39.1**, 51–74.
6. Willis, M., Inscriptions at Udayagiri: Locating domains of devotion, patronage and power in the eleventh century. *South Asian Stud.*, 2001, **17**, 48.
7. Lahiri, N., *Archaeology of Ancient Indian Trade Routes upto c. 300 BC*, Oxford University Press, New Delhi, India, 1992, pp. 368–381.
8. Dass, M. I. and Willis, M., The lion capital from Udayagiri and the antiquity of sun worship in central India. *South Asian Stud.*, 2002, **18**, 25–45.
9. Gangooly, P. (ed.), *Surya Siddhanta, Translated with Notes and Appendix by Rev. Ebenezer Burgess (1880)*, Motilal Banarsidass, New Delhi, 1960.
10. Thibaut, G., Contribution to the explanation of the *Jyotisa-Vedanga. J. Asiat. Soc. Bengal*, 1977, **46**, 411–437.
11. Krishna Deva, Gupta and their feudatories. In *Encyclopaedia of Indian Temple Architecture*, North India: Foundations of North Indian Style c 250 BC–1100 AD (eds Meister, M. W., Dhaky M. A. and Krishna Deva), American Institute of Indian Studies, Princeton University Press, 1988, vol. II, part I, pp. 18–57.
12. Patil, D. R., *The Monuments of the Udayagiri Hill*, Gwalior, 1948, pp. 377–428.
13. Mitra, D., Varāha cave at Udayagiri – an iconographic study. *J. Asiat. Soc.*, 1963, **5**, 99–103.
14. Williams, J., *The Art of Gupta India: Empire and Province*, Princeton University Press, Princeton, USA, 1982, pp. 37–49.
15. Fleet, J. F., Inscriptions of the early Gupta kings and their successors. *Corpus Inscriptionum Indicarum*, 1888, vol. III, p. 25.
16. Majumdar, R. C., In *The History and Culture of the Indian People – Classical Age*, Bharatiya Vidya Bhavan, Mumbai, 1954, vol. 3, pp. 321–323.
17. Balasubramaniam, R., Dass, M. I. and Raven, E. M., On the original image atop the Delhi iron pillar. *Indian J. Hist. Sci.*, 2004, **39.2**, in press.
18. Balasubramaniam, R., Decorative bell capital of the Delhi iron pillar. *J. Met.*, 1998, **50**, 40–47.
19. Balasubramaniam, R., New insights on the corrosion of the Delhi iron pillar based on historical and dimensional analysis. *Curr. Sci.*, 1997, **73**, 1057–1067.
20. Agrawal, V. S., *Chakra-dhwaja: The Wheel Flag of India*, Prithvi Prakashan, Varanasi, 1964, pp. 1–59.

ACKNOWLEDGEMENTS. We thank the Archaeological Survey of India for co-operation and Dr Ellen M. Raven for critical discussions.

Received 5 April 2003; revised accepted 15 December 2003

Shannon's uncertainty principle and gene expression levels

V. Subramaniyam[†], S. K. Gupta and T. C. Ghosh*

Bioinformatics Centre, Bose Institute, P/12, CIT Scheme VII M, Kolkata 700 054, India
[†]Present address: Indian Institute of Information Technology, Allahabad 211 012, India

Shannon's uncertainty principle has been applied to measure the degree of constraints in codon bias in the coding sequences of *Escherichia coli*, *Saccharomyces cerevisiae* and *Haemophilus influenzae*. Our study shows a high degree of correlation between Shannon's uncertainty values and codon adaptation index (CAI). This result suggests that the degree of constraints determined by Shannon's uncertainty principle reflects the level of gene expression and we propose that Shannon's uncertainty principle can be used as an alternative method for predicting the level of gene expression. The main advantage of Shannon's uncertainty values over CAI is that for calculating Shannon's uncertainty values, one does not require any reference set of genes as required in CAI. This gives a potential use of Shannon's uncertainty principle over CAI in predicting the level of gene expression, specially for the newly sequenced genomes where genes are not properly annotated.

THE existence of non-random uses of synonymous codons is well documented. Moreover, codon usage patterns differ significantly among different genes within the same taxon[1]. It has been widely accepted that compositional biases are the only dictators in shaping the codon usage variation among the genes in the extremely AT or GC-rich unicellular organisms[2–4]. It has been suggested that translational selection determines the codon usage bias of highly expressed genes and subsequently, it has been advocated that preferred codons in highly expressed genes are recognized by most abundant tRNAs[5–7]. Recently, it was

*For correspondence. (e-mail: tapash@bic.boseinst.ernet.in)